Environmental Management (2013) 51:1164–1173
DOI 10.1007/s00267-013-0044-6

# Effect of Prescribed Fire on Soil Properties and N Transformation in Two Vegetation Types in South China

Faming Wang · Jian Li · Bi Zou · Xin Xu ·
Zhian Li

Received: 20 October 2012 / Accepted: 3 March 2013 / Published online: 23 April 2013

**Abstract** Prescribed fire is a common site preparation practice in forest management in southern China. However, the effect of fire on soil properties and N transformations is still poorly understood in this region. In this study, soil properties and N transformations in burned and unburned site of two vegetation types (*Eucalyptus* plantation and shrubland) were compared in rainy and dry seasons after 2 years' prescribed fire. Soil pH and soil $NH_4$-N were all higher in the burned site compared to the unburned control. Furthermore, burned sites had 30–40 % lower of soil total phosphorus than conspecific unburned sites. There was no difference in soil organic matter, total N, soil exchangeable cations, available P or $NO_3$-N. Nitrogen mineralization rate of 0–5 cm soil in the unburned site ranged from 8.24 to 11.6 mg N $kg^{-1}$ soil $month^{-1}$ in the rainy season, compared to a lower level of 4.82–5.25 mg N $kg^{-1}$ soil $month^{-1}$ in the burned sites. In contrast, 0–5 cm layer nitrification rate was overall 2.47 mg N $kg^{-1}$ soil $month^{-1}$ in the rainy season, and was not significantly affected by burning. The reduced understory vegetation coverage after burning may be responsible for the higher soil $NH_4$-N in the burned site. This study highlights that a better understanding the effect of prescribed burning on soil nutrients cycling would provide a critical foundation for management decision and be beneficial to afforestation in southern China.

**Keywords** Prescribed burning · Soil properties · *Eucalypt* plantation · N cycling

## Introduction

Prescribed fire is a common site preparation method in forest management. It is usually used to meet several objectives: reduction of fire hazard, facilitation of planting, provision of an environment favorable to seedling growth, reduction of understory vegetation competition, and elimination of disease or insect problems (Sun and others 2011; Certini 2005). As a powerful modifier of the environment, fires have a profound and long-term impact on nutrients cycles in forest ecosystems (Wan and others 2001). Besides the reduction or elimination of aboveground biomass, soil physical, chemical, and biological properties are affected to a greater or lesser extent depending on the severity and duration of fire (Sun and others 2011).

Nitrogen often limits primary productivity in natural ecosystems, the dynamics of N pools and its transformation associated with fire thus is critical for forest management. Generally, fire in forests decreased total ecosystem N by volatilizing N contained in wood, leaf, and forest floor (Knoepp and Swank 1993). However, the soil mineral N and N transformations may response differently. The increase of soil $NH_4$-N after fire has been observed in many studies, mainly due to the deposition of volatilized N and its condensation in the cool soil layer, the increased soil N mineralization rate, and the leaching

---

Faming Wang and Jian Li contributed equally to this paper.

F. Wang · J. Li · B. Zou · X. Xu · Z. Li (✉)
Key Laboratory of Vegetation Restoration and Management of
Degraded Ecosystems, South China Botanical Garden,
Chinese Academy of Sciences, Guangzhou 510160,
People's Republic of China
e-mail: lizan@scbg.ac.cn

J. Li · X. Xu
University of Chinese Academy of Science, Beijing 10000,
People's Republic of China

of N from forest floor into soil after fire (Wan et al. 2001; Knoepp and Swank 1993; Koyama and others 2012). Nitrogen mineralization, a major process supplying mineral N to plants in terrestrial ecosystems, is a microbial process (Wang et al. 2010b). The response of soil N mineralization and nitrification to prescribed fire varied by fire intensity, time after fire, and vegetation type (Wan and others 2001; Monleon and others 1997). In a pine stand, 2 years after burning, Burger and Pritchett (1984) found a decrease in N mineralization rate compared with the control plots. However, Adams and Attiwill (1986) found that fire increased N mineralization and the amount of mineralizable N in *Eucalyptus* spp., and a lack of fire effect on net N mineralization was reported for oak–pine stands in North Carolina (Knoepp and others 2004). These conflicting results point out the variability of microbial N processes response to fires.

The subtropical region of China has large areas of plantations, with most of them as lumber plantations (Wang and others 2010b). To 2010, about 3.68 million ha of *Eucalyptus* spp. were planted in southern China (China *Eucalypt* Center, 2010). Prescribed fire is a common site preparation practice in lumber plantation planting in southern China. However, it is still unclear whether this practice promotes any significant changes in soil properties and N transformations in these plantations. In this study, we examined the effects of prescribed burning on soil properties and N transformations in two vegetation types (Shrubland and *Eucalyptus* plantation). The objective of this study was to compare soil properties and N transformations among different burning plots to evaluate the potential of prescribed fire on recuperate degraded land in southern China. We hypothesized that prescribed fire would increase soil nutrients availability due to the reduction of understory layer and the direct release of nutrients in the fire.

## Methods

### Study Area

The experiment was conducted at the Heshan National Field Research Station of Hillyland Forest Ecosystem (HNFRS, 60.7 m *a.s.l.*, 112°50′E, 22°34′N), a subtropical region of southern China. The soil type is Acrisols developed from sandstone, with a pH of about 4.0 (Wang and others 2010b). The climate of the region is typically subtropical monsoon (Fig. 1), with a hot and rainy (growing) season (from April to September) and a cool and dry (dormant) season (from October to March). Climax vegetation of this region is subtropical evergreen broad-leaved forest.

