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Interrelationship of soil carbon pools, enzyme activities and nutrient availability under various bamboo species

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Abstract

Soil carbon pools primarily depend upon the C inputs from plants and C effluxes via microbial mineralization moreover, soil nutrient availability can also affect SOC pools by impacting the microbial activities. In the present investigation soil samples from root rhizosphere were collected from soil under different bamboo species after 15 years of plantation. These soil samples were analyzed for soil available nitrogen, phosphorus, potassium and sulphur, The soil enzymes analyzed were dehydrogenase, acid phosphatase, alkaline phosphatase, urease, β -glucosidase and cellulase, while the carbon pools included TOC, SIC, TC, POXC, POC, SMBC and WSOC. The interrelationship between these parameters was studied to understand the role of biotic and abiotic drivers in soil carbon mineralization. The Pearson's correlation analysis showed strong positive relationships between enzyme activities and the organic carbon fractions. The highest enzyme associations were generally observed with SMBC and POC, whereas SIC showed negative relationships with the measured enzymes. Carbon fractions were also positively related to available nutrients, with SMBC showing a particularly strong association with available potassium ($r = 0.984^{**}$). POC and SMBC were very strongly correlated with each other ($r = 0.994^{**}$). Overall, our study provides insights into the soil biological and soil chemical properties in association with SOC fractions, and contributes to understanding the impact of these factors on soil organic carbon pools in soil under bamboo plantation.

Keywords: Soil organic carbon, Bamboo species, Carbon pools, Soil enzymes, Nutrient availability, Microbial biomass carbon, Pearson's correlation analysis

Introduction

Bamboo is a renewable, fast-growing and versatile forest resource widely distributed across the tropical, subtropical and temperate regions of India. India is one of the world's major bamboo-rich countries and possesses considerable taxonomic diversity, with about 136 bamboo species belonging to 23 genera, including a large proportion of indigenous species. The extensive distribution, rapid biomass production, perennial rhizomatous growth habit and substantial litter production make bamboo an important component of forest-based carbon sequestration and ecosystem restoration. Globally, bamboo ecosystems have been estimated to contain substantial above-ground, below-ground and soil organic carbon stocks, highlighting their potential as important carbon sinks (Yuen *et al.*, 2017) ^[21]. The India State of Forest Report (ISFR) 2023 provides the latest national assessment of bamboo resources and recognizes bamboo as an important component of India's forest and vegetation resources (Forest Survey of India, 2023) ^[8].

Beyond above-ground biomass accumulation, an important component of bamboo-mediated carbon sequestration is the transformation and stabilization of carbon within the soil. Continuous deposition of bamboo leaves, fine roots, rhizodeposits and decomposing organic residues provides sustained inputs of organic carbon to the rhizosphere, thereby influencing both the quantity and quality of soil organic carbon (SOC). Soil carbon is not a homogeneous pool but consists of fractions differing in their turnover rate, biological availability and degree of stabilization. Labile and particulate organic carbon fractions generally respond more rapidly to changes in vegetation and management and serve as important substrates for microbial

activity, whereas less-labile and non-labile fractions contribute more substantially to long-term carbon stabilization (Ghosh *et al.*, 2012; Kaushal *et al.*, 2021) ^[11].

The accumulation and transformation of different carbon fractions are closely associated with microbial activity and extracellular enzyme processes. Labile carbon fractions provide readily available substrates and energy for soil microorganisms, which regulate the decomposition of plant residues and the transformation of organic nutrients. Consequently, soil enzymes such as dehydrogenase, β -glucosidase, urease and phosphatases can serve as important biochemical indicators linking carbon dynamics with nutrient cycling. In bamboo ecosystems, significant variations in dehydrogenase, β -glucosidase, acid phosphatase and alkaline phosphatase activities have been reported among different bamboo species, and these variations were associated with differences in soil organic carbon, litter quality, quantity and root exudation (Kaushal *et al.*, 2020) ^[10]. Dehydrogenase reflects the oxidative activity of the soil microbial community, whereas β -glucosidase participates in the decomposition of cellulose-derived carbon compounds and provides readily available substrates for microorganisms (Kaushal *et al.*, 2020) ^[10]. Phosphatases are particularly important because they hydrolyse organic phosphorus compounds and release inorganic phosphorus that can contribute to plant-available P (Kaushal *et al.*, 2020) ^[10].

