<https://helda.helsinki.fi>

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

Cai, Xiaoqing

2018-08-15

Cai , X , Lin , Z , Penttinen , P , Li , Y , Li , Y , Luo , Y , Yue , T , Jiang , P & Fu , W 2018 , ' Effects of conversion from a natural evergreen broadleaf forest to a Moso bamboo plantation on the soil nutrient pools, microbial biomass and enzyme activities in a subtropical area ' , Forest Ecology and Management , vol. 422 , pp. 161-171 . <https://doi.org/10.1016/j.foreco.2018.04.022>

<http://hdl.handle.net/10138/326533>

<https://doi.org/10.1016/j.foreco.2018.04.022>

cc_by_nc_nd

acceptedVersion

Downloaded from Helda, University of Helsinki institutional repository.

This is an electronic reprint of the original article.

This reprint may differ from the original in pagination and typographic detail.

Please cite the original version.

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

Xiaoqing Cai ^{a, b}, Ziwen Lin ^{a, b}, Petri Penttinen ^{a, c}, Yongfu Li ^{a, b, *}, Yongchun Li ^{a, b}, Yu Luo ^d, Tian Yue ^{a, b}, Peikun Jiang ^{a, b}, Weijun Fu ^{a, b}

^a State Key Laboratory of Subtropical Silviculture, Zhejiang Provincial Key Laboratory of Carbon Cycling in Forest Ecosystems and Carbon Sequestration, Zhejiang A & F University, Lin'an 311300, China

^b Zhejiang Provincial Collaborative Innovation Center for Bamboo Resources and High-efficiency Utilization, Zhejiang A & F University, Lin'an 311300, China

^c Department of Environmental Sciences, PO Box 65 (Viikinkaari 2a), 00014, University of Helsinki, Finland

^d Zhejiang Provincial Key Laboratory of Agricultural Resources and Environment, Zhejiang University, Hangzhou 310058, China

* Corresponding author:

E-mail: yongfuli@zafu.edu.cn (Y. Li)

Tel.: +86-571-611-02592; Fax.: +86-571-637-40889

Number of text pages: 35; Number of figures: 7; Number of tables: 1

Submitted to: Forest Ecology and Management

Type of papers: Original Research Paper (Full Length Article)

Date of preparation: February 23, 2018

Revised: April 8, 2018

Abstract

Converting natural forests to plantations would markedly change soil physiochemical and biological properties, as a consequence of changing plant vegetative coverage and management practices. However, the effects of such land-use change on the soil nutrient pools and related enzymes activities still remain unclear. The aim of this study was to explore the effects of conversion from natural evergreen broadleaf forests to Moso bamboo plantations on the pool sizes and forms of soil N, P and K, microbial biomass, and nutrient cycling related enzyme activities. Soil samples from four adjacent evergreen broadleaf forest-Moso bamboo plantation pairs were collected from a subtropical region in Zhejiang Province, China. The soil organic C (SOC), total N (TN), total P (TP) and total K (TK) concentrations and stocks and different N, P and K forms were measured, and the microbial biomass C (MBC), microbial biomass N (MBN), microbial biomass P (MBP) and four soil enzymes (protease, urease, acid phosphatase and catalase) were determined. The results showed that converting broadleaf forests to Moso bamboo plantations decreased the concentration and stock of SOC but increased those of TK in both soil layers (0–20 and 20–40 cm), and such land-use change increased the concentration and stock of TN and TP only in the 0–20 cm soil layer ($P < 0.05$). This land-use conversion increased the concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, resin- P_i , $\text{NaHCO}_3\text{-P}_i$, NaOH-P_i , HCl-P_i , available K and slowly available K, but decreased the concentrations of water-soluble organic nitrogen (WSON), $\text{NaHCO}_3\text{-P}_o$ and NaOH-P_o ($P < 0.05$). Further, this land-use change decreased the microbial biomass and activities of protease, urease, acid phosphatase and catalase ($P < 0.05$). In addition, the acid phosphatase activity correlated

positively with the concentrations of MBP and $\text{NaHCO}_3\text{-P}_{\text{o}}$, and the activities of urease and protease correlated positively with the concentrations of MBN and WSON ($P < 0.01$). To conclude, converting natural broadleaf forests to Moso bamboo plantations had positive effects on soil inorganic N, P and K pools, and negative effects on soil organic N and P pools, and on N- and P-cycling related enzyme activities. Therefore, management practices that increase organic nutrient pools and microbial activity are needed to be developed to mitigate the depletion of organic nutrient pools after the land-use conversion.

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

1. Introduction

Land-use conversion can significantly affect the soil physicochemical and biological properties (Yang et al., 2004; Don et al., 2011; Moghimian et al., 2017). Over the past few decades, in order to gain higher economic benefits and to supply the growing demands of timber, paper and fuel, among other commodities, the conversion from natural forests to plantations is becoming more frequent (Burton et al., 2007; Li et al., 2014; Hu et al., 2018). To increase the growth of plantations after land-use change, intensive management practices, mainly including fertilization, understory vegetation control, and deep ploughing, have been commonly adopted (Li et al., 2013; Zhang et al., 2015a; Dangal et al., 2017; Zhang et al., 2017a). Various studies have revealed that the intensive management practices applied can significantly change the soil pH, nutrient status, and microbial biomass and community composition (Li et al., 2013; Yuan et al., 2015; Xie et al., 2017), and consequently influence soil fertility and plant growth (Pransiska et al., 2016; Tiecher et al., 2017). Therefore, it is great of significance to investigate the effects of land-use change and subsequent management practices on the pool sizes and forms of soil nutrients and associated enzyme activities.

The effects of land-use change from natural forest to plantation on soil nutrient status and associated enzyme activities may include the following: (1) the input of exogenous fertilizer can have a direct effect on the pool sizes and forms of soil nutrients (Chang et al., 2007; Sainju et al., 2012; Yang et al. 2017; Li et al. 2018), and (2) the differences in chemical composition and root exudates of different vegetation types may change the

microbial growth environment, which affects microbial biomass and soil enzyme activity (Yang et al., 2010; Li et al., 2011; Wang et al., 2013; Yuan et al., 2015). For example, the input of exogenous organic fertilizer and root exudates can increase the availability of water-soluble nitrogen (N) (Scott and Rothstein, 2011; Sainju et al., 2012; Li et al., 2017a). In addition, an increase in N fertilizer application can reduce soil enzyme activity and microbial biomass (Shen et al., 2010; Zhang et al., 2015b). Previous studies showed that understory vegetation plays important roles in cycling nutrients and decreasing soil erosion (Fukuzawa et al., 2006; Zhang et al., 2010).

The classification of soil nutrients can help to determine soil nutrient status (Ross et al., 1999; Yang et al., 2010). Different forms of N, such as $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ and water-soluble organic N (WSO), can jointly indicate the N supply capacity of soils (Schimel and Bennett, 2004; Chen and Xu, 2008; Yan et al., 2008; Wu et al., 2010). The different forms of phosphorus (P) in soils are formed through the combination of P with different mineral components and can significantly affect N- and P-cycling (Yang et al., 2010; Wei et al., 2017). In addition, the soil potassium (K) supply is closely associated with the transformation rate of different forms of K in soils (Darunsontaya et al., 2012). The different forms of nutrients respond differently to land-use change. For example, Ouyang et al. (2013) reported that after conversion from wetland to paddy field, the total K concentration increased but the available K concentration decreased in soils. Yang et al. (2004) reported that converting secondary forests to rubber plantations increased the concentration of inorganic N but decreased the concentration of total N. In addition, Yang et al. (2010) found that converting natural forests to larch plantations increased the

concentrations of total P (TP) and inorganic P (IP) but decreased the concentrations of microbial biomass P (MBP) and organic P (OP). Therefore, exploring the responses of different forms of soil nutrients to land-use change will enable us to elucidate the mechanisms associated with the land-use conversion effects on the soil nutrient status.