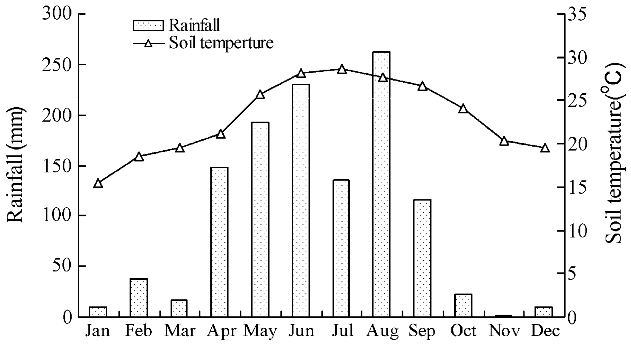

**Fig. 1** The monthly rainfall and mean soil temperature in the experiment site in 2007, Heshan, Guangdong, China

### Experimental Design

A completed randomized design was used in this study. The detailed site preparation and the whole experiment design were described by Sun and others (2011), Wang and others (2010b). Briefly, there were four treatments in this study: burned shrubland and unburned shrubland, burned *E. urophylla* plantation and unburned *E. urophylla* plantation. The prior vegetation type of the four treatments was secondary shrubland after logging all trees (*Pinus elliottii*). In March 2005, the logging residues and the shrubs were left untouched in the unburned plots but were burned in the burned plots (Sun and others 2011). *E. urophylla* seedlings were planted in both treatment plots at a spacing of 2 × 3 m, while shrubland was restored naturally without any disturbance (Wang and others 2010b). Each treatment has three replicate plots with each plot of 1 ha. Totally, there were 12 plots in this study. In October 2006, vegetation investigation was conducted in each plot (Table 1). In the *Eucalyptus* plantations, *E. urophylla* was the dominant tree species (~50 % coverage). In shrubland, the dominant tree species were *Trema tomentosa and Litsea cubeba* (Table 1). Burned plots always had higher understory coverage (combined the data in shrub layer and herb layer: ~75 %) than the corresponding unburned plots (~35 %), with the dominant species being *Dicranopteris dichotoma and Miscanthus sinensis* in all plots. Soil samplings were conducted from June and December 2007, which represented the rainy and dry seasons in this region (Wang and others 2010b).

### Soil N Transformations

In June and December 2007, an in situ soil-core technique (Raison and others 1987) was used to estimate soil net nitrogen mineralization. Briefly, in each replicate plot, nine subplots were randomly located. In each of these points, two PVC (polyvinyl chloride) tubes of 4.6 cm in diameter and 15 cm in height were hammered into the soil to a depth

**Table 1** Vegetation description of shrubland and *Eucalyptus* plantation at Heshan station

| | Tree layer | | | | Shrub layer | | | Herb layer | |
|---|---|---|---|---|---|---|---|---|---|
| | Dominant species | Height (m) | dbh (cm) | Coverage (%) | Dominant species | Height (m) | Coverage (%) | Dominant species | Coverage (%) |
| EU | *E. urophylla* | 3.43 | 3.82 | 48.83 | *Rhodomyrtus tomentosa* and *Clerodendrum fortunatum* | 0.5–1 | 9.18 | *Dicranopteris dichotoma* and *Miscanthus sinensis* | 66.29 |
| EB | *E. urophylla* | 3.37 | 3.81 | 58.90 | *Rhodomyrtus tomentosa* and *Clerodendrum fortunatum* | 0.5–1 | 12.58 | *Dicranopteris dichotoma* and *Miscanthus sinensis* | 19.01 |
| SU | *Trema tomentosa and Litsea cubeba* | 2.01 | – | 17.44 | *Rhodomyrtus tomentosa* and *Clerodendrum fortunatum* | 0.5–1 | 15.54 | *Dicranopteris dichotoma* and *Miscanthus sinensis* | 58.81 |
| SB | *Trema tomentosa* | 1.17 | – | 16.36 | *Rhodomyrtus tomentosa* and *Clerodendrum fortunatum* | 0.5–1 | 8.57 | *Dicranopteris dichotoma* and *Miscanthus sinensis* | 29.11 |

Data were collected in October 2006, one and a half years after initial planting

*EB Eucalyptus* plantation burned, *EU eucalyptus* plantation unburned, *SB* shrubland burned, *SU* shurbland unburned, *dbh* diameter at breast height

of 10 cm. Before sampling, forest floor litter was removed. One of the two tubes from each subplot was retrieved and sent to the lab. The other tube, with a lid on the top, was retained in situ for 1 month, 30 days, before being retrieved.

All soil cores were transported to the lab immediately and stored at 4 °C, and extracted for mineral N within 48 h. Before extraction, each of the nine cores from the same plot was manually divided into two layers (0–5 and 5–10 cm) and soils from the same section (from the same plot) were pooled and mixed thoroughly. Visible roots and stones were removed manually. Twenty grams of fresh soil from each layer were extracted with 100 ml of 2 M KCl solution (1:5 ratio) and filtered (Shuangquan quantitative filter paper 202#). Concentrations of ammonium ($NH_4^+$) and nitrate ($NO_3^-$) in the extraction solution were determined by a flow injection autoanalyzer (FIA) (Lachat Instruments, USA), ammonium by the salicylate-nitroprusside method and nitrate by sulfanilamide colorimetry after the Cd-core reduction to nitrite. Soil moisture was determined by weight loss after oven drying at 105 °C for 24 h. Bulk density (dry soil) was calculated based on soil weight in all tubes and soil moisture. Net N mineralization was calculated as the increase in ammonium plus nitrate N between the initial soil sample and the incubated sample, while net nitrification was the increase in nitrate and net ammonification was the increase in ammonia.

### Soil General Properties

Soil chemical properties (i.e., soil pH, organic matter, total N, total P, soil exchangeable cations) were determined using the initial soil samples obtained in June 2007. All soil samples were air-dried and passed through a 2-mm sieve. Soil pH was measured in a 1:2.5 mixture of soil:deionized water. Soil exchangeable $K^+$, $Na^+$, $Ca^{2+}$, and $Mg^{2+}$ were extracted with 1 M $NH_4Ac$, following the guidelines of Liu and others (1996) and measured by ICP (Perkin Elmer, USA). Soil available P was extracted with Bray-2 solution (Bray and Kurtz 1945) and determined by the molybdate blue colorimetric method. Soils for analyses of total N (TN) and organic matter were grounded to pass through 0.25-mm (60 mesh) sieve. Total N concentration was determined by micro-Kjeldahl digestion followed by salicylate-nitroprusside colorimetric determination on the Lachat FIA. The measured total N thus only included organic N and ammonium. Soil organic carbon (SOC) was determined by the wet combustion method (Walkley and Black 1934), with SOM calculated as with Van Bemmelen's factor, following the guidelines of Liu and others (1996).

### Statistical Analyses

In this study, vegetation type (*Eucalyptus* vs shrubland) and burning treatments (burned vs unburned) were the main factors. Thus, a two-way analysis of variance (ANOVA) was used to analyze the effects of vegetation types and burning treatments on soil variables in each soil layers. A LSD post hoc test after a one-way ANOVA was used to test the difference of above variables between each treatment in each soil layers. The homogeneity of the data was tested by Levene's test, and exchangeable K was log transformed before analysis due to the inequality of variance. All analyses and computations were performed in SPSS 18.0 (SPSS Inc., USA) and Excel 2003 (Microsoft Corp., USA) software.

