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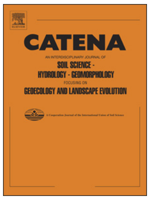

Soil aggregate stability and aggregate-associated carbon and nitrogen in natural restoration grassland and Chinese red pine plantation on the Loess Plateau

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ABSTRACT

Artificial afforestation and natural recovery from abandoned cropland are two typical recovery types on the Loess Plateau, China. However, few studies have investigated the difference of natural secondary vegetation restoration and man-made plantation in soil aggregate physicochemical properties and soil aggregate stability. Therefore, we have selected natural restoration grassland and Chinese red pine plantation to study the differences of soil aggregate size distributions, aggregate carbon (C) and nitrogen (N) distributions, soil aggregate stability index (fractal dimension, D; mean weight diameter, MWD; geometric mean diameter, GMD; percentage of aggregation destruction, PAD) as well as their relationships. The results showed that after ~15 years restoration from abandoned cropland, natural restoration grassland had higher soil organic carbon (SOC), total nitrogen (TN), ammonium nitrogen (AN), microbial biomass nitrogen (MBN) and MWD compared to Chinese red pine forest, but Chinese red pine forest had higher aggregate C and N, D, GMD and PAD. In addition, SOC positively correlated with MWD in natural restoration grassland but opposite in Chinese red pine forest. In detail, the differences of soil general properties and aggregate size fraction percentages between two land use types were found mainly in 2–5 mm, 1–2 mm, 0.25 mm and clay water-stable aggregate size fractions. The results suggested that higher C content would further contribute the soil aggregate stability in natural restoration grassland, and higher N content would be more important in Chinese red pine plantation.

1. Introduction

For terrestrial ecosystems, land use changes probably will have the largest effect, followed by climate change, nitrogen (N) deposition, biotic exchange and elevated carbon dioxide concentration (Sala et al., 2000). Human beings face the growing challenge of managing trade-offs between immediate human needs and maintaining the capacity of the biosphere to provide goods and services due to irrational land uses (Foley et al., 2005; Smith et al., 2016). China's "Grain for Green" Program, which has launched since 1999, focused on local environment restoration by planting trees in semi-arid regions and by protecting natural recovery (Deng et al., 2014a, 2014b). Over the past decade, land use and vegetation types on the semi-arid Loess Plateau have changed significantly, converting cropland to other land uses, such as artificial grassland, shrub land, forest or abandoned cropland (Liu et al., 2014).

Land use changes, especially of abandoned cropland may rapidly change soil quality (Deng et al., 2013, 2014a, 2014b; Deng and Shangguan, 2016). Several studies have demonstrated that vegetation restoration could significantly enhance the soil organic carbon (SOC), N content and soil aggregate stability (An et al., 2010; Jiao et al., 2012; Raiesi, 2012; Deng et al., 2016; Deng and Shangguan, 2016), and increase mean weight diameter (Liu et al., 2014), soil fractal dimension and geometric mean diameter (Zhuang et al., 2012). In addition, soil aggregate size distribution and stability are important indicators of soil physical quality (Castro Filho et al., 2002; Shrestha et al., 2007). As we know, soil organisms and soil chemistry had a causal relation with soil physical quality. Jin et al. (2015) have indicated soil structure losses in soils due to lower SOC inputs, this result was the same with many studies (Pagliai et al., 2004; Haynes, 2005). Plant microbial symbionts also played a significant role in aggregate stability (Hosseini et al., 2015). Meanwhile, soil aggregation may be determined by the mean weight diameter (MWD), the geometric mean diameter (GMD) (Castro Filho et

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al., 2002), soil fractal dimension (D) (Ahmadi et al., 2011) and the percentage of aggregation destruction (PAD) (Yu et al., 2013).