The relationship between bamboo, soil carbon and nutrient cycling is further supported by studies examining nutrient transformations in bamboo ecosystems. Bamboo induced changes in soil carbon fractions may influence nutrient availability through their effects on microbial biomass, substrate availability and extracellular enzyme activity. Greater inputs of organic residues can provide substrates for microbial decomposition, resulting in the mineralization and recycling of organically bound nutrients. Carbon-degrading enzymes facilitate the decomposition of organic substrates, nitrogen-cycling enzymes contribute to the transformation of organic N, while phosphatases regulate the release of inorganic P from organic phosphorus compounds. Therefore, the carbon pool-microbial biomass-enzyme activity-nutrient availability pathway represents an important functional linkage in bamboo soils (Kaushal *et al.*, 2020; Wu *et al.*, 2018) ^[10, 20].

This linkage is particularly important when comparing different bamboo species because species differ in growth rate, litter production, litter quality, root distribution, rhizodeposition and nutrient uptake characteristics. Such differences can modify the quantity and quality of organic matter returned to the soil and, consequently, influence microbial activity, carbon stabilization and nutrient cycling (Kaushal *et al.*, 2020; Kaushal *et al.*, 2021) ^[10, 11]. Therefore, assessment of soil carbon fractions in combination with soil enzyme activities and available nutrient status provides a more comprehensive understanding of the ecological functioning of bamboo plantations than measurement of total SOC or available nutrients alone.

Accordingly, this study was undertaken to determine the correlations between soil enzyme activities and carbon pools, between carbon fractions and available N, P, K and S, and among the different carbon fractions themselves in a bamboo plantation located in the sub-montane region of Maharashtra after 15 years of mixed bamboo plantation.

Materials and methods

Experimental site

The present investigation was carried out at the Zonal Agricultural Research Station, Shenda Park, Kolhapur, situated in the sub-montane zone of Maharashtra within the Western Ghats agro-climatic zone (16°42'17.24" N latitude, 74°14'10.74" E longitude; elevation 605 m above mean sea

level). The site is characterised by shallow, light-textured Entisols with gently undulating topography and a slope of about 5%, and receives an annual rainfall of 900-1200 mm, mainly from the south-west monsoon (June-September); mean maximum temperature ranges from 32 to 36 °C in summer, while mean minimum temperature ranges from 14 to 18 °C in winter. The study was conducted in a 15-year-old bamboo plantation (established in September 2010) comprising six bamboo species - *Bambusa tulda*, *Bambusa balcooa*, *Bambusa bambos*, *Dendrocalamus asper*, *Dendrocalamus strictus*, and *Melocanna baccifera* - laid out in a Randomized Block Design with four replications at a spacing of 5.0 × 5.0 m.

Soil sampling

Composite rhizosphere soil samples were collected from each of the six bamboo species plots (four replications each) at 0-15 cm depth during the active growing season of 2025. A soil sample from an adjacent non-bamboo fallow area of similar slope and soil characteristics was also collected to serve as a control/baseline for comparison. The samples were air-dried, ground with a wooden mortar and pestle, and passed through a 2 mm sieve for physico-chemical analysis. For biological and biochemical determinations, a portion of the field-moist soil was rejuvenated to field capacity and stored at 4 °C; these sub-samples were analysed within two weeks of collection for enzyme activities and within three weeks for microbial biomass carbon, in order to stabilise microbiological activity prior to analysis.

Analytical methods

Total organic carbon (TOC) was determined by the wet oxidation method of Nelson and Sommers (1982) ^[14], and total carbon (TC) by the wet oxidation procedure of Mebius (1960) ^[13] involving extensive heating at 150 °C for half an hour under reflux. Soil inorganic carbon (SIC) was calculated as the difference between TC and TOC (SIC = TC - TOC), following Wagner *et al.* (1998) ^[18]. Permanganate oxidizable carbon (POXC) was estimated by oxidation with 0.02 M KMnO₄ following Blair *et al.* (1995) ^[1], with absorbance read at 550 nm. Particulate organic carbon (POC, 53-2000 μ fraction) was determined by the physical fractionation method of Cambardella and Elliott (1992) ^[3], using sodium hexametaphosphate dispersion followed by wet sieving through a 53 μ screen. Soil microbial biomass carbon (SMBC) was estimated by the chloroform-fumigation-incubation method of Brookes *et al.* (1985) ^[2], and water-soluble organic carbon (WSOC) by the hot/cold water extraction method of McGill *et al.* (1986) ^[12]; both were quantified by dichromate titration against ferrous ammonium sulphate using ferroin indicator.