## Results

### Soil General Properties

Although there was no statistically difference on soil organic matter (SOM) in 0–5 and 5–10 cm layers between burned and unburned sites ($P = 0.46$ and $P = 0.12$, respectively), the mean values of SOM in unburned plots were always 3–8 g/kg greater than those in burned plots in each vegetation type (Table 2). Burning also did not greatly change soil total N (TN) concentration in 0–5 cm layer ($P = 0.46$), but marginally changed TN in 5–10 cm layer ($P = 0.10$). In 5–10 cm layer, burned shrubland had the greatest TN concentration (0.46 ± 0.04 g/kg), which was significantly greater than the value in unburned shrubland (0.38 ± 0.02 g/kg). Soil total P (TP) was greater in unburned plots in both soil layers ($P = 0.03$, $P = 0.00$ for 0–5 and 5–10 cm, respectively). On average, burned plots had 30–40 % lower of TP than conspecific unburned plots in both soil layers. Soil bulk density was not affected by fire. Soil pH was marginally changed by fire ($P = 0.11$ for 0–5 and $P = 0.09$ for 5–10 cm, respectively). Burned plots always had greater pH values than conspecific unburned plots (Table 2). Prescribed fire also greatly increased soil moisture in both soil layers ($P < 0.001$ for both soil layers).

### Soil Exchangeable Cations

Due to the large variation, burning did not change soil exchangeable K concentrations in either soil layer. However, the mean values of exchangeable K$^{+}$ showed that burned plots had higher K concentrations than unburned plots (Table 3), especially in the 0–5 cm layer. For instance, burned shrubland (93.51 ± 45.91 mg/kg) had nearly two times greater K$^{+}$ concentration than unburned shrubland plots (47.65 ± 3.72 mg/kg) in the surface layer. Other soil exchangeable cations (i.e., Na, Ca, and Mg) also did not vary greatly among vegetation types or burning treatments in either soil layers (Table 3).

### Soil Available P and Inorganic N

Soil available P did not vary greatly among vegetation types or burning treatments in either seasons or layers (Table 4). However, the seasonal variation of soil available P was obvious (Fig. 2a, b). In the rainy season, the average soil available P concentration was over 2 mg/kg in the 0–5 cm layer, while in the dry season, this value has greatly declined, with <1 mg/kg in the both soil layers (Fig. 2b). The surface soil layer always had greater available P concentrations than the sub-layer.

Burning treatments greatly affected soil extractable NH$_4$-N in both soil layers in the rainy season (Table 4, $P = 0.02$ for 0–5 layer, and $P = 0.07$ for 5–10 cm layer). In this season, burned plots always had greater NH$_4$-N concentrations than the unburned plots. In the dry season, vegetation types became the main factor affecting soil NH$_4$-N concentration; shrublands always had greater NH$_4$-N concentrations than *Eucalyptus* plantations in the 0–5 ($P = 0.14$) and 5–10 cm ($P = 0.04$) layers in this dry season (Fig. 2d).

In contrast to soil NH$_4$-N, soil NO$_3$-N concentration did not differ among vegetation types or burning treatments in

**Table 2** Soil general properties in shrubland and *Eucalyptus* plantation at Heshan Station, South China

| Variables | Soil depth (cm) | Eucalyptus plantation | | Shrubland | | *P* values | | |
|---|---|---|---|---|---|---|---|---|
| | | Unburned | Burned | Unburned | Burned | Ve | Bu | Ve × Bu |
| SOM (g/kg) | 0–5 | 34.2$^{a}$ ± 5.21 | 31.3$^{a}$ ± 7.50 | 30.3$^{a}$ ± 4.13 | 24.6$^{a}$ ± 4.28 | 0.36 | 0.46 | 0.8 |
| | 5–10 | 22.5$^{a}$ ± 4.33 | 14.1$^{a}$ ± 1.13 | 20.3$^{a}$ ± 3.59 | 16.4$^{a}$ ± 4.03 | 0.99 | 0.12 | 0.54 |
| TN (g/kg) | 0–5 | 0.55$^{a}$ ± 0.05 | 0.51$^{a}$ ± 0.01 | 0.51$^{a}$ ± 0.02 | 0.47$^{a}$ ± 0.10 | 0.53 | 0.46 | 0.99 |
| | 5–10 | 0.40$^{a,b}$ ± 0.02 | 0.40$^{a,b}$ ± 0.00 | 0.38$^{b}$ ± 0.02 | 0.46$^{a}$ ± 0.04 | 0.52 | 0.10 | 0.13 |
| TP (g/kg) | 0–5 | 0.25$^{a,b}$ ± 0.04 | 0.17$^{b}$ ± 0.02 | 0.29$^{a}$ ± 0.05 | 0.21$^{a,b}$ ± 0.02 | 0.30 | 0.03 | 0.98 |
| | 5–10 | 0.29$^{a}$ ± 0.01 | 0.17$^{b}$ ± 0.03 | 0.31$^{a}$ ± 0.02 | 0.19$^{b}$ ± 0.03 | 0.34 | <0.01 | 0.99 |
| BD (g/cm$^{3}$) | 0–5 | 1.30$^{a}$ ± 0.06 | 1.40$^{a}$ ± 0.04 | 1.29$^{a}$ ± 0.07 | 1.28$^{a}$ ± 0.07 | 0.31 | 0.47 | 0.38 |
| | 5–10 | 1.54$^{a}$ ± 0.05 | 1.56$^{a}$ ± 0.12 | 1.29$^{a}$ ± 0.06 | 1.34$^{a}$ ± 0.06 | 0.83 | 0.54 | 0.73 |
| pH | 0–5 | 3.87$^{a}$ ± 0.05 | 4.02$^{a}$ ± 0.04 | 3.95$^{a}$ ± 0.07 | 4.02$^{a}$ ± 0.08 | 0.54 | 0.11 | 0.54 |
| | 5–10 | 3.97$^{a}$ ± 0.05 | 4.03$^{a}$ ± 0.01 | 3.95$^{a}$ ± 0.05 | 4.02$^{a}$ ± 0.01 | 0.59 | 0.09 | 0.85 |
| SWC | 0–5 | 0.19$^{c}$ ± 0.01 | 0.38$^{a}$ ± 0.03 | 0.22b$^{c}$ ± 0.02 | 0.28$^{b}$ ± 0.02 | 0.24 | <0.01 | 0.02 |
| | 5–10 | 0.18$^{b}$ ± 0.01 | 0.28$^{a}$ ± 0.02 | 0.20$^{b}$ ± 0.02 | 0.25$^{a}$ ± 0.02 | 0.83 | <0.01 | 0.12 |

*Note* The data represents mean ± one SE ($n = 3$)

*Ve* vegetation type, *Bu* burn treatment *SWC* soil water content, *BD* bulk density, *TN* total N, *TP* total phosphorus.

