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Carbon Stock, Carbon Fraction and Nitrogen Fraction of Soil Under Bamboo (*Dendrocalamus asper* Back.) and Non-Bamboo Vegetation

Lintang Panjali Siwi Pambayun[1], Benito Heru Purwanto[1,2*] and Sri Nuryani Hidayah Utami[1]

[1]Department of Soil Science, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia;
[2]Center for Environmental Studies, Universitas Gadjah Mada, Yogyakarta, Indonesia

[*]*Corresponding author:* benito@ugm.ac.id

Abstract

The type of vegetation and soil organic matter affect the carbon fraction, nitrogen fraction and soil carbon stocks that contribute to the global carbon cycle. Therefore, the calculation of the composition of the fractions in different land covers is very important as a potential indicator of the effect of land management practices on soil organic carbon dynamics and supports the reduction of carbon dioxide (CO_2) and soil carbon storage. This research aimed to determine the composition of the carbon fraction, nitrogen fraction and soil carbon stock in different land cover. There were six types of land cover with vegetations of 10-year-old bamboo, 30-year-old bamboo, 50-year-old bamboo, bulrush, a mixture of brushwood and bulrush, and a mixture of *Albizia falcataria* and brushwood, each of which was sampled three times. Soil samples were used to determine microbial biomass, particulate organic, humic acid, fulvic acid and soil carbon stock. The six land cover types showed significant differences in all fractions and soil carbon stocks. Fifty-year-old bamboo vegetation has the highest carbon storage of 0.029 g g^{-1} soil. The stable carbon fraction, in the form of humic acid and fulvic acid, in 50-year-old bamboo vegetation is more excellent than that in other vegetation. This study shows that 50-year-old bamboo vegetation has the potential to sequester carbon and store carbon in forms that decompose slowly, namely humic acid and fulvic acid, in the soil for a longer period.

Keywords: carbon dynamics; carbon storage; nitrogen labile; soil organic carbon; vegetation

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INTRODUCTION

Atmospheric carbon dioxide (CO_2) concentrations have increased by 25% since the late 18th century (Khorramdel et al., 2019). Conventional management, intensive processing, use of fossil fuels, changes in land cover conditions (grasslands to dry land and deforestation) and burning of crop residues are some of the factors that increase the concentration of CO_2 in the atmosphere (Li et al., 2015). An increase in the content of CO_2 in the atmosphere will cause an increase in the earth's temperature due to the greenhouse effect (Anderson et al., 2016; Ahima, 2020). Soil can potentially expand carbon sequestration and allow a prospective way of mitigating increases in atmospheric CO_2 (Lal, 2004). Soil is a storehouse of absorption/storage of carbon from the atmosphere through plants (Lal et al., 2015). Management of aboveground vegetation is considered one of the strategies for climate change mitigation and is related to carbon storage (Kwiatkowski et al., 2023).

Sustainable agriculture is an effort to maintain the survival of farmers, resources and communities with more environmentally friendly and profitable farming practices (Mehmet Tuğrul, 2020). Sustainable agriculture can be interpreted as returning nutrients to the soil by minimizing

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the use of non-renewable natural resources to maintain or improve environmental quality and conserve natural resources (Muhie, 2022). Bamboo plants can use carbon sources from the air (Lobovikov et al., 2012). Bamboo plants can absorb carbon, which will later be converted into soil organic carbon (SOC) (Zachariah et al., 2016). Carbon absorption in the air helps reduce global warming (Nath et al., 2009). Bamboo plants also use little or no artificial fertilizers, thereby minimizing the use of artificial fertilizers (Saputri et al., 2021). The litter produced from bamboo can also provide a source of nutrients to the soil and can be used by other plants (Sofiah et al., 2018). Bamboo can be used as biochar material (Huang et al., 2011). Biochar in the soil can increase nutrient uptake, increase water holding capacity, reduce nutrient leaching and soil degradation, increase cation exchange capacity (CEC), increase biomass and microorganism abundance, and help neutralize soil pH (Houben et al., 2013; K. Lu et al., 2017; C. Wang et al., 2018).

Bamboo plants can contribute to climate change mitigation efforts and reduce CO_2 in the atmosphere (Yiping et al., 2010). Studies that have been conducted show that the bamboo plant ecosystem can store between 92 to 392 tons of carbon per hectare (tC ha^{-1}) (King et al., 2021). The mechanism of the carbon cycle occurs when CO_2 is absorbed during photosynthesis, stored in biomass and released due to the decomposition of dead organic matter (Dwivedi et al., 2019). Bamboo plants have higher biomass production, thus contributing high soil organic matter and affecting carbon storage in the soil (Li et al., 2015). Sujarwo (2016) stated that carbon storage in bamboo vegetation (*Dendrocalamus asper* Back.) was 43.67 mg ha^{-1}. Previous research conducted by Sohel et al. (2015) in the Lawachara Protected Forest of Bangladesh showed that carbon storage in bamboo plants was more potential (15.53 ton ha^{-1} $year^{-1}$) than that in other fast-growing tree species vegetation, such as *Acacia auriculiformis* (10.21 ton ha^{-1} $year^{-1}$) and *Eucalyptus camaldulensis* (10.12 ton ha^{-1} $year^{-1}$). Another study by Song et al. (2011) showed that total carbon storage capacity in bamboo ecosystem (*Phyllostachys pubescens*) in India was 106.36 ton ha^{-1}, where the above-soil biomass stored carbon of 34.3 ton ha^{-1} (32.3% of total carbon) and underground biomass (0 to 60 cm soil depth) stored carbon of 72.2 ton ha^{-1} (67.7% of total carbon).

