Ecological Engineering 87 (2016) 263–270

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Shifts in soil organic carbon and nitrogen dynamics for afforestation in central China

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ARTICLE INFO

Article history:
Received 21 April 2015
Received in revised form
23 November 2015
Accepted 27 November 2015

Keywords:
Afforestation
$\delta^{13}C$
Density fractionation
$\delta^{15}N$
Soil aggregates
Soil organic matter

ABSTRACT

The afforestation has been proposed as a primary means of sequestering carbon (C) from the atmosphere, thereby mitigating climate change. However, consequences of afforestation on soil organic C and nitrogen (N) dynamics due to spatial heterogeneity are not fully understood. The objectives of this study were to identify the consequences of 18 years of afforestation on C and N dynamics in the Danjiangkou Reservoir area of central China. Soil samples from the woodland, shrubland, cropland and adjacent open area soils (i.e. the control) were separated into four aggregate sizes (>2000 μm, 250–2000 μm, 53–250 μm and <53 μm), and three density fractions [free light fraction (LF), intra-aggregate particulate organic matter (iPOM) and mineral-associated organic matter (mSOM)]. All fractions were analyzed for their C and N content, and $\delta^{13}C$ and $\delta^{15}N$ values. Afforestation enhanced the soil C and N storage, primarily due to increases in soil C and N storage of macroaggregates (>2000 μm) with the largest (65–87%) fraction in iPOM. The C: N ratios generally increased from the cropland to shrubland to woodland across all fractions. The ^{13}C values indicated that the fastest decay rates ($k = 0.024\ yr^{-1}$) in LF of macroaggregates (>2000 μm) was in woodland, but the fastest decay rates (0.114–0.137 yr^{-1}) in iPOM of all aggregates were observed in cropland. Meanwhile, the most enriched $\delta^{15}N$ values (0.87–3.81) were found in cropland soil. Our results suggest that afforestation could alter weight distribution of soil fractions and increase the soil organic C and N storage, thereby affecting the turnover and stability of SOM.

1. Introduction

Land use change, a key component of global change, has a profound influence on soil carbon (C) and nitrogen (N) dynamics in terrestrial ecosystems (e.g. Batlle-Bayer et al., 2010; Cotrufo et al., 2011; Lu et al., 2014). Various land use changes, such as deforestation, cultivation, agricultural managements and livestock farming, cause serious environmental problems such as rapid losses in soil C and N and soils erosion (Mishra et al., 2010; Cao et al., 2010a, 2011; Zhang et al., 2012; Xiong et al., 2014; Zheng and Cao, 2015). In contrast, afforestation may reverse the consequences of deforestation and enhance C accumulation, according to the Kyoto Protocol (IPCC, 2007). Scientists recently pay more attention to the changes in soil C sequestration and water cycling following afforestation (Huang et al., 2011; Tang and Li, 2013; Cao and Zhang, 2015), but usually ignore the soil N dynamic after afforestation for decades, which may not be enough to capture the trends in long-term soil organic matter (SOM) dynamics (Davidson et al., 2007). It has been suggested afforestation can impact the soil organic C and N dynamics by altering SOM input and decomposition rate (Dou et al., 2013; Deng et al., 2014; Fang et al., 2015). However, our understanding of soil organic C and N dynamics is still limited, particularly the different turnover of SOM fractions in response to afforestation (Marin-Spiotta et al., 2009; Huang et al., 2011; Cheng et al., 2013).

