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Soil microbial functional diversity and biomass as affected by different thinning intensities in a Chinese fir plantation

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ABSTRACT

Understanding forest management-associated soil microbial changes is central to linking aboveground and belowground forest structures and functions. Thinning is an important and widely used silvicultural treatment to improve the remaining tree growth and stand regeneration, and it has direct and indirect effects on soil microorganisms. However, few previous studies have focused on the response of soil microbial biomass (SMB) and functional diversity to thinning. To study the effect of thinning treatments on the soil microbial community, soils were sampled in autumn, winter, spring, and summer in Chinese fir plantations in Lishui, southeast China at sites with the following thinning intensities: control plots (CK) with no thinning, low-intensity thinning (LIT) sites with 30% of the trees removed, and high-intensity thinning (HIT) sites with 70% of the trees removed. The soil microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) and Biolog™ Ecoplate (Biolog, Inc., Hayward, CA, USA) substrate use patterns were determined for each sample. Here, we show that the soil microbial functional diversity, MBC and MBN were influenced by the thinning intensity, soil depth and season. Generally, MBC and MBN were higher in the HIT, whereas soil microbial functional diversity, expressed as the Shannon diversity index (SDI), was higher in the LIT. The soil temperature, MBC/MBN, total phosphorus, and total organic carbon/total nitrogen ratio (TOC/TN) explained the most significant variations in the amount of soil microbial community functional diversity. Our study suggests that seasonal variations in microbial properties among the control and different thinning intensity treatments may be caused by differences in the substrate inputs into the soil and by microclimatic variation. To the best of our knowledge, this study is the first to provide evidence for different thinning intensity effects on SMB and functional diversity in a Chinese fir plantation.

1. Introduction

Soil microorganisms play an important role in forest ecosystems by governing a large number of essential soil processes including soil nutrient biochemical cycling (Cruz-Martínez et al., 2009; Mele and Crowley, 2008; Paul, 2007), the decomposition of both above- and belowground litters (Allison et al., 2013) and the formation of stable soil organic matter (Cotrufo et al., 2013), thus controlling forest productivity (Balser and Firestone, 2005). During the past two decades, soil biodiversity and ecosystem functioning have aroused increasing concern. Soil is one of the major biodiversity reservoirs in the world, and the loss of soil biodiversity makes soils more vulnerable to other soil degradation processes (Gaublomme et al., 2006). Thus, gaining a more detailed understanding of the microbial community in forest soils is imperative for evaluating the stability and resilience of forest ecosystems. Although soil microbial biomass (SMB) is a relatively small pool of nutrients and soil organic matter (SOM), it can act as a pathway for the incorporation of organic matter into the soil, a mediator to transform nutrients between organic and inorganic

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components and a short-term sink for soil nutrients (Powlson and Jenkinson, 1981; Zak et al., 1994; Zogg et al., 2000). To determine the optimal forest management strategies to maximize the productivity of forest ecosystems, several soil biological properties, such as SMB and functional diversity, are considered to be simple and cost-effective indicators for forest soil health and soil quality (Anderson, 2003; Sparling et al., 1997).

Thinning, an important and widely used silvicultural treatment, reduces tree density by removing a proportion of trees in a forest with a relatively dense canopy, thereby allowing water and sunlight to reach the forest floor to favor the remaining trees. Thinning practices improve the remaining tree growth and stand regeneration by redistributing resources and improving nutrient availability (Tian et al., 2010). In addition, thinning enhances the ability of the forest to resist fire and insects by developing a structurally and compositionally complex stand (McGlone et al., 2009) and increases the wildlife diversity in thinned forest plantations (Cahall et al., 2013; Verschuyl et al., 2011). However, this silvicultural treatment may affect the forest soil, especially biotic factors, in direct or indirect ways. Both above- and belowground changes of the forest ecosystems due to thinning may influence soil microbial communities. Due to alterations in the canopy and stand densities, thinning increases the soil temperature and moisture, which may create more favorable conditions for soil microorganisms (Barg and Edmonds, 1999; Christ et al., 1997). The removal of organic matter may also reduce the nutrient return to the forest soil and may result in a biology-driven acceleration of soil weathering (Blanco et al., 2008; Grady and Hart, 2006; Vadeboncoeur et al., 2014). In addition, variation in aboveground plant species composition changes the quality and quantity of the substrate inputs into the soil, subsequently altering soil microbial activity and composition (Bowman et al., 2004; Kominoski et al., 2009; Shi et al., 2011). However, the available data on the responses of microbial functional diversity and biomass to thinning are contradictory and limited. Both Thibodeau et al. (2000) and Bolat (2014) observed that thinning increased MBC and MBN, but other studies showed that MBC and MBN were decreased or unchanged after thinning (Barg and Edmonds, 1999; Giai and Boerner, 2007; Schilling et al., 1999). To date, few studies have focused on soil microbial diversity changes associated with thinning, although Cookson et al. (2008) and Giai and Boerner (2007) found that thinning had a significant effect on soil functional diversity. However, few of these studies used seasonal data to study soil functional microbial diversity.