Soil microbes play an important role in the decomposition and mineralization of soil organic matter (Malchair and Carnol, 2009; Guo et al., 2016; Ge et al., 2017; Li et al., 2017b; Luo et al., 2017). Soil enzymes are closely related to the transformation of soil nutrients, and their activities are closely associated with the level of soil organic matter, soil physicochemical properties and soil microbial biomass (Xu et al., 2010; Liu et al., 2015; Chavarría et al., 2016; Ma et al., 2016). For example, Bhattacharyya et al. (2005) found that there was a pronounced linear correlation between soil urease and microbial biomass. Additionally, Yang et al. (2010) found that acid phosphatase activity was positively correlated with the concentrations of $\text{NaHCO}_3\text{-P}_i$, $\text{NaHCO}_3\text{-P}_o$, and MBP in a subtropical forest soil. Land-use change can markedly affect the soil enzyme activity as well as the soil microbial biomass and nutrient forms (Dawoe et al., 2014; Guo et al., 2016). However, it remains unclear whether the changes in soil enzyme activity caused by land-use change are closely linked with the changes in soil microbial biomass or nutrient forms.

Natural evergreen broadleaf forests contribute to maintain biodiversity; these forests are considered to be an important vegetation type in the subtropical regions of China (Wang et al., 2007). However, large areas of natural forests have been transformed into plantations over the past two decades (Yan et al., 2015; Chen et al., 2017), most

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

2. Materials and methods

2.1. Experimental site

The study was carried out in Congkeng (30°14'N, 119°42'E), Hangzhou, Zhejiang, China. The study area belongs to a subtropical monsoon climate zone with four distinct seasons, with an average annual temperature of 15.8 °C and average annual precipitation

of 1420 mm. The annual sunshine duration and frost-free period of this site are 1946 hours and 239 days, respectively. The elevation of the study area is approximately 150 m. The soils at this experimental site are classified as Ferralsols (World Reference Base for Soil Resources (WRB) 2006).

We chose two different land-use types, i.e., natural evergreen broadleaf forests and Moso bamboo plantations, to investigate the differences in soil properties. The main tree species in the natural evergreen broadleaf forests were *Cyclobalanopsis glauca*, *Castanopsis eyrie*, and *Castanopsis sclerophylla*, which accounted for approximately 70% of the canopy cover. The understory vegetation in this natural forest was mainly *Litsea cubeba*, *Lindera glauca*, and *Camellia cuspidata*, of which the surface cover was approximately 85%. Part of the natural evergreen broadleaf forests had been transformed into Moso bamboo plantations. The Moso bamboo plantation in the present study was established in 2004. The bamboo plantation had been managed intensively for 11 years after the land-use conversion. The stocking density in the bamboo plantation was 3,000 stems ha⁻¹, with 10.1 cm mean diameter at breast height. Every year from late June to early July the bamboo plantation was fertilized with urea (200 kg N ha⁻¹), superphosphate (60 kg P ha⁻¹), and potassium chloride (70 kg K ha⁻¹). The fertilizer was usually applied on the soil surface, followed by plowing to a depth of 30–35 cm. The understory vegetation in the bamboo plantation was manually removed each year.

2.2. Experimental design and soil sampling

A paired-plot approach was adopted to investigate the effects of land-use conversion on soil properties. One paired-plot included two adjacent plots, i.e., one in the natural evergreen broadleaf forest and the other in the Moso bamboo plantation. Each paired plot had the same geographic and environmental factors, including soil type, slope (15–20°) and aspect (south). We selected four different locations within ~3 km² in the area described above to establish four different paired plots in April 2015; the plot size was 20 m × 20 m (400 m²). Within one paired-plot, the distance between the two plots (one in the natural evergreen broadleaf forest and the other in the Moso bamboo plantation) was less than 100 m, and there were 4 replications for each land-use type.

In each plot, we collected soil samples from five randomly selected points at the 0–20 and 20–40 cm soil layers. For each soil layer, the five samples were thoroughly mixed to form a composite sample. The soil samples were kept on ice before further processing. A 2-mm sieve was used to homogenize the samples, and visible roots were removed. Samples were divided into two portions: one portion was stored at 4 °C for further analyses, and the other portion was air-dried. We used a bulk density corer with a 200-cm³ volume to collect samples from the two soil layers to determine the bulk density. The average values for the selective physicochemical properties (see methods described below) in the 0–20 cm soil layer for the aforementioned two forest types were listed below: (1) natural evergreen broadleaf forest: pH of 5.67, bulk density of 0.96 g cm⁻³, sand of 301 g kg⁻¹, silt of 413 g kg⁻¹, and clay of 286 g kg⁻¹; (2) Moso bamboo plantation: pH of 5.16, bulk density of 1.06 g cm⁻³, sand of 324 g kg⁻¹, silt of 401 g kg⁻¹, and clay of 275 g kg⁻¹.

2.3. Determination of soil physicochemical properties

The soil pH was measured at a soil-to-water ratio of 1:2.5 (w:v) using a pH meter. The soil moisture content was measured by calculating the mass loss after oven drying at 105 °C for more than 12 hours. The soil bulk density was determined by collecting a fresh 20-g soil subsample from a metal density corer with known volume and oven drying the sample for more than 24 hours at a temperature of 105 °C. The concentrations of soil organic carbon (SOC) and total N (TN) were determined using an elemental analyzer (model CHN-O-RAPID, Heraeus, Germany). The total P (TP) concentration was determined by digesting soil samples with a mixture of concentrated H₂SO₄ and HClO₄, and the molybdate-blue colorimetry method (Murphy and Riley 1962) was used to measure the P concentration in the digest. The soil total K (TK) concentration was determined using the NaOH melting method according to Hanway and Heidel (1952). Soil texture was determined using the pipette method after pre-treating the soil samples with solutions of H₂O₂ and Na₄P₂O₇ (Gee and Bauder 1986). The stocks of SOC, TN, TP and TK were calculated using the following formula:

$$Y_{\text{stock}} (\text{Mg ha}^{-1}) = X \times BD \times th \times 0.1 \quad (1)$$

Where X is the concentration (g kg⁻¹) of SOC, TN, TP or TK, BD is the bulk density of the soil layer (Mg m⁻³), and th is the thickness of the soil layer (cm).

2.4. Determination of soil N forms

The concentrations of NO_3^- -N and NH_4^+ -N in each soil sample were determined according to the method of Li et al. (2014). Briefly, a soil sample was extracted with KCl solution (2 mol L^{-1}), and the concentrations of NO_3^- -N and NH_4^+ -N in the extract were determined using a Dionex ICS 1500 ion chromatograph (Dionex Corp., Atlanta, USA). The WSON concentration was determined according to Jones and Willett et al. (2006). In short, a fresh subsample equivalent to 20 g of oven-dried soil was suspended in 40 mL of distilled water, shaken for 0.5 hours at 150 rpm at 25 °C and then centrifuged for 20 minutes at $8,000 \times g$. The supernatant was passed through a 0.45- μm membrane filter (Millipore Corp, USA). The concentration of water-soluble N (WSN) in the filtrate was measured using an automated TOC-TN analyzer (TOC-Vcph, Shimadzu, Kyoto, Japan). The concentrations of NH_3^- -N and NH_4^+ -N in the filtrate were determined using an ion chromatograph, and the WSON concentration was calculated using the following formula:

$$\text{WSON} = \text{WSN} - (\text{NO}_3^- \text{-N}) - (\text{NH}_4^+ \text{-N}) \quad (2)$$

2.5. Determination of P forms

The concentrations of different forms of P were determined by adopting the Hedley procedure (Hedley et al., 1982; Eriksson et al., 2015). (1) Resin- P_i : a fresh soil sample equivalent to 0.5 g of oven-dried soil was suspended in 30 mL of distilled water. Together

with a strip of NaHCO_3 -form anion exchange resin membrane (BDH No. 55164) pretreated by the method of Schoenau and Huang (1991), the suspension was shaken for 16 hours at 150 rpm at 25 °C, and the P absorbed into the resin membrane (resin- P_i) was recovered by shaking the resin membrane in 50 mL of 0.5 mol L^{-1} HCl for 1 h. (2) $\text{NaHCO}_3\text{-P}_i$ and $\text{NaHCO}_3\text{-P}_o$: two drops of toluene were added to minimize organic P decomposition to the residue from (1) before shaking in 30 mL of 0.5 mol L^{-1} NaHCO_3 (pH = 8.5) for 16 hours. (3) NaOH-P_i and NaOH-P_o : 30 mL of 0.1 mol L^{-1} NaOH was added to the residue from (2) and then shaken for 16 hours. (4) HCl-P_i : the residue from (3) was shaken in 30 mL of 1.0 mol L^{-1} HCl for 16 hours. (5) Residual-P: the residue from (4) was digested in concentrated H_2SO_4 and H_2O_2 , followed by shaking for 16 hours. After steps (1) to (5), the suspension was centrifuged at 12,000 $\times g$ for 10 minutes. The supernatants were passed through a 0.45- μm membrane filter (Millipore Corp., USA), and the inorganic P concentration in the filtrates were measured using the molybdate-blue method (Murphy and Riley, 1962). In (2) and (3), the TP concentration in the extracts was measured by digesting the extracts in concentrated H_2SO_4 and H_2O_2 , and the organic P concentration in the extracts was calculated as the difference between the TP concentration and the inorganic P concentration.

