Soil microbial biomass, community composition and soil nitrogen cycling in relation to tree species in subtropical China

Zhiqun Huang [a,*], Xiaohua Wan [a], Zongming He [b], Zaipeng Yu [a], Minghuang Wang [a], Zhenhong Hu [a], Yusheng Yang [a,*]

[a] College of Geographical Science, Fujian Normal University, Fuzhou 350007, China
[b] College of Forestry, Fujian Agriculture and Forestry University, Fuzhou 350002, China

ABSTRACT

We investigated microbial biomass and composition (lipid profile), mineral N pools and soil physico-chemical parameters in the top 5-cm soils 19 years after reforestation of Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook) woodland with itself or a native broadleaf species, *Mytilaria laosensis*. The results suggested that tree species transition had a large impact on microbial biomass and a small impact on the composition of the microbial community as indicated by the relative abundance of individual lipid biomarkers. Between November 2011 and October 2012, there was on average 50% greater microbial biomass carbon (C) *measured* by the *fumigation* extraction *procedure* under *M. laosensis* than under *C. lanceolata*. A one-time measurement of phospholipid fatty acids in soil samples collected in May 2012 suggested *M. laosensis* plots had greater content of individual lipid biomarkers than *C. lanceolata* plots. Using a litter manipulation experiment, we found that the increases in content of lipid biomarkers under *M. laosensis* can be attributed to changed litter chemistry. Analysis of soil mineral N pools indicated that there were significantly lower NH_4^+ and NO_3^- pools as well as potential net N mineralization rates in *M. laosensis* soil than in *C. lanceolata* soil. The relationships among N dynamics, soil chemistry and microbial properties were analysed. The results suggested tree species induced differences in soil N mineralization rates and mineral N pools were related to labile C availability, soil C:N ratio and the composition of the microbial community. Our data of mineral N pools and soil $\delta^{15}N$ implied that the transition of land use from *C. lanceolata* to *M. laosensis* leads to an enhanced N retention in the plantation.

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1. Introduction

Nitrogen (N) is an important factor limiting the growth of trees in many forest ecosystems (Vitousek, 2004). Many studies have documented effects of tree species on soil N mineralization rates and N availability in forest ecosystems (Giardina et al., 2001; Lovett et al., 2004). Species effects on soil N cycling can be attributed to both above- and below-ground controls, and may work through multiple mechanisms. Above-ground litterfall provides an important input of C and N to forest soils. Some field studies comparing soil N mineralization beneath different tree species have found strong relationships between above-ground litter quality and soil N dynamics, but poor correlation between litterfall quantity and net N mineralization (Scott and Binkley, 1997). These studies suggested that inter-species variation in litter chemistry (e.g. C:N and

lignin:N) rather than litter quantity regulates the rate of net N mineralization in forest ecosystems (Binkley and Giardina, 1998). Other studies however failed to detect any relationship between soil N transformations and litter quality, but suggested that litter quality may directly or indirectly affect the quality of organic C and N in mineral soil and this could, in turn, affect ecosystem processes including soil N cycling (Finzi et al., 1998; Lovett et al., 2004).

Soil microbial communities regulate key processes that control ecosystem N cycling, and they potentially represent a mechanistic link between the composition of tree species and soil N cycling. Studies have shown that a shift in soil microbial community composition and biomass can impact on ecosystem N cycling (Fraterrigo et al., 2006). For example, fungi typically require less N per unit biomass than bacteria for assimilation (i.e., the C:N ratio of fungi is often higher than the C:N ratio of bacteria), consequently several studies have demonstrated that gross N mineralization and fungi-to-bacteria ratios are negatively correlated (Hogberg et al., 2007). Similarly, the abundance of Gram-positive bacterial biomass was reported to be positively correlated with soil N

mineralization, but the abundance of the arbuscular mycorrhizal fungal biomass was negatively correlated suggesting that Gram-positive bacteria may contribute to a faster cycling of N than arbuscular mycorrhizal fungi (Fraterrigo et al., 2006). On the other hand, microbial biomass and net N mineralization are often inversely related because available N should be assimilated by soil microbes to maintain or form new biomass (Finzi et al., 1998; Lovett and Rueth, 1999; Zak et al., 1986).

Studies examining tree species effects on soil microbial communities and biomass have suggested tree species significantly influence the composition of the soil microbial community (Lejon et al., 2005; Templer et al., 2003; Ushio et al., 2008). Laboratory incubation studies have demonstrated that addition of litter with a high C and/or nutrient availability (low C:N ratio) to agricultural soil activated a copiotrophic microbial community, such as Gram-negative bacteria (Bastian et al., 2009; Potthast et al., 2010). After addition of low quality litter (high C:N ratio) to soil, the ratio of oligotrophic microorganisms, such as Gram-positive bacteria, increased (Bastian et al., 2009; Potthast et al., 2010). However, the impacts of inter-species variation in litter chemistry on soil microbial community composition and biomass in forest ecosystems are still unclear. Especially, broadleaf and needle leaved conifer species differ markedly in their litter chemistry (Yang et al., 2004) and an improved understanding of how these differences impact on soil microbial community and soil N transformations is of both ecological and practical importance.