The impacts of afforestation on soil C and N dynamics remain a widely debated topic (e.g. Davidson et al., 2007; Carvalho et al., 2010; Lozano-García and Parras-Alcántara, 2013). The carbon sequestration expected to result from the large-scale afforestation projects is a good goal, but occasionally negatively impacts ecosystem health (Cao et al., 2010b; Wang and Cao, 2011; Qu et al., 2014). For example, it was shown that afforestation may lead to average increases in the soil C by 42% (Guo and Gifford, 2002; Throop et al., 2013). Conversely, other studies have indicated that afforestation can lead to either decrease (Neufeldt et al., 2002; De Koning et al., 2003; Bautista-Cruz and del Castillo, 2005), or it may have a negligible effect on the soil C and N pools (Guo and Gifford, 2002; Davis

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http://dx.doi.org/10.1016/j.ecoleng.2015.11.052
0925-8574/

et al., 2007; Smal and Olszewska, 2008). These inconsistent results may be caused by multiple factors, such as land use history, disturbances, planted species, climate impacting and nutrient status (Cao et al., 2010a, 2011; Tang and Li, 2013; Edmondson et al., 2014; Xiong et al., 2014). Accordingly, insights into SOM dynamics in response to afforestation is becoming more imperative at present. However, detecting changes in soil C and N dynamics following afforestation can be difficult, for the SOM consists of a variety of compounds with different microbial degradability and turnover time (John et al., 2005; Jiménez et al., 2008; Rumpel and Kögel-Knabner, 2011).

The SOM physical fractionation technique together with natural variation in stable C and N isotopic composition, have been considered to be an effective approach for quantifying SOM dynamics following land use change (Del Galdo et al., 2003; Cheng et al., 2013; Crow et al., 2014; Wang et al., 2014). Insights into SOM dynamics are obtained using size and density fractionation techniques to separate bulk soil into fractions that differ in microbial degradability and turnover time (e.g., Del Galdo et al., 2003; Marin-Spiotta et al., 2009). For instance, macroaggregation formed around fresh coarse residues was more sensitive to afforestation and cultivation practices than microaggregation (Puget et al., 2000; John et al., 2005; Ashagrie et al., 2007). Meanwhile, the light fraction commonly referred to a plant-like and less stable fraction due to contain physically unprotected plant debris (Gregorich and Janzen, 1996), whereas the heavy fraction was shown to be a major sink for C storage with a more stable fraction due to more recalcitrant component (Tan et al., 2007; Zotarelli et al., 2007). On the other hand, the mean $\delta^{13}C$ of SOM reflects the $\delta^{13}C$ signal of vegetative input (e.g. Van Kessel et al., 2000; Throop et al., 2013). Land use change such as afforestation involves a shift in plant species, and therefore, new C input and soil C cycling can be quantified using $\delta^{13}C$ abundance after shift in the $\delta^{13}C$ of plant input following change in $\delta^{13}C$ of SOM (Van Kessel et al., 2000; Hobbie et al., 2004; Cheng et al., 2013). Simultaneously, the soil $\delta^{15}N$ can be applied in the studies of N-cycling processes that are affected by afforestation (Marin-Spiotta et al., 2009; Dou et al., 2013; Deng et al., 2014). For instance, afforestation has been suggested to decrease both inorganic N concentrations and net N mineralization, resulting in lower $\delta^{15}N$ values of the afforested soil (Deng et al., 2014; Li et al., 2014). Furthermore, the $\delta^{15}N$ values in soil can be used as an index to estimate the degree of SOM decomposition (Liao et al., 2006; Templer et al., 2007; Marin-Spiotta et al., 2009).

This study was designed to examine effects of afforestation on soil organic C and N dynamics in Danjiangkou Reservoir. Our previous studies in this field experiment have shown that afforestation has increased the litter input with higher C:N ratios, thereby increasing soil C stocks (Cheng et al., 2013; Deng et al., 2014). In this study, we hypothesized that the afforestation for 18 years would significantly change SOM storage and fractionation due to changes in the quantity and quality of litter input. To test this hypothesis, we build on our previous findings and utilize the natural abundance of $\delta^{13}C$ and $\delta^{15}N$ together with soil physical fractionation technique to evaluate dynamics in the soil organic C and N fractions following afforestation. The objectives of this study were to examine the following issues: (1) how afforestation has potentially impacted the C and N pools in the SOM fractions; and (2) how afforestation affects new C inputs and turnover rates of the native SOM fractions.