Soil carbon stocks are organic carbon stores in the soil (Buraka et al., 2022). The carbon fraction, nitrogen fraction and soil carbon stock are affected by organic matter in the soil (Frazão et al., 2021). The carbon and nitrogen fractions in the soil play an important role in maintaining the quality of soil fertility and plant growth and affecting soil carbon stores (Gerke, 2022; Huntingford et al., 2022). Nitrogen and carbon in the soil have stable and labile fractions (Wijanarko and Purwanto, 2017). The labile carbon and nitrogen fractions are microbial biomass carbon, microbial biomass nitrogen, organic particulate carbon and organic particulate nitrogen (J. Wang and Sainju, 2014). The stable carbon fractions are humic and fulvic acids (Sijabat et al., 2018). Soil microbial biomass carbon refers to the microbial biomass that decomposes organic matter (Lepcha and Devi, 2020). Microbial biomass nitrogen is the most volatile source of soil nitrogen because it is related to nitrogen mineralization (Moore et al., 2000). Organic particulate carbon is a substrate and carbon source used for metabolic processes affecting soil aggregation (Semenov et al., 2019). The organic particulate nitrogen fraction is the primary nitrogen source for soil microbes (Martínez et al., 2017). Soil-stable carbon fractions, including humic acid and fulvic acid, have a role in high CEC, the ability of soil to hold water, increasing plant growth and improving soil fertility (Kusumawati et al., 2020). Soil carbon stocks are organic carbon stores in the soil (Buraka et al., 2022). Carbon fraction, nitrogen fraction and carbon stock are influenced by organic matter in the soil (Frazão et al., 2021).

The composition of the labile and stable fractions in the soil will affect soil carbon stores (Qian et al., 2021). The labile carbon fraction is a fraction that is easily decomposed by microorganisms, so its presence in the soil is quickly lost (Zhang et al., 2020). The stable carbon fraction is a fraction that is decomposed very slowly by microorganisms so that its presence in the soil lasts longer than the labile fraction (Gautam et al., 2021). Understanding the impact of changes in land cover on carbon fractions, nitrogen fractions and SOC stocks is very important in designing sustainable management of carbon stocks. Improving the ability of soils to store carbon is essential, both for sustainable agriculture and climate change mitigation. Information on the content of carbon fractions, nitrogen fractions and SOC stocks in Indonesia still needs to be improved. Therefore, this study aimed to determine the composition of carbon fractions, nitrogen fractions and soil carbon stocks and their effect on the physico-chemical properties of soil on bamboo and non-bamboo vegetation.

MATERIALS AND METHOD

Study area

This research was conducted from March to September 2022. Sampling was carried out at six locations with different vegetation (Figure 1; Table 1) in Sleman Regency. In each location, three sample points were determined as replications. Sites 1 and 2 are located in Kepuharjo Village, Cangkringan Sub-district. Sites 3, 4, 5 and 6 are located in Girikerto Village, Turi Sub-district. The vegetation in sites 1, 3 and 5 is bamboo (*D. asper* Back.) with an estimated age of 10, 30 and 50 years. The vegetation in site 2 is bulrush, in site 4 are brushwood and bulrush, and in site 6 are *Albizia falcataria* and brushwood. The soil at the research site is categorized as Inceptisols soil type, located within ± 8.5 km from the peak of Mount Merapi.

Soil sampling and analysis

Soil sampling was carried out using a soil drill and sample rings. Each location is taken three points as a test in the field. The distance between the sample points and the bamboo trees is 3 to 5 m (Figure 2). Meanwhile, the distance between points on non-bamboo land is 10 to 20 m (Figure 2). Sampling of disturbed soil using a soil drill was carried out at a soil depth of 0 to 40 cm (Olson and Al-Kaisi, 2015). According to the research results by Donato et al. (2011), soil depth of 0 to 50 cm has high organic matter. Sample of undisturbed soil was taken using a sample ring as deep as 15 to 20 cm. Soil samples were put in plastic bags to be analyzed in the laboratory. Laboratory analysis was conducted at the Soil Physics and Chemistry Laboratory, Faculty of Agriculture, Universitas Gadjah Mada.

