EFFECTS OF MULCHING MANAGEMENT ON SOIL AND FOLIAR C, N AND P STOICHIOMETRY IN BAMBOO (*PHYLLOSTACHYS VIOLASCENS*) PLANTATIONS

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GUO Z, CHEN S, YANG Q, LI Y & ZHUANG M. 2014. Effects of mulching management on soil and foliar C, N and P stoichiometry in bamboo (*Phyllostachys violascens*) plantations. Mulching with rice straw and chaff in bamboo (*Phyllostachys violascens*) plantations for early shooting and high profit resulted in stand degradation in Zhejiang, China. The present study explored the possible mechanisms of degradation by analysing the effects of intensive mulching on soil and foliar carbon (C), nitrogen (N), phosphorous (P) stoichiometry in bamboo plantations. Results showed that mulching for 3 and 6 years increased soil C, N, P and the ratios of C:P and N:P but decreased soil pH. Mulching decreased foliar C, N and P but increased the C:N, C:P and N:P ratios. Foliar N:P ratio had positive correlation with soil P and pH and negative correlation with soil N:P and C:P ratios. It appeared that changes in soil C, N and P stoichiometry caused by long-term mulching management resulted in enhanced function of P as the limiting factor and soil acidification. Therefore, bamboo stand degradation caused by mulching management may cause imbalance in the relationship between C, N and P, inhibit absorption of N and P by roots as well as decrease foliar C assimilation capacity.

Keywords: Stand degradation, P limitation, soil acidification, nutrient imbalance

INTRODUCTION

Phyllostachys violascens is important for shoot production in many provinces of southern China. It is easy to plant and has rapid growth rate, early shoot sprouting and high shoot yield. To ensure high shoot yield and economic benefits for bamboo farmers, intensive mulching of *P. violascens* stands was carried out in many provinces, especially in Zhejiang province. However, intensive mulching over an extended period, especially using organic materials (rice straw and rice chaff) to topsoil during shoot sprouting, often result in serious degradation of bamboo stands (Liu & Chen 2009), accompanied by loss in stand productivity. However, little is known about the soil and foliar carbon (C), nitrogen (N) and phosphorous (P) stoichiometry of the *P. violascnes* ecosystem under intensive mulching.

Soil N and P often act as important limitation factors for plant growth (Elser et al. 2003), while C provides the structural basis of the plant (~ 50%) (Agren 2008). There is a close doubt that soil C, N and P play a pivotal role in nutrient utilisation and energy cycling. There is no relationship between soil and foliar stoichiometry, content and balance of C, N and P elements. The relationship should influence the growth and development of individual plants (Wang et al. 2006, Wei et al. 2012), community fitness and overall productivity (Chu et al. 2007). Content of foliar N and P and the N:P ratio (especially its threshold) are important indicators of the supply capacity of soil nutrients (Aerts & Chapin 2000, Güsewell 2004). The N:P ratio has been recognised as a diagnostic tool for nutrient limitations and plant adaptive strategies (Han et al. 2005, Ratnam et al. 2008). Type and intensity of landuse influence the bioavailability of soil C, N and P dramatically and cause substantial variation in N and P uptake and utilisation by plants, resulting in varied C:N:P ratios.

The present study investigated the possible mechanisms of degradation by analysing the effects of intensive mulching management on soil and foliar C, N, and P stoichiometry in bamboo

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plantations. In addition, the responses and adaptive strategies of foliar element stoichiometry to intensive mulching, ecological indicators of the N:P ratio for ecosystem health and theoretical guidance for the regeneration of degraded bamboo plantations were also explored.

MATERIALS AND METHODS

Experimental site

The study was conducted at Taihuyuan town, Lin'an county (30° 24' N, 119° 32' E), Zhejiang province, China. Taihuyuan town is reknowned for its intensive mulching management of *P. violascnes* stands over the past two decades with an area of nearly 10,000 ha. This area has subtropical climate with annual precipitation of 1442 mm. Average annual temperature is 15.9 °C with maximum of 41.9 °C and minimum of -13.4 °C. There is an average of 233 frost-free days per year. Soils are derived from granite and classified as Ferrisols.