2.6. Analysis of K forms

The different forms of soil K determined included available K, slowly available K and mineral K. The available K concentration was determined by the method of Zhang et

al. (2013). Briefly, 10 g of oven-dried soil sample was suspended in 50 mL of 1.0 mol L⁻¹ NH₄OAc, shaken for 0.5 hours at 150 rpm at 25°C, and the suspension was centrifuged at 5,000 × g for 10 minutes and then passed through a 0.45-μm membrane filter (Millipore Corp, USA). The concentration of K in the filtrate was measured using a flame photometer (Tiecher et al. 2017). The slowly available K concentration was determined by suspending 10 g of oven-dried soil in 50 mL of 1.0 mol L⁻¹ HNO₃, heated to boiling in an oil bath for 10 minutes, transferred to a 100-mL volumetric flask, and the K concentration was measured using a flame photometer. The soil total K (TK) concentration for each soil sample was determined using the NaOH melting method (Hanway and Heidel, 1952). Slowly available K was calculated as the difference between the concentration of K extracted by the hot HNO₃ solution and the concentration of the K extracted by the NH₄OAc solution. Mineral K was calculated as the difference between the concentration of total K and the concentration of the K extracted by the hot HNO₃ solution.

2.7. Analysis of soil microbial biomass and soil enzymes

The concentrations of microbial biomass C (MBC) and microbial biomass N (MBN) were determined using the chloroform fumigation-K₂SO₄ extraction method as described in Vance et al. (1987). In brief, fumigated and non-fumigated soil samples were suspended in 40 mL of 0.5 mol L⁻¹ K₂SO₄, shaken at 150 rpm for 30 minutes at 25 °C, centrifuged for 5 minutes at 3500 × g, and the supernatants were passed through a 0.45-μm membrane filter (Millipore Corp, USA). The concentrations of C and N in the extracts were measured

in an automated TOC-TN analyzer (TOC-Vcph, Shimadzu, Kyoto, Japan). The soil MBC concentration was calculated as the difference in the concentration of C between the fumigated and non-fumigated samples (Wu et al., 1990; Burton et al., 2010). Similarly, the soil MBN concentration was calculated as the difference in the concentration of N between the fumigated and non-fumigated samples (Li et al., 2014). The concentration of MBP was determined following the method of Brookes et al. (1982). Briefly, the MBP was calculated as the difference between the concentrations of inorganic P extracted with 0.5 mol L⁻¹ NaHCO₃ (pH = 8.5) from fumigated and non-fumigated soil.

The soil protease (EC 3.4.2.21–24) activity was measured following the method of Ladd and Butler (1972). 1 g of fresh sample was mixed with 2.5 mL of Tris buffer (0.1 mol L⁻¹, pH = 8.1) and 2.5 mL of 2% sodium caseinate, and incubated at 50 °C for 2 hours. At the end of the incubation, 1 mL of 17.5% trichloroacetic acid (TCA) was added, then centrifuged for 10 minutes at 5,000 × g. 2 mL of the supernatant was mixed with 3.0 mL Na₂CO₃ (1.4 mol L⁻¹) and 1 mL threefold diluted Folin-Ciocalteu reagent. After 10 minutes, the absorbance was determined at 700 nm. The protease activity is expressed as the amount of tyrosine released per hour per gram of soil (μmol g⁻¹ h⁻¹).

The soil urease (EC 3.5.1.5) activity was determined following the method described in Kandeler and Gerber (1988). Briefly, a fresh soil sample equivalent to 5 g of oven-dried soil was suspended in 2.5 mL of 80 mmol L⁻¹ urea and 20 mL of Tris buffer (0.075 mol L⁻¹, pH = 10), and incubated at 37 °C for 2 hours. After incubation, 50 mL of a mixture of 1 mol L⁻¹ KCl and 10 mmol L⁻¹ HCl was added, and the suspension was shaken at 125 rpm for 30 minutes. The suspension passed through a filter, and the concentration of

ammonia in the filtrate was determined using the colorimetric method described in Marschner et al. (2003). The urease activity is expressed as the amount of $\text{NH}_3\text{-N}$ produced per unit mass of soil per hour ($\mu\text{mol g}^{-1} \text{h}^{-1}$).

The soil acid phosphatase (EC 3.1.3.2) activity was determined following the method of Tabatabai and Bremner (1969). A fresh soil sample equivalent to 1 g of oven-dried soil was suspended in 0.2 mL of toluene, 4 mL of acetate buffer solution ($\text{pH} = 6.5$) and 1 mL of 50 mmol L^{-1} *p*-nitrophenol phosphate solution. The suspension was shaken at 150 rpm at 37°C for 1 hour, and then 1 mL of CaCl_2 solution (0.5 mol L^{-1}) and 4 mL of NaOH solution (0.5 mol L^{-1}) were added. After shaking for several seconds, the suspension was passed through filter paper, and the absorbance of the filtrate was determined at 400 nm. The acid phosphatase activity is expressed as the amount of *p*-nitrophenyl produced per unit mass of soil per hour ($\mu\text{mol g}^{-1} \text{h}^{-1}$).

The soil catalase (EC 1.11.1.6) activity was measured following the method of Johnson and Temple (1964). A fresh soil sample equivalent to 2 g of oven-dried soil was suspended in 40 mL of distilled water and 5 mL of 0.3% H_2O_2 , and shaken at 150 rpm for 20 minutes at 25°C . Then, 5 mL of 3 mol L^{-1} sulfuric acid was added, and the mixture was titrated using 0.1 mol L^{-1} KMnO_4 solution. The baseline was determined by titrating a mixture of 5 mL of 0.3% H_2O_2 and 5 mL of 3 mol L^{-1} sulfuric acid with 0.1 mol L^{-1} KMnO_4 . The catalase activity is expressed as the amount of consumption of KMnO_4 per hour per gram of soil ($\mu\text{mol g}^{-1} \text{h}^{-1}$).

2.8. Statistical analyses

The data presented in this paper are the mean values of four replicates. One-way analysis of variance (ANOVA) and the least significant difference (LSD) test was adopted to determine the land-use conversion effects on the soil physiochemical properties, microbial biomass and enzyme activities. Prior to performing the ANOVA, the normality and homogeneity of variance were evaluated, and data were log-transformed when needed. The relationships between the soil enzyme activity and different soil N and P forms were tested using linear regression analyses. Unless otherwise indicated, differences were taken as statistically significant at $P = 0.05$. Data analyses and visualization were completed using Microsoft Excel 2013 and Origin 9.0, respectively, and the statistical analyses were conducted using SPSS version 18.0 (SPSS, Chicago, IL, USA).

3. Results

3.1. Soil total C, N, P and K concentrations and stocks

Regardless of soil layer, the SOC concentration in the Moso bamboo plantation was lower than that in the evergreen broadleaf forest (Fig. 1a), while the total K concentration in the bamboo plantation was higher than that in the broadleaf forest (Fig. 1g). The total N and P concentrations in the bamboo plantation were higher than those in the broadleaf forest in the 0–20 cm soil layer, while no differences were observed in the 20–40 cm layer (Fig. 1c, e). The effects of land-use conversion on the total C, N, P and K stocks were similar to the effects on the total C, N, P and K concentrations (Fig. 1).

3.2. Soil N forms

Regardless of soil layer, the NO_3^- -N and NH_4^+ -N concentrations in the Moso bamboo plantation were higher than those in the evergreen broadleaf forest (Fig. 2a and b), while the WSON concentration in the bamboo plantation was lower than that in the broadleaf forest (Fig. 2c).