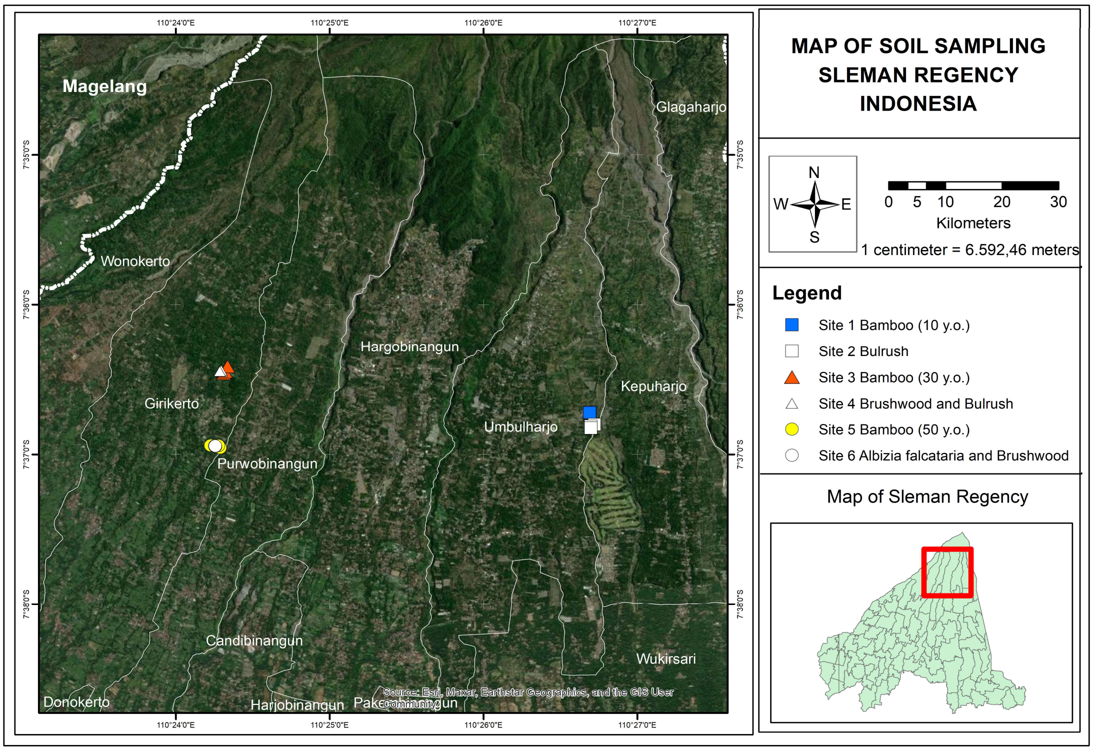

Figure 1. Map of soil sampling

Table 1. Coordinate point of soil sampling research area

Site	Parameter of land cover vegetation	Coordinate point	
1	Bamboo aged 10 years	-7°36’42.87”	110°26’41.71”
2	Bulrush	-7°36’48.01”	110°26’43.33”
3	Bamboo aged 30 years	-7°36’27.47”	110°24’18.66”
4	Brushwood and bulrush	-7°36’26.75”	110°24’17.86”
5	Bamboo aged 50 years	-7°36’56.60”	110°24’17.30”
6	*A. falcataria* and brushwood	-7°36’56.58”	110°24’15.20”