Experimental design and soil sampling

A 4.8 ha experimental bamboo plantation was established in March 2000 on fallow land using bamboo seedlings. The seedlings were 2–3 cm in diameter at breast height and aged between 1 and 2 years. The experimental stand was fully developed in 2003 and divided into 18 plots with an average area of 0.21 ha. Six plots each were randomly selected in 2004 and 2007 for intensive mulching treatments and another six plots were used as control for non-mulching management. The experimental bamboo stand was sampled in September 2010 (Table 1). Intensive mulching treatment was conducted after adequate irrigation at the end of November every year. Mulching (the six plots in 2004 were mulched for 6 years and the six plots in 2007, 3 years) was conducted using rice straw, 15 cm in depth followed by rice chaff, 30 cm in depth. Rice chaff holds the heat produced by fermentation of rice straw, thus, promoting and accelerating shoot sprouting.

Sampling and analysis

In September 2010, six samples from each plot of each age (1, 2 and 3 years) were chosen for foliar samples. The canopy layer of sampling bamboo was divided into three equal sublayers. Samples of 400 g each of fresh, mature and intact foliage were taken from each sublayer to form one composite sample per bamboo plant. Six samples from each bamboo plant of the same age were mixed well and formed one composite sample per plot. These samples were stored in ice bags for transport to the laboratory where they were dried in an oven at 105 °C for 30 min, then dried to constant mass at 85 °C and ground using a ball mill. Samples were then analysed for C, N and P concentrations. C was determined using the H_2SO_4–$K_2Cr_2O_7$ oxidation method while N and P , the Kjeldahl and molybdovanadate methods (Allen 1989).

Soil samples of each plot were collected from the following depth intervals: 0–10, 1–20, 20–30 and 30–50 cm. Three samples were collected from trenches excavated to a total depth of 60 cm and spaced 10 m apart. The three samples from each plot were mixed well and formed one composite sample per depth. Each soil sample was put in a polyethylene bag and transported to the laboratory where it was air dried and sieved through 0.15 mm mesh for chemical analysis—soil pH in water (soil:deionised water = 1:2.5), soil total C (Walkley-Black), soil total N (Kjeldahl) and soil total P (Bray and Kurtz method) (Sparks 1996).

Table 1 Structure of the experimental *Phyllostachys violascens* stands under mulching management

Treatment	Density (stems ha^{-1})	Diameter at breast height (cm)	Age composition (3-year-old: 2-year-old: 1-year-old)
Control	19500	5.35	1:1.26:1.84
3-year plot	18900	5.12	1:1.21:1.76
6-year plot	18060	5.01	1:1.19:1.74

Control = no mulching, 3-year plot = 3 years mulching management, 6-year plot = 6 years mulching management

Data analysis

The average of six replicates for each treatment and standard deviation were calculated. The contents and ratios of C, N and P in soil and foliage and soil pH between treatments, bamboo ages as well as soil depth were compared using one-way ANOVA. Pearson correlation between soil and foliar contents and ratios for C, N, P were analysed. All statistical analyses were conducted using the SPSS 11.0 software package (2002) for Windows.

RESULTS

Response of soil pH, C, N and P contents to mulching management

Overall, soil C, N and P contents decreased significantly ($p < 0.01$) with increase in soil depth, while soil pH increased markedly ($p < 0.05$) (Figure 1). With increase in mulching management time, soil C and N contents in each soil layer increased and there was significant difference ($p < 0.01$) between control and

