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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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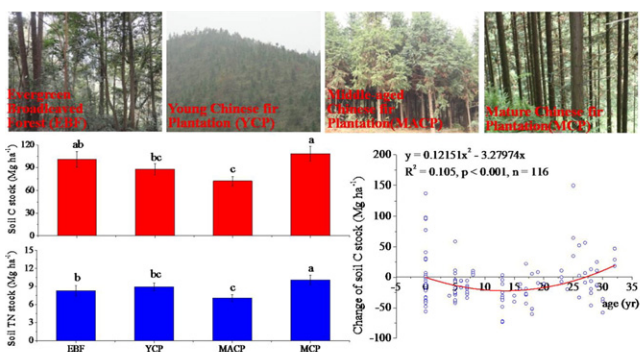
HIGHLIGHTS

- 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

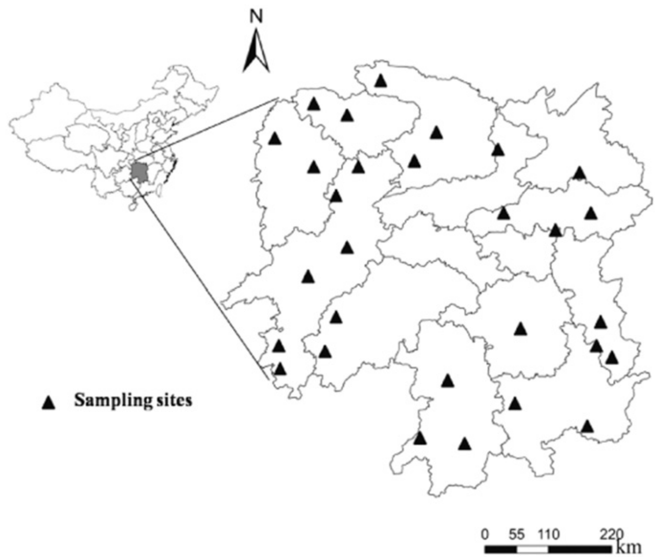

Fig. 1. Location of 29 sampling sites of different forest stands distributed in Hunan Province, China. In each site, evergreen broadleaved forest (EBF), young (YCP), middle-aged (MACP) and mature Chinese fir plantation (MCP) were sampled.

shown in Table 1. The dominant species in tree, shrub and herbaceous layers are listed in Table 2.

2.2. Soil sampling and analysis

A 1000 m^2 (20 m × 50 m) plot was established in each selected forest stand. Soil samples were taken at 0–10, 10–20, 20–30, 30–50, and 50–100 cm depths using a stainless-steel cylinder of 5 cm diameter. In each plot, after the removal of the litter layer and organic horizon, ten soil cores at the same soil depth were collected randomly to pool into a composite soil sample. Then, a soil sample was taken from each of the five soil depths in each plot. All samples were passed through a 2-mm sieve after removing the organic fragments (plant material and root residues). Each sample was air-dried and stored at room temperature for determining soil organic carbon and total nitrogen concentration. Soil samples were ground to 0.25 mm before chemical analysis. Organic carbon and total nitrogen concentrations of all composite soil samples were measured with a C/N analyzer (Elementar, Germany).

Soil bulk density of each soil layer was measured using a soil bulk sampler with a 5.0 cm diameter and 5.0 cm high stainless-steel cutting ring in each plot. Three soil cores (replicates) in each soil layer in each plot were sampled. The original volumes of each soil core and its dry mass after drying at 105 °C were measured. The coarse fractions (soil fraction > 2 mm) of each sample were also recorded.

Table 1
Characteristics of sampled forest stands.

Characteristics	EBF	YCP	MACP	MCP
Age (years)	75 ± 7	6 ± 1	16 ± 1	28 ± 1
Slope (°)	19.9 ± 2.2	18.6 ± 1.4	14.8 ± 1.4	18.3 ± 1.3
Elevation (m)	545 ± 81	316 ± 20	488 ± 45	391 ± 40
Canopy closure (%)	71 ± 2	60 ± 3	65 ± 2	65 ± 2
Community height (m)	18.6 ± 0.7	6.1 ± 0.5	12.2 ± 0.5	16.2 ± 0.5
Average tree height (m)	11.0 ± 0.7	5.2 ± 0.3	9.9 ± 0.5	14.9 ± 0.6
Average DBH (cm)	15.2 ± 1.2	6.7 ± 0.4	13.4 ± 0.5	18.4 ± 0.8
Stand density (stems ha^{-1})	1725 ± 257	2797 ± 154	1714 ± 118	1405 ± 133

EBF, YCP, MACP, MCP denote evergreen broadleaved forest, and young, middle-aged, and mature Chinese fir plantation. Data were mean ± SE.

Table 2
Dominant species of sampled forest stands.

Forest	Tree layer	Shrub layer	Herbaceous layer
EBF	*Castanopsis fargesii*	*Maesa japonica*	*Dicranopteris linearis*
	Castanopsis sclerophylla	*Eurya nitida*	*Urena lobata*
	Lithocarpus glabra	*Sapium discolor*	*Diplopterygium chinense*
	Cyclobalanopsis glauca	*Quercus fabri*	*Carex nemostachy*
			Arthraxon hispidus
YCP	*Cunninghamia lanceolata*	*Maesa japonica*	*Parathelypteris glanduligera*
		Rhus chinensis	*Woodwardia japonica*
		Litsea cubeba	*Miscanthus sinensis*
			Dicranopteris linearis
			Herba lophatheri
MACP	*Cunninghamia lanceolata*	*Rhus chinensis*	*Miscanthus floridulu*
		Lindera glauca	*Dicranopteris linearis*
		Mussaenda esquirolli	*Herba lophatheri*
		Maesa japonica	*Carex tristachya*
MCP	*Cunninghamia lanceolata*	*Maesa japonica*	*Parathelypteris glanduligera*
		Mussaenda esquirolli	*Dicranopteris linearis*
		Rhus chinensis	*Herba lophatheri*
		Ilex aculcolata	

EBF, YCP, MACP, MCP denote evergreen broadleaved forest, and young, middle-aged, and mature Chinese fir plantation.

2.3. Carbon and nitrogen stock calculation

Soil organic carbon stocks were calculated using the following equation:

$$CS_{soil}\left(\mathrm{Mg\,ha^{-1}}\right) = \sum_{i=1}^{n} BD_i \times Cconc_i \times D_i \times (1-S) \tag{1}$$

Where CS_{soil} is the carbon stock of soil (Mg ha^{-1}), BD_i is the soil bulk density in i layer (g cm^{-3}), $Cconc_i$ is the soil organic carbon concentration in i layer (%), D_i is the soil thickness of i layer, i is the layer number of soil, and S is the coarse fraction (%, soil fraction > 2 mm).