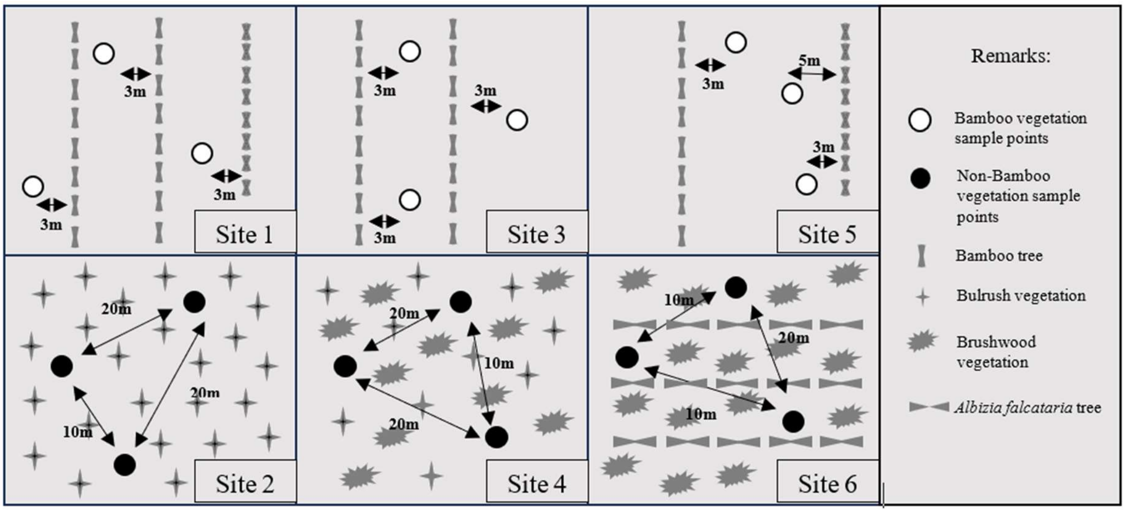

Figure 2. Sampling points in the field on bamboo and non-bamboo vegetation

Soil texture was determined using the pipetting method (Bouyoucos, 1962). The weight of the root density was determined using the method of calculating root weight (g) with volume (cm^3) of soil sampling (Yang et al., 2010). The roots were taken using a sample ring separated from the adhering soil. The weight was calculated and the root weight density was analyzed using the root weight formula divided by the volume of the sample ring. Bulk density was determined using the sample ring method (ISRIC, 1993). SOC was determined using the Walkey and Black method (Graham, 1948). Soil total nitrogen was determined using the Kjehdahl method (ISRIC, 1993). The CEC was estimated using the ammonium chloride method (ISRIC, 1993). Soil pH was calculated using the electrometric method (1:2 soil-water suspension) (ISRIC, 1993). Microbial biomass carbon (C Mic) and microbial biomass nitrogen (N Mic) were measured by the fumigation-extraction method (Voroney et al., 2007). Carbon particulate organic matter (C POM) and nitrogen particulate organic matter (N POM) were determined by the fractionation method (Marriott and Wander, 2006). Total soil carbon stock was obtained from Equations 1, 2 and 3 (FAO, 2018).

Data analysis

Data analysis was performed statistically using analysis of variance (ANOVA) with a 95% confidence level. To see the significant effects of the treatment and their interactions on the variables, a post-hoc test (Duncan's multiple range test/DMRT) was carried out at the 5% significance level. Correlation analysis (Pearson correlation) was used to see the relationship between carbon fraction, nitrogen fraction and SOC stock with the physico-chemical properties of the soil.

RESULTS AND DISCUSSION

Physical and chemical soil characteristics

The results of the ANOVA analysis showed that the type of land cover had a significant effect on CEC (Sig. 0.001), pH (Sig. 0.001), SOC (Sig. 0.000), total nitrogen (Sig. 0.000), C/N ratio (Sig. 0.000) and root weight density (Sig. 0.000). However, there was no significant effect of the type of land cover on the bulk density

$$\text{Soil carbon stock (g g}^{-1}\text{)} = \frac{\pi r^2 \text{ (cm) x soil depth (cm) x BV (g cm}^{-1}\text{)}}{\pi r^2 \text{ (cm) x soil depth (cm) x BV (g cm}^{-1}\text{)}} \text{ x } \frac{\text{SOC}}{100} \quad (1)$$

$$\text{Root carbon stock (g g}^{-1}\text{)} = \frac{\text{root weight (g) x 0.47 x BV (g cm}^{-1}\text{)}}{\pi r^2 \text{(cm) x length of ring sample (cm)}} \quad (2)$$

$$\text{Total soil carbon stock (g g}^{-1}\text{)} = \text{soil carbon stock + root carbon stock} \quad (3)$$

Where, πr^2 = area of the soil sample ring; BV = bulk density soil sample; 100 = conversion (%) to (g g^{-1}); 0.47 = constant of carbon in roots.

(Sig. 0.055). Figure 3 shows the distribution of root weight density, bulk density, SOC and total nitrogen at a soil depth of 0 to 40 cm in all sites.

The root weight density at all sites showed the highest value at a depth of 0 to 10 cm and decreased with the increasing soil depth (Figure 3a). The highest root weight density was in the site with 50-year-old bamboo vegetation, and the lowest was in the sites with mixed vegetation of *A. falcataria* and brushwood (Table 2). The root weight density at the study sites ranged from 3.56 to 20.54 mg cm^{-3}. The root density was higher in the bamboo vegetation (Table 2). The advantage of bamboo plants is that they have a rhizome root system that can last for years and grow laterally to produce new side shoots that develop into new rhizomes (Xiao et al., 2021). This is in line with the results of researchers study, showing that the root weight increased with the increasing age of the bamboo rhizomes at the study site. This study shows that the decrease in root weight that occurs with increasing soil depth is caused by the root system of bamboo plants' rhizomes distribution that occurs maximally at a soil depth of 0 to 30 cm (Shi et al., 2021). Several studies have shown that most trees and shrubs' roots are distributed vertically into the soil to a soil depth of 60 cm (Schmid and Kazda, 2002; Gao et al., 2020). Therefore, in this research, vegetation other than bamboo has a lower root weight.

The bulk density distribution increased with the increasing soil depth (Figure 3b). There was no significant effect of land covers on the bulk density (Table 2). Bulk density at the study sites ranged from 0.89 to 1.39 mg cm^{-3}. Bulk density increased with soil depth in layers 0 to 40 cm (Figure 3b). In line with the results of research by Wu et al. (2023), an increase in bulk density was caused by a gradual decrease in SOC content (Figure 3c) with increasing soil depth, which would reduce soil permeability. In addition, it may also be due to the influence of plant roots. In the top layer (0 to 10 cm), the bulk density value was the lowest compared to other soil layers, which was caused by the abundance of plant roots (Figure 3a) in the top layer. The decrease in bulk density is due to root decomposition, which will increase soil organic matter (Athira et al., 2019). Besides, roots can increase soil porosity and infiltration rate, thereby reducing bulk density (Ontl et al., 2015).