2. Materials and methods

2.1. Study area

The experiment was located at the Wulongchi Experimental Station (32°45′N, 111°13′E; 325–385 m asl) at the Danjiangkou Reservoir site. The studied area is characterized by a typical subtropical monsoon climate in the north subtropical zone with a mean annual temperature of 15.7 °C and monthly average temperatures of 4.2 °C in January and 27.3 °C in July. The mean annual rainfall is approximately 834 mm, 80% of which falls between May and October. The soil is yellow brown soil with 11% sand, 41% silt, and 48% clay in the top 30 cm. The Danjiangkou Reservoir, established in the 1970s with a water surface area of 745 km^2, is a water source area for China's Middle Route of the South-to-North Water Transfer Project (Zhang, 2009). Land use practices, such as deforestation and tillage, around the reservoir have resulted in soil erosion, water pollution and soil C losses (Deng et al., 2014). Following land reorganization by the government 18 years ago, a large uncultivated area was converted to a woodland plantation of coniferous plants (*Platycladus orientalis (Linn.) Franco*), a shrubland plantation (*Robinia pseudoacacia* and *Amorpha fruticosa*) and a cropland plantation of rape and peanut (*Brassica napus* and *Arachis hypogaea*) (Li et al., 2014) with cultivation using conventional agricultural practices, including plowing to a 0.4 m depth, mineral fertilization and chemical weed control. The input rates of mineral fertilizers in the cropland were around 110 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, and 13 kg K_2O ha^{-1} every year. The aboveground cropland biomass was removed through harvesting (Cheng et al., 2013). Although no detailed record of the cultivation history adjacent to the site has been saved, farmers have declared that they typically cultivated wheat (*Triticum aestivum*) and sesame (*Sesamum indicum*). Soil properties (pH, bulk density, C and N content, $\delta^{13}C$, $\delta^{15}N$ of the whole soil) were measured as previously described by Cheng et al. (2013) and Deng et al. (2014).

2.2. Field sample collection and soil fractionations

The experimental design was a randomized complete block design with three blocks. Three blocks/sites were randomly selected. The distances between the three sites were approximately 1 km. Each site was approximately 75 ha (500 m × 1500 m). In this study area, the afforested lands have low vegetation coverage and are often a mosaic of large open areas where no litter or root formation occurs due to soil erosion and poor soil fertility (Zhu et al., 2008; Deng et al., 2014). Thus, woodland, shrubland, cropland and an adjacent open area (i.e. the control, open areas in radius >1 m that had no input of organic matter from vegetation during 18 years) were included at each site. A comprehensive survey of soil and vegetation was conducted in October 2010 to ensure the comparability (e.g., similar soil types and topographies) of the soil sampling plots (Cheng et al., 2013). In July 2012, we randomly placed six sub-plots (2 m × 2 m) around the plant rhizosphere (i.e., the area within the canopy edge) within each woodland, shrubland and cropland stand, six sub-plots were situated in open area where soil was sampled using a 5-cm diameter stainless steel soil sampler at three randomly selected points at the upper soil depth (0–10 cm) with the purpose of conducting the following laboratory experiments. The distances between the sub-plots are approximately 5 m.

Newly produced leaves and litter on the soil surface were collected in each plot. Root sampling blocks were excavated within a 30 × 30 cm quadrant at soil depth (0–30 cm); roots were oven-dried at 65 °C to calculate their biomass in the laboratory. The collected litter was cleaned with a soft brush in the laboratory before being oven-dried at 65 °C to a constant weight and was then weighed. The soil bulk density was measured using conventional methodologies for the woodland, shrubland, and adjacent cropped systems from Cheng et al. (2013). The soil samples were air-dried, after which the large roots and stones were removed by hand. The method for aggregate separation and size density fractionations were adapted from Six et al. (1998). Four aggregate sizes were separated using wet-sieving through a series of sieves (2000, 250, and 53 μm). A 100 g air-dried sample was submerged for 5 min at room