Soil total nitrogen stocks were calculated as follows:

$$TNS_{soil}\left(\mathrm{Mg\,ha^{-1}}\right) == \sum_{i=1}^{n} BD_i \times TNconc_i \times D_i \times (1-S) \tag{2}$$

Where TNS_{soil} is the total nitrogen stock of soil (Mg ha^{-1}), $TNconc_i$ is the soil total nitrogen concentration in i layer (%), BD_i, D_i, i and S are the same with above.

The changes in soil carbon and total nitrogen stocks of Chinese fir plantations compared to EBF were calculated by the following equation:

$$CSC_{change} = CSC_{CP} - CSC_{EBF} \tag{3}$$

$$CSN_{change} = CSN_{CP} - CSN_{EBF} \tag{4}$$

Where CSC_{change} and CSN_{change} are the changes of soil carbon and total nitrogen stocks following the forest conversion, respectively; CSC_{CP} and CSN_{CP} are the soil carbon and total nitrogen stocks of Chinese fir plantations at different development stages, respectively; CSC_{EBF} and CSN_{EBF} are the soil carbon and total nitrogen stocks of EBF. If CSC_{change} or $CSN_{change} < 0$, this indicates that carbon or nitrogen is released from the soil after the forest conversion; if CSC_{change} or $CSN_{change} > 0$, this indicates that carbon or nitrogen sequesters into the soil after the forest conversion.

2.4. Statistical analysis

The changes of soil carbon stocks of every stands compared to the average value of soil carbon stocks of natural evergreen broadleaved forests were calculated following Eq. (3). Multiple regression analysis was performed with forest ages and the changes of soil carbon stocks of every stands, to determine the time needed to recover to the original level of soil carbon stocks before the conversion from natural ever-green broadleaved forest to Chinese fir plantation, using OriginPro 8.5 (OriginLab Corporation).

The effects of forest conversion on soil bulk density, organic carbon and total nitrogen concentrations, C:N ratio, carbon and total nitrogen stocks were analysed via multivariate analysis of covariance with soil depth and forest stage as the main factors and initial soil carbon stocks of EBF as covariate. The changes of carbon stocks were tested using Student's *t*-test. The relationship between soil organic carbon stocks and total nitrogen stocks was examined using Pearson linear regression. Pearson linear regressions were also analysed to assess the relationships between soil organic carbon stocks and soil C:N ratio. All effects were considered significant at the $p < 0.05$ level. Statistical analysis was performed using IBM SPSS Statistics Release 15.0 (SPSS Inc.).

3. Results

3.1. The pattern of soil carbon stocks

There were significant differences in soil bulk density following the conversion from evergreen broadleaved forests to Chinese fir plantations, ranging from 0.81 to 1.24 g cm^{-3} (Fig. 2A, Table 3). When compared with evergreen broadleaved forests, soil bulk densities in YCP, MACP and MCP increased by 19.4, 13.5 and 14.4%, respectively. Moreover, soil bulk density increased significantly with the increases of soil depth (Fig. 2). Soil organic carbon concentrations varied significantly following the forest conversion in the order: EBF > MCP > MACP = YCP, ranging from 6.72 to 41.05 g kg^{-1} (Fig. 2B, Table 3).

Soil carbon stocks varied significantly following the conversion from evergreen broadleaved forests to Chinese fir plantations, ranging from 77.7 to 106.5 Mg ha^{-1} (Fig. 3A). Soil carbon stocks of MCP and EBF were significantly greater than that of MACP. There were significant differences among soil carbon stocks in different soil layers. Soil carbon stock in the 0–10 cm soil layer was more than those in the 10–20 cm and 20–30 cm layers.

The initial values of soil carbon stocks of EBF had a significant effect on soil carbon stocks of Chinese fir plantations after forest conversion, but there were no significant effects of initial soil carbon stocks on soil bulk density and carbon concentration (Table 3).

3.2. The pattern of soil total nitrogen stock

There were significant differences among soil total nitrogen concentrations following the forest conversion, ranging from 0.75 to 2.98 g kg^{-1} (Fig. 2C, Table 3). Soil total nitrogen concentrations in YCP and MACP decreased significantly by 28.9 and 28.2%, respectively, compared with EBF. Soil total nitrogen concentrations decreased significantly with the increases of soil depth. Soil C:N ratio varied significantly following the conversion, ranging from 12.1 to 14.0 at the depth of 0–10 cm (Fig. 2D, Table 3). Soil C:N ratios also decreased with the increase of soil depth. The initial values of soil carbon stocks had no effects on soil total nitrogen concentration and C:N ratio (Table 3).

There were significant differences among soil total nitrogen stocks following the conversion, ranging from 7.7 to 10.0 Mg ha^{-1} (Fig. 3B). Soil total nitrogen stocks decreased significantly with the increase of soil depth. Soil total nitrogen stock in 0–10 cm soil layer was significantly more 40.2 and 68.2% than that in 10–20 cm and 20–30 cm soil layers, respectively. In addition, the initial values of soil carbon stocks didn't affect soil total nitrogen stocks of Chinese fir plantations (Table 3).