The SOC was the highest in the top layer of soil with a depth of 0 to 10 cm and decreased with the increasing soil depth (Figure 3c). There was no significant effect of land covers on the SOC (Table 2), but SOC was higher in the bamboo vegetation. SOC at the study site ranged from 2.07 to 55.12 g kg^{-1} soil. The type of vegetation and soil depth influence SOC. In this study, SOC was the highest in layers 0 to 10 cm (Figure 3c) and decreased with the increasing soil depth at sites 3, 4, 5 and 6. The high SOC was due to the accumulation of litter and distribution of high roots. Carbon in the soil will increase if there is plant litter on the ground and root decomposition by microorganisms (Zhou et al., 2013). Plant roots also affect the organic carbon content of the soil. A well-developed root system can increase SOC because organic carbon is released through root exudation and dead root tissue (Y. Wang et al., 2015). Litter on bamboo plants is abundant and easily decomposed, thereby increasing SOC (Qin et al., 2017). The results of the analysis conducted by Maulana et al. (2020) reported that the lignin content of bamboo (*D. asper* Back.) leaves was 24.8%, which is included in the medium criteria, so it is easy to decompose. The decomposition process results in fulvic acid and humic acid, which are part of the organic carbon in the soil (Syamsiyah et al., 2019).

The total nitrogen decreased with the increasing soil depth at all sites (Figure 3d). Total nitrogen (Table 2) significantly differed at all locations, except sites 3 and 4. It was higher in bamboo vegetation. Total nitrogen at the study site ranged from 0.67 to 2.75 g kg^{-1} soil. This aspect was affected by the type of vegetation and soil depth. In this study, total nitrogen decreased with the increasing soil depth. Nitrogen reduction is caused by vegetation biomass and biomass quality (X. Lu et al., 2021). Litter decomposition is influenced by nitrogen concentration and the C/N ratio of biomass. A low C/N ratio of biomass means that it has a relatively higher nitrogen concentration, which will accelerate microbial activity and increase litter decomposition because microorganisms are not limited by nitrogen (Dong et al., 2023). This is in line with the results of this study, showing that nitrogen in bamboo vegetation is higher because bamboo litter is easily decomposed, thereby increasing soil nitrogen content. Soil nitrogen content was higher at a depth of 0 to 20 cm than that at a depth of 20 to 40 cm. This is because there is more supply of organic matter in the top layer than in the bottom layer. This is also influenced by the presence of soil microorganisms that accelerate the decomposition process. According to Meng et al. (2022), an increase in soil nitrogen is

