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Soil microbial community and its interaction with soil carbon and nitrogen dynamics following afforestation in central China

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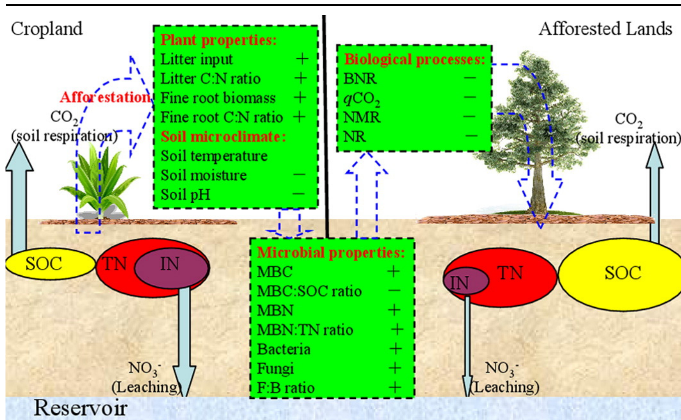
HIGHLIGHTS

- Afforestation enhanced microbial carbon (C) but reduced its ratio to soil organic C.
- Afforestation enhanced both microbial nitrogen (N) and its ratio to soil total nitrogen.
- Afforestation enhanced the ratio of fungi to bacteria in soil.
- Shifts of microbial community correlated with microbial respiration and metabolic quotient.
- Shifts of microbial community correlated with net N mineralization and nitrification.

GRAPHICAL ABSTRACT



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ABSTRACT

Afforestation may alter soil microbial community structure and function, and further affect soil carbon (C) and nitrogen (N) dynamics. Here we investigated soil microbial carbon and nitrogen (MBC and MBN) and microbial community [e.g. bacteria (B), fungi (F)] derived from phospholipid fatty acids (PLFAs) analysis in afforested (implementing woodland and shrubland plantations) and adjacent croplands in central China. Relationships of microbial properties with biotic factors [litter, fine root, soil organic carbon (SOC), total nitrogen (TN) and inorganic N], abiotic factors (soil temperature, moisture and pH), and major biological processes [basal microbial respiration, microbial metabolic quotient (qCO_2), net N mineralization and nitrification] were developed. Afforested soils had higher mean MBC, MBN and MBN:TN ratios than the croplands due to an increase in litter input, but had lower MBC:SOC ratio resulting from low-quality (higher C:N ratio) litter. Afforested soils also had higher F:B ratio, which was probably attributed to higher C:N ratios in litter and soil, and shifts of soil inorganic N forms, water, pH and disturbance. Alterations in soil microbial biomass and community structure following afforestation were associated with declines in basal microbial respiration, qCO_2, net N mineralization and nitrification, which likely maintained higher soil carbon and nitrogen storage and stability.

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1. Introduction

Soil degradation has directly limited sustainable development of terrestrial ecosystems, and constitutes one of the main environmental issues worldwide (IPCC, 2007). To address this issue, many countries including China have established national afforestation programs to increase plantation areas in the world (Liu et al., 2012a; Liu et al., 2012b). Afforestation significantly affects many of the biological and chemical processes in terrestrial ecosystems (Larchevêque et al., 2006; Céspedes-Payret et al., 2012), and the most rapid and prominent change is the modification of microbial community structure and function (Bastida et al., 2006; Cookson et al., 2007; Fu et al., 2015). Numerous studies have examined the influence of afforestation on soil carbon (C) and nitrogen (N) pool size and microbial decomposition (e.g., Davis et al., 2007; Li et al., 2012; Deng et al., 2014; Xiong et al., 2014; Ye et al., 2015), but only limited studies have attempted to explore the microbial interactions with soil C and N dynamics during afforestation (e.g., Cookson et al., 2007; Fierer et al., 2009).

Microbial interactions with soil C and N dynamics can be affected by afforestation primarily by changing the quantity and quality of litter input and soil properties such as soil temperature, moisture and pH (Six et al., 2006; Fierer et al., 2009). Afforestation usually increases soil C inputs through plant root exudation and litter production, which in turn can stimulate microbial decomposition of the soil organic C (SOC) (Montane et al., 2007; Cheng et al., 2013). However, microbial responses to increased substrate availability during afforestation have been observed to exhibit highly variable patterns due to diverse plant species and soil properties (Grayston and Prescott, 2005; Högberg et al., 2007). Previous studies have also found that soil temperature and moisture play key roles in controlling soil microbial communities and respiration rates (e.g. Fierer et al., 2009; Deng et al., 2010). Changes in soil pH can induce alterations in fungi and/or bacteria community composition (e.g. Högberg et al., 2007; Fierer et al., 2009; Rousk et al., 2009; Deng et al., 2010). In addition, the cessation of tillage operations generally reduces disturbances and provides better protection of SOC against microbial decomposition, and in turn alters microbial biomass and community structure (Six et al., 2006).

