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Recovery time of soil carbon pools of conversional Chinese fir plantations from broadleaved forests in subtropical regions, China

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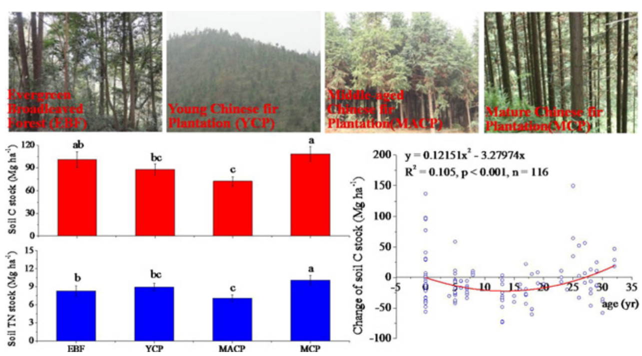
HIGHLIGHTS

- Soil carbon stocks decreased initially and finally restored after subtropical forest conversion.
- The recovery time of soil carbon stocks after subtropical forest conversion was 27 years.
- The forest conversion didn't affect the soil carbon pool in the long-term.
- Soil total nitrogen had a similar trend with soil carbon stocks after subtropical forest conversion.
- Soil carbon stocks were positively correlated to soil nitrogen stocks and soil C:N ratio.

GRAPHICAL ABSTRACT



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ABSTRACT

The conversion from natural forest to plantation has been widely applied, with consequences on ecosystem carbon pool. The experimental results of changes of soil carbon stocks after forest conversion are often contradictory. Moreover, the recovery time of soil carbon stocks after forest conversion varies among different sites. To examine the changes of soil carbon stocks following the forest conversions in the long-term and to estimate the recovery time, we selected 116 subtropical forests, including 29 pair-wise replicates for evergreen broadleaved forests (EBF, 40–100-year-old), young Chinese fir plantations (*Cunninghamia lanceolata*) (YCP, 4–8-year-old), middle-aged Chinese fir plantations (MACP, 13–20-year-old), and mature Chinese fir plantations (MCP, 23–32-year-old), and estimated soil carbon stocks. Soil carbon stocks of YCP and MACP decreased in average 12.5 and 28.7 Mg ha^{-1} compared with EBF, and showed no variation between MCP and EBF. Soil carbon stocks were positively correlated to soil total nitrogen stocks and C:N ratio. Our results showed that the forest conversions didn't cause a variation of soil carbon stocks in the long-term, although there was a short-term decline after conversion. The recovery time of soil carbon stock is 27 years. These results indicate that the conversion from evergreen broadleaved forests to Chinese fir plantations in subtropical region of China causes soil carbon release in early stage, but has no effect on soil carbon stocks in the long-term. Prolonging the rotation period (>27 years) would offset the adverse effects of the forest conversion on soil carbon stocks, and be critical in alleviating global climate change.

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1. Introduction

Soil organic carbon stock, which is a major component of the terrestrial ecosystem carbon reservoir, plays a key role in global carbon dynamics (Grace, 2004). The amount of soil organic carbon is as much as three times the size of the atmospheric pool and 4.5 times the size of the biotic pool (Lal, 2004). Moreover, CO_2 emission from soils is one of the largest fluxes in the global carbon cycle (Schlesinger and Andrews, 2000). Therefore, even slight changes in the soil organic carbon pool can have a large effect on atmospheric CO_2 concentration and global carbon budget (Schlesinger and Andrews, 2000; Amundson, 2001). Accurate quantify of soil organic carbon stock is essential to understand the global carbon cycle (Morisada et al., 2004; Wang et al., 2013c).

The forest conversion of natural forest to plantation and agriculture is occurring globally and results in variations of soil organic carbon stocks (Guo and Gifford, 2002; Paul et al., 2002; Li et al., 2012). Although the loss of soil carbon stocks by the conversion of natural forest to plantation is well known (Guo and Gifford, 2002; Murty et al., 2002; de Blecourt et al., 2013; Ferré et al., 2014; Wei et al., 2014; van Straaten et al., 2015), a few studies reported that no change of soil carbon stocks after forest conversion (Khasanah et al., 2015; Lewis et al., 2016). It is widely accepted that the changes of soil carbon stocks are highly time-dependent, with an initial decline of soil organic carbon stocks but a finial recovery in the long-term (Paul et al., 2002; Mao et al., 2010; Song et al., 2014; Khasanah et al., 2015; Li et al., 2015).

The recovery time of soil organic carbon stocks varied among different ecosystems and sites, ranging from 15 years to several centuries. Mao et al. (2010) reported that soil organic carbon stocks recovered to the initial level after 15 years. The recovery time of soil organic carbon stocks after forest conversion reported by Li et al. (2015) is >26 years. Paul et al. (2002) found that soil carbon content decreased by 3.5% per year during the first 5 years and increased after 30 years of afforestation. Guo and Gifford (2002) suggested that soil carbon stocks restored to original level in plantations >40 years old after forest conversion. Forest particulate organic matter carbon concentration declined after 20 years of cultivation and then recovered after 50 years of cultivation (Anaya and Huber-Sannwald, 2015). Soil carbon stocks of reforested Douglas-fir plantation will take 600 years to recover similar value of soil carbon stocks of non-managed stands (Blanco, 2012).