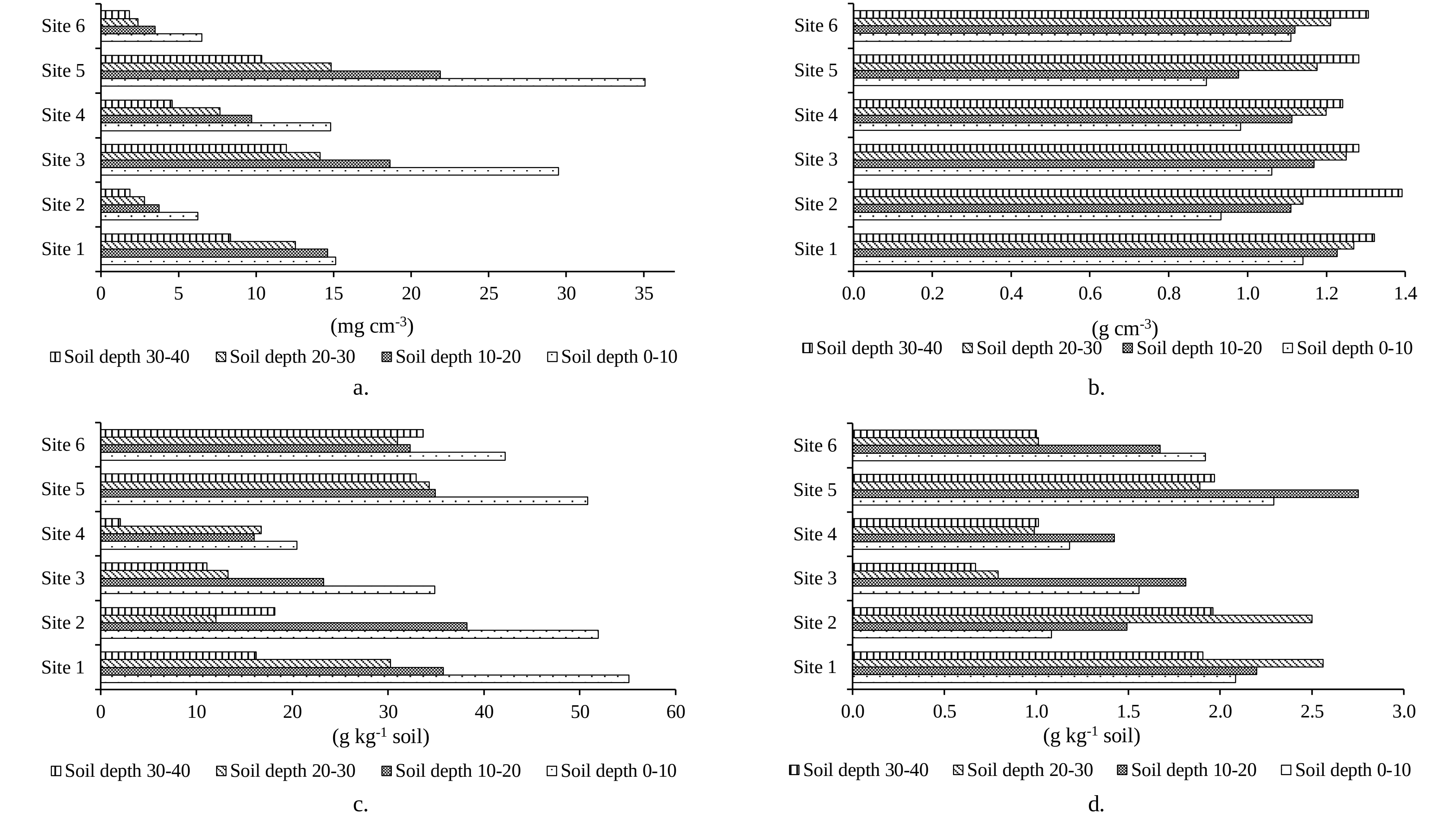

Figure 3. Distribution of (a) root weight density, (b) bulk density, (c) SOC and (d) total nitrogen at soil depth of 0 to 40 cm

Note: site 1 = 10-year-old bamboo; site 2 = bulrush; site 3 = 30-year-old bamboo; site 4 = brushwood and bulrush; site 5 = 50-year-old bamboo; site 6 = *A. falcataria* and brushwood

Table 2. Soil characteristics and root weight density in bamboo and non-bamboo vegetation at soil depth of 0 to 40 cm

Site	Parameter of land cover vegetation	Root weight density (mg cm^{-3})	Bulk density (g cm^{-3})	SOC (g kg^{-1})	Total nitrogen (g kg^{-1})	C/N Ratio	CEC (cmol kg^{-1})	Soil pH	Soil texture
1	Bamboo aged 10 years	12.67±2.93^{b}	1.24±0.09^{b}	34.33±15.01^{b}	2.19±0.26^{c}	15.68 ±6.64^{a}	33.44 ± 9.27^{c}	6.34±0.11^{c}	Loamy sand
2	Bulrush	3.67±1.70^{a}	1.14±0.17^{ab}	30.07±16.85^{b}	1.76±0.60^{b}	17.08±5.71^{a}	21.65±1.33^{a}	6.12±0.09^{a}	Loamy sand
3	Bamboo aged 30 years	18.56±7.22^{c}	1.19±0.09^{ab}	20.62±10.33^{a}	1.21±0.51^{a}	17.04±4.88^{a}	29.18±11.85^{c}	6.19±0.27^{ab}	Sandy loam
4	Brushwood and bulrush	9.19±3.96^{b}	1.13±0.10^{ab}	19.16±3.45^{a}	1.15±0.18^{a}	16.66±4.65^{a}	30.94±3.17^{c}	6.32±0.19^{bc}	Sandy loam
5	Bamboo aged 50 years	20.54±9.96^{c}	1.08±0.16^{a}	38.23±7.92^{b}	2.23±0.39^{c}	17.14±3.89^{a}	23.92±3.15^{ab}	6.13±0.12^{a}	Loamy sand
6	*A. falcataria* and brushwood	3.56±1.88^{a}	1.19±0.09^{ab}	34.78±4.83^{b}	1.40±0.46^{a}	24.84±9.02^{b}	27.32±6.67^{abc}	6.12±0.13^{a}	Loamy sand

Note: means followed by the same lowercase letters in the same column are not significantly different according to DMRT 5%

obtained directly from the decomposition of organic matter, which will produce organic acids in the soil.

There was no significant effect of the type of land cover on the soil C/N ratio (Table 2). The soil C/N ratio was higher in bamboo vegetation. The value of the C/N ratio of the soil at the study site ranged from 15.68 to 28.84. The C/N ratio of soil in non-bamboo vegetation land was greater than that in bamboo vegetation land. The low nitrogen content of non-bamboo vegetation will result in the low activity of microorganisms due to a lack of nitrogen elements, so the decomposition process runs slowly (Meng et al., 2022). The C/N ratio is used to indicate the possibility of nitrogen deficiency and competition among microbes and higher plants in using available nitrogen in the soil (Jones et al., 2018). There was no significant effect of the type of land cover on the CEC (Table 2). The CEC at the study sites ranged from 21.65 to 33.44 cmol kg^{-1} soil. The high CEC in this study was influenced by soil organic matter content and soil pH (H. Wang et al., 2015). In line with the research of Juhos et al. (2021), the CEC is linearly correlated with soil pH, meaning that an increase in soil pH will cause an increase in CEC. In this study, it was proven that the CEC increased with the increasing soil pH (Table 2). Organic matters have greater cation adsorption capacity because organic materials will increase the negative charge, thereby increasing the CEC. Humus colloid is a source of 20 to 70% CEC (Nesic et al., 2015).