Soil enzyme activities were assayed following standard colorimetric procedures. Dehydrogenase (DHA) activity was determined by the triphenyltetrazolium chloride (TTC) reduction method of Casida *et al.* (1964) ^[4]. Acid and alkaline phosphatase (ACP/ALKP) activities were assayed by the p-nitrophenyl phosphate method of Eivazi and Tabatabai (1977) ^[6]. Urease activity was determined by the method of Tabatabai and Bremner (1972) ^[17], with the released ammoniacal nitrogen estimated by the micro-Kjeldahl method. β -Glucosidase activity was assayed using p-nitrophenyl- β -D-glucopyranoside as substrate, following Eivazi and Tabatabai (1988) ^[7], and cellulase activity by the carboxymethyl cellulose-DNS method of Schinner and Von Mersi (1990). Absorbance for the colorimetric enzyme assays was recorded on a UV-VIS spectrophotometer against standard curves, and activity was expressed per gram of soil per hour. Available macronutrients were determined by standard procedures: available nitrogen by the alkaline permanganate method of Subbiah and Asija (1956); available

phosphorus by 0.5 M NaHCO₃ extraction (pH 8.5) following Watanabe and Olsen (1965) [19]; available potassium by 1 N NH₄OAc extraction (Jackson, 1973) [9]; and available sulphur by the turbidimetric method of Chesnin and Yien (1950) [5].

Statistical analysis

Pearson's correlation coefficients (r) were computed among enzyme activities, carbon pool fractions, and available macronutrients to evaluate the strength and direction of their relationships. Correlations were considered significant at the 0.05 (**) and 0.1 (*) probability levels.

Results and Discussion

3.1 Correlation between Soil Enzyme Activities and Carbon Pool Fractions

Data presented in Table 1 showed a clear positive association between the organic carbon pools and soil enzyme activities, whereas SIC was negatively related to the enzymes. TOC was strongly correlated with dehydrogenase (r = 0.776**), acid phosphatase (r = 0.744**), alkaline phosphatase (r = 0.885**), urease (r = 0.913**), β -glucosidase (r = 0.949**) and cellulase (r = 0.913**). Among the carbon fractions, SMBC showed consistently high positive correlations with the enzymes, including dehydrogenase (r = 0.863**), acid phosphatase (r = 0.872**), alkaline phosphatase (r =

0.947**), urease (r = 0.956**), β -glucosidase (r = 0.975**) and cellulase (r = 0.962**).

POC also maintained strong positive relationships with all measured enzymes: dehydrogenase (r = 0.813**), acid phosphatase (r = 0.855**), alkaline phosphatase (r = 0.944**), urease (r = 0.938**), β -glucosidase (r = 0.968**) and cellulase (r = 0.941**). Similar positive associations were observed for WSOC, with coefficients of 0.838**, 0.835**, 0.861**, 0.949**, 0.873** and 0.947** for the same enzymes, respectively. POXC showed moderate to strong positive relationships with dehydrogenase (r = 0.626*), alkaline phosphatase (r = 0.720**), urease (r = 0.817**), β -glucosidase (r = 0.795**) and cellulase (r = 0.810**), while its correlation with acid phosphatase was 0.547 and non-significant. In contrast, SIC was negatively correlated with each enzyme, with r values of -0.303 for dehydrogenase, -0.313 for acid phosphatase, -0.368 for alkaline phosphatase, -0.306 for urease, -0.288 for β -glucosidase and -0.343 for cellulase. The pattern indicates that the biologically active organic carbon pools, particularly SMBC, POC and WSOC, were closely associated with enzyme activity in the studied soil. These carbon fractions may provide substrates that support microbial growth and metabolic activity, although the correlation analysis alone does not establish a causal relationship.

