Forest Ecology and Management 422 (2018) 161–171

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Effects of conversion from a natural evergreen broadleaf forest to a Moso bamboo plantation on the soil nutrient pools, microbial biomass and enzyme activities in a subtropical area

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ARTICLE INFO

Keywords:
Evergreen broadleaf forest
Land-use conversion
Microbial biomass
Moso bamboo plantation
Soil nutrient form
Soil enzyme

ABSTRACT

Converting natural forests to plantations would markedly change soil physiochemical and biological properties, as a consequence of changing plant vegetative coverage and management practices. However, the effects of such land-use change on the soil nutrient pools and related enzymes activities still remain unclear. The aim of this study was to explore the effects of conversion from natural evergreen broadleaf forests to Moso bamboo plantations on the pool sizes and forms of soil N, P and K, microbial biomass, and nutrient cycling related enzyme activities. Soil samples from four adjacent evergreen broadleaf forest-Moso bamboo plantation pairs were collected from a subtropical region in Zhejiang Province, China. The soil organic C (SOC), total N (TN), total P (TP) and total K (TK) concentrations and stocks and different N, P and K forms were measured, and the microbial biomass C (MBC), microbial biomass N (MBN), microbial biomass P (MBP) and four soil enzymes (protease, urease, acid phosphatase and catalase) were determined. The results showed that converting broadleaf forests to Moso bamboo plantations decreased the concentration and stock of SOC but increased those of TK in both soil layers (0–20 and 20–40 cm), and such land-use change increased the concentration and stock of TN and TP only in the 0–20 cm soil layer ($P < 0.05$). This land-use conversion increased the concentrations of NH_4^+-N, NO_3^--N, resin-P_i, $NaHCO_3$-P_i, NaOH-P_i, HCl-P_i, available K and slowly available K, but decreased the concentrations of water-soluble organic nitrogen (WSON), $NaHCO_3$-P_o and NaOH-P_o ($P < 0.05$). Further, this land-use change decreased the microbial biomass and activities of protease, urease, acid phosphatase and catalase ($P < 0.05$). In addition, the acid phosphatase activity correlated positively with the concentrations of MBP and $NaHCO_3$-P_o, and the activities of urease and protease correlated positively with the concentrations of MBN and WSON ($P < 0.01$). To conclude, converting natural broadleaf forests to Moso bamboo plantations had positive effects on soil inorganic N, P and K pools, and negative effects on soil organic N and P pools, and on N- and P-cycling related enzyme activities. Therefore, management practices that increase organic nutrient pools and microbial activity are needed to be developed to mitigate the depletion of organic nutrient pools after the land-use conversion.

1. Introduction

Land-use conversion can significantly affect the soil physicochemical and biological properties (Yang et al., 2004; Don et al., 2011; Moghimian et al., 2017). Over the past few decades, in order to gain higher economic benefits and to supply the growing demands of timber, paper and fuel, among other commodities, the conversion from natural forests to plantations is becoming more frequent (Burton et al., 2007; Li et al., 2014; Hu et al., 2018). To increase the growth of plantations after land-use change, intensive management practices, mainly including fertilization, understory vegetation control, and deep ploughing, have been commonly adopted (Li et al., 2013; Zhang et al., 2015a; Dangal

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https://doi.org/10.1016/j.foreco.2018.04.022
Received 23 February 2018; Received in revised form 8 April 2018; Accepted 10 April 2018
0378-1127/

et al., 2017; Zhang et al., 2017a). Various studies have revealed that the intensive management practices applied can significantly change the soil pH, nutrient status, and microbial biomass and community composition (Li et al., 2013; Yuan et al., 2015; Xie et al., 2017), and consequently influence soil fertility and plant growth (Pransiska et al., 2016; Tiecher et al., 2017). Therefore, it is great of significance to investigate the effects of land-use change and subsequent management practices on the pool sizes and forms of soil nutrients and associated enzyme activities.

The effects of land-use change from natural forest to plantation on soil nutrient status and associated enzyme activities may include the following: (1) the input of exogenous fertilizer can have a direct effect on the pool sizes and forms of soil nutrients (Chang et al., 2007; Sainju et al., 2012; Yang et al., 2017; Li et al., 2018), and (2) the differences in chemical composition and root exudates of different vegetation types may change the microbial growth environment, which affects microbial biomass and soil enzyme activity (Yang et al., 2010; Li et al., 2011; Wang et al., 2013; Yuan et al., 2015). For example, the input of exogenous organic fertilizer and root exudates can increase the availability of water-soluble nitrogen (N) (Scott and Rothstein, 2011; Sainju et al., 2012; Li et al., 2017a). In addition, an increase in N fertilizer application can reduce soil enzyme activity and microbial biomass (Shen et al., 2010; Zhang et al., 2015b). Previous studies showed that understory vegetation plays important roles in cycling nutrients and decreasing soil erosion (Fukuzawa et al., 2006; Zhang et al., 2010).