The type of land cover did not significantly affect soil pH of H_2O (Table 2). The soil pH of H_2O at the study sites ranged from 6.12 to 6.34, which is included in acidic pH criteria. The soil pH of H_2O in the bamboo vegetation land was higher and close to neutral pH. Neutral soil pH is influenced by organic matter. The decomposition process will produce negatively charged organic compounds that can bind cations (Rahmadaniarti and Mofu, 2020). Organic matter has the ability to buffer soil pH because in organic matter, there are carboxyl functional groups that can release or bind H^+ (Wong and Swift, 2001). Soil texture at the study site is dominated by sand texture. The soil texture in sites 1, 2, 5 and 6 is loamy sand, while in sites 3 and 4, the soil texture is sandy loam (Table 2). This difference occurs because there is an increase in clay and silt at sites 3 and 4, causing different texture groups. Soil texture will affect the soil's ability to store and provide plant nutrients (Chakraborty and Mistri, 2015). The clay fraction can attract and hold nutrients so that a few nutrients will be lost by water flowing through the soil (Anaba et al., 2020). In addition, soil texture also affects root development and growth; sandy soil has better soil aeration and low resistance to root penetration, thus creating a favorable environment for root length growth and branching (Fang et al., 2019).

Carbon fractions

The results of the ANOVA analysis showed that the type of land cover had a significant effect on C POM (Sig. 0.000), C Mic (Sig. 0.000), humic acid (Sig. 0.000) and fulvic acid (Sig. 0.026). C POM at sites 5 and 6 was significantly affected by the type of land cover (Table 3). However, at sites 1, 2, 3 and 4, the bamboo and non-bamboo land cover did not show significant effect. All sites showed higher C POM values in bamboo vegetation (Table 3). The value of C POM at the study sites ranged from 1.04 to 2.45 g kg^{-1} soil.

C POM has a significant positive correlation with humic acid (r = 0.433), fulvic acid (r = 0.407), N POM (r = 0.814), soil carbon stock (r = 0.662), SOC (r = 0.729), total nitrogen (r = 0.611) and root weight density (r = 0.249), and it is significantly negatively correlated to bulk density (r = -0.377) and pH (r = -0.236) (Table 4). Overall, the C POM concentration was higher in bamboo vegetation and was highest in bamboo vegetation (50 years) of 2.45 g kg^{-1} soil. The correlation results signify that C POM is positively related to N POM, soil carbon stock, SOC and total nitrogen. This research is in line with the study of Xing et al. (2022), reporting that an increase in N POM, soil carbon stock, SOC and nitrogen was followed by an increase in C POM content. This research showed that bamboo vegetation had higher SOC and nitrogen values (Table 4). Higher soil carbon and nitrogen come from litter decomposition resulting in higher C POM concentrations. The results of this study align with the results of the research by Bu et al. (2015) stating that the amount of organic matter (litter) is the main factor controlling the C POM content in the soil. In addition, land without tillage will also increase residues on the soil surface and reduce the decomposition rate (Desrochers et al., 2020), resulting in the accumulation of organic matter and improving soil aggregation. Increasing soil aggregation will increase the C POM (Chan, 2003).

The C Mic at all sites was not significantly affected by the type of land cover (Table 3). Sites 1, 2, 3 and 4 showed higher C Mic values in non-bamboo vegetation, while sites 5 and 6 showed higher C Mic values in bamboo vegetation. The C Mic values at the study sites ranged from 3.46 to 12.05 μg kg^{-1} soil. C Mic had a significant positive correlation with root weight density (r = 0.328), and a significant negative correlation with bulk density (r = -0.525) and pH (r = -0.394) (Table 4). The results showed that at sites 1, 2, 3 and 4, the activity of microorganisms occurred more on non-bamboo vegetation land as indicated by the higher C Mic. Meanwhile, the opposite happened at sites 5 and 6. The correlation results showed that C Mic had a negative relationship with soil pH. Differences in C Mic content are caused by environmental factors in the soil. These environmental factors include nutrients, soil pH, aeration and drainage, and the availability of energy sources (Rahman et al., 2021). These factors will affect the activity of microorganisms, thereby affecting soil microbial biomass. In addition, C Mic is correlated to root weight density. Roots are a place of life and a source of energy for microorganisms. High root weight indicates that the activity of microorganisms in the soil is high since carbon in root exudate provides a food supply for soil microorganisms (Xiao et al.,