The different lowercase in each column indicating a significant difference by LSD ($P < 0.05$)

**Table 3** Soil exchangeable cations in shrubland and *Eucalyptus* plantation at Heshan Station, South China

| Variables | Soil depth (cm) | Eucalyptus Plantation | | Shrubland | | *P* values | | |
|---|---|---|---|---|---|---|---|---|
| | | Unburned | Burned | Unburned | Burned | Ve | Bu | Ve × Bu |
| $K^+$ (mg/kg) | 0–5 | $54.2^{a} \pm 10$ | $91.6^{a} \pm 49$ | $47.7^{a} \pm 3.7$ | $93.5^{a} \pm 46$ | 0.95 | 0.26 | 0.9 |
| | 5–10 | $29.6^{a} \pm 3.6$ | $35.0^{a} \pm 1.3$ | $28.1^{a} \pm 1.0$ | $31.4^{a} \pm 5.2$ | 0.45 | 0.22 | 0.75 |
| $Na^+$ (mg/kg) | 0–5 | $23.0^{a} \pm 1.5$ | $18.5^{a} \pm 0.9$ | $19.3^{a} \pm 1.4$ | $20.1^{a} \pm 1.2$ | 0.45 | 0.18 | 0.07 |
| | 5–10 | $18.5^{a} \pm 1.3$ | $16.2^{a} \pm 0.7$ | $17.2^{a} \pm 0.4$ | $16.9^{a} \pm 0.7$ | 0.75 | 0.18 | 0.28 |
| $Ca^{2+}$ (mg/kg) | 0–5 | $61.1^{a} \pm 4.9$ | $69.9^{a} \pm 8.3$ | $70.9^{a} \pm 9.0$ | $71.1^{a} \pm 6.7$ | 0.48 | 0.56 | 0.58 |
| | 5–10 | $37.1^{a} \pm 0.5$ | $38.2^{a} \pm 3.4$ | $42.7^{a} \pm 5.0$ | $44.4^{a} \pm 1.5$ | 0.09 | 0.67 | 0.92 |
| $Mg^{2+}$ (mg/kg) | 0–5 | $17.1^{a} \pm 1.8$ | $15.9^{a} \pm 1.2$ | $15.0^{a} \pm 0.8$ | $17.2^{a} \pm 3.8$ | 0.88 | 0.82 | 0.47 |
| | 5–10 | $10.6^{a} \pm 0.4$ | $11.1^{a} \pm 1.5$ | $10.1^{a} \pm 0.6$ | $10.6^{a} \pm 1.4$ | 0.65 | 0.65 | 0.99 |

*Note* The data represents mean ± one SE ($n = 3$)

*Ve* Vegetation type, *Bu* burn treatment

**Table 4** The *P* value in the ANOVA analysis of soil available nutrients and N transformations ($n = 3$)

| Variables | Soil depth (cm) | Rainy season | | | Dry season | | |
|---|---|---|---|---|---|---|---|
| | | Ve | Bu | Ve × Bu | Ve | Bu | Ve × Bu |
| Available P (mg/kg) | 0–5 | 0.55 | 0.91 | 0.31 | 0.61 | 0.97 | 0.71 |
| | 5–10 | 0.96 | 0.48 | 0.65 | 0.39 | 0.08 | 0.68 |
| $NH_4{}^+$-N (mg/kg) | 0–5 | 0.38 | 0.02 | 0.15 | 0.14 | 0.32 | 0.35 |
| | 5–10 | 0.74 | 0.07 | 0.77 | 0.04 | 0.52 | 0.38 |
| $NO_3{}^-N$ (mg/kg) | 0–5 | 0.12 | 0.11 | 0.21 | 0.02 | 0.07 | 0.06 |
| | 5–10 | 0.44 | 0.47 | 0.19 | 0.30 | 0.40 | 0.28 |
| Ammonification (mg N $kg^{-1}$ soil $month^{-1}$) | 0–5 | 0.01 | 0.00 | 0.31 | 0.77 | 0.53 | 0.70 |
| | 5–10 | 0.97 | 0.11 | 0.47 | 0.97 | 0.66 | 0.07 |
| Nitrification (mg N $kg^{-1}$ soil $month^{-1}$) | 0–5 | 0.53 | 0.62 | 0.28 | 0.97 | 0.40 | 0.63 |
| | 5–10 | 0.59 | 0.55 | 0.23 | 0.33 | 0.07 | 0.87 |
| N mineralization (mg N $kg^{-1}$ soil $month^{-1}$) | 0–5 | 0.14 | 0.00 | 0.07 | 0.89 | 0.36 | 0.82 |
| | 5–10 | 0.83 | 0.18 | 0.95 | 0.96 | 0.54 | 0.12 |

*Ve* Vegetation type, *Bu* burn treatment

the rainy season (Table 4). However, the multi-comparison results (LSD) have shown that the $NO_3$-N in 0–5 cm layer of burned shrubland plots was the highest among the four treatments, and significantly greater than the value of EU plots ($P < 0.05$, Fig. 2e). In the dry season, vegetation types ($P = 0.02$) and burning treatments ($P = 0.07$) affected or marginally affected soil $NO_3$-N concentrations in the 0–5 cm layer. The multi-comparison found that burned shrubland treatments still had the highest concentrations, and was significantly greater than other three treatments ($P < 0.05$, Fig. 2f).

## Nitrogen Transformations

Soil ammonification rate was significantly different among burning treatments in 0–5 cm layer in the rainy season ($P < 0.001$, Fig. 3). Soil ammonification rates under unburned plots were all greater than the conspecific burned plots ($P < 0.05$, Fig. 3). Vegetation types also greatly affected soil ammonification rate in 0–5 cm soil layer in the rainy season ($P = 0.01$, Fig. 3). For instance, unburned *Eucalyptus* had greater rate of ammonification than the unburned shurbland in the surface layer ($P < 0.05$, Fig. 3). In the dry season, soil ammonification rate were negative in all plots and did not show any difference among vegetation types or burning treatments (Table 4; Fig. 3).

Vegetation types or burning treatment did not affect soil nitrification rates in either soil layers or seasons (Table 4). However, the seasonal pattern of nitrification rate was obvious (Fig. 3). In the 0–5 cm layer, the rainy season nitrification rate was over 3 mg N $kg^{-1}$ soil $month^{-1}$, while in the dry season, the nitrification rate was negligible (Fig. 3).