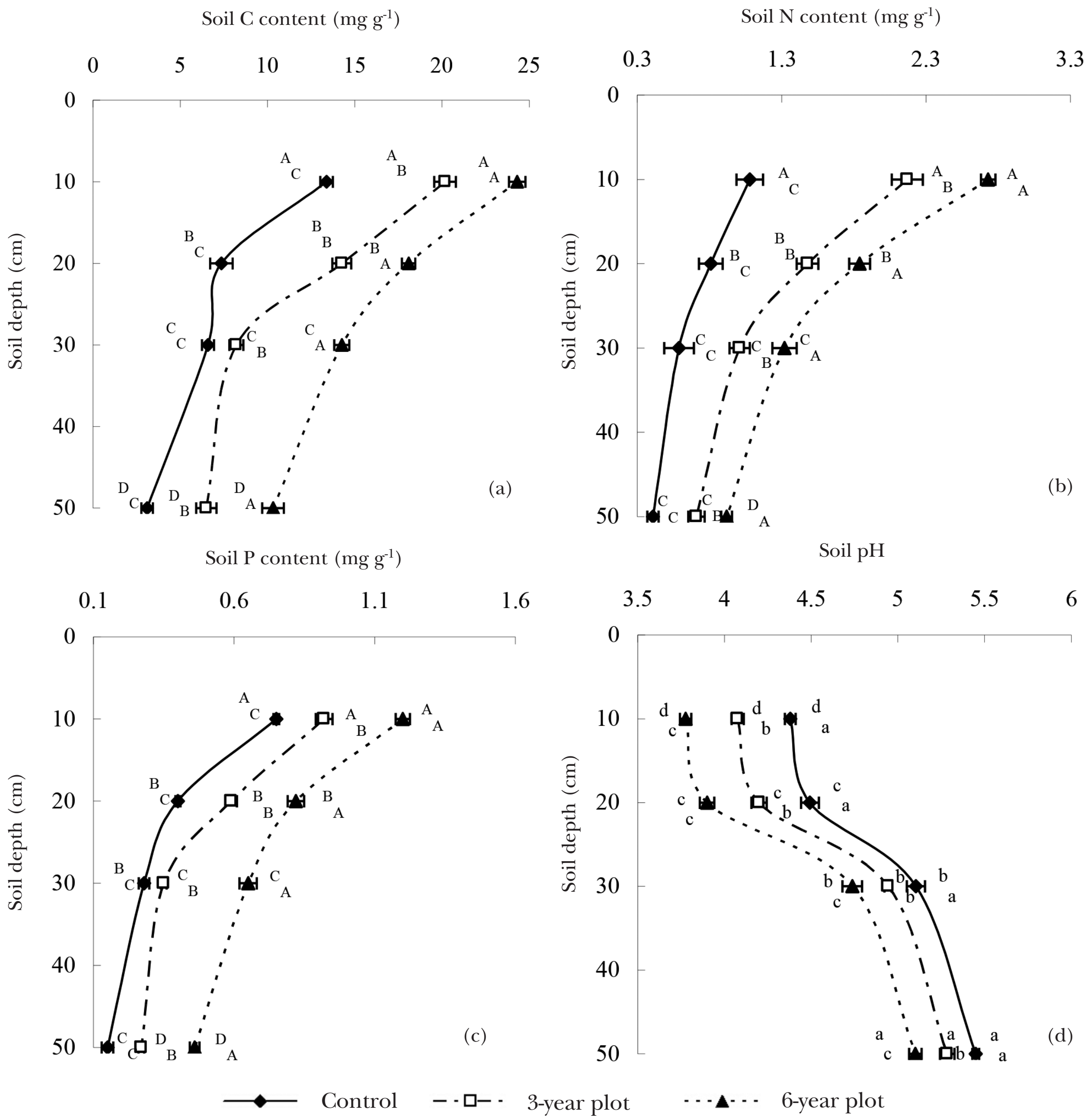

Figure 1 Variation of soil C, N, P contents and soil pH of *Phyllostachys violascens* stands under mulching management; different letters indicate significant differences at $p < 0.01$ (capital letters) and $p < 0.05$ (lower case letters) between treatments in the same soil layer; different superscript letters indicate significant differences at $p < 0.01$ (capital letters) and $p < 0.05$ (lower case letters) between different soil layers under the same treatment

treatment plots (Figurea 1a, b). Soil total P content also increased with increase in mulching management time and there was significant ($p < 0.01$) difference in the same soil layer between treatments except for between control and the 3-year plot at 20–30 cm (Figure 1c). However, with extended mulching time, soil pH decreased significantly and exhibited marked differences ($p < 0.05$) at each soil depth interval between control and treatments (Figure 1d). It may be concluded that both soil C, N and P contents and soil acidity increased significantly due to mulching management.

Response of foliar C, N and P contents to mulching management

As shown in Figure 2, bamboo foliar C, N and P contents over 3 years ranged from 542.50 to 614.58, 22.01 to 27.06 and 1.24 to 1.94 mg g^{-1}, with coefficients of variation of 3.99, 7.16 and 16.25% respectively. As bamboo age increased, foliar C, N and P contents