Broadleaf and Chinese fir (*Cunninghamia lanceolata*) forests are main forest types in subtropical China. Plantations of *C. lanceolata* alone cover 9.11 million hectares and account for more than 18% and 5% of all forest plantations in China and the world, respectively (Huang et al., 2013; Wei et al., 2012). Field observation suggested that growth of *C. lanceolata* in replanted forests is significantly reduced compared with its previous rotation and this problem occurs in many regions (Wei et al., 2012). As a result, plantings of native broadleaved tree species at *C. lanceolata* sites are currently encouraged to provide environmental benefits of enhanced biodiversity and improve soil fertility (Xu, 2011; Yu, 2002). Broadleaf trees usually provide a higher proportion of fine litterfall with lower C:N and lignin:N ratios compared with coniferous *C. lanceolata* (Yang et al., 2004). Plantings of *C. lanceolata* and a broadleaf species in adjoining replicated plots in 1993, after harvest of *C. lanceolata*, provided a unique opportunity to examine the impact of these differences in litter quality on the soil microbial community and soil N transformations.

The objective of this study was to assess the potential impact of a land use transition from *C. lanceolata* to *Mytilaria laosensis* plantation forest on soil microbial community composition and the dynamics of the plant-available N pool. *M. laosensis* (Hamamelidaceae) is an evergreen broadleaf tree and one of the commercial tree species which is increasingly planted following *C. lanceolata* harvest (Wu, 2005). We hypothesized that: (1) a land use transition from *C. lanceolata* to *M. laosensis* plantation would result in increases in soil microbial biomass and the proportion of Gram-negative bacteria because of input of litter with lower C:N and lignin:N ratios; and (2) there would be lower soil net N mineralization rates and N availability under the *M. laosensis* compared with under the *C. lanceolata* because of the changed microbial community composition and increased microbial biomass. Lower soil N availability and N mineralization rates can have consequences for forest N retention (increased soil N concentration) as higher mineral N concentration, if coupled with higher nitrification rates, can potentially lead to greater leaching losses and reduced forest N retention. We therefore determined the impact of land use transition on soil $\delta^{15}N$ as this parameter serves as a valuable integrator of the complex N transformations that occur in the soil (Frank and Evans, 1997). Interpretation of the variation in soil $\delta^{15}N$ has evolved over recent decades (Hobbie and Högberg, 2012). Because discrimination against ^{15}N occurs during each N transfer, i.e., ammonification, nitrification and denitrification, the product of each of these reactions is depleted in ^{15}N relative to the substrate, except when the conversion of the substrate is complete. Consequently, N lost from the soil system during ammonia volatilization, denitrification, and leaching leads to ^{15}N enrichment of the remaining soil. Therefore, soils enriched in ^{15}N generally have more open N cycles with greater rates of N loss than more closed systems (more forest N retention) which have soil less enriched with $\delta^{15}N$ (Hobbie and Ouimette, 2009).

2. Materials and methods

2.1. Site description and experimental design

The experimental site is located at Xiayang forest farm (26°48′N, 117°58′E), northwest Fujian Province, South Eastern China (Huang et al., 2013). The site has a deep red soil classified as a sandy clay *loam* Ferric Acrisol according to the FAO/UNESCO classification. The experimental site has a humid subtropical climate, with short and mild winters in January and February, and long, hot and humid summers between June and October. Spring and autumn are warm transitional periods. Annual precipitation is concentrated in spring and summer. Mean annual rainfall and average temperature in 2011 were 1669 mm and 19.3 °C, respectively.

In October 1992, a second rotation plantation of *C. lanceolata* with an area of 5 ha was harvested using chainsaws at age 29. The understory vegetation was slashed and all surface organic matter was burnt on the site. In April 1993, eight 20 m × 30 m plots were established on hill slopes (230–278 m elevation) at the harvesting site. Two species were then planted in the eight plots as pure forest plantations with four plots of *C. lanceolata* seedlings and four plots of *M. laosensis* seedlings. The trees were spaced at 2 m × 2 m to make up 150 trees per plot (2500 stems ha^{-1}). The plots were separated by more than 10 buffer *tree rows*.

2.2. Measurements in the eight experimental plots

2.2.1. Tree growth and monthly litterfall measurement

In July 2011, tree height and diameter at breast height (DBH, measured at 1.3 m above-ground) were recorded for all trees within plots. The trees were about 2/3 way through their average growth period to maturity. The basal area of a tree was calculated as $\pi \times (DBH/2)^2$. Litterfall was measured monthly from five 0.5 m^2 litter traps, systematically positioned within each plot from July 2011 for 12 months. The trap comprised a bag of 1 mm mesh window screen raised 80 cm above the ground on a PVC frame. The litter from the five traps for each plot was bulked, oven dried at 60 °C and weighed. A sub-sample of each litter type (*C. lanceolata* and *M. laosensis*) was finely ground for determination of C and N concentrations using an Elementar Vario EL III CN analyzer. Lignin concentrations in litter were determined using the Klason lignin procedure (Hatfield et al., 1994).

2.2.2. Monthly dynamics of soil mineral N and microbial biomass in 0–5 cm layer

Monthly variations in soil mineral N pools and microbial biomass were monitored using the techniques described by Raison et al. (1987). Briefly, PVC tubes were driven into the soil to a depth of 5 cm at 12 random locations in each plot. These cores were immediately removed, sieved and bulked to produce 4 samples (each of 3 cores). Each bulked sample was thoroughly mixed, stones and visible roots removed, then sieved (<2 mm) and stored at field