The patterns of soil N mineralization among vegetation types ($P = 0.14$) and burning treatments ($P < 0.001$) were similar as that of soil ammonification (Table 4). Net N

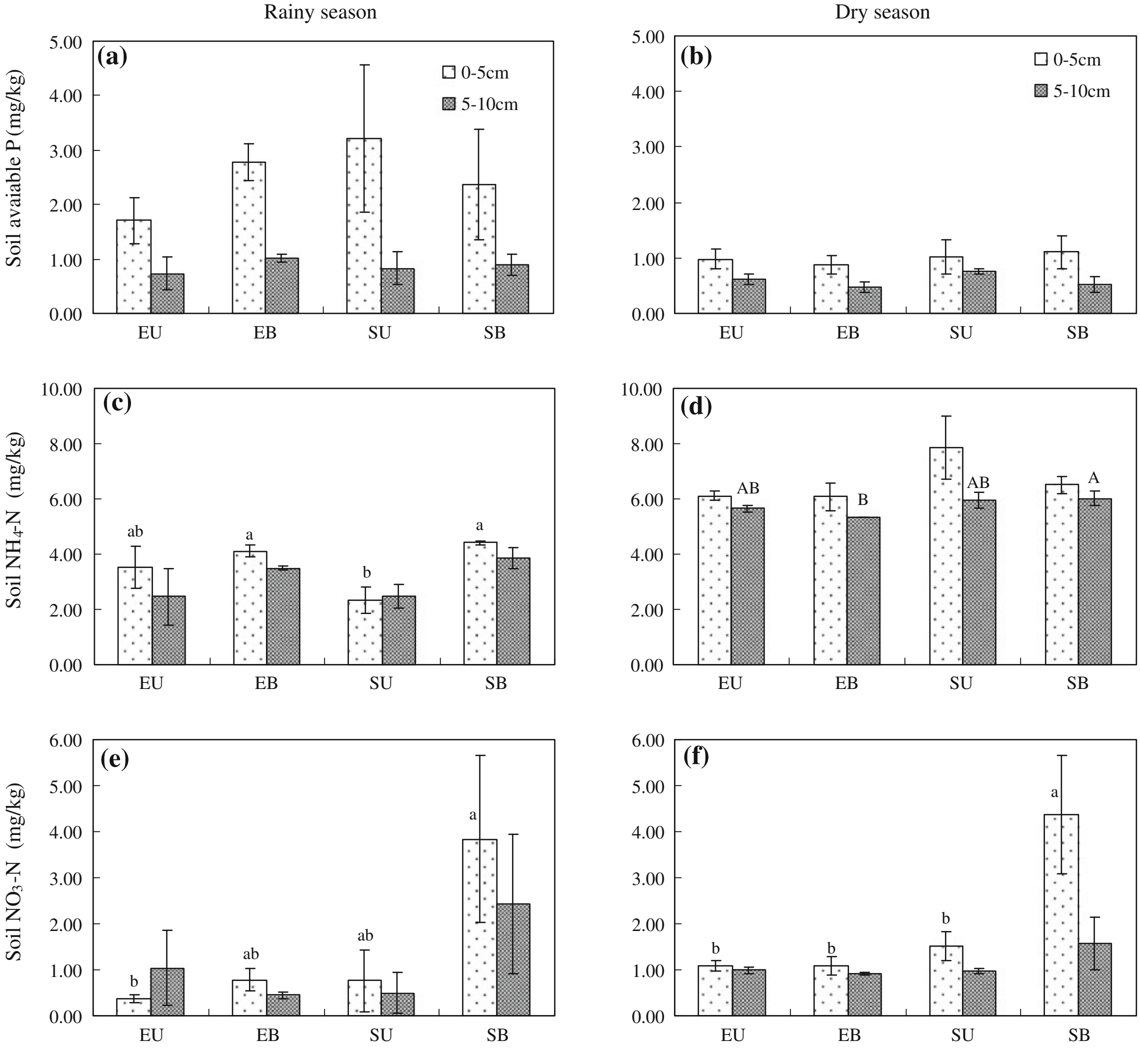

**Fig. 2** Concentrations of soil available P, soil extractable $NH_4$-N and $NO_3$-N under different treatments in the rainy and dry seasons of 2007. Data are illustrated as means; *Error bars* represent 1 SE, $n = 3$. In each layer, one-way ANOVA was used to detect difference among forest types, and *bars* sharing the same *superscript* (*lowercase letters* for 0–5 cm soils, and *uppercase letters* for 5–10 cm soils) were not significantly different at $P = 0.05$ (LSD). *EU* eucalyptus plantation unburned, *EU* eucalyptus burned, *SU* shrubland unburned, *SB* shrubland burned

mineralization rates were high in the rainy season, but negative (net immobilization) in the dry season. Ammonification dominated the process of N mineralization. In the rainy season, more than 70 % of mineralized N was $NH_4$-N. Soil ammonification rates were negative in the dry season, which was similar to the trend of N mineralization (Fig. 3).

## Discussion

### Burning Effects on Soil Properties

The effect of fire on soil C and N are highly dependent on fire type (i.e., prescribed fire vs wild fire) and time since the fire (Johnson and Curtis 2001). It is common to observe losses of organic C from the surface mineral soils during and shortly after fire, followed by gains in soil organic C over a period of years thereafter. However, wildfire and prescribed fire perform differently on soil C and N in a longer term. Intense fire or wildfire always reaches a very high temperature, while prescribed fire does not. The high temperature could change the chemistry of soil C and had a long-term effect on soil C and N cycles. For example, Rovira and others (2012) observed decades reduction of soil C after wild fire. In this study, we observed no significant effect of the prescribed burning on soil organic C or total N content. The reason might be the low intensity of the prescribed fire that resulted in only slight effect on soil C and N stock. In China, prescribed fire is set as site