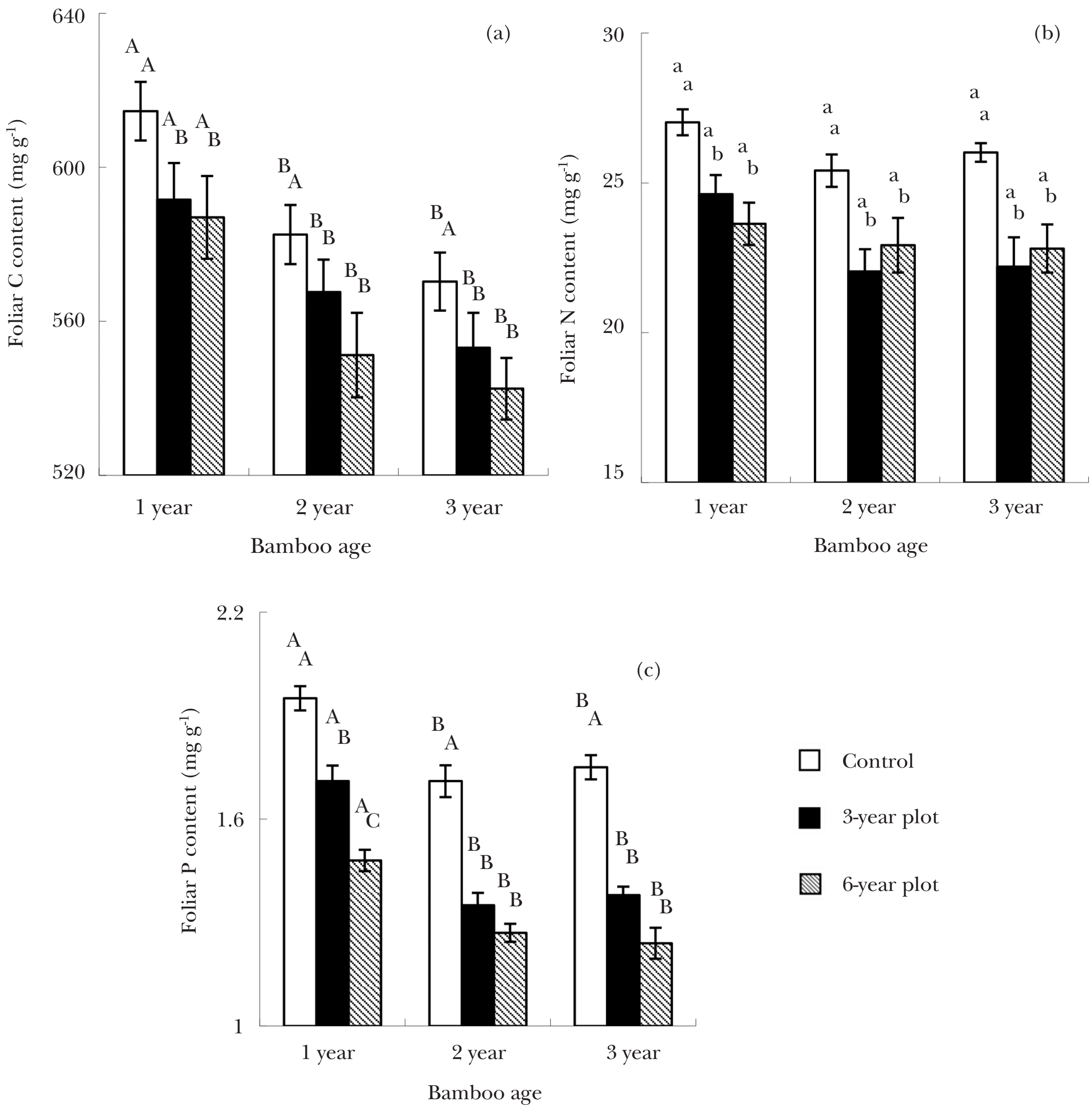

Figure 2 Foliar C, N and P contents of *Phyllostachys violascens* stands under mulching management; different letters indicate significant differences at $p < 0.01$ (capital letters) and $p < 0.05$ (lower case letters) between different bamboo ages with the same treatment; different subscript letters indicate significant differences at $p < 0.01$ (capital letters) and $p < 0.05$ (lower case letters) between different treatments of the same bamboo age

declined significantly. With increase in mulching management time, foliar C, N and P contents of the same age decreased. There was no difference in foliar C and N between the 3- and 6-year plots and both were significantly lower than control. As mulching management time increased, foliar P content of 1-year-old bamboo decreased significantly. However, no significant difference was observed with the 2- and 3-year-old bamboo between 3- and 6-year plots. When mulching time increased, foliar P contents of 2- and 3-year-old bamboo in the control were higher than that of the mulching treatments.