3.3. Soil P forms

Regardless of soil layer, the resin- P_i and NaHCO_3 - P_i concentrations in the Moso bamboo plantation were higher than those in the evergreen broadleaf forest, while the NaHCO_3 - P_o concentration in the bamboo plantation was lower than that in the broadleaf forest (Table 1). The NaOH - P_i , HCl - P_i and residual-P concentrations in the bamboo plantation were higher than those in the broadleaf forest in the 0–20 cm soil layer, while no differences were detected in the 20–40 cm layer (Table 1). The NaOH - P_o concentration in the bamboo plantation was lower than that in the broadleaf forest in the 0–20 cm soil layer, while no significant difference was found in the 20–40 cm layer (Table 1).

3.4. Soil K forms

Regardless of soil layer, the total K, available K and slowly available K

concentrations in the Moso bamboo plantation were higher than those in the evergreen broadleaf forest (Fig. 3a–c). The mineral K concentration in the bamboo plantation was higher than that in the broadleaf forest in the 0–20 cm soil layer, while no difference was found in the 20–40 cm layer (Fig. 3d).

3.5. Soil microbial biomass and enzyme activities

Regardless of soil layer, the MBC, MBN and MBP concentrations in the Moso bamboo plantation were higher than those in the evergreen broadleaf forest (Fig. 4). Regardless of soil layer, the activities of protease, urease, and acid phosphatase in the bamboo plantation were lower than those in the broadleaf forest (Fig. 5 a–c). The catalase activity in the bamboo plantation was lower than that in the broadleaf forest in the 0–20 cm soil layer, while no difference was found in the 20–40 cm layer (Fig. 5d). Acid phosphatase activity correlated positively with MBP and $\text{NaHCO}_3\text{-P}_o$ (Fig. 6), and urease and protease activities correlated positively with the concentrations of MBN and WSON (Fig. 7) ($P < 0.01$).

4. Discussion

4.1. Land-use conversion effects on soil nutrient pools

Our results revealed that the land-use conversion from evergreen broadleaf forests to

Moso bamboo plantations significantly decreased the concentration and stock of SOC (Fig. 1). This result coincides with that of Guillaume et al. (2015), who reported that conversion from lowland rainforests to intensively managed rubber plantations significantly decreased the SOC stock. The decrease in concentration and stock of SOC due to the land-use change in our study has two possible explanations. Practices of fertilization and tillage may accelerate the mineralization of SOC and the leaching of soluble soil organic matter (Mancinelli et al., 2010; Sheng et al., 2015; Liu et al., 2018), and the removal of understory vegetation in the plantations may decrease C input into the soil (Wang et al., 2011; Li et al., 2013; Zhang et al., 2014).

In addition, this land-use conversion significantly increased the concentrations and stocks of N, P and K (Fig. 1), which is in agreement with Yang et al. (2010) and Zhang et al. (2017b), who reported that conversion from natural forests to larch and pine plantations, respectively, increased the concentrations and stocks of N in the surface soil. Plausibly, the main sources for the increased concentrations and stocks of N, P and K were the synthetic fertilizers applied in the Moso bamboo plantation, as the natural evergreen broadleaf forest did not receive any fertilization.

4.2. Land-use conversion effects on different soil N forms

In this study, we found that the conversion from broadleaf forest to bamboo plantation increased the concentrations of NO_3^- -N and NH_4^+ -N (Fig. 2), in agreement with Yang et al. (2004) who reported that the concentration of NO_3^- -N increased after the conversion from secondary forest to a larch plantation. In addition, we also found that the aforementioned land-use change significantly decreased the WSON concentration (Fig. 2),

which accords with the result of Li et al. (2014), who reported that the conversion of natural shrub forests to intensively managed Chinese chestnut plantations significantly reduced the WSON concentration in the soil.

The changes in soil N forms caused by land-use change can be attributed to a number of possible mechanisms. Intensive **managements** that **include** fertilization, tillage and understory vegetation removal, could lead to a decrease in water and soil conservation ability, and consequently cause the loss of WSON (Yüksek et al., 2009; Sheng et al., 2015). Fertilization can accelerate the mineralization of organic N and enhance the uptake of soluble organic N by plants, consequently reducing the WSON concentration in soils (Schimel and Bennett, 2004; Tao et al., 2018). The increase in NO_3^- -N and NH_4^+ -N concentrations in soils after land-use change are evidently related to the increase in N input from fertilization (Asadiyan et al., 2013).

4.3. Land-use conversion effects on different soil P forms

Results of the present study revealed that converting broadleaf forests to Moso bamboo plantations increased the resin- P_i and NaHCO_3 - P_i concentrations but decreased the NaHCO_3 - P_o concentration (Table 1). Similarly, Yang et al. (2010) found that **converting natural secondary forests to larch plantations increased the TP and iron-bound P (Fe-P) concentrations in soils but decreased the MBP and NaHCO_3 - P_o concentrations.**

The changes in soil P forms caused by land-use change have two possible explanations. Fertilization significantly increased the inorganic P concentration but

reduced the organic P concentration in intensively managed rubber and oil palm plantations (Maranguit et al. 2017). In addition, Yang et al. (2012) showed that fertilization caused a significant increase in the inorganic P concentration and a significant decrease in the organic P concentration in soils. Thus, the increase in the concentration of inorganic P fractions is at least partially related to the application of phosphate fertilizer in the Moso bamboo plantation. In addition, the intensive management measures, e.g. deep tillage and fertilization, applied in the Moso bamboo plantation may decrease the organic P concentration since they can promote the mineralization of P-containing organic matter (Yang et al., 2012; Obour et al., 2017).

4.4. Land-use conversion effects on different soil K forms

Studying the effects of land-use change on different forms of K can help us to understand the response of K nutrient status to land-use conversion (Wang et al., 2016; Islam et al., 2017). The available K concentration increased after the conversion of natural evergreen broadleaf forests to *Phyllostachys praecox* stands and in the conversion from virgin natural forests to alder and sequoia plantations (Zhang et al. 2013; Moghimian et al. 2017). Likewise, our results indicated that conversion from broadleaf forests to Moso bamboo plantations significantly increased the concentrations of total K, available K, slowly available K, and mineral K (Fig. 3).

The KCl fertilizer applied in the Moso bamboo plantation was the possible source of the increased K in soils. The fertilizer can quickly increase the available K, and a part of

the available K will be transformed to slowly available K and mineral K forms (Rupa et al., 2003; Islam et al., 2017).

4.5. Land-use conversion effects on soil microbial biomass and enzyme activity

The soil microbial biomass is a sensitive index of the soil nutrient pool, since soil nutrients provide the basis for the survival of soil microbes (Guo et al., 2016; Vitali et al., 2016). In agreement with Fang et al. (2017), who reported that converting natural old-growth broadleaf Korean pine mixed forest to a spruce plantation caused a reduction in the soil MBC concentration, we noticed that the soil MBC concentration was lower in the Moso bamboo plantation than in the broadleaf forest (Fig. 4). In line with our previous study where the MBN concentration decreased significantly 10 years after the conversion from shrub forests to Chinese chestnut plantations (Li et al., 2014), the land-use change in this study decreased the concentrations of MBN and MBP (Fig. 4). The decreased concentrations of MBC, MBN and MBP in the bamboo plantation might have been partially due to the lower pH, which is known to inhibit microbial growth (Luo et al., 2013; Guo et al., 2016; Moghimian et al., 2017). Another possible explanation is the markedly decreased SOC concentration, which might have had a negative impact on the growth of soil microorganisms (Vitali et al., 2016; Moghimian et al., 2017).

The soil enzyme activity is one of the most sensitive indicators of soil nutrient status and fertility, and it is greatly affected by land-use conversion and alterations in management practices (Moghimian et al., 2017). Converting tropical forests to rubber

plantations decreased the activity of acid phosphatase, catalase activity decreased after the conversion from a broadleaf forest to a *Michelia macclurei* Dandy plantation, and acid phosphatase activity decreased after converting a broadleaf forest to a *Pinus massoniana* Lamb plantation (Yang et al. 2012; Wang et al. 2013). In this study, the activities of protease, urease, acid phosphatase and catalase, involved in N and P cycling, were significantly lower in soils after the land-use change of broadleaf forests to bamboo plantations (Fig. 5). Low soil pH is likely to have a negative effect on the activity of some soil enzymes (Wallenius et al., 2011; Zhang et al., 2015b), which may partially explain the lower activities in bamboo plantation. Also, the lower activities might have resulted from lower microbial biomass. Since soil enzymes originate mainly from soil microorganisms, changes in microbial growth, activity and function resulting from land-use change could affect enzyme activities (Yang et al., 2012; Kader et al., 2017). Zhang et al. (2015b) found a significant relationship between the decrease in acid phosphatase activity and the application of calcium superphosphate fertilizer. Furthermore, urease activity decreased significantly with an increase in nitrogen fertilizer application (Shen et al. 2010). Thus, fertilization in the bamboo plantation might have decreased the soil enzyme activity.