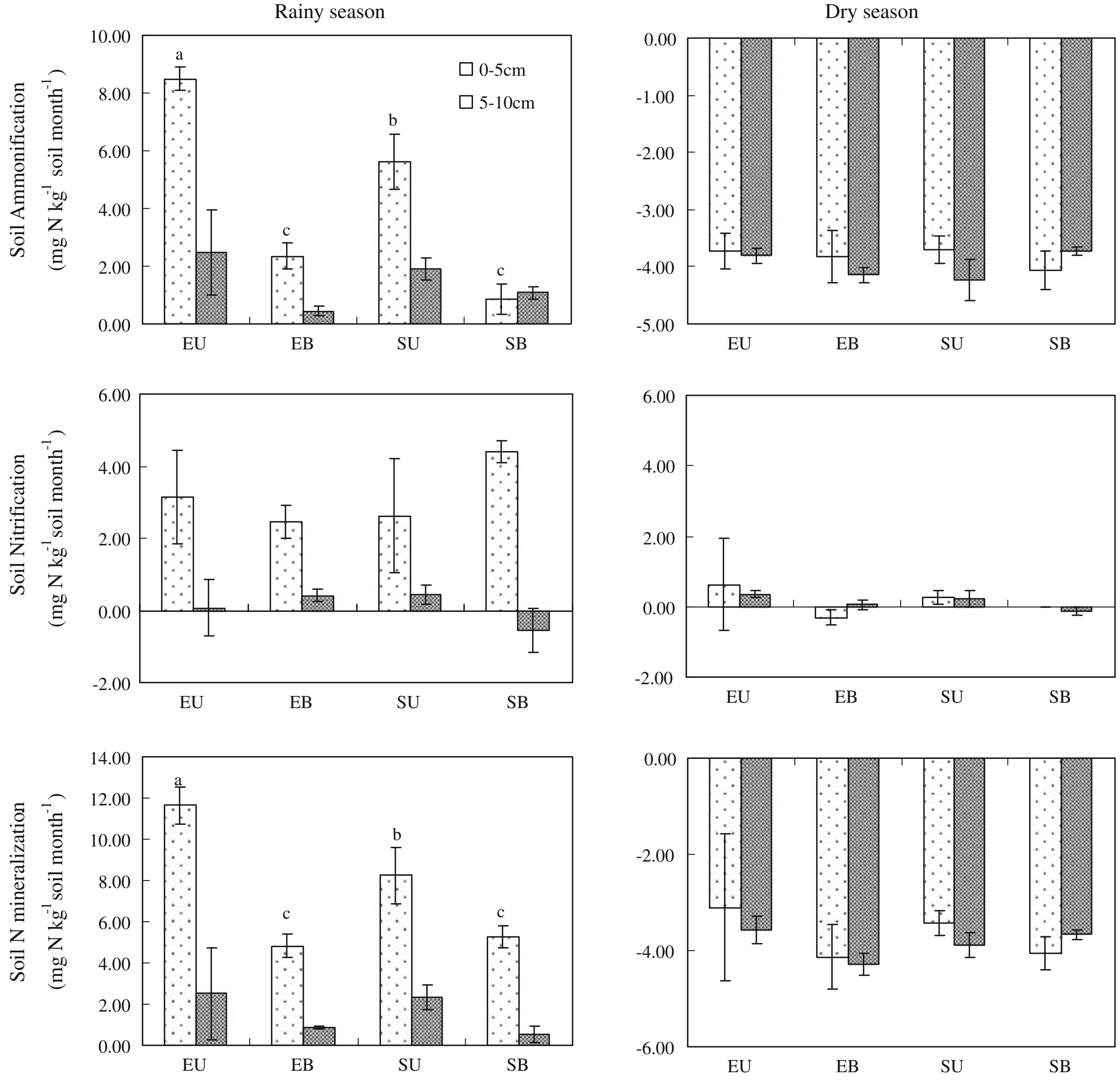

**Fig. 3** Soil net ammonification, nitrification, and N mineralization rates in the four experiment treatments in Heshan station in 2007. Data are illustrated as means; *Error bars* represent 1 SE, $n = 3$. In each layer, one-way ANOVA was used to detect difference among forest types, and means sharing the same superscript (*lowercase letters* for 0–5 cm soils, and *uppercase letters* for 5–10 cm soils) were not significantly different at $P = 0.05$ (LSD). *EU* eucalyptus plantation unburned, *EU* eucalyptus burned, *SU* shrubland unburned, *SB* shrubland burned

preparation of afforestation when all trees of the site have been clearly logged, and just residues and shrubs remains on site. Limited load of organic materials on the floor lead to low intensity of prescribed fire. In addition, the prescribed fire would have reduced soil C pool during the burning. However, such effect might not last for long. Two years allowed for recovery of C and N pool to some extent, especially in the vegetation reintroduction sites (Certini 2005).

Phosphorus is an important nutrient in subtropical plantations as it always limited the productivity of ecosystems. In this study, soil total P was significantly reduced after burning in the both vegetation types. This finding is consistent with the reports of many previous studies (Duguy and others 2007; Marafa and Chau 1999; Silvana Longo and others 2011). It has been shown that immediately after fire occurrence, there is an increase in phosphorous levels that tend to decrease with time (Silvana Longo and others 2011; Certini 2005). Galang and others (2010) have proved that fire could convert the organic soil P to inorganic P, the sole form of P available to biota and to leaching. In this study, we thus assumed that soil available P would be increased immediately after fire, however, due to the quick uptake of vegetation and serious leaching in 2 years, the available P pool decreased to unburned plots level, and further caused the decline of soil total P pool.

There was no significant increase in soil bulk density after prescribed burning. In conifer forests, it has been reported that severe or repeated burning lead to higher soil bulk density (Agee 1993), and such effects are typically less evident after low severity burning (Agee 1993; Boerner and others 2009). Our findings was similar to the results showed by Boerner and others (2009), who have observed the effect of prescribed fire on soil properties in 12 sites in US, and also found no significant increase in soil bulk density. One factor contributing to lack of such an effect by prescribed fire may be the fire intensity. Compared to wild fire, prescribed fires usually have lower severity (González-Pérez and others 2004), because the timing of prescribed burning can be manipulated such that fires occur when soil is moderately moist (Boerner and others 2009), and only a small fraction of biomass is burned as prescribed fire is usually used to destroy only part of aboveground biomass.

Soil pH usually increased by soil heating as a result of organic acids denaturation (Certini 2005). Ulery and others (1993) found that the topsoil pH could increase as much as three units immediately after burning. Arocena and Opio (2003) also observed higher soil pH and exchangeable K, Na, Ca, and Mg in burnt plots compared to unburned plots 2 years after prescribed fire in sub-boreal forest. In this study, soil pH was marginally increased by burning in both vegetation types. We also observed an increase of soil exchangeable K (although not statistically significant). The correlation analysis indicated that soil pH was positively associated with exchangeable Mg and Ca (data not shown). Potassium, Na, Ca, and Mg are major components of ash and rendered soluble. After prescribed fire, the high Ca, Mg, and K contents of ash can increase the pH of the soil through displacing the H and Al ions adsorbed on the negative charge of the soil colloids (Arocena and Opio 2003).