Response of soil C, N and P stoichiometry to mulching management

The ratios of soil C:N, C:P and N:P were 7.21–10.46, 17.85–24.17 and 1.72–3.03 respectively with corresponding coefficients of variation of 10.4, 9.4 and 15.8%. As soil depth increased, the C:N ratio in all treatments decreased, while soil C:P and N:P ratios increased. Variations of C:N, C:P and N:P ratios at 0–20 cm soil layers were obvious (Figure 3). There was no difference in soil C:N ratios between treatments within the same layers, but soil C:P ratios of the 3- and 6-year plots were

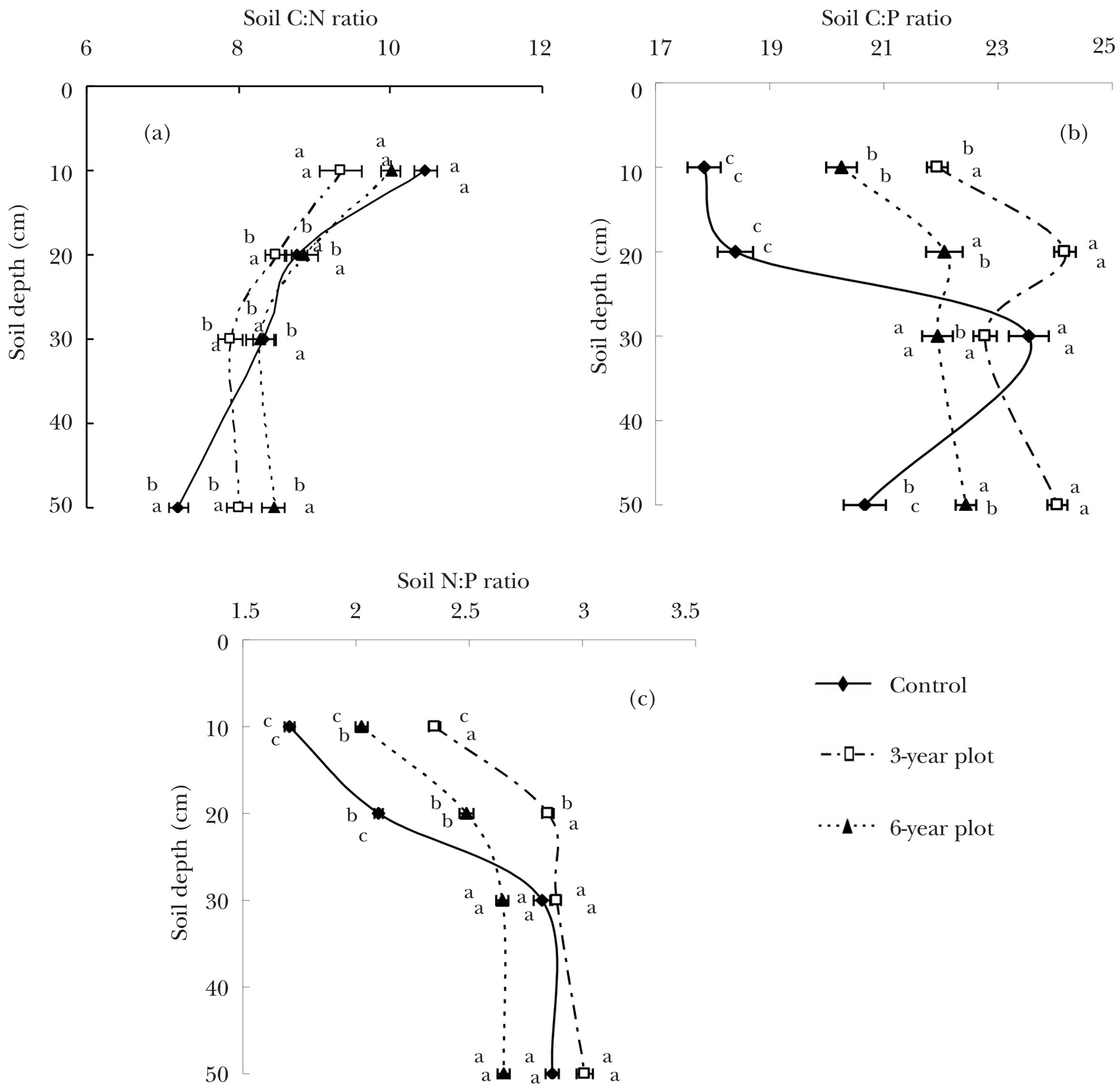

Figure 3 Stoichiometry characteristics of soil C, N and P of *Phyllostachys violascens* stands under mulching management; different letters indicate significant differences at p < 0.01 (capital letters) and p < 0.05 (lower case letters) between different treatments of the same soil layer; different subscript letters indicate significant differences at p < 0.01 (capital letters) and p < 0.05 (lower case letters) between different layers with the same treatment

