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Effects of exotic plantation forests on soil edaphon and organic matter fractions

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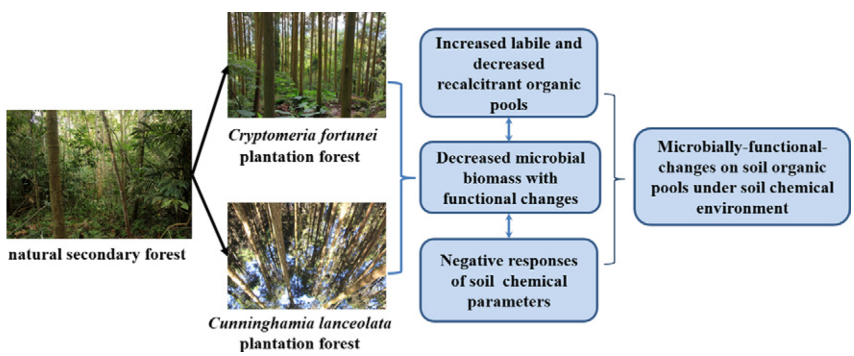
HIGHLIGHTS

- The conversion of secondary natural forest into plantation forests caused soil microbial abundance and function changes.
- Plantation forests altered the efficiencies of microbial substrate use following soil chemical parameter changes.
- Plantation systems have the potential to improve carbon release due to enlarged proportion of soil labile fractions.

GRAPHICAL ABSTRACT



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ABSTRACT

There is uncertainty and limited knowledge regarding soil microbial properties and organic matter fractions of natural secondary forest accompanying chemical environmental changes of replacement by pure alien plantation forests in a hilly area of southwest of Sichuan province China. The aim of this study was to evaluate the impact of natural secondary forest (NSF) to pure *Cryptomeria fortunei* forest (CFF) and *Cunninghamia lanceolata* forest (CLF) on soil organic fractions and microbial communities. The results showed that the soil total phospholipid fatty acids (PLFAs), total bacteria and fungi, microbial carbon pool, organic recalcitrant carbon (C) and (N) fractions, soil microbial quotient and labile and recalcitrant C use efficiencies in each pure plantation were significantly decreased, but their microbial N pool, labile C and N pools, soil carbon dioxide efflux, soil respiratory quotient and recalcitrant N use efficiency were increased. An RDA analysis revealed that soil total PLFAs, total bacteria and fungi and total Gram-positive and Gram-negative bacteria were significantly associated with exchangeable Al^{3+}, exchangeable acid, Al^{3+}, available P and Mg^{2+} and pH, which resulted into microbial functional changes of soil labile and recalcitrant substrate use efficiencies. Modified microbial C- and N-use efficiency due to forest conversion ultimately meets those of rapidly growing trees in plantation forests. Enlarged soil labile fractions and soil respiratory quotients in plantation forests would be a potential positive effect for C source in the future forest management. Altogether, pure plantation practices could provoke regulatory networks and functions of soil microbes and enzyme activities, consequently leading to differentiated utilization of soil organic matter fractions accompanying the change in environmental factors.

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1. Introduction

Secondary forest as a major forest resource covers an area of approximately 62% of the land surface in China (Zhu and Liu, 2007). Nevertheless, there are mounting demands for timber supplied from the forests. Thus, extensive areas of hilly secondary forests in Southwest China have been replaced by pure plantation forests since 1950s (Bao, 2000). Today, represented by *Cryptomeria fortunei* forest (CFF) and *Cunninghamia lanceolata* forest (CLF) in Sichuan province, China, the majority of natural evergreen broad-leaved forests have been replaced by pure, fast-growing plantations (Liu et al., 2009). Stimulated development of pure plantation forest due to rapid urbanization, industrialization, population growth and infrastructure development in China may translate to a quick profit but at the expense of forest ecological functions. Unfortunately, the growth of pure plantations with fast-growing exotic species impacts environmental variation and degradation (Burton et al., 2010; Parfitt et al., 2003), which has led to a decline in the soil environment through changes in the quantity or quality of carbon and nitrogen (Rothstein et al., 2004), direct chemical interference (Zhang and Fu, 2009), soil acidification resulting from the removal of plant materials and nitrogen (N) cycling (Zhou et al., 2014), and soil microbial communities and biomass (Huang et al., 2013). Indeed, alien plantation forest can cause large uncertainties in projections of soil nutrient and edaphon feedback with consequent changes in the soil chemical environment.

Soil microorganisms play a central role not only in decomposition, nutrient mineralization and nearly all soil ecological processes in forest ecosystems (Chen et al., 2013) but also in forest ecosystem function and the sustainability of soil nutrients (Burton et al., 2010). The interactions between the microbial community and biochemical processes in soil and their variations from forest to forest have recently aroused increasing attention (van der Putten, 2010). Some experiments have suggested that tree species significantly influence the composition of the soil microbial community (Huang et al., 2013; Lejon et al., 2005; Ushio et al., 2008). Soil microbial traits are more sensitive to land use changes than soil physicochemical properties (Romaniuk et al., 2012). Additionally, changes in soil microbial community composition are positively correlated with soil nutritional stress and negatively with resource availability (Fierer et al., 2003; Moore-Kucera and Dick, 2008). Understanding how environmental changes affect soil microbial communities will help to predict how biogeochemical cycles respond to plantation conversion more broadly and enhance the sustainable management of plantations (Chen et al., 2013).