## Burning Effects on Soil N and its Transformations

Soil inorganic N ($NH_4$-N and $NO_3$-N) can be easily taken up by plants and thus played a vital role in plant growth (Wan and others 2001). Previous studies in conifer stands have demonstrated an increase of $NH_4$-N and $NO_3$-N after fire (Covington and others 1991; Covington and Sackett 1992). In this study, we observed a significant positive effect of burning on soil $NH_4$-N in the rainy season, although the soil total N was not affected by fire. This result thus was consistent with what has been reported in many other studies (DeLuca and Zouhar 2000; Wan and others 2001; Boerner and others 2009; Knoepp and Swank 1993). In a meta-analysis of the effects of fire on N, Wan and others (2001) interpreted the increase of $NH_4$-N as being the result of a combination of liberation from organic matter degraded during the fire and increased N mineralization due to altered microclimate, soil pH, and soil microbial activities.

While burning substantially increased soil $NH_4$-N, negative response of net N mineralization to burning was observed in our study. This result contrasted with those of many studies that have demonstrated increase in net N mineralization after fire (Wan and others 2001). In Australian *Eucalyptus* plantations, Adams and Attiwill (1986) found that fire increased N mineralization and the amount of inorganic N. However, Burger and Pritchett (1984) observed a decrease in N mineralization rates 2 years after burning in a southern pine stand in USA. Increase in N mineralization are often attributed to the alteration of organic matter by fire which render it more susceptible to microbial activity, and to changes in microclimate (Boerner and others 2009). Prieto-Fernández and others (1998) found that soil microbial C and N were greatly reduced after wildfire, and this effect lasted for 4 years after burning. Sun and others (2011) quantified the soil microbial activities and community structure in our site, and found a significant decrease of soil bacterial and fungal biomass under burned site. As N mineralization is a microbial process, the reduced soil microbial activities might account for the low N mineralization rate.

Thus, the increase in $NH_4$-N that we observed after burning must have been result of other factors independent of the N mineralization process. In this study, the land slope is 20°–30°, and the vegetation investigation in Oct. 2006 (Table 1) showed that burned site had much lower understory vegetation coverage in comparison with control. Our recent study has found that understory played an important role in regulating soil nutrients availability (Wang and others unpublished). Zhao and others (2011) in a nearby plantation had observed an increase of soil $NH_4$-N after understory removal. We thus assumed that the increase of soil $NH_4$-N in burned site may caused by the reduced uptake of aboveground vegetation after fire.

Soil ammonification largely predominated over nitrification in both the unburned and the burned soils, which is consistent with the findings in a acid Humic Cambisol (Prieto-Fernandez and others 1993). In nearby young plantations, Wang and others (2010b) also found that ammonification was the dominant N mineralization process, with limited nitrification. However, in tropical forest, the nitrification usually is the dominant process in N mineralization (Chapin and others 2002). In old growth plantations of this region, nitrification rate was about 90 % of net N mineralization rate (Wang and others 2010a). Compared to old growth forests, soils in this study were less fertile, with lower SOM, TN, and available N (Table 1; Fig. 2). The ecosystem thus was highly limited by N availability. This result indicated that soil microbes would intend to immobilize $NH_4$-N rather than to nitrify it in this N-limiting soil.

The seasonal variation of soil N transformations in this study was large. The rate of N transformation in rainy season was high, while in the dry season the rate was negligible (Nitrification) and even negative (Ammonification). Seasonal changes of soil N transformation has been reported by many previous studies (Wang and others 2010a, b; Smith and others 1998; van der Krift and Berendse 2001; Zhu and Carreiro 2004), and the seasonal pattern of temperature and moisture should be responsible for this variation in N transformations. The rapid reduction of N transformations in the dry season can be explained by the altered temperature and water availability, which directly regulate soil microbial activity (Yan and others 2008). Wang and others (2010b) have observed a significant relationship between soil moisture and N mineralization in a nearby site, indicating the regulation of N mineralization by soil moisture in this region. Sun and others (2011) have compared the soil microbial community in the burned and unburned sites of this study, and found that soil total PLFAs (representing soil microbial biomass and activity) in the rainy season were 2–3 times higher than those in the dry season. It thus highly possible that reduced rainfall in the dry season (Fig. 1) caused lower soil water content, which limited the activities of soil microbes, and further reduced soil N transformation rates.

## Conclusion

Prescribed fire is a common site preparation practice in subtropical area of China. Our results showed that prescribed fire of pre-afforestation influenced soil variables, many of which, however, would not last for over 2 years, including SOM and Total N. Two years later after the fire, soil pH and $NH_4$-N were still all higher in the burned site compared to unburned control. Soil total P was reduced 30–40 % largely as a result of burning, which might be a detrimental factor for plantation growth. Soil N mineralization rate was significantly lower in burned site, but not was nitrification rate. The reduced understory vegetation coverage after burning may be responsible for the higher soil $NH_4$-N in burned site. This study highlights that a better understanding the effect of prescribed burning on soil nutrients cycling would be beneficial to afforestation and provide a critical foundation for management decision in southern China.

**Acknowledgments** This study was funded by National Basic Research Program of China (2011CB403200), National Natural Science Foundation of China (30870442), NSFC-Guangdong Joint Project (U1131001), Guangdong Natural Science Foundation (S2011040005712), the Knowledge Innovation Program of the Chinese Academy of Sciences (KSCX2-EW-J-28) and the “Strategic Priority Research Program—Climate Change: Carbon Budget and Related Issues” of the Chinese Academy of Sciences (XDA05070307), and Guangdong Forestry Innovation Project (2012KJCX013-02) .

## References

Adams M, Attiwill P (1986) Nutrient cycling and nitrogen mineralization in eucalypt forests of south-eastern Australia. Plant Soil 92(3):341–362. doi:10.1007/bf02372483

Agee JK (1993) Fire ecology of Pacific Northwest forests. Island, Washington

Arocena JM, Opio C (2003) Prescribed fire-induced changes in properties of sub-boreal forest soils. Geoderma 113(1–2):1–16. doi:10.1016/s0016-7061(02)00312-9

Boerner REJ, Huang J, Hart SC (2009) Impacts of fire and fire surrogate treatments on forest soil properties: a meta-analytical approach. Ecol Appl 19(2):338–358. doi:10.1890/07-1767.1

Bray RH, Kurtz LT (1945) Determination of total, organic and available forms of phosphorus in soil. Soil Sci 59:39–45

Burger JA, Pritchett WL (1984) Effects of clearfelling and site preparation on nitrogen mineralization in a Southern pine stand. Soil Sci Soc Am J 48(6):1432–1437. doi:10.2136/sssaj1984.03615995004800060045x

Certini G (2005) Effects of fire on properties of forest soils: a review. Oecologia 143(1):1–10. doi:10.1007/s00442-004-1788-8

Chapin FSI, Mooney HA, Chapin MC (2002) Principles of Terrestrial Ecosystem Ecology. Springer-Verlag, New York