significantly higher than that of control except for the 20–30 cm layer. Soil C:P ratios of the former plot was also higher than that of the latter (Figures 3a and b). As mulching management time extended, soil N:P ratios initially increased but decreased afterwards. There was significant difference between treatments in soil N:P at 0–20 cm with maximum ratio in the 3-year plot. However, there was no difference in N:P at 30–50 cm between treatments, indicating a dramatic mulching influence on soil N:P at 0–20 cm (Figure 3c).

Response of foliar C, N and P stoichiometry to mulching management

Ratios of foliar C:N, C:P and N:P were 21.92–25.85, 315.17–437.50 and 14.03–18.41 respectively, with corresponding variation coefficients of 5.13, 12.42 and 9.89%. Foliar C:N, C:P and N:P ratios increased with increasing time of mulching management (Figure 4). There was significant difference in foliar C:N ratios between treatments. The C:N ratios for 1-year-old bamboo was in the order of 6-year plot >

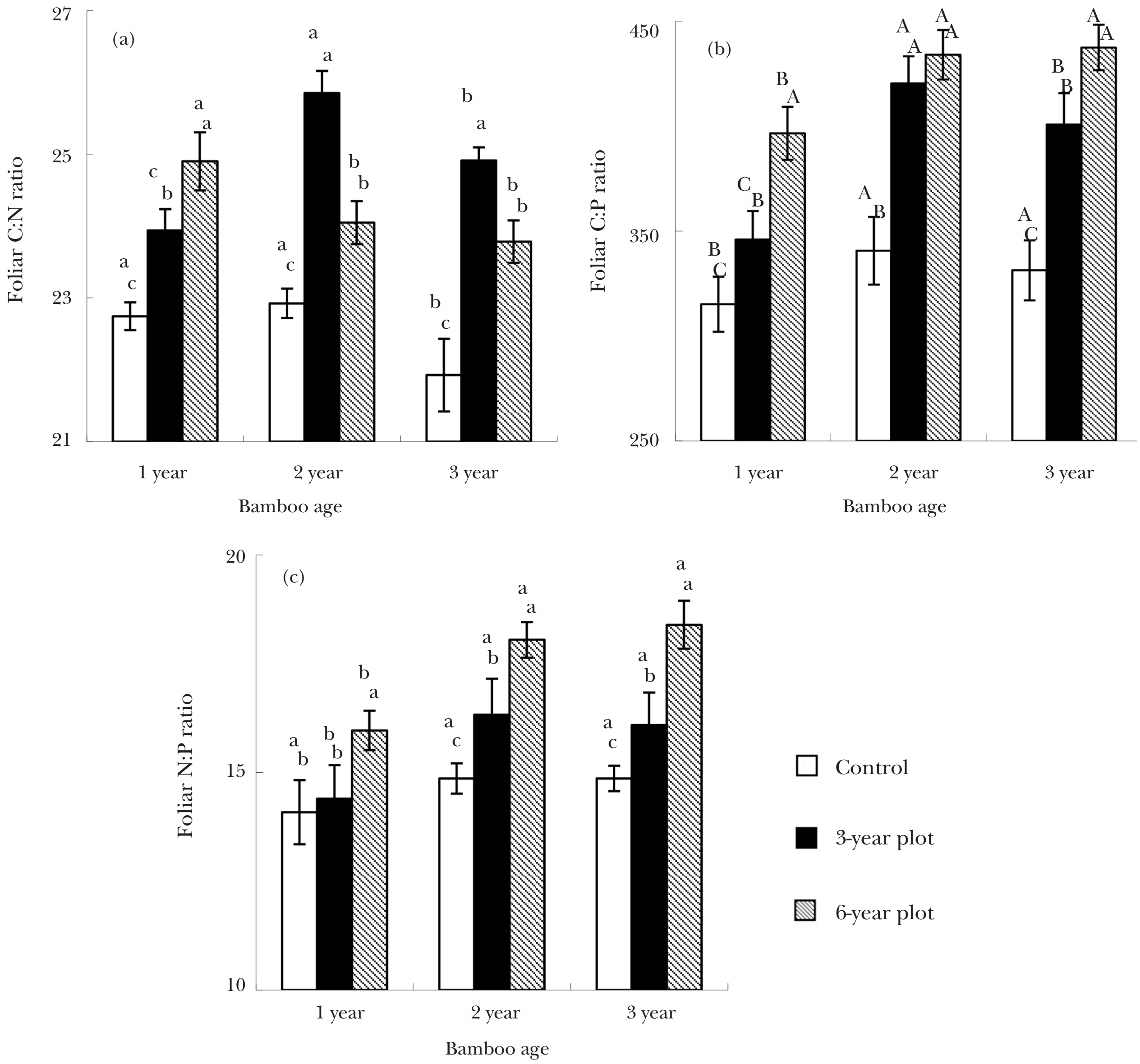

Figure 4 Stoichiometry characteristics of foliar C, N and P of *Phyllostachys violascens* stands under mulching management; different letters indicate significant differences at $p < 0.01$ (capital letters) and $p < 0.05$ (lower case letters) between the different treatments of the same bamboo age; different subscript letters indicate significant differences at $p < 0.01$ (capital letters) and $p < 0.05$ (lower case letters) between different bamboo ages with the same treatment

3-year plot > control and for 2- and 3-year-old bamboo it was 3-year plot > 6-year plot > control (Figure 4a). There was no difference in foliar C:P ratio for 2-year-old bamboo between the 3- and 6-year plots, while both treatments were significantly higher than control. Furthermore, foliar C:P ratio for 1- and 3-year-old bamboo increased greatly with increased time of mulching management, and significant difference ($p < 0.01$) was found between treatments (Figure 4b). Foliar N:P ratio increased with time of mulching management, and no difference was found between