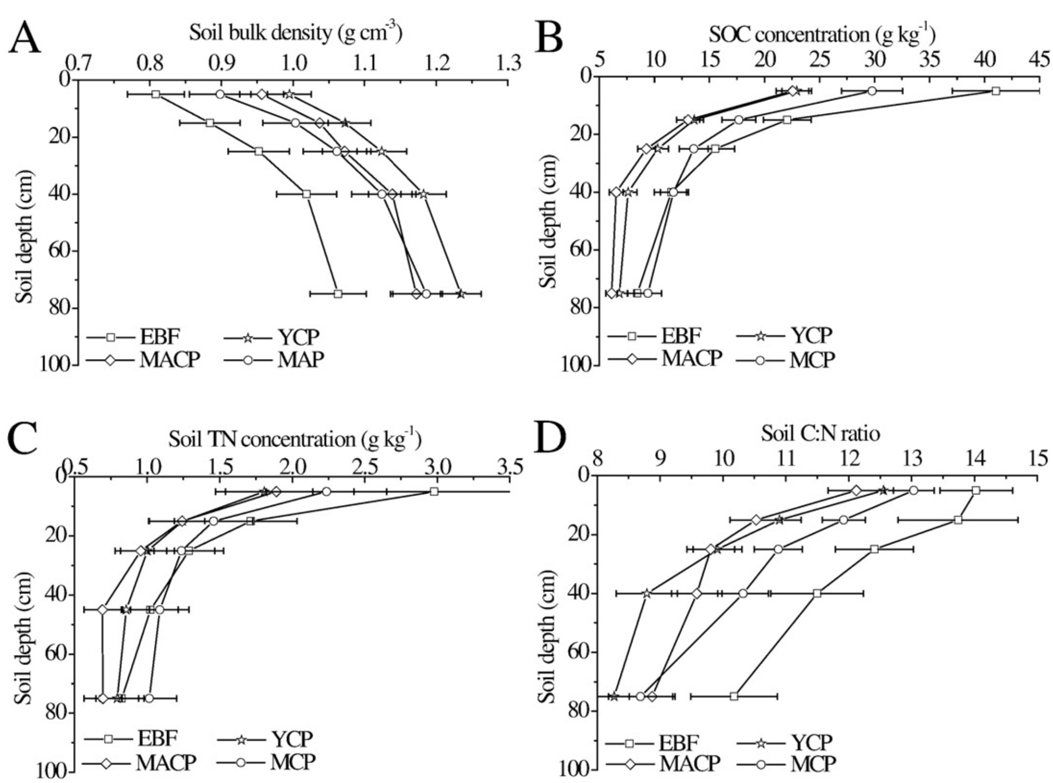

Fig. 2. Changes in soil bulk density (A), SOC concentration (B), soil TN concentration (C), and C:N ratio (D) following conversion of evergreen broadleaved forests to developing Chinese fir plantations in subtropical China. EBF, YCP, MACP and MCP denote evergreen broadleaved forest, and young, middle-aged, and mature Chinese fir plantation. SOC and TN signify soil organic carbon and total nitrogen, respectively.

Table 3
Multivariate analysis of covariance for soil depth, development stage, and depth × stage interaction with covariate of original soil C stocks of EBF found for soil bulk density, SOC concentration, TN concentration, C:N ratio, C stock, and TN stock in Chinese fir plantations in Hunan province, subtropical China.

Variables	Original C stock		Depth		Stage		Depth × stage	
	F	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Soil bulk density	1.790	0.182	19.899	<0.001	4.207	0.016	0.141	0.997
SOC concentration	3.295	0.07	88.764	<0.001	21.839	<0.001	0.501	0.856
Soil TN concentration	1.665	0.198	69.596	<0.001	16.079	<0.001	0.416	0.911
Soil C:N ratio	3.165	0.076	40.887	<0.001	7.068	0.001	0.88	0.533
Soil C stock	6.222	0.013	23.333	<0.001	20.097	<0.001	2.820	0.005
Soil TN stock	2.379	0.124	38.06	<0.001	16.878	<0.001	5.23	<0.001

SOC, C and TN denote soil organic carbon, carbon and total nitrogen, respectively. EBF denote evergreen broadleaved forest.

3.3. Relationships of soil carbon stock with soil C:N ratio and total nitrogen stock

Across all the stands, soil carbon stocks were positively correlated to soil total nitrogen stock ($p < 0.0001$; Fig. 4A) and soil C:N ratio ($p < 0.0001$; Fig. 4B).

3.4. The net changes of soil carbon and total nitrogen stocks following forest conversion

The changes in soil carbon stocks following forest conversion varied across plantation ages. At the young stage, the change was negative (-12.5 Mg ha^{-1}) (Fig. 5). With increasing plantation age, the changes in soil carbon stocks became much less and reached -28.7 Mg ha^{-1}. However, the changes recovered to zero and became positive at the mature stage (7.2 Mg ha^{-1}) (Fig. 5a).

Changes in soil total nitrogen stocks following the forest conversion varied significantly. At the early stage of the forest conversion, the changes were positive (0.6 Mg ha^{-1}). With forest development, the changes of soil total nitrogen stocks declined and were negative (-1.3 Mg ha^{-1}). Finally, the changes recovered and were positive (0.7 Mg ha^{-1}) (Fig. 5b).

The non-linear relationship between forest ages and changes of soil carbon stocks of every stands compared with the average value of soil carbon stocks of EBF was significant, with the trend of initial decline of soil carbon stocks and finial recovery to original value before forest

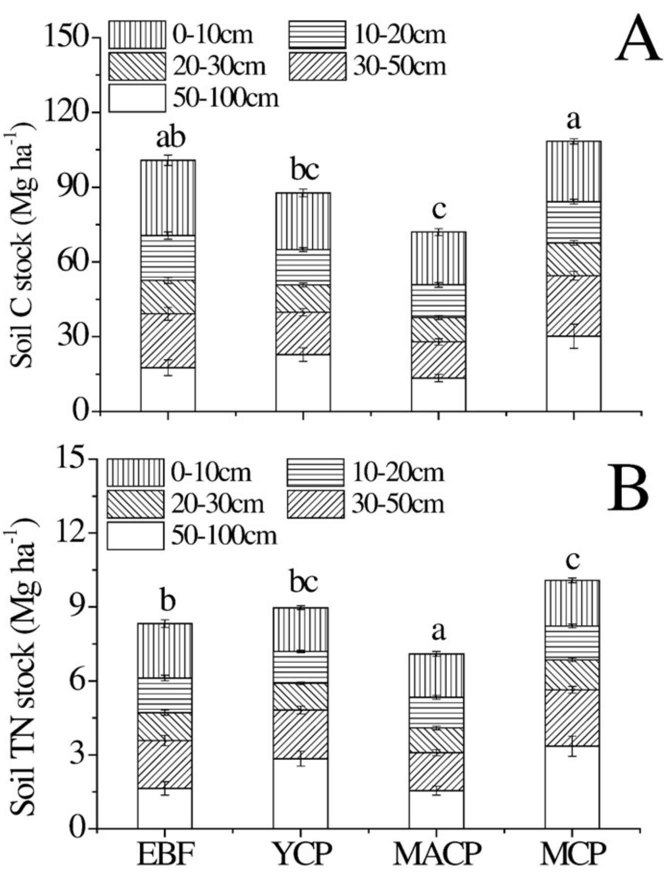

Fig. 3. The pattern of soil carbon (A) and total nitrogen (B) stocks of evergreen broadleaved forest and Chinese fir plantations in subtropical China. Letters on columns indicate significant differences of soil carbon and total nitrogen among evergreen broadleaved forest and Chinese fir plantations at $p < 0.05$ (ANOVA using Tukey's honestly significant difference test). EBF, YCP, MACP, MCP denote evergreen broadleaved forest, and young, middle-aged, and mature Chinese fir plantation.