Covington WW, Sackett SS (1992) Soil mineral nitrogen changes following prescribed burning in ponderosa pine. Forest Ecol Manag 54(1–4):175–191. doi:10.1016/0378-1127(92)90011-W

Covington WW, Debano LF, Huntsberger TG (1991) Soil-nitrogen changes associated with slash pile burning in pinyon-juniper woodlands. Forest Sci 37(1):347–355

DeLuca TH, Zouhar KL (2000) Effects of selection harvest and prescribed fire on the soil nitrogen status of ponderosa pine forests. Forest Ecol Manag 138(1–3):263–271. doi:10.1016/s0378-1127(00)00401-1

Duguy B, Rovira P, Vallejo R (2007) Land-use history and fire effects on soil fertility in eastern Spain. Eur J Soil Sci 58(1):83–91. doi:10.1111/j.1365-2389.2006.00802.x

Galang MA, Markewitz D, Morris LA (2010) Soil phosphorus transformations under forest burning and laboratory heat treatments. Geoderma 155(3–4):401–408. doi:10.1016/j.geoderma.2009.12.026

González-Pérez JA, González-Vila FJ, Almendros G, Knicker H (2004) The effect of fire on soil organic matter–a review. Environ Int 30(6):855–870. doi:10.1016/j.envint.2004.02.003

Johnson DW, Curtis PS (2001) Effects of forest management on soil C and N storage: meta analysis. Forest Ecol Manag 140(2–3):227–238. doi:10.1016/s0378-1127(00)00282-6

Knoepp JD, Swank WT (1993) Site preparation burning to improve southern appalachian pine hardwood stands - nitrogen responses in soil, soil-water, and streams. Can J For Res 23(10):2263–2270. doi:10.1139/X93-280

Knoepp JD, Vose JM, Swank WT (2004) Long-term soil responses to site preparation burning in the southern appalachians. Forest Science 50(4):540–550

Koyama A, Stephan K, Kavanagh KL (2012) Fire effects on gross inorganic N transformation in riparian soils in coniferous forests of central Idaho, USA: wildfires v. prescribed fires. Int J Wildland Fire 21(1):69–78. doi:10.1071/wf10132

Liu GS, Jiang NH, Zhang LD, Liu ZL (1996) Soil physical and chemical analysis and description of soil profiles. Standards press of China, Beijing

Marafa LM, Chau KC (1999) Effect of hill fire on upland soil in Hong Kong. Forest Ecol Manage 120(1–3):97–104. doi:10.1016/s0378-1127(98)00528-3

Monleon VJ, Cromack K, Landsberg JD (1997) Short- and long-term effects of prescribed underburning on nitrogen availability in ponderosa pine stands in central Oregon. Can J For Res 27(3):369–378. doi:10.1139/cjfr-27-3-369

Prieto-Fernandez A, Villar MC, Carballas M, Carballas T (1993) Short-term effects of a wildfire on the nitrogen status and its mineralization kinetics in an Atlantic forest soil. Soil Biol Biochem 25(12):1657–1664. doi:10.1016/0038-0717(93)90167-a

Prieto-Fernández A, Acea MJ, Carballas T (1998) Soil microbial and extractable C and N after wildfire. Biol Fert Soils 27(2):132–142. doi:10.1007/s003740050411

Raison RJ, Connell MJ, Khanna PK (1987) Methodology for studying fluxes of soil mineral-N in situ. Soil Biol Biochem 19(5):521–530

Rovira P, Romanyà J, Duguy B (2012) Long-term effects of wildfires on the biochemical quality of soil organic matter: a study on Mediterranean shrublands. Geoderma 179–180:9–19. doi:10.1016/j.geoderma.2012.02.011

Silvana Longo M, Urcelay C, Nouhra E (2011) Long term effects of fire on ectomycorrhizas and soil properties in *Nothofagus pumilio* forests in Argentina. Forest Ecol. Manage. 262(3):348–354. doi:10.1016/j.foreco.2011.03.041

Smith CK, Gholz HL, Oliveira FD (1998) Soil nitrogen dynamics and plant-induced soil changes under plantations and primary forest in lowland Amazonia. Brazil Plant Soil 200(2):193–204

Sun YX, Wu JP, Shao YH, Zhou LX, Mai BX, Lin YB, Fu SL (2011) Responses of soil microbial communities to prescribed burning in two paired vegetation sites in southern China. Ecol Res 26(3):669–677. doi:10.1007/s11284-011-0827-2

Ulery AL, Graham RC, Amrhein C (1993) Wood-ash composition and soil-ph following intense burning. Soil Sci 156(5):358–364. doi:10.1097/00010694-199311000-00008

van der Krift TAJ, Berendse F (2001) The effect of plant species on soil nitrogen mineralization. J Ecol 89(4):555–561. doi:10.1046/j.0022-0477.2001.00580.x

Walkley A, Black IA (1934) An examination of the Degtjareff method for determining organic carbon in soils: effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci 63:251–263

Wan SQ, Hui DF, Luo YQ (2001) Fire effects on nitrogen pools and dynamics in terrestrial ecosystems: a meta-analysis. Ecol Appl 11(5):1349–1365 10.1890/1051-0761(2001)011[1349:Feonpa]2.0.Co;2

Wang FM, Li ZA, Xia HP, Zou B, Li NY, Liu J, Zhu WX (2010a) Effects of nitrogen-fixing and non-nitrogen-fixing tree species on soil properties and nitrogen transformation during forest restoration in southern China. Soil Sci Plant Nutr 56(2):297–306. doi:10.1111/j.1747-0765.2010.00454.x

Wang FM, Zhu WX, Xia HP, Fu SL, Li ZA (2010b) Nitrogen mineralization and leaching in the early stages of a subtropical reforestation in Southern China. Restor Ecol 18:313–322. doi:10.1111/j.1526-100X.2009.00642.x

Yan ER, Wang XH, Huang JJ, Li GY, Zhou W (2008) Decline of soil nitrogen mineralization and nitrification during forest conversion of evergreen broad-leaved forest to plantations in the subtropical area of Eastern China. Biogeochemistry 89(2):239–251. doi:10.1007/s10533-008-9216-5

Zhao J, Wang X, Shao Y, Xu G, Fu S (2011) Effects of vegetation removal on soil properties and decomposer organisms. Soil Biol Biochem 43(5):954–960. doi:10.1016/j.soilbio.2011.01.010

Zhu WX, Carreiro MA (2004) Temporal and spatial variations in nitrogen transformations in deciduous forest ecosystems along an urban - rural gradient. Soil Biol Biochem 36(2):267–278. doi:10.1016/j.soilbio.2003.09.013