Soil enzyme activity is closely associated with the level of soil nutrients (Chen et al., 2003; Islam et al., 2011; Zhang et al., 2015b). Xing et al. (2010) reported that the decomposition of soil organic N into NH_4^+ -N could be enhanced by increased activities of urease and protease in the subtropics of China. Chen (2003) found that soil acid phosphatase activity in a subtropical fir (*Cunninghamia lanceolata*) plantation in China was closely related with most of the inorganic P fractions except Ca-P. In this study, we

found that acid phosphatase activity correlated positively with MBP and $\text{NaHCO}_3\text{-P}_o$ (Fig. 6), and urease and protease activities correlated positively with the concentrations of MBN and WSON (Fig. 7). Therefore, the effects of land-use conversion on the soil enzyme activities may be attributed to its effect on the soil nutrient pools.

5. Conclusions

Converting natural evergreen broadleaf forests to intensively managed Moso bamboo plantation significantly decreased the soil pH and the concentration and stock of SOC, but significantly increased the concentrations and stocks of TN, TP and TK. Further, this land-use conversion increased the concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, resin- P_i , $\text{NaHCO}_3\text{-P}_i$, NaOH-P_i , HCl-P_i , residual-P, available K, slowly available K and mineral K but significantly decreased the concentrations of WSON, $\text{NaHCO}_3\text{-P}_o$, and NaOH-P_o , as well as the soil microbial biomass and enzyme activity. These results clearly demonstrate that the aforementioned land-use conversion had positive effects on the soil inorganic N, P and K pools, while the effects on the soil organic N, P and K pools were negative. Therefore, to manage the Moso bamboo plantations sustainably, it is advisable to increase the organic nutrient pools by applying organic fertilizers and re-establishing understory vegetation. As the duration under intensive management will markedly affect the soil nutrient status, both the short- and long-term effects of intensive management on soil N, P and K forms and enzyme activity need to be explored in further studies.

Acknowledgements

This research was financially supported by the National Natural Science Foundation of China (No. 31470626) and the Natural Science Foundation for Distinguished Young Scholars of Zhejiang Province (No. LR18C160001).

References

- Asadiyan, M., Hojjati, S.M., Pourmajidian, M.R., Fallah, A., 2013. Impact of land-use management on nitrogen transformation in a mountain forest ecosystem in the north of Iran. *J. Forestry Res.* 24, 115-119.
- Bhattacharyya, P., Chakrabarti, K., Chakraborty, A., 2005. Microbial biomass and enzyme activities in submerged rice soil amended with municipal solid waste compost and decomposed cow manure. *Chemosphere* 60, 310-318.
- Brookes, P.C., Powlson, D.S., Jenkinson, D.S., 1982. Measurement of microbial biomass phosphorus in soil. *Soil Biol. Biochem.* 14, 319-329.
- Burton, J., Chen, C.R., Xu, Z.H., Ghadiri, H., 2007. Gross nitrogen transformations in adjacent native and plantation forests of subtropical Australia. *Soil Biol. Biochem.* 39, 426-433.
- Burton, J., Chen, C.R., Xu, Z.H., Ghadiri, H., 2010. Soil microbial biomass, activity and community composition in adjacent native and plantation forests of subtropical Australia. *J. Soil. Sediment.* 10, 1267-1277.

546 Chang, E.H., Chung, R.S., Tsai, Y.H., 2007. Effect of different application rates of
547 organic fertilizer on soil enzyme activity and microbial population. J. Soil Sci. Plant
548 Nut. 53, 132-140.

549 Chavarría, D.N., Verdenelli, R.A., Serri, D.L., Restovich, S.B., Andriulo, A.E., Meriles,
550 J.M., Vargas-Gil, S., 2016. Effect of cover crops on microbial community structure
551 and related enzyme activities and macronutrient availability. Eur. J. Soil Biol. 76, 74-
552 82.

553 Chen, C.R., Xu, Z.H., 2008. Analysis and behavior of soluble organic nitrogen in forest
554 soils. J. Soil. Sediment. 8, 363-378.

555 Chen, H., 2003. Phosphatase activity and P fractions in soils of an 18-year-old Chinese fir
556 (*Cunninghamia lanceolata*) plantation. Forest Ecol. Manag. 178, 301-310.

557 Chen, L.C., Wang, H., Yu, X., Zhang, W.D., Lü, X.T., Wang, S.L., 2017. Recovery time
558 of soil carbon pools of conversional Chinese fir plantations from broadleaved forests
559 in subtropical regions, china. Sci. Total Environ. 587, 296-304.

560 Dangal, S.P., Das, A.K., Paudel, S.K., 2017. Effectiveness of management interventions
561 on forest carbon stock in planted forests in Nepal. J. Environ. Manage. 196, 511-517.

562 Darunsontaya, T., Suddhiprakarn, A., Kheoruenromne, I., Prakongkep, N., Gilkes, R. J.,
563 2012. The forms and availability to plants of soil potassium as related to mineralogy
564 for upland Oxisols and Ultisols from Thailand. Geoderma 170, 11-24.

565 Dawoe, E.K., Quashie-Sam, J.S., Oppong, S.K., 2014. Effect of land-use conversion from
566 forest to cocoa agroforest on soil characteristics and quality of a Ferric Lixisol in
567 lowland humid Ghana. Agroforestry Syst. 88, 87-99.

568 Don, A., Schumacher, J., Freibauer, A., 2011. Impact of tropical land-use change on soil
 569 organic carbon stocks-a meta-analysis. *Global Change Biol.* 17, 1658-1670.

570 Eriksson, A.K., Gustafsson, J.P., Hesterberg, D., 2015. Phosphorus speciation of clay
 571 fractions from long-term fertility experiments in Sweden. *Geoderma* 241, 68-74.

572 Fang, X., Zhang, J., Meng, M.J., Guo, X.P., Wu, Y.W., Liu, X., Zhao, K.L., Ding, L.Z.,
 573 Shao, Y.F., Fu, W.J., 2017. Forest-type shift and subsequent intensive management
 574 affected soil organic carbon and microbial community in southeastern China. *Eur. J.*
 575 *Forest Res.* 136, 689-697.

576 Fukuzawa, K., Shibata, H., Takagi, K., Nomura, M., Kurima, N., Fukazawa, T., Satoh, F.,
 577 Sasa, K., 2006. Effects of clear-cutting on nitrogen leaching and fine root dynamics
 578 in a cool-temperate forested watershed in northern Japan. *Forest Ecol. Manag.* 225,
 579 257-261.

580 Ge, T.D., Wei, X.M., Bahar, R.S., Zhu, Z.K., Hu, Y.J., Kuzyakov, Y., Jones, D.L., Jinshui
 581 Wu, J.S., 2017. Stability and dynamics of enzyme activity patterns in the rice
 582 rhizosphere: Effects of plant growth and temperature. *Soil Biol. Biochem.* 113: 108-
 583 115.

584 Gee, G.W., Bauder, J.W., 1986. Particle-size analysis. In: Klute, A., (ed) *Methods of soil*
 585 *analysis. Part 1, vol 9, 2nd edn, Agron Monogr. Soil Sci Soc Am J, Madison, pp 383-*
 586 *412.*

587 Guan, F.Y., Tang, X.L., Fan, S.H., Zhao, J.C., Peng, C., 2015. Changes in soil carbon and
 588 nitrogen stocks followed the conversion from secondary forest to Chinese fir and
 589 Moso bamboo plantations. *Catena* 133, 455-460.

590 Guillaume, T., Damris, M., Kuzyakov, Y., 2015. Losses of soil carbon by converting
591 tropical forest to plantations: erosion and decomposition estimated by $\delta^{13}\text{C}$. *Global*
592 *Change Biol.* 21, 3548-3560.

593 Guo, X., Chen, H.Y.H., Meng, M., Biswas, S.R., Ye, L. Zhang, J., 2016. Effects of land
594 use change on the composition of soil microbial communities in a managed
595 subtropical forest. *Forest Ecol. Manag.* 373, 93-99.