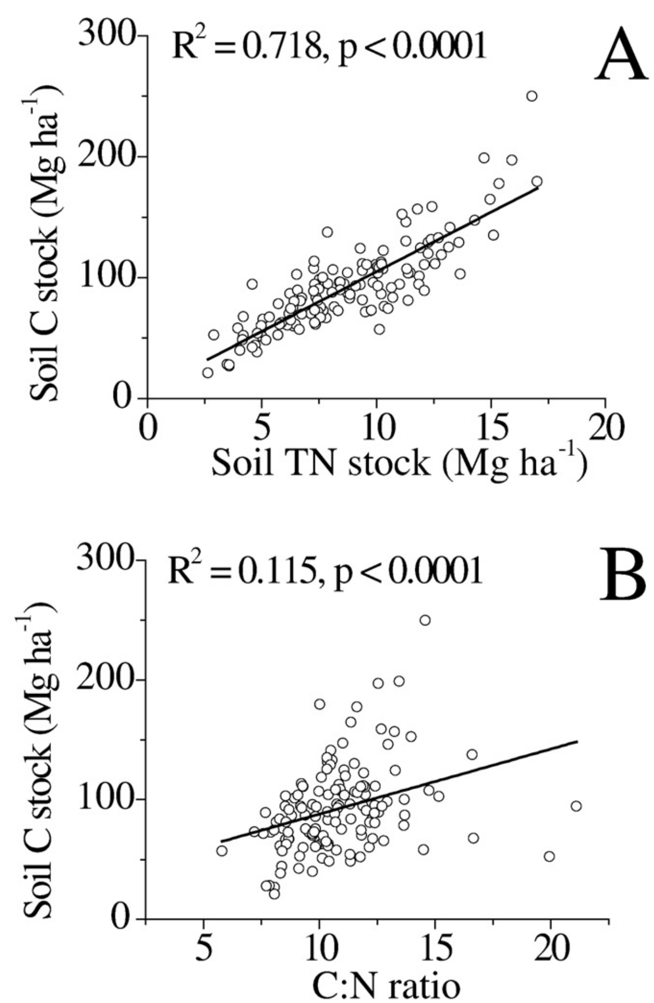

Fig. 4. Relationship of soil carbon stocks with soil TN stock (A) and C:N ratio (B) in subtropical forests. TN denotes soil total nitrogen.

conversion. Following such a relationship, we can find that soil carbon stocks reach the maximum depletion at the age of 14 years, and the time needed to recover to original level of soil carbon stocks is about 27 years after subtropical forest conversion (Fig. 6).

4. Discussion

4.1. Spatial patterns of soil carbon and total nitrogen stocks

Soil carbon stocks in EBF, YCP, MACP and MCP ranged from 71.6 Mg ha^{-1} to 107.4 Mg ha^{-1}. These values were well within the ranges of soil carbon stocks (60.3–123.9 Mg ha^{-1}) reported for subtropical forests in China (Chen et al., 2005; Yang et al., 2005; Gong et al., 2011; Zeng et al., 2013; Sun and Guan, 2014). Soil carbon stocks in this study are lower than that of mixed plantations (186.6–266.6 Mg ha^{-1}) in Guangxi of China (He et al., 2013), but higher than that of Chinese fir plantation (58.7 Mg ha^{-1}) in Zhejiang Province of China (Jiang et al., 2011). These differences may be due to the depth of soil sampling and litter decomposition (Prescott et al., 2000; Prescott, 2010; Wiesmeier et al., 2012). In our study, the soil samples were taken at 0–100 cm depths, however, the depth of soil sampling was only 60 cm in Zhejiang province, resulting in lower soil carbon stocks of Chinese fir plantations in Zhejiang province. Soil total nitrogen stocks in EBF, YCP, MACP and MCP ranged from 7.0 Mg ha^{-1} to 10.0 Mg ha^{-1}. They were consistent with the ranges of soil total nitrogen stocks (7.8–8.7 Mg ha^{-1}) reported for subtropical forests in China (Yang et al., 2005; Guo et al., 2006). However, soil total nitrogen stocks in this study were greater than those of *Pinus densiflora* plantations (1.0–7.6 Mg ha^{-1}) in Korea (Noh et al., 2010), a *P. strobes* plantation (4.7 Mg ha^{-1}) in (Hooker and Compton, 2003) and *Populus euramericana* plantations (2.8–4.6 Mg ha^{-1}) in Northeast China (Mao et al., 2010). This difference may be due to the difference of climate zone across those studies. Li et al. (2012) suggested that the lower litterfall input and decomposition rate result in lower soil nitrogen accumulation rates in the cooler climate region and the accumulation of soil nitrogen is the highest in the subtropical region. *Pinus densiflor*, *P. strobes* and *Populus euramericana* plantations were located at temperate region, however, forest stands in our study were from subtropical region, resulting in the difference between soil nitrogen stocks of Chinese fir plantation and above temperate plantations.

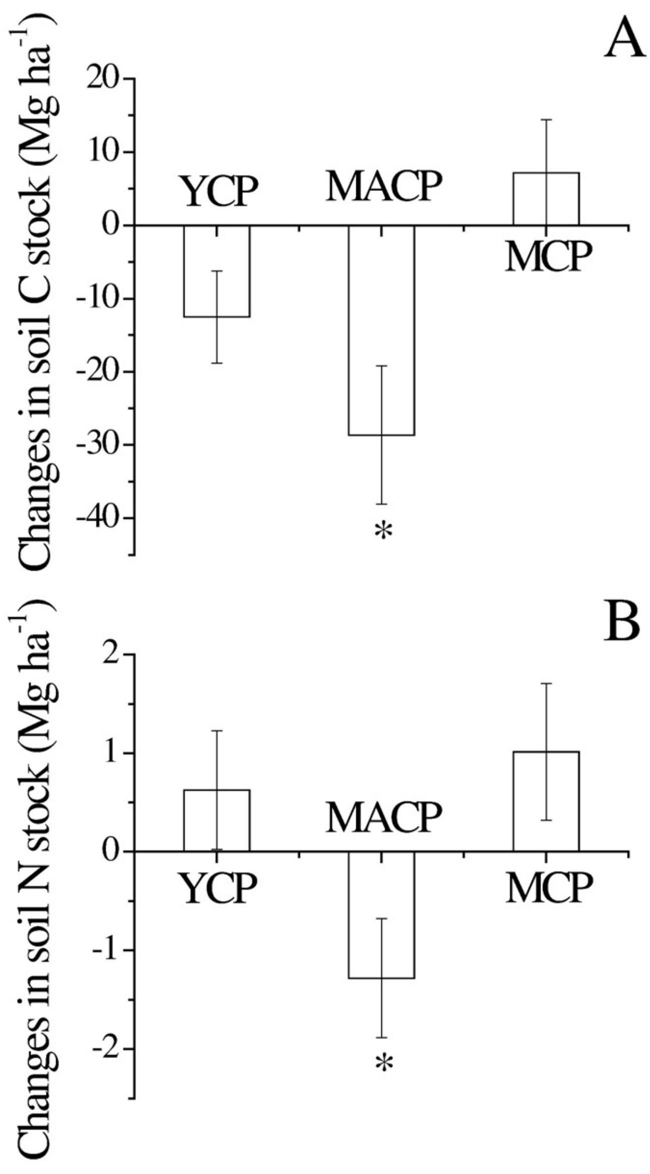

Fig. 5. Changes in soil carbon stocks following forest conversion of EBF to Chinese fir plantations. YCP, MACP, MCP denote young, middle-aged, and mature Chinese fir plantation. Stars indicate significant differences between the changes of soil carbon of Chinese fir plantations to EBF and zero at $p < 0.05$ using Student's *t*-test.