The classification of soil nutrients can help to determine soil nutrient status (Ross et al., 1999; Yang et al., 2010). Different forms of N, such as NH_4^+-N, NO_3^--N and water-soluble organic N (WSON), can jointly indicate the N supply capacity of soils (Schimel and Bennett, 2004; Chen and Xu, 2008; Yan et al., 2008; Wu et al., 2010). The different forms of phosphorus (P) in soils are formed through the combination of P with different mineral components and can significantly affect N- and P-cycling (Yang et al., 2010; Wei et al., 2017). In addition, the soil potassium (K) supply is closely associated with the transformation rate of different forms of K in soils (Darunsontaya et al., 2012). The different forms of nutrients respond differently to land-use change. For example, Ouyang et al. (2013) reported that after conversion from wetland to paddy field, the total K concentration increased but the available K concentration decreased in soils. Yang et al. (2004) reported that converting secondary forests to rubber plantations increased the concentration of inorganic N but decreased the concentration of total N. In addition, Yang et al. (2010) found that converting natural forests to larch plantations increased the concentrations of total P (TP) and inorganic P (IP) but decreased the concentrations of microbial biomass P (MBP) and organic P (OP). Therefore, exploring the responses of different forms of soil nutrients to land-use change will enable us to elucidate the mechanisms associated with the land-use conversion effects on the soil nutrient status.

Soil microbes play an important role in the decomposition and mineralization of soil organic matter (Malchair and Carnol, 2009; Guo et al., 2016; Ge et al., 2017; Li et al., 2017b; Luo et al., 2017). Soil enzymes are closely related to the transformation of soil nutrients, and their activities are closely associated with the level of soil organic matter, soil physicochemical properties and soil microbial biomass (Xu et al., 2010; Liu et al., 2015; Chavarría et al., 2016; Ma et al., 2016). For example, Bhattacharyya et al. (2005) found that there was a pronounced linear correlation between soil urease and microbial biomass. Additionally, Yang et al. (2010) found that acid phosphatase activity was positively correlated with the concentrations of $NaHCO_3$-P_i, $NaHCO_3$-P_o, and MBP in a subtropical forest soil. Land-use change can markedly affect the soil enzyme activity as well as the soil microbial biomass and nutrient forms (Dawoe et al., 2014; Guo et al., 2016). However, it remains unclear whether the changes in soil enzyme activity caused by land-use change are closely linked with the changes in soil microbial biomass or nutrient forms.

Natural evergreen broadleaf forests contribute to maintain biodiversity; these forests are considered to be an important vegetation type in the subtropical regions of China (Wang et al., 2007). However, large areas of natural forests have been transformed into plantations over the past two decades (Yan et al., 2015; Chen et al., 2017), most commonly into bamboo plantations (Guan et al., 2015). The area of Moso bamboo (*Phyllostachys edulis*) plantations has increased to 4.2 million ha due to their substantial economic benefit (Yuen et al., 2017). At present, most of the Moso bamboo plantations are intensively managed, with the application of fertilizers, the removal of understory vegetation, and tillage (Li et al., 2013; Yang et al., 2017). It is expected that conversion from natural evergreen broadleaf forests to Moso bamboo plantations, in combination with subsequent management practices, will markedly change the soil physical, chemical and biological characteristics. However, the effects of the aforementioned land-use change on soil nutrient pools and enzyme activities remain unclear. Therefore, the purposes of the present study were (1) to analyze the effects of conversion from evergreen broadleaf forests to Moso bamboo plantations on the pool sizes and different forms of soil nutrients, (2) to investigate the aforementioned land-use conversion effects on the soil microbial biomass and activity of soil enzymes regarding nutrient cycling, and (3) to reveal the relationship between soil enzyme activity and the different forms of soil nutrients or soil microbial biomass.

2. Materials and methods

2.1. Experimental site

The study was carried out in Congkeng (30°14′N, 119°42′E), Hangzhou, Zhejiang, China. The study area belongs to a subtropical monsoon climate zone with four distinct seasons, with an average annual temperature of 15.8 °C and average annual precipitation of 1420 mm. The annual sunshine duration and frost-free period of this site are 1946 h and 239 days, respectively. The elevation of the study area is approximately 150 m. The soils at this experimental site are classified as Ferralsols (World Reference Base for Soil Resources (WRB) 2006).

We chose two different land-use types, i.e., natural evergreen broadleaf forests and Moso bamboo plantations, to investigate the differences in soil properties. The main tree species in the natural evergreen broadleaf forests were *Cyclobalanopsis glauca*, *Castanopsis eyrie*, and *Castanopsis sclerophylla*, which accounted for approximately 70% of the canopy cover. The understory vegetation in this natural forest was mainly *Litsea cubeba, Lindera glauca*, and *Camellia cuspidata*, of which the surface cover was approximately 85%. Part of the natural evergreen broadleaf forests had been transformed into Moso bamboo plantations. The Moso bamboo plantation in the present study was established in 2004. The bamboo plantation had been managed intensively for 11 years after the land-use conversion. The stocking density in the bamboo plantation was 3000 stems ha^{-1}, with 10.1 cm mean diameter at breast height. Every year from late June to early July the bamboo plantation was fertilized with urea (200 kg N ha^{-1}), superphosphate (60 kg P ha^{-1}), and potassium chloride (70 kg K ha^{-1}). The fertilizer was usually applied on the soil surface, followed by plowing to a depth of 30–35 cm. The understory vegetation in the bamboo plantation was manually removed each year.

2.2. Experimental design and soil sampling

A paired-plot approach was adopted to investigate the effects of land-use conversion on soil properties. One paired-plot included two adjacent plots, i.e., one in the natural evergreen broadleaf forest and the other in the Moso bamboo plantation. Each paired plot had the same geographic and environmental factors, including soil type, slope (15–20°) and aspect (south). We selected four different locations within ~3 km^2 in the area described above to establish four different paired plots in April 2015; the plot size was 20 m × 20 m (400 m^2). Within one