Table 1: Correlation between soil enzyme activities and carbon pool fractions

	DHA	ACP	ALKP	Urease	β -Glucosidase	Cellulase
TOC	0.776**	0.744**	0.885**	0.913**	0.949**	0.913**
SIC	-0.303	-0.313	-0.368	-0.306	-0.288	-0.343
TC	0.775**	0.741**	0.882**	0.912**	0.949**	0.911**
POXC	0.626*	0.547	0.720**	0.817**	0.795**	0.810**
POC	0.813**	0.855**	0.944**	0.938**	0.968**	0.941**
SMBC	0.863**	0.872**	0.947**	0.956**	0.975**	0.962**
WSOC	0.838**	0.835**	0.861**	0.949**	0.873**	0.947**

* Significant correlation at 0.1 level; ** Significant correlation at 0.05 level

3.2 Correlation between Carbon Pool Fractions and Available Macronutrients

The correlation analysis between carbon fractions and available soil nutrients (Table 2) demonstrated predominantly positive associations. Total organic carbon (TOC) exhibited strong and significant positive correlations with available nitrogen (r = 0.962**), phosphorus (r = 0.668*), potassium (r = 0.936**), and sulphur (r = 0.940**). In contrast, soil inorganic carbon was negatively associated with all measured nutrients, with correlation coefficients of -0.187, -0.420, -0.548, and -0.253 for available N, P, K, and S, respectively. Similarly, total carbon (TC) maintained significant positive relationships with available N (r = 0.965**), P (r = 0.661*), K (r = 0.929**), and S (r = 0.940**). Permanganate oxidizable carbon (POXC), representing the active carbon pool, was also positively related to nutrient availability, with correlation coefficients of 0.927**, 0.563 (non-significant), 0.816**, and 0.833** for N, P, K, and S, respectively. The labile carbon fractions further exhibited favourable associations with soil nutrients. Particulate organic carbon (POC) was positively correlated with available N (r = 0.927**), P (r = 0.807**), K (r = 0.974**), and S (r = 0.962**). Likewise, soil microbial biomass carbon (SMBC) showed positive relationships with available N (r = 0.922**), P (r = 0.824**), K (r = 0.984**), and S (r = 0.945**). Water-soluble organic carbon (WSOC) also displayed positive correlations with nutrient availability, recording coefficients of 0.893**, 0.918**, 0.912**, and 0.875** for available N, P, K, and S, respectively. Overall, the results suggest that higher levels of organic and biologically active carbon fractions are closely associated with improved availability of essential soil nutrients, whereas inorganic carbon tends to exhibit an inverse relationship with nutrient status, in close agreement with Aumtong, who

reported positive correlations of organic carbon fractions with available nutrients.

Table 2: Correlation between carbon pool fractions and available macronutrients

	N	P	K	S
TOC	0.962**	0.668*	0.936**	0.940**
SIC	-0.187	-0.420	-0.548	-0.253
TC	0.965**	0.661*	0.929**	0.940**
POXC	0.927**	0.563	0.816**	0.833**
POC	0.927**	0.807**	0.974**	0.962**
SMBC	0.922**	0.824**	0.984**	0.945**
WSOC	0.893**	0.918**	0.912**	0.875**

* Significant correlation at 0.1 level; ** Significant correlation at 0.05 level

3.3 Inter-relationship Among Carbon Pool Fractions

Correlation analysis among the different carbon pool fractions (Table 3) highlighted a close functional association among the organic carbon pools, whereas soil inorganic carbon exhibited contrasting relationships with these fractions. Total organic carbon (TOC) and total carbon (TC) were perfectly correlated (r = 1.000**), reflecting the predominance of organic carbon in determining total carbon content. TOC further exhibited strong positive correlations with permanganate oxidizable carbon (POXC; r = 0.940**), particulate organic carbon (POC; r = 0.974**), soil microbial biomass carbon (SMBC; r = 0.961**), and water-soluble organic carbon (WSOC; r = 0.888**). These associations suggest that increases in the total organic carbon pool are accompanied by proportional enrichment of both labile and biologically active carbon fractions, likely due to the continuous addition and transformation of bamboo litter, root turnover and

rhizodeposition. In contrast, soil inorganic carbon (SIC) showed negative correlations with all organic carbon fractions, with relatively stronger inverse relationships observed for WSOC ($r = -0.427$), SMBC ($r = -0.414$), and POC ($r = -0.401$). This opposing trend may be attributed to the distinct biogeochemical pathways governing inorganic and organic carbon dynamics: organic carbon accumulation is primarily driven by litter deposition, root turnover, and microbial processing, whereas inorganic carbon is largely governed by carbonate formation and precipitation processes that are less dependent on biological activity.