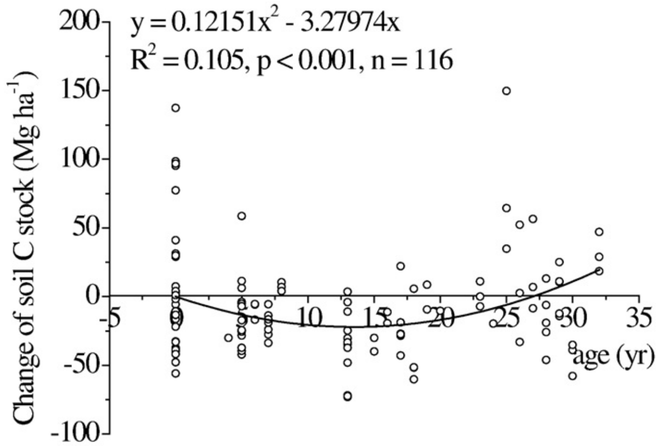

Fig. 6. Multiple regression analysis of ages and changes of soil carbon stocks of every stands.

4.2. Dynamics of soil carbon and total nitrogen stocks

After the conversion from the natural evergreen broadleaved forest to Chinese fir plantation, soil carbon stocks decreased significantly at the early stage of reforestation (becoming negative), and recovering (becoming positive) in mature forests. This result is consistent with the findings from a few previous studies (Mao et al., 2010; Li et al., 2013; Nave et al., 2013). The change rate of soil carbon stocks during the process of forest development is determined by the balance between carbon input and output. In the early stage of forest conversion, although soil respiration decreased compared with that of evergreen broadleaved forest (Guo et al., 2010), soil carbon output was far greater than soil carbon input. This is because leaf litter was scarce and root biomass was low (Liao et al., 2000; Ning et al., 2009). This resulted in the depletion of soil carbon pool in the early stage of forest conversion (Vesterdal et al., 2002). Litterfall in Chinese fir plantations gradually increases with stand age and reached 44.8 Mg ha^{-1} yr^{-1} at the mature stage (about 26 years) (Liao et al., 2000). However, annual soil respiration was only 4.5 Mg ha^{-1} yr^{-1} at the mature stage of Chinese fir plantation (Yang et al., 2007). This resulted in soil carbon accumulation at the mature stage and recovery to carbon stock levels before the forest conversion.

The original value of soil carbon stocks significantly affected soil carbon stocks of Chinese fir plantations, indicating that the original soil carbon stock impacts on the soil carbon stock reconstitution after forest conversion. It means that more is the initial soil carbon stock, shorter could be the time of soil carbon stock reconstitution. An initial high soil carbon stock may induce a better biogeochemical condition, such as higher nutrient availability, for the reforested vegetation development, resulting in high biomass production and litter return. The high litter return will facilitate soil carbon stock reconstitution.

Soil total nitrogen stocks fluctuated with stand age and exhibited similar trends to soil carbon stocks following the forest conversion. Our results were consistent with past studies (Mao et al., 2010; Noh et al., 2010; Li et al., 2012). Li et al. (2012) reported that soil carbon and total nitrogen stock changes had similar temporal patterns, with initial decline during the early stage after afforestation and gradual return of stocks to the pre-afforestation levels and then final net gains. Li et al. (2013) found soil total nitrogen stocks of *P. bungeana* plantations decreased from the 16-year-old stand to the 35-year-old stand and then increased with stand age, reaching the highest value in the 68-year-old stand. Noh et al. (2010) found that soil total nitrogen stocks of *P. densiflora* plantation increased initially, decreased with stand development, and finally increased in the 71-year-old stand. Change in soil total nitrogen stock is a balance between nitrogen input and output (Li et al., 2012). Soil nitrogen input mainly includes atmospheric nitrogen deposition and biological nitrogen fixation (Morris et al., 2007; Yang et al., 2011). Soil nitrogen output is mainly due to nitrogen uptake by plants and nitrogen leaching to groundwater or emission to the atmosphere (Li et al., 2012). Plant nitrogen demand is generally higher when forests are growing actively before canopy closure. If there is no sustainable nitrogen input, increasing nitrogen uptake for the fast growth of trees would result in a decrease in total soil nitrogen stocks. With forest development to the mature stage, nitrogen uptake declines owing to the decrease in growth rate. Nitrogen input is maintained, and even increases, due to the increase of root biomass, resulting in soil nitrogen accumulation.

Nitrogen dynamics is a key parameter in the regulation of long-term terrestrial carbon sequestration (Luo et al., 2004). Nitrogen addition increased soil carbon stocks of forests (Lovett et al., 2013). More carbon was sequestered into the soil in forests containing nitrogen-fixing trees (Hoogmoed et al., 2014). In our study, soil carbon stocks were positively correlated to soil total nitrogen stocks, suggesting that soil nitrogen increment stimulated the accumulation of soil carbon. This was likely due to the reduction in soil respiration or the decline of leaching of older dissolved organic carbon in response to increased N availability (Bowden et al., 2004; Mo et al., 2008; Hagedorn et al., 2012). On the other hand, the lack of soil total nitrogen stocks in MACP stands was due to the enhancement of biomass production, and it will lead to the increase of soil carbon stocks in a few years, because of the return of enhanced biomass production. In turn, the accumulation of soil carbon with forest succession promoted ecosystem nitrogen retention, resulting in the accumulation of soil total nitrogen (Lewis et al., 2014). Luo et al. (2004) suggested that increased soil carbon stocks cause nitrogen to be sequestered in organic matter. This may be due to the change in soil C:N ratio following the forest conversion. Soil C:N ratio is an important factor that affects soil nutrient availability and soil enzyme activity (Weintraub et al., 2013; Ng et al., 2014). Soil C:N ratio also affects soil carbon accumulation and sequestration (Hungate et al., 2003). It well explains our finding that soil C:N ratio was positively correlated to soil carbon stock (Fig. 4B).