control and 3-year plot in 1-year-old bamboo, but these ratios were significantly higher in the 6-year plot. Furthermore, foliar N:P ratios in 2- and 3-year-old bamboo in the 3- and 6-year plots were significantly higher than control and these ratios for 6-year plot treatment were also significantly higher than the 3-year plot (Figure 4c). As bamboo age increased, foliar C:N ratios of control and 6-year plot decreased, with the 1-year-old bamboo having higher values than that of 3-year-old bamboo. However, foliar C:N ratios of the 3-year plot increased in 2-year-old bamboo but decreased thereafter (Figure 4a). Foliar C:P ratios increased with bamboo age and the C:P ratios of 2- and 3-year-old bamboo were higher than that of 1-year-old bamboo. Foliar C:P ratios for 2-year-old bamboo in the 3-year plot were higher than that of 3-year-old bamboo, but no differences between 2- and 3- year-old bamboo were found in the control and 6-year plot (Figure 4b). There was no difference in foliar N:P ratios between bamboo ages in the control but foliar N:P ratios of 2- and 3-year-old bamboo in the 3- and 6-year plots were significantly higher than that of 1-year-old bamboo (Figure 4c).

Response of relationships between C, N and P stoichiometry and mulching management

Soil N content had significant ($p < 0.01$) negative relationship with foliar N content but not with foliar P content and foliar N:P ratios. Soil P content had significant ($p < 0.01$) negative relationship with foliar P content and significant positive relationship with foliar N:P ratios, but no significant relationship was observed with foliar N content. Soil N:P ratios had significant negative relationships with foliar N content ($p < 0.05$) and foliar N:P ratios ($p < 0.01$) but significant ($p < 0.05$) positive relationship with foliar P content. Soil pH had significant ($p < 0.01$) negative relationship with foliar P content and significant ($p < 0.01$) positive relationships with foliar C:P and N:P ratios. Soil C:P ratios had significant ($p < 0.05$) negative relationships with foliar C:P and N:P ratios (Table 2).