Microbial biomass and community structure could affect soil C and N cycling by interacting with plant and soil properties (Waring et al., 2013). As mentioned above, afforestation could alter soil C storage due to plant residual input (Cheng et al., 2013), but C accumulation following afforestation depends largely on the trade-offs between the biomass input and microbial decomposition (Dawson and Smith, 2007; Simpson et al., 2007). The magnitude of microbial decomposition is governed by the interactions between the amount of microbial biomass, microbial community structure, soil properties and microclimate (Six et al., 2006; Waring et al., 2013). For example, fungi are known to have slower biomass turnover rates (Rousk and Bååth, 2011) and, potentially, lower microbial metabolic quotient (qCO_2) than bacteria (Six et al., 2006). Changes in the ratio of fungi to bacteria (F:B ratio) and their total biomass may affect the storage and fluxes of C and N in terrestrial ecosystems (Bailey et al., 2002). Thus, a better understanding of mechanisms of microbial mediations on soil C and N dynamics is critical for the long-term C accumulation and sustainable development of afforested ecosystems (Teixeira et al., 2014).

The Danjiangkou Reservoir, with a drainage area of 95,200 km^2, is a water source for the central route of China's South-to-North Water Transfer Project (Zhang et al., 2009). Water quality and riparian ecosystem function are of great concern to both the government and the public (Chen et al., 2007; Zhu et al., 2008). Human activities such as deforestation and tillage around the reservoir have resulted in soil erosion, water pollution and soil C and N losses in the region (Zhu et al., 2010; Liu et al., 2012a; Liu et al., 2012b). In recent decades, to resolve this critical issue, local government has encouraged farmers to cease agriculture activities in degraded areas or protected these areas using precision fertilization, conservation tillage and afforestation. As a result, studies on the importance of afforestation (implementing woodland and shrubland plantations) in protecting and restoring riparian ecosystems around the Danjiangkou Reservoir have received growing attention from both research and management communities (Chen et al., 2007; Zhang et al., 2009). A previous work in this region has demonstrated that afforestation could enhance soil C sequestration (Cheng et al., 2013), reduce soil net N mineralization (Deng et al., 2014), inorganic N (IN, including NH_4^+-N and NO_3^--N) (Li et al., 2014), and soil erosion (Zhu et al., 2010). However, there is still a lack of information on the mechanism and potential of soil C and N dynamics during afforestation, especially the contribution of soil microbes.

In this study, we investigated soil microbial community structure and biomass, soil C and N dynamics, plant traits and soil properties in the afforested (implementing woodland and shrubland plantations) and the adjacent cropped lands. We calculated the MBC:SOC, MBN:TN and fungi:bacteria (F:B) ratios and assessed microbial interacts with soil C and N dynamics. The major objectives of this study were to examine: 1) the impacts of 15 years of afforestation (i.e., the creation of woodland and shrubland plantations) on soil microbial C and N biomass and microbial community (bacteria, fungi, F:B ratio); and 2) the relationships of microbial properties with biotic factors (litter, fine root, SOC, TN and inorganic N), abiotic factors (soil temperature, moisture and pH), and major biological processes (basal microbial respiration, qCO_2, net N mineralization and nitrification rate).

2. Materials and methods

2.1. Site description and experimental design

This study was conducted at the Wulongchi Experimental Station (32°45′N, 111°13′E) in the Danjiangkou Reservoir region (Cheng et al., 2013; Deng et al., 2014). The elevation at the station is approximately 280–400 m. The Danjiangkou Reservoir lies within the northern subtropical zone and has a subtropical monsoon climate, with a mean annual temperature of 15.7 °C and monthly averages of 27.3 °C in July and 4.2 °C in January. The annual precipitation is 749.3 mm, of which 70–80% falls between April and October. The soil is a yellow brown soil (Chinese soil classification system) consisting of 11% sand, 41% silt, and 48% clay in the top 30 cm (Zhu et al., 2010). Human activities, such as deforestation and tillage, around the reservoir have resulted in soil erosion, water pollution and soil C and N losses in the region (Zhu et al., 2010; Liu et al., 2012a; Liu et al., 2012b). Approximately 15 years ago, large areas of croplands were converted to woodland plantations of coniferous plants (*Platycladus orientalis* (Linn.) Franco), and shrubland plantations (*Robinia pseudoacacia* and *Amorpha fruticosa*) (Zhu et al., 2010). Although a detailed record of the adjacent cropland cultivation history at the sites was not available, farmers reported that they typically cultivated wheat and maize. Maize and wheat cultivation was managed by conventional agricultural practices, including plowing to a 0.4 m depth, mineral fertilizations and chemical weeding. The aboveground biomass of wheat straw and maize was removed through harvesting.

The experimental design was a randomized complete block design with three blocks/sites. The distances between the three sites were approximately 1 km. Each site was approximately 75 ha (500 m × 1500 m). Three adjacent land types—woodland, shrubland, and cropland (i.e. the control)—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 among the three land types (Cheng et al., 2013).

2.2. Soil samplings and measurements

Soils were sampled from each land type at each site. We randomly set 5 sub-plots (2 m × 2 m) for each land use type. Soil from each sub-