596 Hanway, J.J., Heidel, H., 1952. Soil analysis methods as used in Iowa State College Soil
597 Testing Laboratory. *Iowa Agric* 57, 1-31

598 Hedley, M.J., Stewart, J.W.B., Chauhan, B.S., 1982. Changes in inorganic and organic
599 soil phosphorus fractions induced by cultivation practices and by laboratory
600 incubations. *Soil Sci. Soc. Am. J.* 46, 970-976.

601 Hu, S.D., Li, Y.F., Chang, S.X., Li, Y.C., Yang, W.J., Fu, W.J., Liu, J., Jiang, P.K., Lin,
602 Z.W. 2018. Soil autotrophic and heterotrophic respiration respond differently to
603 land-use change and variations in environmental factors. *Agr. Forest Meteorol.* 250,
604 290-298.

605 Islam, A., Karim, A.J.M.S., Solaiman, A.R.M., Saleque, M.A., Islam, M.S., 2017. Eight-
606 year long potassium fertilization effects on quantity/intensity relationship of soil
607 potassium under double rice cropping. *Soil Till. Res.* 169, 99-117.

608 Islam, M.R., Chauhan, P.S., Kim, Y., Kim, M., Sa, T., 2011. Community level functional
609 diversity and enzyme activities in paddy soils under different long-term fertilizer
610 management practices. *Biol. Fert. Soils* 47, 599-604.

611 Johnson, J.L., Temple, K.L., 1964. Some variables affecting the measurement of "Catalase

612 Activity” in soil. *Soil Sci. Soc. Am. J.* 28, 207-209.

613 Jones, D.L., Willett, V.B., 2006. Experimental evaluation of methods to quantify
614 dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in soil. *Soil*
615 *Biol. Biochem.* 38, 991-999.

616 Kader, M.A., Yeasmin, S., Akter, M., Sleutel, S., 2017. Response of hydrolytic enzyme
617 activities and nitrogen mineralization to fertilizer and organic matter application in
618 subtropical paddy soils. *Eur. J. Soil Biol.* 80, 27-34.

619 Kandeler, E., Gerber, H., 1988. Short-term assay of soil urease activity using colorimetric
620 determination of ammonium. *Biol. Fert. Soils* 6, 68-72.

621 Ladd, J.N., Butler, J.H.A., 1972. Short-term assays of soil proteolytic enzyme activities
622 using proteins and dipeptide derivatives as substrates. *Soil Biol. Biochem.* 4, 19-30.

623 Li, R., Tao, R., Ling, N., Chu, G.X., 2017a. Chemical, organic and bio-fertilizer
624 management practices effect on soil physicochemical property and antagonistic
625 bacteria abundance of a cotton field: implications for soil biological quality. *Soil Till.*
626 *Res.* 167, 30-38.

627 Li, Y., Lee, C.G., Watanabe, T., Murase, J., Asakawa, S., Kimura, M., 2011. Identification
628 of microbial communities that assimilate substrate from root cap cells in an aerobic
629 soil using a DNA-SIP approach. *Soil Biol. Biochem.* 43, 1928-1935.

630 Li, Y.C., Li, Y.F., Chang, S.X., Liang, X., Qin, H., Chen, J.H., Xu, Q.F., 2017b. Linking
631 soil fungal community structure and function to soil organic carbon chemical
632 composition in intensively managed subtropical bamboo forests. *Soil Biol.*
633 *Biochem.* 107, 19-31.

634 Li, Y.F., Hu, S.D., Chen, J.H., Müller, K., Li, Y.C., Fu, W.J., Lin, Z.W., Wang, H.L.,
 635 2018. Effects of biochar application in forest ecosystems on soil properties and
 636 greenhouse gas emissions: a review. J. Soil. Sediment. 18, 546-563.

637 Li, Y.F., Zhang, J.J., Chang, S.X., Jiang, P.K., Zhou, G.M., Fu, S.L., Yan, E.R., Wu, J.S.,
 638 Lin, L., 2013. Long-term intensive management effects on soil organic carbon pools
 639 and chemical composition in Moso bamboo (*phyllostachys pubescens*) forests in
 640 subtropical China. Forest Ecol. Manag. 303, 121-130.

641 Li, Y.F., Zhang, J.J., Chang, S.X., Jiang, P.K., Zhou, G.M., Shen, Z.M., Wu, J.S., Lin, L.,
 642 Wang, Z.S., Shen, M.C., 2014. Converting native shrub forests to Chinese chestnut
 643 plantations and subsequent intensive management affected soil C and N pools. Forest
 644 Ecol. Manag. 312, 161-169.

645 Liu, D., Li, S., Islam, E., Chen, J.Z., Wu, J.C., Ye, Z.Q., Peng, D.L., Yan, W.B., Lu, K.P.,
 646 2015. Lead accumulation and tolerance of Moso bamboo (*Phyllostachys pubescens*)
 647 seedlings: applications of phytoremediation. J. Zhejiang Univ.-Sci. B. 16, 123-130.

648 Liu, H., Li, J., Zhao, Y., Xie, K., Tang, X., Wang, S., Li, Z., Liao, Y., Xu, J., Di, H., Li, Y.,
 649 2018. Ammonia oxidizers and nitrite-oxidizing bacteria respond differently to
 650 long-term manure application in four paddy soils of south of China. Sci. Total
 651 Environ. 633, 641-648.

652 Luo, Y., Durenkamp, M., De Nobili, M., Lin, Q., Devonshire, B.J., Brookes, P.C., 2013.
 653 Microbial biomass growth, following incorporation of biochars produced at 350 °C
 654 or 700 °C, in a silty-clay loam soil of high and low pH. Soil Biol. Biochem. 57,
 655 513-523.

656 Luo, Y., Zang, H., Yu, Z., Chen, Z., Gunina, A., Kuzyakov, Y., Xu, J., Zhang, K.,
 657 Brookes, P.C., 2017. Priming effects in biochar enriched soils using a three-source-
 658 partitioning approach: ^{14}C labelling and ^{13}C natural abundance. *Soil Biol. Biochem.*
 659 106, 28-35.

660 Ma, B., Wang, H.Z., Dsouza, M., Lou, J., He, Y., Dai, Z.M., Brookes, P.C., Xu, J.M.,
 661 Gilbert, J.A., 2016. Geographic patterns of co-occurrence network topological
 662 features for soil microbiota at continental scale in eastern China. *The ISME*
 663 *Journal* 10, 1891-1901.

664 Malchair, S., Carnol, M., 2009. Microbial biomass and C and N transformations in forest
 665 floors under European beech, sessile oak, Norway spruce and Douglas-fir at four
 666 temperate forest sites. *Soil Biol. Biochem.* 41, 831-839.

667 Mancinelli, R., Campiglia, E., Tizio, A.D., Marinari, S., 2010. Soil carbon dioxide
 668 emission and carbon content as affected by conventional and organic cropping
 669 systems in Mediterranean environment. *Appl. Soil Ecol.* 46, 64-72.

670 Maranguit, D., Guillaume, T., Kuzyakov, Y., 2017. Land-use change affects phosphorus
 671 fractions in highly weathered tropical soils. *Catena* 149, 385-393.

672 Marschner, P., Kandeler, E., Marschner, B., 2003. Structure and function of the soil
 673 microbial community in a long-term fertilizer experiment. *Soil Biol. Biochem.* 35,
 674 453-461.

675 Moghimian, N., Hosseini, S.M., Kooch, Y., Darki, B.Z., 2017. Impacts of changes in land
 676 use/cover on soil microbial and enzyme activities. *Catena*, 157, 407–414.

677 Murphy, J., Riley, J.P., 1962. A modified single solution method for the determination of

678 phosphate in natural waters. *Anal. Chim. Acta* 27, 31-36.

679 Obour, A.K., Mikha, M.M., Holman, J.D., Stahlman, P.W., 2017. Changes in soil surface
680 chemistry after fifty years of tillage and nitrogen fertilization. *Geoderma* 308, 46-53.

681 Ouyang, W., Xu, Y.M., Hao, F.H., Wang, X.L., Siyang, C, Lin, C.Y., 2013. Effect of
682 long-term agricultural cultivation and land use conversion on soil nutrient contents in
683 the Sanjiang Plain. *Catena* 104, 243-250.