In the Loess Plateau, due to the implementation of "Grain for Green" Program, artificial afforestation and natural recovery from abandoned cropland are two typical recovery methods on the Loess Plateau. Recent research mainly focused on the effects of nutrient addition on soil aggregate stability and soil C and N cycles (Martens, 2000; Mizuta et al., 2015; Mohanty et al., 2015; Wang et al., 2016a), the effects of land uses on aggregation and SOC and N fractions and soil aggregate stability (Huang et al., 2010; Liu et al., 2014; Li et al., 2016), and the effects of soil chronosequence on SOC and soil quality (An et al., 2008; Duchicela et al., 2013; Deng et al., 2014a, 2016). In addition, several studies also focused on the relationship between soil physicochemical properties and soil aggregate stability (Six et al., 2004; Sarathjith et al., 2014; Chaplot and Cooper, 2015). However, few studies have investigated the difference of two land uses (natural restoration grassland and man-made Chinese red pine forest) in soil aggregate physicochemical properties and soil aggregate stability.

In this study, we examined the effect of natural restoration grassland and Chinese red pine plantation on soil physicochemical properties in Ziwuling Forest Farm on the Loess Plateau, China. The objectives of this study were: (1) to determine the difference of dry sieving and wet sieving soil aggregate size distributions and wet sieving aggregate-associated C and N distributions in two land use types, (2) to make clear the differences of soil aggregate stability index (D, MWD, GMD, PAD) of dry sieving and wet sieving in two land use types, and (3) to find the relationships between soil aggregate stability index and it's soil physicochemical properties in the two land use types on Loess Plateau. We expected that the reasonable land use type will be predicted in this area.

2. Materials and methods

2.1. Study area

The experimental site was managed on the Lianjiabian Forest Farm of the Heshui County, Gansu Province, China (108°10′–109°18′E, 35°03′–36°07′N), located in the hinterland of the Loess Plateau. The Ziwuling forest region, covering a total area of 23 km^2. The altitude of the region's hilly and gully land-forms is 1211–1453 m.a.s.l., their relative height difference is about 200 m, the area's mean annual temperature is 10 °C, mean annual rainfall is 587 mm (Deng et al., 2013, 2016; Wang et al., 2016b), accumulative temperature is 2761 °C, and the annual frost-free period is 112–140 days. Soils of this region are largely loessial, having developed from primitive or secondary loess parent materials, which are evenly distributed at thicknesses of 50–130 m above red earth consisting of calcareous cinnamon soil. The artificial communities throughout the region are *Pinus tabulaeformis* (Carr.), *Hippophae rhamnoides* (Linn.) and *Robinia pseudoacacia* (Linn.). These forests canopy density ranging between 80% and 90%.

In the Ziwuling forest region, duo to China's government launched 'Grain to Green Program' to plant trees and protect natural recovery since 1999, the Lianjiabian Forest Farm had planted many Chinese red pine forest on abandoned farmlands, meanwhile, lots of farmlands had been abandoned. Under the background of 'Grain to Green Program' implementation, many Chinese red pine forest and natural restoration grasslands were distributed in the study area. Through ~15 years vegetation restoration, the canopy density of the Chinese red pine is about 85% and coverage of the natural grassland is about 75%. *Bothriochloa ischaemum* (Linn.) Keng, *Carex lanceolate* Boott, *Potentilla chinensis* (Ser) and *Stipa bungeana* Trin are the main grassland species. Chinese red pine forest is pure forest and has a high canopy density. In addition, the surface soil of Chinese red pine forest is covered by pine needles, therefore, the single undergrowth plant in Chinese red pine forest mainly are *C lanceolate* Boott, *Hippophae rhamnoides* (Linn.) seedlings and *Pinus tabulaeformis* (Carr.) seedlings.