4.3. Recovery time of soil carbon stocks after forest conversion

Our results showed that the time needed to recover to original level of soil carbon stocks after subtropical forest conversion from evergreen broadleaved forest to Chinese fir plantation was about 27 years. It was nearly close to the recovery time reported by Li et al. (2015) who showed that recovery time of soil carbon stocks is about 26 years. Paul et al. (2002) and Nave et al. (2013) also suggested that soil carbon stocks recover at about 30 years after vegetation conversion. Using meta-analysis, Li et al. (2012) found that soil carbon stocks declined for 30 years after afforestation, and then increased with increasing stand age. However, a few documents reported that the recovery time of soil carbon stocks after vegetation conversion was less than that of our result. Mao et al. (2010) reported that forest soils recovered to the initial soil organic carbon stocks was found at age 15. It may be due to the planted tree species composition after forest conversion (Tang and Li, 2013; Wei and Blanco, 2014). The broadleaved litter decomposed faster than needles (Prescott et al., 2000), resulting in higher rate of soil carbon accumulation of broadleaved plantation reported by Mao et al. (2010) compared to conifer plantation in our study.

In contrast, few document reported that the recovery time of soil carbon stocks after forest conversion was >30 years. Li et al. (2011) reported that soil carbon stocks declined initially after establishing *Pinus koraiensis* plantations and recover by the stand age of 35 years. The recovery time of soil carbon stocks of *Pinus bungeana* plantations is about 50 years old (Li et al., 2013). Soil carbon stocks of reforested Douglas-fir plantation will need 600 years to recover similar value of soil carbon stocks of non-managed stands (Blanco, 2012). This difference may be explained by climate zone. Our study took place in subtropical zone of China, and forest conversions reported by Li et al. (2011, 2013) and Blanco (2012) were in temperate zone. In the cooler climate zone, the lower decomposition rate of litter impede the decomposed carbon into soil, resulting in lower soil carbon accumulation rate and longer soil carbon recovery (Li et al., 2012). These results show that stand age is an important factor influencing soil carbon stock levels following the forest conversion, and the estimation of recovery time of soil carbon stocks after forest conversion is critical in forest management measures (such as rotation period) to alleviate global climate change. So, in the long-term, forest conversion from natural broadleaved forests to Chinese fir plantations didn't vary soil carbon pool, in spite of the peak valley fluctuation of soil carbon stocks following forest development.

The decline of soil carbon at early stage of forest development and final recovery at about 27 years after reforestation indicated that the soil always released CO_2 into atmosphere before 27 years and then sequestered atmospheric CO_2 into soil after 27 years after the conversion from evergreen broadleaved forests to Chinese fir plantations. Due to the decrease of litterfall of Chinese fir plantations at mature stage (Liao et al., 2000), the soil carbon input decreased with forest developed, and thus may result that the soil carbon stock would maintain a balance after 30 years in the forest conversion (Chen et al., 2013). It indicated that the rotation period of Chinese fir plantations is critical in maintaining soil carbon stocks. If the rotation period of Chinese fir plantations is above 27 years, then the soil carbon stocks would restore into initial level, resulting in the recovery of soil carbon pool. Otherwise, the soil carbon stocks would not restore, inevitably resulting in the depletion of soil carbon pool, if the rotation period is below 27 years. Prolonging the rotation period would be an effective strategy to compensate the depletion of soil carbon pools, and be benificial to the recovery of soil carbon stocks after the forest conversion.

5. Conclusions

Soil carbon and total nitrogen stocks varied significantly across the Chinese fir plantations with different ages, ranging from 77.7 to 106.5 Mg ha^{-1} and from 7.7 to 10.0 Mg ha^{-1}, respectively. Changes in soil carbon stocks was negative at early stage of forest conversion (-12.5 Mg ha^{-1}), deepened the extent of negative effects with forest development (-28.7 Mg ha^{-1}), and then turned to positive at mature stages of stand development (7.2 Mg ha^{-1}). The recovery time of soil carbon stocks is estimated as 27 years after the conversion from natural evergreen broadleaved forests to Chinese fir plantations in subtropical region of China. These results indicate that the forest conversion do not vary the soil carbon pool of reforested Chinese fir plantations during the long period of forest development after the forest conversion, although there is a decline of soil carbon stocks at early development stage of Chinese fir plantations. Prolonging the rotation period (>27 years) would be an effective management strategy to maintain the soil carbon pools after the conversion from evergreen broadleaved forests to Chinese fir plantations.