Total carbon also maintained strong positive associations with POXC ($r = 0.938^{**}$), POC ($r = 0.970^{**}$), SMBC ($r = 0.958^{**}$), and WSOC ($r = 0.883^{**}$), further emphasizing the substantial contribution of organic carbon fractions to the total soil carbon pool. POXC was positively correlated with POC ($r = 0.889^{**}$), SMBC ($r = 0.848^{**}$), and WSOC ($r = 0.843^{**}$), indicating that readily oxidizable carbon serves as an important substrate supporting microbial activity and the formation of other labile carbon pools. Among the organic

fractions, POC exhibited exceptionally strong positive relationships with SMBC ($r = 0.994^{**}$) and WSOC ($r = 0.953^{**}$). The near-perfect correlation between POC and SMBC suggests that particulate organic matter constitutes a major energy and nutrient source for the soil microbial community, thereby stimulating microbial biomass development. The positive association between POC and WSOC reflects the progressive decomposition and solubilization of particulate organic matter into dissolved organic compounds, while SMBC also showed a strong positive correlation with WSOC ($r = 0.948^{**}$), highlighting the dynamic exchange between microbial turnover and soluble carbon pools. Overall, these findings indicate that the various organic carbon fractions operate as an integrated continuum, linked through decomposition, microbial assimilation, and transformation processes, with inorganic carbon following a comparatively independent pedogenic pathway. These results closely agree with those of Aumtong, who reported a similar inter-relationship among carbon fractions.

Table 3: Inter-relationship among different carbon pool fractions

	TOC	SIC	TC	POXC	POC	SMBC	WSOC
TOC	1.000**						
SIC	-0.296	1.000**					
TC	1.000**	-0.272	1.000**				
POXC	0.940**	-0.287	0.938**	1.000**			
POC	0.974**	-0.401	0.970**	0.889**	1.000**		
SMBC	0.961**	-0.414	0.958**	0.848**	0.994**	1.000**	
WSOC	0.888**	-0.427	0.883**	0.843**	0.953**	0.948**	1.000**

* Significant correlation at 0.1 level; ** Significant correlation at 0.05 level

3.4 Overall Relationship among Carbon Pools, Enzyme Activities and Nutrient Availability

The correlation analysis revealed a close interrelationship among carbon dynamics, soil biological activity and nutrient availability in the bamboo rhizosphere. Total organic carbon and labile carbon fractions, particularly particulate organic carbon (POC), soil microbial biomass carbon (SMBC) and water-soluble organic carbon (WSOC), showed positive relationships with soil enzyme activities, indicating enhanced microbial activity and nutrient transformation under carbon-rich conditions. The strong association of SMBC with β -glucosidase, cellulase, urease and phosphatase further highlighted the role of microbial biomass in carbon turnover and nutrient cycling. POC was positively related to SMBC, suggesting that particulate organic matter provided an important substrate for microbial activity, while WSOC supported readily available carbon for microbial metabolism. Positive relationships between carbon fractions and available N, P, K and S indicated close coupling between carbon turnover and nutrient availability. In contrast, soil inorganic carbon generally showed negative relationships with organic carbon fractions, enzyme activities and available nutrients. Overall, POC, SMBC and WSOC emerged as useful indicators of biological fertility and nutrient-cycling activity in long-term bamboo plantation soils, although the correlations indicate associations rather than direct causation.

Conclusion

Correlation analysis in this study demonstrated that soil enzyme activities (dehydrogenase, acid phosphatase, alkaline phosphatase, urease, β -glucosidase, and cellulase) were strongly and positively associated with organic carbon fractions, particularly soil microbial biomass carbon, particulate organic carbon and water-soluble organic carbon, while being negatively associated with soil inorganic carbon. Carbon pool fractions likewise showed strong positive correlations with available macronutrients (N, P, K and S), and among the carbon fractions, particulate organic carbon

and soil microbial biomass carbon exhibited a near-perfect relationship. The strong association of labile carbon pools with enzyme activities and nutrient availability indicates that carbon turnover and microbial processes are closely linked with nutrient cycling in the bamboo rhizosphere. These results suggest that POC, SMBC and WSOC can serve as useful indicators of biologically active soil carbon and soil biological fertility. However, the observed correlations represent statistical associations and should not be interpreted as direct causal relationships. Overall, the findings demonstrate an integrated relationship among carbon pools, microbial activity, enzyme-mediated processes and nutrient availability under long-term bamboo plantation soils.