2.2. Samplings and measurements

2.2.1. Experimental design and sampling

In this study, we had used a paired design. Each Chinese red pine forest stand was paired with adjacent natural restoration grassland to ensure the two restoration types had similar land use history (abandoned cropland). The two land use types scattered embedded in the study area. Generally, there have 2000–5000 m^2 area for each vegetation patch. In August 2015, we randomly set up five 20 m × 20 m plots in a ~15 years man-made planting Chinese red pine forest and a ~15 years natural restoration grassland to collect soil samples, respectively in each of the five sites. They were both converted from abandoned cropland. Each paired site is of similar physiographic conditions and slope gradients, and the two plots of each pair are separated 10–20 m. Within the center and four corners of each plot, five 1 m × 1 m quadrats were chosen to sample soils, in total, there are 25 quadrats for each vegetation type. Meanwhile, soil bulk density and undisturbed soil samples were obtained in a random selection of digging pit from each plot.

In each quadrat, soil sampling, done in five soil layers: 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm and 80–100 cm, was using a soil drilling sampler, and 5 samples were taken from the center and four corners of each plot and mixed to form a bulk sample of about 2 kg for the measurement of soil physical and chemical properties. Each soil was sieved (2 mm) to remove large roots, stones and the macrofauna, and determination of MBC and MBN need soils stored on ice bags. Soil bulk density was measured using a soil bulk sampler with a 5 cm diameter and a 5 cm high stainless steel cutting ring (3 replicates) at 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm and 80–100 cm soil layers. The original volume of each soil core and its dry mass after oven-drying at 105 °C were measured. In addition, three undisturbed soil samples were taken for aggregate stability analysis at 0–20, 20–40, 40–60, 60–80 and 80–100 cm soil layers from each plot, sealed in lunch box and transported to the laboratory, where they were air dried at room temperature.

2.2.2. Soil physical and chemical properties

Chemical analysis was performed on soil samples at 2 mm, ammonium nitrogen (AN) and nitrate nitrogen (NN) analysis were performed on soil samples at 1 mm, using standard methods. Soil pH and ion exchange (EC) were determined using the method of acidity agent (soil-water ration of 1:5) (PHS-3C pH acidometer, China) and a DDS-307 model Electric Conductivity Detector (Lei-ci, China), respectively. Soil organic carbon (SOC) content was determined by the $K_2Cr_2O_7$–H_2SO_4 oxidation method (Nelson and Sommers, 1996). Soil total nitrogen (TN) content was assayed using the Kjeldahl method (Bremner, 1996). Inorganic or mineral N in soil was extracted by shaking samples in 1 mol L^{-1}KCL [1:5(w/w) soil: KCL solution] for 1 h and subsequent filtering through filter paper (Bremner and Keeney, 1966). The filtrate was analyzed for NH_4^+-N (Crooke and Simpson, 1971) and NO_3^--N (Best et al., 1976) with a Chemlab Auto-Analyzer. Soil microbial biomass C (MBC) and N (MBN) were determined using the fumigation-extraction method (Brookes et al., 1985; Wu et al., 1990).

BD was calculated depending on the inner diameter of the core sampler, sampling depth and the oven dried weight of the composite soil samples. Soil water content was measured gravimetrically and expressed as a percentage of soil water to dry soil weight. A laser particle analyzer that operates over a range of 0.02–2000 μm (Mastersizer 2000 particle size analyzer, Malvern Instruments, Ltd., UK) and based on the laser diffraction technique was used to measure particle size.

Aggregates were separated following the modified method described by Six et al. (1998). An air-dried bulk soil consisting of aggregates of diameter equal or lesser than 10 mm was fractionated into 10 mm, 7 mm, 5 mm, 3 mm, 2 mm, 1 mm, 0.5 mm and 0.25 mm classes. In a proportional manner, 50 g of these aggregate fractions was then transferred to a set of five stacking sieves with opening of 5 mm, 2 mm, 1 mm, 0.5 mm and 0.25 mm, resulting in the collection of five aggregate size fraction: >5 mm, 2–5 mm, 1–2 mm, 0.5–1 mm, 0.25–