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References

Amundson, R., 2001. The carbon budget in soils. Annu. Rev. Earth Pl. Sc. 29, 535–562.
Anaya, C.A., Huber-Sannwald, E., 2015. Long-term soil organic carbon and nitrogen dynamics after conversion of tropical forest to traditional sugarcane agriculture in East Mexico. Soil Tillage Res. 147, 20–29.
Blanco, J.A., 2012. Forests may need centuries to recover their original productivity after continuous intensive management: an example from Douglas-fir stands. Sci. Total Environ. 437, 91–103.
Bowden, R.D., Davidson, E., Savage, K., Arabia, C., Steudler, P., 2004. Chronic nitrogen additions reduce total soil respiration and microbial respiration in temperate forest soils at the Harvard Forest. For. Ecol. Manag. 196, 43–56.
Chen, G.S., Yang, Y.S., Xie, J.S., Guo, J.F., Gao, R., Qian, W., 2005. Conversion of a natural broad-leafed evergreen forest into pure plantation forests in a subtropical area: effects on carbon storage. Ann. For. Sci. 62, 659–668.
Chen, G.S., Yang, Z.J., Gao, R., Xie, J.S., Guo, J.F., Huang, Z.Q., Yang, Y.S., 2013. Carbon storage in a chronosequence of Chinese fir plantations in southern China. For. Ecol. Manag. 300, 68–76.
de Blecourt, M., Brumme, R., Xu, J., Corre, M.D., Veldkamp, E., 2013. Soil carbon stocks decrease following conversion of secondary forests to rubber (*Hevea brasiliensis*) plantations. PLoS One 8, e69357.
Ferré, C., Comolli, R., Leip, A., Seufert, G., 2014. Forest conversion to poplar plantation in a Lombardy floodplain (Italy): effects on soil organic carbon stock. Biogeosciences 11, 6483–6493.
Finzi, A.C., Moore, D.J.P., deLucia, E.H., Lichter, J., Hofmockel, K.S., Jackson, R.B., Kim, H.S., Matamala, R., McCarthy, H.R., Oren, R., Pippen, J.S., Schlesinger, W.H., 2006. Progressive nitrogen limitation of ecosystem processes under elevated CO_2 in a warm-temperate forest. Ecology 87, 15–25.
Fleming, T.L., Freedman, B., 1998. Conversion of natural, mixed-species forests to conifer plantations: implications for dead organic matter and carbon storage. Ecoscience 5, 213–221.
Gong, C., Wang, S., Zeng, Z., Deng, S., Chen, J., Long, K., 2011. Carbon storage and its distribution pattern of evergreen broad-leaf forests at different succession stages in mid-subtropical China. Chin. J. Ecol. 30, 1935–1941.
Grace, J., 2004. Understanding and managing the global carbon cycle. J. Ecol. 92, 189–202.
Guo, B.L., Gifford, R.M., 2002. Soil carbon stocks and land use change: a meta-analysis. Glob. Chang. Biol. 8, 345–360.
Guo, J.F., Yang, Y.S., Chen, G.S., Xie, J.S., Gao, R., Qian, W., 2010. Effects of clear-cutting and slash burning on soil respiration in Chinese fir and evergreen broadleaved forests in mid-subtropical China. Plant Soil 333, 249–261.
Guo, J.-F., Yang, Y.-S., Chen, G.-S., Xie, J.-S., Lin, P., 2006. Soil C and N pools in Chinese fir and evergreen broadleaf forests and their changes with slash burning in mid-subtropical China. Pedosphere 16, 56–63.
Hagedorn, F., Kammer, A., Schmidt, M.W.I., Goodale, C.L., 2012. Nitrogen addition alters mineralization dynamics of ^{13}C-depleted leaf and twig litter and reduces leaching of older DOC from mineral soil. Glob. Chang. Biol. 18, 1412–1427.
He, Y.J., Qin, L., Li, Z.Y., Liang, X.Y., Shao, M.X., Tan, L., 2013. Carbon storage capacity of monoculture and mixed-species plantations in subtropical China. For. Ecol. Manag. 295, 193–198.
Hoogmoed, M., Cunningham, S.C., Baker, P.J., Beringer, J., Cavagnaro, T.R., 2014. Is there more soil carbon under nitrogen-fixing trees than under non-nitrogen-fixing trees in mixed-species restoration plantings? Agric. Ecosyst. Environ. 188, 80–84.
Hooker, T.D., Compton, J.E., 2003. Forest ecosystem carbon and nitrogen accumulation during the first century after agricultural abandonment. Ecol. Appl. 13, 299–313.
Hungate, B.A., Dukes, J.S., Shaw, M.R., Luo, Y., Field, C.B., 2003. Nitrogen and climate change. Science 302, 1512–1513.
Jiang, P.K., Meng, C.F., Zhou, G.M., Xu, Q.F., 2011. Comparative study of carbon storage in different forest stands in subtropical China. Bot. Rev. 77, 242–251.
Khasanah, N.m., van Noordwijk, M., Ningsih, H., Rahayu, S., 2015. Carbon neutral? No change in mineral soil carbon stock under oil palm plantations derived from forest or non-forest in Indonesia. Agric. Ecosyst. Environ. 211, 195–206.
Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304, 1623–1627.
Lewis, D.B., Castellano, M.J., Kaye, J.P., 2014. Forest succession, soil carbon accumulation, and rapid nitrogen storage in poorly remineralized soil organic matter. Ecology 95, 2687–2693.
Lewis, T., Smith, T.E., Hogg, B., Swift, S., Verstraten, L., Bryant, P., Wehr, B.J., Tindale, N., Menzies, N.W., Dalal, R.C., 2016. Conversion of sub-tropical native vegetation to introduced conifer forest: impacts on below-ground and above-ground carbon pools. For. Ecol. Manag. 370, 65–75.
Li, C., Zha, T., Liu, J., Jia, X., 2013. Carbon and nitrogen distribution across a chronosequence of secondary lacebark pine in China. Forest. Chron. 89, 192–198.
Li, D.J., Niu, S.L., Luo, Y.Q., 2012. Global patterns of the dynamics of soil carbon and nitrogen stocks following afforestation: a meta-analysis. New Phytol. 195, 172–181.
Li, S., Su, J., Liu, W., Lang, X., Huang, X., Jia, C., Zhang, Z., Tong, Q., 2015. Changes in biomass carbon and soil organic carbon stocks following the conversion from a secondary coniferous forest to a pine plantation. PLoS One 10, e0135946.
Li, X., Yi, M.J., Son, Y., Park, P.S., Lee, K.H., Son, Y.M., Kim, R.H., Jeong, M.J., 2011. Biomass and carbon storage in an age-sequence of Korean pine (Pinus koraiensis) plantation forests in central Korea. J. Plant Biol. 54, 33–42.
Liao, L.P., Wang, S.L., Chen, C.Y., Yao, X.Q., 2000. Litterfall and its ecological function in Chinese fir plantation at different development phase. Chin. J. Appl. Ecol. 11, 127–130 Supp..
Lovett, G.M., Arthur, M.A., Weathers, K.C., Fitzhugh, R.D., Templer, P.H., 2013. Nitrogen addition increases carbon storage in soils, but not in trees, in an eastern US deciduous forest. Ecosystems 16, 980–1001.
Luo, Y., Su, B., Currie, W.S., Dukes, J.S., Finzi, A., Hartwig, U., Hungate, B., Mcmurtric, R.E., Oren, R., Parton, W.J., 2004. Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide. Bioscience 54, 731–739.
Lutze, J.L., Gifford, R.M., 1995. Carbon storage and productivity of a carbon dioxide enriched nitrogen limited grass sward after one year's growth. J. Biogeogr. 22, 227–233.
Maaroufi, N.I., Nordin, A., Hasselquist, N.J., Bach, L.H., Palmqvist, K., Gundale, M.J., 2015. Anthropogenic nitrogen deposition enhances carbon sequestration in boreal soils. Glob. Chang. Biol. 21, 3169–3180.
Mao, R., Zeng, D.H., Hu, Y.L., Li, L.J., Yang, D., 2010. Soil organic carbon and nitrogen stocks in an age-sequence of poplar stands planted on marginal agricultural land in Northeast China. Plant Soil 332, 277–287.
Mo, J., Zhang, W., Zhu, W., Gundersen, P., Fang, Y., Li, D., Wang, H., 2008. Nitrogen addition reduces soil respiration in a mature tropical forest in southern China. Glob. Chang. Biol. 14, 403–412.
Morisada, K., Ono, K., Kanomata, H., 2004. Organic carbon stock in forest soils in Japan. Geoderma 119, 21–32.
Morris, S., Bohm, S., Haile-Mariam, S., Paul, E., 2007. Evaluation of carbon accrual in afforested agricultural soils. Glob. Chang. Biol. 13, 1145–1156.
Murty, D., Kirschbaum, M.U.F., Mumurtrie, R.E., McGilvray, H., 2002. Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. Glob. Chang. Biol. 8, 105–123.
Nave, L.E., Vance, E.D., Swanston, C.W., Curtis, P.S., 2010. Harvest impacts on soil carbon storage in temperate forests. For. Ecol. Manag. 259, 857–866.
Nave, L.E., Swanston, C.W., Mishra, U., Nadelhoffer, K.J., 2013. Afforestation effects on soil carbon storage in the United States: a synthesis. Soil Sci. Soc. Am. J. 77, 1035–1047.
Ng, E.L., Patti, A.F., Rose, M.T., Schefe, C.R., Wilkinson, K., Cavagnaro, T.R., 2014. Functional stoichiometry of soil microbial communities after amendment with stabilised organic matter. Soil Biol. Biochem. 76, 170–178.
Ning, X.B., Xiang, W.H., Wang, G.J., Fang, X., Yan, W.D., Deng, X.W., 2009. Litterfall production and dynamic for twenty years of a successive replanting *Cunninghamia lanceolata* plantation at Huitong. Hunan. Acta Ecol. Sin. 29, 5122–5129.
Noh, N.J., Son, Y., Lee, S.K., Seo, K.W., Heo, S.J., Yi, M.J., Park, P.S., Kim, R.H., Son, Y.M., Lee, K.H., 2010. Carbon and nitrogen storage in an age-sequence of *Pinus densiflora* stands in Korea. Sci. China-Life Sci. 53, 822–830.
Paul, K.I., Polglase, P.J., Nyakuengama, J.G., Khanna, P.K., 2002. Change in soil carbon following afforestation. For. Ecol. Manag. 168, 241–257.
Prescott, C.E., 2010. Litter decomposition: what controls it and how can we alter it to sequester more carbon in forest soils? Biogeochemistry 101, 133–149.
Prescott, C.E., Zabek, L.M., Staley, C.L., Kabzems, R., 2000. Decomposition of broadleaf and needle litter in forests of British Columbia: influences of litter type, forest type, and litter mixtures. Can. J. For. Res. 30, 1742–1750.
Rastetter, E.B., Ågren, G.I., Shaver, G.R., 1997. Response of N-limited ecosystems to increased CO_2: a balanced-nutrition, coupled-element-cycles model. Ecol. Appl. 7, 444–460.
Schlesinger, W.H., Andrews, J.A., 2000. Soil respiration and the global carbon cycle. Biogeochemistry 48, 7–20.
SFA, 2014. The bulletin of forestry and ecological construction in China. State Forestry Administration of China Beijing.
Song, X., Peng, C., Zhou, G., Jiang, H., Wang, W., 2014. Chinese Grain for Green Program led to highly increased soil organic carbon levels: a meta-analysis. Sci. Rep. 4, 4460.
Sun, L., Guan, D.S., 2014. Carbon stock of the ecosystem of lower subtropical broadleaved evergreen forests of different ages in Pearl River Delta. China. J. Trop. For. Sci. 26, 249–258.