Soil enzyme activities are often used as indices of microbial growth and activity, which directly mediate carbon and nitrogen cycling in soil. In spite of numerous studies reporting on links microorganism and enzymatic activities (Acosta-Martínez et al., 2007), there have been controversial and contradictory conclusions regarding the contribution of microbes to the activities of extracellular enzymes (Phillips et al., 2014; Talbot et al., 2013). Identifying the relative contribution of specific soil organic pool availability to enzymatic degradation is an important step toward understanding the potential mechanisms involved in soil ecological processes.

Soil organic matter (SOM), characterized in different pools of soil carbon and nitrogen with a variety of chemical complexity (Davidson and Janssens, 2006), is profoundly affected by forest conversion (Qi and Yang, 2017). Moreover, soil organic carbon has shown sensitivity to land cover changes (Wiesmeier et al., 2012), which shape both C inputs and losses (Lu et al., 2013) and may potentially influence ecosystem C cycling and atmospheric CO_2 concentration. Studies have shown that SOC experimentally exposed to species-related land use practices demonstrate a range of responses in soil C–from loss (Shi et al., 2009) to increase (Liao et al., 2010)–leaving the question of land cover effects inconclusive. Furthermore, Qi and Yang (2017) emphasized the pivotal role of soil microbes in cycling of SOC decomposition response to forest conversion. Soil pH is another crucial factor to alter soil microbial activities and decomposition of organic matter due to different plant residue input (Xu et al., 2006). Thus, it is essential to thoroughly understand soil organic matter dynamics following disturbances on soil microorganisms and pH, especially for the long-time phases of succession (Foote and Grogan, 2010).

Hitherto, several studies have attempted to elucidate the effects of forest conversion on soil biota in different climatic zone (Curlevski et al., 2010; Vitali et al., 2016; Zhang et al., 2017). Together, these results indicated composition, structure and potentially function activity of soil microbial communities under pure plantation forest were largely different from those of natural forest, and these differences are strongly controlled by aboveground plant input and soil environmental conditions. Changes in soil microorganism detected by phospholipid fatty acid analysis (PLFA) demonstrated a decreased abundance of fungal and bacterial (Yu et al., 2012; Zhang et al., 2017). However, these studies were based on the soil biota that offered little detail on soil organic compound-driven microbial community functions. Moreover, little information is currently available on the effects of forest conversion on changes of aboveground-vegetation-driven SOM fractions. A more thorough understanding of forest conversion on SOC pool-driven soil microbial functions and communities is needed if we are to illuminate the potential mechanisms of the effects on forest conversion on soil ecological processes, which ultimately may be a positive guide in a trajectory regarding management of forest ecosystems.

Specifically, the aim of this study to test the following hypotheses: (i) the responses of soil microbes and organic pools will be potentially different between natural secondary and plantation forests; (ii) pure alien plantation forests will accelerate the depletion of soil active compound substrate; (iii) pure exotic-species forests will alter the soil N use efficiency by microbes due in part to high N requirements.

2. Materials and methods

2.1. Study site and sampling

The study site is on the Hongya forest farm (102°49′–103°32′ E, 29°24′–30°00′ N, 600–3800 m above sea level), in Hongya county, Sichuan Province China, which is a hilly region with mountain yellow soil (Chinese Soil Taxonomy). This area is characterized by a subtropical humid monsoon climate with a warm and rainy summer and a dry and cold winter. The mean annual temperature is 9.7 °C, with the minimum temperature occurring during January (−4 °C) and the maximum temperature occurring during July (38.5 °C). The frost-free period fluctuates approximately 307 d, with an early frost in October and late frost in March. This area receives a mean annual precipitation of 1435 mm with over 50–69% falling between June and September, and the relative humidity is 85–90%. Fog occurs in this area on 121–279 days annually (Bao, 2000).

Wawushan farm forest (E102.58°and N29.38°, 1800 m a.s.l.), in Hongya forest farm, was chosen in our present study. This farm forest sporadically occupies an area of 22 km^2 secondary natural forest and 16 km^2 of plantation forest, in which *Cryptomeria fortunei* and *Cunninghamia lanceolate* are the dominant introduced trees (Local government issued data). The NSF adjacent to CFF and CLF was included as a reference of a relatively stable ecosystem. All the plantation stands were in their first rotation. The main features and management history of each forest type are presented in Table 1.

In 1980, 30 fixed and fenced 20 × 20 m plots designed for evaluating vegetation restoration were preserved after deforestation in 1956 (Bao, 2000). Six fixed plots were chosen in natural secondary forest and considered as reference forests with virtually no anthropogenic impacts. Six fixed 20 × 20 m plots were randomly selected from 30 plots in the planted pure CFF and CLF, and therefore, a total 18 plots were established for sample collection. The first soil samples were collected from the natural secondary forest in September 1980 and analyzed for basic soil parameters (see Table 2). There were no significant