DISCUSSION

It has been generally accepted that change in landuse intensity can markedly change soil C, N, P contents and pH (Falkengren-Grerup et al. 2006, Zhao et al. 2007). Our results show that mulching management on bamboo plantations caused excessive amounts of C, N and P to accumulate in the soil system and soil pH to decrease. This findings are consistent with those of Cao et al. (2004) and Zhang et al. (2012). Our study show that increments of soil C, N and P contents at 0–20 cm were more than twice those at 20–50 cm, exhibiting a surplus accumulation of C, N and P at that depth. Decrements of soil pH at 0–20 cm were more than 1.5 times those at

Table 2 Relationships of C, N and P stoichiometry between soil and foliage of *Phyllostachys violascens* stands under mulching management

Characteristic	Foliar C	Foliar N	Foliar P	Foliar C:N ratio	Foliar C:P ratio	Foliar N:P ratio
Soil total C	-0.261	-0.251	-0.076	0.054	-0.002	-0.015
Soil total N	-0.313	-0.621**	0.162	0.627*	-0.121	-0.227
Soil total P	0.327	0.268	-0.767**	-0.011	0.789**	0.752**
Soil pH	0.297	0.383	-0.904**	-0.236	0.865**	0.857**
Soil C:N ratio	-0.199	-0.054	-0.148	-0.203	0.033	0.059
Soil C:P ratio	-0.561*	-0.549	0.501	0.136	-0.601*	-0.599*
Soil N:P ratio	-0.531*	-0.705*	0.889**	0.459	-0.878**	-0.911**

*p < 0.05, **p < 0.01

20–50 cm, representing serious soil acidification at 0–20 cm. Excessive accumulation of N in the topsoil strengthened soil N nitrification, H^+ production and activation of aluminium (Álvarez et al. 2005), while incomplete decomposition of organic materials on the soil surface and topsoil enhanced soil C content sharply and induced accumulation of phenolic acid and inhibition of enzyme activity (Zheng 2006). All of these have tremendous impact on the concentration and biogeochemical cycling of soil C, N and P, thus, greatly change the balance of soil H^+ eco-cycle (Sun et al. 2009). Eventually these will result in serious and irreversible soil quality deterioration.

To some degree, contents of foliar nutrient elements and their stoichiometry reflect plant adaptation to the soil environment (Yi et al. 2010). To meet growth demand, plants usually absorb N and P from soil in proportion to their structure, substance biosynthesis and C assimilation (Wu et al. 2010). In this study, foliar C, N and P contents of 1- to 3-year-old bamboo in stands with mulching management are significantly lower than that of non-mulched stands, indicating that adverse impacts on bamboo growth and vigour were caused by long-term mulching with rice straw and chaff. The possible mechanism underlying the declining bamboo growth by mulching management may be related to the excessive accumulation of N causing a decrease in soil pH. The resulting soil acidification led to aluminium activation, which is toxic to bamboo roots and therefore decrease N and P uptake by the roots. Excessive accumulation of N in topsoil also inhibit the activity of rubsico, the key enzyme of C assimilation (Nakaji et al. 2002). It has been reported that foliar N and P have a positive relationship with foliar photosynthesis (Barbaroux & Breda 2002, McGroddy et al. 2004). Therefore, the decrease in foliar N and P contents and inhibition of rubisco must result in the decease of foliar C content.

Bamboo usually adapts to deteriorated soil environment by enhanced C assimilation (by unit N and P contents) to maintain population stability, so foliar C:N and C:P ratios increase greatly. Foliar N:P ratios increased significantly with time of mulching management. Dramatic variation in soil C, N and P stoichiometry has adverse impact on soil acidification, aluminium activation, accumulation of allelochemicals and the decrease in enzyme activity (Zheng 2006). These C, N and P stoichiometry changes can induce harmful effects on root and rhizome growth, and cause a sharp decline in plant growth and N and P absorption ability (Sterner & Elser 2002). Passive absorption of N and P by roots also occurred, which disrupted the absorption balance of N and P and moved the C, N and P stoichiometry away from a healthy balance.

The bioavailability of N and P in ecosystems is one of the most important limiting factors of plant growth (Güsewell 2004) and the foliar N:P ratio is an important indicator of soil N and P limitation (Reich & Oleksyn 2004). Various studies suggest that N limitation likely occurs at N:P ratios < 14, with P limitation probable at values > 16, while at N:P ratios ranging from 14 to 16, N and P co-limitation occurs (Aerts & Chapin 2000, Elser et al. 2003, Drenovsky & Richards 2004). In this study, foliar N:P ratios of bamboo from mulched stands ranged from 14.05 to 18.41, with a mean of 15.87, indicating that growth of bamboo under mulching management was not limited by soil N content but dramatically limited by soil P content. Foliar N:P ratios of mulched stands were obviously higher than those of non-mulched stands. This indicates that mulching management of bamboo stands induced P limitation. The results also show that N and P stoichiometry, especially the N:P ratio, was a crucial ecological indicator for good growth of bamboo and the health of the bamboo forest ecosystem.

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