Tang, G.Y., Li, K., 2013. Tree species controls on soil carbon sequestration and carbon stability following 20 years of afforestation in a valley-type savanna. For. Ecol. Manag. 291, 13–19.
van Straaten, O., Corre, M.D., Wolf, K., Tchienkoua, M., Cuellar, E., Matthews, R.B., Veldkamp, E., 2015. Conversion of lowland tropical forests to tree cash crop plantations loses up to one-half of stored soil organic carbon. PNAS 112, 9956–9960.
Vesterdal, L., Ritter, E., Gundersen, P., 2002. Change in soil organic carbon following afforestation of former arable land. For. Ecol. Manag. 169, 137–147.
Wang, Q., Wang, S., Yu, X., 2011. Decline of soil fertility during forest conversion of secondary forest to Chinese fir plantations in subtropical China. Land Degrad. Dev. 22, 444–452.
Wang, Q.K., Wang, S.L., Zhong, M.C., 2013a. Ecosystem carbon storage and soil organic carbon stability in pure and mixed stands of *Cunninghamia lanceolata* and *Michelia macclurei*. Plant Soil 370, 295–304.
Wang, Q.K., Xiao, F.M., He, T.X., Wang, S.L., 2013b. Responses of labile soil organic carbon and enzyme activity in mineral soils to forest conversion in the subtropics. Ann. For. Sci. 70, 579–587.
Wang, X.G., Zhu, B., Hua, K.K., Luo, Y., Zhang, J., Zhang, A.B., 2013c. Assessment of soil organic carbon stock in the upper Yangtze River basin. J. Mt. Sci. 10, 866–872.
Wei, X., Blanco, J.A., 2014. Significant increase in ecosystem C can be achieved with sustainable forest management in subtropical plantation forests. PLoS One 9, e89688.
Wei, X., Huang, L., Xiang, Y., Shao, M., Zhang, X., Gale, W., 2014. The dynamics of soil OC and N after conversion of forest to cropland. Agric. For. Meteorol. 194, 188–196.
Weintraub, S.R., Wieder, W.R., Cleveland, C.C., Townsend, A.R., 2013. Organic matter inputs shift soil enzyme activity and allocation patterns in a wet tropical forest. Biogeochemistry 114, 313–326.
Wiesmeier, M., Spörlein, P., Geuß, U., Hangen, E., Haug, S., Reischl, A., Schilling, B., Lützow, M., Kögel-Knabner, I., 2012. Soil organic carbon stocks in southeast Germany (Bavaria) as affected by land use, soil type and sampling depth. Glob. Chang. Biol. 18, 2233–2245.
Wu, J.S., Jiang, P.K., Chang, S.X., Xu, Q.F., Lin, Y., 2010. Dissolved soil organic carbon and nitrogen were affected by conversion of native forests to plantations in subtropical China. Can. J. Soil Sci. 90, 27–36.
Yang, K., Shi, W., Zhu, J.J., 2013. The impact of secondary forests conversion into larch plantations on soil chemical and microbiological properties. Plant Soil 368, 535–546.
Yang, Y., Luo, Y., Finzi, A.C., 2011. Carbon and nitrogen dynamics during forest stand development: a global synthesis. New Phytol. 190, 977–989.
Yang, Y.S., Guo, J., Chen, G., Xie, J., Gao, R., Li, Z., Jin, Z., 2005. Carbon and nitrogen pools in Chinese fir and evergreen broadleaved forests and changes associated with felling and burning in mid-subtropical China. For. Ecol. Manag. 216, 216–226.
Yang, Y.S., Chen, G.S., Guo, J.F., Xie, J.S., Wang, X.G., 2007. Soil respiration and carbon balance in a subtropical native forest and two managed plantations. Plant Ecol. 193, 71–84.
Yu, Y.J., Shen, W.S., Yin, Y.F., Zhang, J.B., Cai, Z.C., Zhong, W.H., 2012. Response of soil microbial diversity to land-use conversion of natural forests to plantations in a subtropical mountainous area of southern China. Soil Sci. Plant Nutr. 58, 450–461.
Zeng, Z.Q., Wang, S.L., Zhang, C.M., Gong, C., Hu, Q., 2013. Carbon storage in evergreen broad-leaf forests in mid-subtropical region of China at four succession stages. J. For. Res. 24, 677–682.