Moreover, most of results on the changes of soil organic carbon stocks after forest conversion were derived from tropical, temperate, and boreal forests. Li et al. (2015) evaluated the changes of soil organic carbon stocks following the conversion from a second coniferous forest to a pine plantation in Yunnan province, China. de Blecourt et al. (2013) also researched the change of soil organic carbon stocks after conversion from secondary forest to rubber plantation in Yunnan province, China. The change of carbon stocks after conversion from natural forest to conifer plantation was studied in New Brunswick, Canada (Fleming and Freedman, 1998). However, it is still lack of the researches in the effect of subtropical forest conversion on soil organic carbon stocks (Chen et al., 2005; Wei and Blanco, 2014). Determining the recovery time to original level of soil organic carbon stocks after conversion from native forest to plantation would be helpful to optimize the management practices to resolve the tradeoff between soil organic carbon pool and wood production in the plantation. Long-term research on soil carbon stock following vegetation conversion is needed to correctly understand the dynamics of soil carbon stocks following forest conversion.

Soil nitrogen content and dynamics is an important driver for the long-term soil carbon dynamics (Luo et al., 2004; Finzi et al., 2006). Increasing nitrogen supply would influence ecosystem carbon sequestration (Lutze and Gifford, 1995; Prescott, 2010; Maaroufi et al., 2015). Similarly, nitrogen stored in ecosystems determines the long-term trend of ecosystem carbon sinks, in that increases in total ecosystem nitrogen enable organic matter to accumulate in both vegetation and soils (Rastetter et al., 1997). Consequently, it is imperative to quantify soil nitrogen stocks over time following the conversion of native forests to plantations.

Over the past five decades, there has been a large scale conversion from native forests to plantations in China, largely due to economic growth and enhanced demands for timber. The area of plantations in China now exceeds 69 million hectares, constituting about 73% of the global plantation area (SFA, 2014). The conversion from native forests to plantations has significant influence on soil properties, such as soil chemistry (Yang et al., 2013), labile soil organic carbon and enzyme activity (Wu et al., 2010; Wang et al., 2013b), soil microbial diversity (Yu et al., 2012), and soil fertility (Wang et al., 2011). However, there have been few studies focused on the changes of soil carbon stocks following the forest conversion (Chen et al., 2013). Moreover, the high spatial and temporal heterogeneity of soil carbon content and stocks (Nave et al., 2010), results in difficulty to detect the effects of forest conversion on soil carbon stocks within an individual site. Studies with diverse sites and large scales would be needed to identify underlying changes of soil carbon stocks following the forest conversion and avoid false conclusions.

To investigate the long-term effects of forest conversion on soil organic carbon and total nitrogen stocks in the subtropical area of China, we selected 29 pair-wise forest stands, including evergreen broadleaved forest, young, middle-aged, and mature Chinese fir plantations, and measured soil carbon and nitrogen concentrations and soil bulk density at five levels to 1 m depth. We hypothesized that the forest conversion from native broadleaved forests to plantation resulted in an initial decline of soil carbon stock, and finally recovered with forest development. We also quantified the recovery time of soil carbon stocks after forest conversion.

2. Materials and methods

2.1. Study area

The study was conducted in Hunan Province (108°47′–114°15′ E, 24°38′–30°08′ N) situated in mid-subtropical zone of China (Fig. 1). Hunan Province is located at the transition zone from Yunnan-Guizhou plateau to the lower mountains and hills along the southern bank of the Yangtze River. The altitude ranges from 21 m to 2122 m above sea level. The region is typical of a humid mid-subtropical monsoon climate. The mean annual temperature is 16–18 °C with mean minimum in January and mean maximum in July. The mean annual precipitation is 1200–1700 mm occurring mostly between April and October. The soil derived from shale and slate is red-yellow and is classified as Plinthudults, a Subgroup of Ultisols according to U.S. Soil Taxonomy (Wang et al., 2013a). The soil also exhibits a grayish upper horizon found above the reddish argillic horizon.

The natural forest is evergreen broadleaved forest typical of subtropics, with *Castanopsis fargesii* Franch., *C. eyrei* (Champ.) Tutch., *Lithocarpus glabra* Rehd., *Quercus spp*., and *Cyclobalanopsis glauca* (Thunb.) Oerst. as the dominant species. Large areas of the native forests in this region were clear-cutting for timber production. The area was slashed and burned, which removed all surface organic matter. The conversion from native broadleaved forest to plantations was accomplished by planting fast-growing and highly productive commercial tree species, especially *Cunninghamia lanceolata* (Lamb.) Hook.

We selected 116 stands located at 29 pair-wise sites on each of four forests – the natural evergreen broadleaved forests (EBF), young Chinese fir plantations (YCP), middle-aged Chinese fir plantations (MACP), and mature Chinese fir plantations (MCP) (Fig. 1). YCP, MACP and MCP, with the same history of land use, were established after clear-cutting and slash-burning the originally existing natural evergreen broadleaved forests. The average ages of YCP, MACP and MCP were 6, 16 and 28 years old. Distance between forest stands representing each forest type was >1 km. The main characteristics of selected forests, such as age, slope, elevation, canopy closure, etc., are