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References

1. Blair GJ, Lefroy RD, Lisle L. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. *Australian Journal of Agricultural Research*. 1995;46(7):1459-1466.
2. Brookes PC, Landman A, Pruden G, Jenkinson DS. Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil. *Soil Biology and Biochemistry*. 1985;17(6):837-842.
3. Cambardella CA, Elliott ET. Particulate soil organic-matter changes across a grassland cultivation sequence.

- Soil Science Society of America Journal. 1992;56(3):777-783.
4. Casida LE, Klein DA, Santoro T. Soil dehydrogenase activity. *Soil Science*. 1964;98(6):371-376.
5. Chesnin L, Yien CH. Turbidimetric determination of available sulphates. *Soil Science Society of America Proceedings*. 1950;15:149-151.
6. Eivazi F, Tabatabai MA. Phosphatases in soils. *Soil Biology and Biochemistry*. 1977;9(3):167-172.
7. Eivazi F, Tabatabai MA. Glucosidases and galactosidases in soils. *Soil Biology and Biochemistry*. 1988;20(5):601-606.
8. Forest Survey of India. India State of Forest Report 2023. Ministry of Environment, Forest and Climate Change, Government of India; 2023.
9. Jackson ML. *Soil Chemical Analysis*. New Delhi: Prentice Hall of India Pvt. Ltd.; 1973.
10. Kaushal R, Singh I, Thapliyal SD, Gupta AK, Mandal D, Tomar JMS, *et al.* Rooting behaviour and soil properties in different bamboo species of Western Himalayan Foothills, India. *Scientific Reports*. 2020;10. DOI:10.1038/s41598-020-61418-z.
11. Kaushal R, Tewari S, Thapliyal SD, Kumar A, Roy T, Islam S, *et al.* Build-up of labile, non-labile carbon fractions under fourteen-year-old bamboo plantations in the Himalayan foothills. *Heliyon*. 2021;7:e07850.
12. McGill WB, Cannon KR, Robertson JA, Cook FD. Dynamics of soil microbial biomass and water-soluble organic C in Breton L after 50 years of cropping to two rotations. *Canadian Journal of Soil Science*. 1986;66(1):1-19.
13. Mebius LJ. A rapid method for the determination of organic carbon in soil. *Analytica Chimica Acta*. 1960;22:120-124.
14. Nelson DW, Sommers LE. Total carbon, organic carbon, and organic matter. In: Page AL, Miller RH, Keeney DR, editors. *Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties*. 2nd ed. Agronomy Monograph 9. Madison, WI: ASA-SSSA; 1982. p. 539-579.
15. Schinner F, Von Mersi W. Xylanase-, CM-cellulase- and invertase activity in soil: an improved method. *Soil Biology and Biochemistry*. 1990;22(4):511-515.
16. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. *Current Science*. 1956;25(8):259-260.
17. Tabatabai MA, Bremner JM. Assay of urease activity in soils. *Soil Biology and Biochemistry*. 1972;4(4):479-487.
18. Wagner SW, Hanson JD, Olness A, Voorhees WB. A volumetric inorganic carbon analysis system. *Soil Science Society of America Journal*. 1998;62(3):690-693.
19. Watanabe FS, Olsen SR. Test of an ascorbic acid method for determining phosphorus in water and NaHCO₃ extracts from soil. *Soil Science Society of America Proceedings*. 1965;29(6):677-678.
20. Wu C, Mo Q, Wang H, Zhang Z, Huang G, Ye Q, *et al.* Moso bamboo invasion affects soil phosphorus dynamics in adjacent coniferous forests in subtropical China. *Annals of Forest Science*. 2018;75:24. DOI:10.1007/s13595-018-0703-0.
21. Yuen JQ, Fung T, Ziegler AD. Carbon stocks in bamboo ecosystems worldwide: estimates and uncertainties. *Forest Ecology and Management*. 2017;393:113-138.