Chinese fir (*Cunninghamia lanceolata* [Lamb.] Hook) is a fast-growing, evergreen coniferous tree species that has been widely planted in southeast China for more than 1000 years (Chen, 2003). Due to the considerable economic and ecological benefits obtained from this species, many Chinese fir monocultures have been established during the past century in place of natural broadleaf forests (Tian et al., 2011; Tian et al., 2011). The total plantation area is now approximately 9.21 million ha, representing nearly one-third of the total plantations in China (Lei, 2005). However, since the 1980s, to meet the rising demand for timber, shortening the rotations and harvesting by clear-cutting have become common practices, consequently leading to soil nutrient depletion and yield reductions of the plantations (Chen et al., 1990; Tian et al., 2011). This silvicultural practice has been a source of concern in recent years, particularly with respect to the maintenance of soil productivity and ecosystem sustainability.

The specific objectives of this study were (1) to assess how different forest thinning intensities (0%, 30% and 70% stem-only thinning) influence SMB and functional diversity and (2) to examine whether thinning effects differ with season and soil depth.

2. Materials and methods

2.1. Study site

The study was conducted in a 26-year-old Chinese fir plantation at the Lishui Tree Farm Research Station (119°01′E, 31°36′N) of Nanjing Forestry University in Jiangsu, China. The site is located at an altitude of 100 m and has a slope of 15° with a southern orientation. The type of soil is Haplic Luvisol (FAO) and the soil is generally no more than 30-cm deep. The climate of the study area is subtropical with a mean annual temperature of 15.5 °C, a mean annual sunshine duration of 2146 h, a mean annual precipitation of 1005.7 mm, and a mean frost-free period of 220 days per year. The average monthly rainfall and temperature of the study site during the sampling period are shown in Fig. 1.

Nine study plots (20 × 20 m) with an overstory dominated by Chinese fir were established in a randomized design with three replicates for each of the three treatments. To reduce potential edge effects, each plot was surrounded by buffer zones that were 5-m-wide. Thinning was performed from February to April 2006. Treatments included (1) CK: control intact forest, (2) LIT: low-intensity thinning (30% of the trees removed), (3) HIT: high-intensity thinning (70% of the trees removed). The thinning retained the individual Chinese fir possessing good external stem quality and evened the distribution of the remaining trees. Next, all the material thinned from the selected trees was removed from the plots and used for commercial wood. Thinning produced a stand density of 1020 ± 53 trees ha^{-1} (high-intensity thinning, HIT) or 2073 ± 34 trees ha^{-1} (low-intensity thinning, LIT), and the density of the un-thinned stand was 3049 ± 22 trees ha^{-1} (control plots, CK). The stand characteristics found in different treatments, such as the plant species (Table 1), mean tree height (m), diameter at breast height (DBH, cm), and stand density (trees ha^{-2}) (Table 2) were measured in October 2012.

2.2. Soil sampling

Soil sampling was conducted in the 9 sample plots at two different soil depths (0–10 cm (S1) and 10–25 cm (S2)) during the fall (October 3, 2012), winter (January 3, 2013), spring (April 3, 2013), and summer (July 3, 2013) using a 4.0-cm auger. The soil samples were sieved (2 mm), and visible roots and insects were removed. Soil samples were stored at 4 °C until analysis. The mean soil temperature at the 10-cm soil depth was measured using a temperature sensor (DS1921G-F5#, Maxim, USA) with a recording rate of one measurement per half hour.

2.3. Chemical and biochemical analyses

Soil pH was determined using a glass electrode with a soil: solution ratio of 1:2.5, and the moisture content was determined

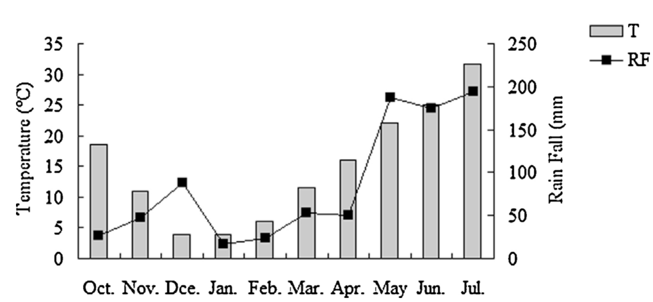

Fig. 1. Monthly variation in temperature and rainfall at Lishui, Jiangsu, China. T: temperature, RA: rain fall.