684 Pransiska, Y., Triadiati, T., Tjitrosoedirjo, S., Hertel, D., Kotowska, M.M., 2016. Forest
685 conversion impacts on the fine and coarse root system, and soil organic matter in
686 tropical lowlands of Sumatera (Indonesia). *Forest Ecol. Manag.* 379, 288-298.

687 Ross, D.J., Tate, K.R., Scott, N.A., Feltham, C.W., 1999. Land-use change: effects on soil
688 carbon, nitrogen and phosphorus pools and fluxes in three adjacent ecosystems. *Soil
689 Biol. Biochem.* 31, 803-813.

690 Rupa, T.R., Srivastava, S., Swarup, A., Sahoo, D., Tembhare, B.R., 2003. The availability
691 of potassium in Aeric Haplaquept and Typic Haplustert as affected by long-term
692 cropping, fertilization and manuring. *Nutr. Cycl. Agroecosys.* 65, 1-11.

693 Sainju, U.M., Lenssen, A.W., Caesar-TonThat, T., Jabro, J.D., Lartey, R.T., Evans, R.G.,
694 Allen, B.L., 2012. Dryland soil nitrogen cycling influenced by tillage, crop rotation,
695 and cultural practice. *Nutr. Cycl. Agroecosys.* 93, 309-322.

696 Schimel, J.P., Bennett, J., 2004. Nitrogen mineralization: challenges of a changing
697 paradigm. *Ecology* 85, 591-602.

698 Schoenau, J.J., Huang, W.Z., 1991. Anionâ-exchange membrane, water, and sodium
699 bicarbonate extractions as soil tests for phosphorus. *Commun. Soil Sci. Plan.* 22, 465-

700 492.

701 Scott, E.E., Rothstein, D.E., 2011. Amino acid uptake by temperate tree species
 702 characteristic of low- and high-fertility habitats. *Oecologia* 167, 547-557.

703 Shen, W.S., Lin, X.G., Shi, W.M., Ju, M., Nan, G., Zhang, H.Y., Yin, R., He, X.H., 2010.
 704 Higher rates of nitrogen fertilization decrease soil enzyme activities, microbial
 705 functional diversity and nitrification capacity in a Chinese polytunnel greenhouse
 706 vegetable land. *Plant Soil* 337, 137-150.

707 Sheng, Z., Zhou, P., Zhang, Y., Kuzyakov, Y., Zhou, Q., Ge, T., Wang, C., 2015. Loss of
 708 labile organic carbon from subsoil due to land-use changes in subtropical china. *Soil*
 709 *Biol. Biochem.* 88, 148-157.

710 Tabatabai, M.A., Bremner, J.M., 1969. Use of *p*-nitrophenyl phosphate for assay of soil
 711 phosphatase activity. *Soil Biol. Biochem.* 1, 301-307.

712 Tao, R., Wakelin, S.A., Liang, Y., Hu, B., Chu, G., 2018. Nitrous oxide emission and
 713 denitrifier communities in drip-irrigated calcareous soil as affected by chemical and
 714 organic fertilizers. *Sci. Total Environ.* 612, 739-749.

715 Tiecher, T., Calegari, A., Caner, L., Rheinheimer, D.D.S., 2017. Soil fertility and nutrient
 716 budget after 23-years of different soil tillage systems and winter cover crops in a
 717 subtropical Oxisol. *Geoderma* 308, 78-85.

718 Vance, E.D., Brookes, P.C., Jenkinson, D.S., 1987. An extraction method for measuring
 719 soil microbial biomass C. *Soil Biol. Biochem.* 19, 703-707.

720 Vitali, F., Mastromei, G., Senatore, G., Caroppo, C., Casalone, E., 2016. Long lasting
 721 effects of the conversion from natural forest to poplar plantation on soil microbial

722 communities. Microbiol. Res. 182, 89-98.

723 Wallenius, K., Rita, H., Mikkonen, A., Lappi, K., Lindström, K., Hartikainen, H.,
724 Raateland, A., Niemi, R.M., 2011. Effects of land use on the level, variation and
725 spatial structure of soil enzyme activities and bacterial communities. Soil Biol.
726 Biochem. 43, 1464-1473.

727 Wang, H.Y., Cheng, W., Li, T., Zhou, J.M., Chen, X.Q., 2016. Can nonexchangeable
728 potassium be differentiated from structural potassium in soils? Pedosphere 26, 206-
729 215.

730 Wang, Q., Wang, S., Yu, X., 2011. Decline of soil fertility during forest conversion of
731 secondary forest to Chinese fir plantations in subtropical china. Land Degrad. Dev.
732 22, 444-452.

733 Wang, Q., Xiao, F., He, T., Wang, S., 2013. Responses of labile soil organic carbon and
734 enzyme activity in mineral soils to forest conversion in the subtropics. Ann. Forest
735 Sci. 70, 579-587.

736 Wang, X.H., Kent, M., Fang, X.F., 2007. Evergreen broad-leaved forest in Eastern China:
737 Its ecology and conservation and the importance of resprouting in forest restoration.
738 Forest Ecol. Manag. 245, 76-87.

739 Wei, X.M., Hu, Y.J., Peng, P.Q., Zhu, Z.K., Atere, C.T., G O'Donnell, A., Wu, J.S., Ge,
740 T.D., 2017. Effect of P stoichiometry on the abundance of nitrogen-cycle genes in
741 phosphorus-limited paddy soil. Biol. Fert. Soils 53: 767-776.

742 World Reference Base for Soil Resources (WRB), 2006. A Framework for International
743 Classification, Correlation and Communication. Food and Agriculture Organization

744 of the United Nations, Rome.

745 Wu, J., Joergensen, R.G., Pommerening, B., Chaussod, R., Brookes, P.C., 1990.

746 Measurement of soil microbial biomass C by fumigation-extraction-an automated

747 procedure. *Soil Biol. Biochem.* 22, 1167-1169.

748 Wu, J.S., Jiang, P.K., Chang, S.X., Xu, Q.F., Yang, L., 2010. Dissolved soil organic

749 carbon and nitrogen were affected by conversion of native forests to plantations in

750 subtropical china. *Can. J. Soil Sci.* 90, 27-36.

751 Xie, X.F., Pu, L.J., Wang, Q.Q., Zhu, M., Xu, Y., Zhang, M., 2017. Response of soil

752 physicochemical properties and enzyme activities to long-term reclamation of coastal

753 saline soil, Eastern China. *Sci. Total Environ.* 607, 1419-1427.

754 Xing, S.H., Chen, C.R., Zhou, B.Q., Zhang, H., Nang, Z.M., Xu, Z.H., 2010. Soil soluble

755 organic nitrogen and active microbial characteristics under adjacent coniferous and

756 broadleaf plantation forests. *J. soil. Sediment.* 10, 748-757.

757 Xu, Z.F., Hu, R., Xiong, P., Wan, C., Cao, G., Liu, Q., 2010. Initial soil responses to

758 experimental warming in two contrasting forest ecosystems, Eastern Tibetan Plateau,

759 China: Nutrient availabilities, microbial properties and enzyme activities. *Appl. Soil*

760 *Ecol.* 46, 291-299.

761 Yan, E.R., Wang, X.H., Huang, J.J., Li, G.Y., Zhou, W., 2008. Decline of soil nitrogen

762 mineralization and nitrification during forest conversion of evergreen broad-leaved

763 forest to plantations in the subtropical area of Eastern China. *Biogeochemistry* 89,

764 239-251.

765 Yan, W.B., Mahmood, Q., Peng, D.L., Fu W.J., Chen, T., Wang, Y., Li, S., Chen, JR., Liu,

766 D., 2015. The spatial distribution pattern of heavy metals and risk assessment of
 767 moso bamboo forest soil around lead–zinc mine in Southeastern China. *Soil Till. Res.*
 768 153, 120-130.

769 Yang, J.C., Huang, J.H., Pan, Q.M., Tang, J.W., Han, X.G., 2004. Long-term impacts of
 770 land-use change on dynamics of tropical soil carbon and nitrogen pools, *J. Environ.*
 771 *Sci-China.* 16, 256-261.

772 Yang, K., Zhu, J.J., Yan, Q.L., Sun, J.X.O.S., 2010. Changes in soil P chemistry as
 773 affected by conversion of natural secondary forests to larch plantations. *Forest Ecol.*
 774 *Manag.* 260, 422-428.

775 Yang, M., Li, Y.F., Li, Y.C., Chang, S.X., Yue, T., Fu, W.J., Jiang, P.K., Zhou, G.M., 2017.
 776 Effects of inorganic and organic fertilizers on soil CO₂ efflux and labile organic
 777 carbon pools in an intensively managed Moso bamboo (*Phyllostachys pubescens*)
 778 plantation in subtropical China. *Commun. Soil Sci. Plan.* 48, 332-344.

779 Yang, W., Cheng, H., Hao, F., Ouyang, W., Liu, S., Lin, C., 2012. The influence of land-
 780 use change on the forms of phosphorus in soil profiles from the Sanjiang Plain of
 781 China. *Geoderma* 189, 207-214.

782 Yuan, H.Z., Ge, T.D., Chen, X.B., Liu, S.L., Zhu, Z.K., Wu, X.H., Wei, W.X., Whiteley,
 783 A.S., Wu, J.S., 2015. Abundance and diversity of CO₂-assimilating bacteria and algae
 784 within red agricultural soils are modulated by changing management practice. *Microb.*
 785 *Ecol.* 70, 971-980.

786 Yuen, J.Q., Fung, T., Ziegler, A.D., 2017. Carbon stocks in bamboo ecosystems
 787 worldwide: Estimates and uncertainties. *Forest Ecol. Manag.* 393, 113-138.

788 Yksek, T., Gl, C., Yksek, F., Yksel, E.E., 2009. The effects of land-use changes on
789 soil properties: the conversion of alder coppice to tea plantations in the Humid
790 Northern Blacksea Region. *Afr. J. Agr. Res.* 4, 665-674.

791 Zhang, C.S., Xie, G.D., Fan, S.H., Zhen, L., 2010. Variation in vegetation structure and
792 soil properties, and the relation between understory plants and environmental
793 variables under different *phyllostachys pubescens* forests in southeastern China.
794 *Environ. Manage.* 45, 779-792.

795 Zhang, J.J., Li, Y.F., Chang, S.X., Qin, H., Fu, S.L., Jiang, P.K., 2015a. Understory
796 management and fertilization affected soil greenhouse gas emissions and labile
797 organic carbon pools in a Chinese chestnut plantation. *Forest Ecol. Manag.* 337, 126-
798 134.

799 Zhang, J.J., Li, Y.F., Chang, S.X., Jiang, P.K., Zhou, G.M., Liu, J., Wu, J.S., Shen, Z.M.,
800 2014. Understory vegetation management affected greenhouse gas emissions and
801 labile organic carbon pools in an intensively managed Chinese chestnut plantation.
802 *Plant Soil* 376, 363-375.

803 Zhang, R., Zhang, Y.L., Song, L.L., Song, X.Z., Hnninen, H., Wu, J.S. 2017a. Biochar
804 enhances nut quality of *torreya grandis*, and soil fertility under simulated nitrogen
805 deposition. *Forest Ecol. Manag.* 391, 321-329.

806 Zhang, T., Li, Y.F., Chang, S.X., Jiang, P.K., Zhou, G.M., Liu, J., Lin, L., 2013.
807 Converting paddy fields to Lei bamboo (*Phyllostachys praecox*) stands affected soil
808 nutrient concentrations, labile organic carbon pools, and organic carbon chemical
809 compositions. *Plant Soil* 367, 249-261.

810 Zhang, X.Y., Dong, W.Y., Dai, X.Q., Schaeffer, S., Yang, F.T., Radosevich, M., Xu, L.L.,
811 Liu, X.Y., Sun, X.M., 2015b. Responses of absolute and specific soil enzyme
812 activities to long term additions of organic and mineral fertilizer. *Sci. Total Environ.*
813 536, 59-67.

814 Zhang, Z.L., Yuan, Y.S., Zhao, W.Q., He, H.L., Li, D.D., He, W., Liu, Q., Yin, H.J.,
815 2017b. Seasonal variations in the soil amino acid pool and flux following the
816 conversion of a natural forest to a pine plantation on the eastern Tibetan plateau,
817 China. *Soil Biol. Biochem.* 105, 1-11.

Figure captions

Fig. 1 Effects of conversion from evergreen broadleaf forests to Moso bamboo plantations on the total stocks (a, c, e and g) and concentrations (b, d, **f and h**) of C, N, P and K in soils. Error bars are the standard deviations of the mean ($n = 4$); different lowercase letters within each panel indicate significant differences between different land-use types in each soil layer at $P = 0.05$ level based on the least significant difference (LSD) test.

Fig. 2 Effects of conversion from evergreen broadleaf forests to Moso bamboo plantations on the (a) NH_4^+ -N concentration, (b) NO_3^- -N concentration, and (c) water soluble organic N (WSO_N) concentration in soils. Error bars are standard deviations of the mean ($n = 4$); different lowercase letters within each panel indicate significant differences between different land-use types in each soil layer at $P = 0.05$ level based on the least significant difference (LSD) test.

Fig. 3 Effects of conversion from evergreen broadleaf forests to Moso bamboo plantations on the (a) total K concentration, (b) available K concentration, (c) slowly available K concentration, and (d) mineral K concentration in soils. Error bars are the standard deviations of the mean ($n = 4$); different lowercase letters within each panel indicate significant differences between different land-use types in each soil layer at $P = 0.05$ level based on the least significant difference (LSD) test.

Fig. 4 Effects of conversion from evergreen broadleaf forests to Moso bamboo plantations

on the (a) microbial biomass C, (b) microbial biomass N, and (c) microbial biomass P.

Error bars are the standard deviations of the mean ($n = 4$); different lowercase letters

within each panel indicate significant differences between different land-use types in each

soil layer at $P = 0.05$ level based on the least significant difference (LSD) test.

Fig. 5 Effects of conversion from evergreen broadleaf forests to Moso bamboo plantations

on the soil (a) protease activity, (b) urease activity, (c) acid phosphatase activity, and (d)

catalase activity. Error bars are the standard deviations of the mean ($n = 4$); different

lowercase letters within each panel indicate significant differences between different land-

use types in each soil layer at $P = 0.05$ level based on the least significant difference (LSD)

test.

Fig. 6 Relationship between acid phosphatase activity and (a) microbial biomass P, (b)

$\text{NaHCO}_3\text{-P}_\text{O}$, and (c) $\text{NaHCO}_3\text{-P}_\text{i}$ in the evergreen broadleaf forest and Moso bamboo

plantation.

Fig. 7 Relationships (a-d) between urease activity and the concentrations of $\text{NH}_4^+\text{-N}$,

$\text{NO}_3^-\text{-N}$, WSON and MBN, and (e-h) between protease activity and the concentrations of

$\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, WSON and MBN in the evergreen broadleaf forest and Moso bamboo

plantation. WSON: water soluble organic N; MBN: microbial biomass N.

Table 1 Effect of conversion from evergreen broadleaf forests to Moso bamboo plantations on different P forms in the soil

Forest type	Resin-P _i (mg kg ⁻¹)	NaHCO ₃ -P _i (mg kg ⁻¹)	NaHCO ₃ -P _o (mg kg ⁻¹)	NaOH-P _i (mg kg ⁻¹)	NaOH-P _o (mg kg ⁻¹)	HCl-P _i (mg kg ⁻¹)	Residual-P (mg kg ⁻¹)
			0-20 cm				
Broadleaf forest	2.17 (0.21) b	4.50 (0.26) b	32.1 (2.7) a	47.5 (4.2) b	67.1 (3.9) a	5.89 (0.53) b	241.7 (14.3) b
Bamboo plantation	3.51 (0.18) a	7.23 (0.48) a	24.0 (1.7) b	56.7 (2.6) a	54.7 (2.9) b	9.25 (0.52) a	312.6 (30.4) a
			20-40 cm				
Broadleaf forest	1.12 (0.10) b	4.20 (0.31) b	27.0 (2.1) a	48.3 (3.0) a	63.2 (3.2) a	6.24 (0.52) a	226.0 (24.0) a
Bamboo plantation	1.86 (0.13) a	6.79 (0.37) a	21.3 (2.1) b	52.4 (4.6) a	58.3 (4.3) a	7.12 (0.47) a	249.3 (24.9) a

Means with different letters within a column indicate significant differences between the land uses for each parameter within each soil layer at $P = 0.05$ level according to the least significant difference (D) test.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

886

887 **Fig. 6**

Fig. 7