Table 3. Composition of soil carbon fraction at soil depth 0 to 40 cm

Site	Parameter of land cover vegetation	C POM (g kg^{-1})	C Mic (μg kg^{-1})	Humic acid (%)	Fulvic acid (%)
1	Bamboo age 10 years	$1.77±0.40^{b}$	$4.41±2.83^{ab}$	$0.38±0.09^{c}$	$0.43±0.11^{b}$
2	Bulrush	$1.88±0.97^{b}$	$8.72±5.63^{ab}$	$0.11±0.02^{a}$	$0.30±0.14^{a}$
3	Bamboo age 30 years	$1.04±0.19^{a}$	$7.73±8.88^{ab}$	$0.13±0.07^{a}$	$0.36±0.10^{ab}$
4	Brushwood and bulrush	$0.94±0.24^{a}$	$12.05±17.16^{b}$	$0.09±0.05^{a}$	$0.32±0.06^{a}$
5	Bamboo age 50 years	$2.45±0.72^{c}$	$8.35±5.97^{ab}$	$0.30±0.08^{bc}$	$0.43±0.10^{b}$
6	*A. falcataria* and brushwood	$1.56±0.24^{b}$	$3.46±1.40^{a}$	$0.27±0.20^{b}$	$0.38±0.06^{ab}$

Note: means followed by the same lowercase letters in the same column are not significantly different according to DMRT 5%

2021). C Mic is also related to soil organic matter as an energy substrate. If there is a change in soil conditions, especially an increase or decrease in plant residues, soil microbial biomass will respond quickly and result in the changes in the concentration of microbial biomass (Kushwaha et al., 2000). In addition, the high concentration of C Mic at sites 3 and 4 was caused by an increase in clay at these sites (Table 1). Research by Yang et al. (2022) found that C Mic was affected by soil texture, in which an increase in clay and silt was followed by an increase in C Mic.

Humic acid at sites 1 and 2 was significantly affected by the type of land cover (Table 3). However, at sites 3, 4, 5 and 6, the bamboo and non-bamboo land cover was not significantly different. All sites showed higher humic acid values in bamboo vegetation (Table 3). The humic acid value at the study sites ranged from 0.09% to 0.38%. Humic acid has a significant positive correlation with C POM (r = 0.433), fulvic acid (r = 0.500), N POM (r = 0.367), soil carbon stock (r = 0.636), CEC (r = 0.258), SOC (r = 0.590), total nitrogen (r = 0.565) and root weight density (r = 0.289) (Table 4). Fulvic acid at sites 1 and 2 were also significantly affected by the type of land cover (Table 3). However, at sites 3, 4, 5 and 6, the bamboo and non-bamboo land cover was not significantly different. All sites showed higher fulvic acid values in bamboo vegetation (Table 3). Fulvic acid values at the study sites ranged from 0.30 to 0.43%. Fulvic acid has a significant positive correlation with C POM (r = 0.407), humic acid (r = 0.500), N Mic (r = -0.313), soil carbon stock (r = 0.545), SOC (r = 0.459) and total nitrogen (r = 0.399) (Table 4).

Overall, the concentration of humic acid is higher in bamboo vegetation. This acid has a positive correlation with SOC content. The humic acid fraction contains about 60% organic carbon (Sible et al., 2021). It has a positive correlation with total soil nitrogen. The results of research by Ampong et al. (2022) showed that humic acid increased the nitrogen content in the soil compared to the control treatment. The results of this present study also showed a positive correlation between humic acid and CEC, which can be seen in the data (Table 2), showing that the highest humic acid was in bamboo vegetation (10 years) followed by high CEC in bamboo vegetation (10 years). Research conducted by Ampong et al. (2022) produced the same results, in which an increase in humic acid was followed by an increase in CEC. Overall, the concentration of fulvic acid was higher in bamboo vegetation. This research showed a correlation between fulvic acid and N Mic. The most elevated fulvic acid was found in bamboo vegetation (10 and 50 years), followed by the highest N Mic in bamboo vegetation (10 years). Research by Sootahar et al. (2019) revealed that fulvic acid affected the growth of soil microbial biomass and microbial activity. Fulvic acid is the active ingredient providing carbon and energy for microorganisms. Fulvic acid is positively correlated to SOC, nitrogen and soil carbon

Table 4. Pearson's correlation (r) between soil characteristics and carbon fraction, nitrogen fraction and soil carbon stock

Correlations	C Mic	C POM	Humic acid	Fulvic acid	N Mic	N POM	Soil C-stock
C Mic	1	.091	-.136	.000	-.113	.005	.167
C POM	.091	1	.433**	.407**	-.159	.814**	.662**
Humic acid	-.136	.433**	1	.500**	.014	.367**	.636**
Fulvic acid	.000	.407**	.500**	1	-.313**	.224	.545**
N Mic	-.113	-.159	.014	-.313**	1	-.104	-.215
N POM	.005	.814**	.367**	.224	-.104	1	.587**
Soil carbon Stock	.167	.662**	.636**	.545**	-.215	.587**	1
SOC	.076	.729**	.590**	.459**	-.101	.674**	.835**
Total nitrogen	.004	.611**	.565**	.399**	-.016	.682**	.676**
C/N ratio	.017	.211	.070	.100	-.030	.105	.227
CEC	.132	-.228	.258*	-.016	.034	-.187	.191
pH	-.394**	-.236*	-.124	.019	-.048	-.332**	-.372**
Bulk density	-.525**	-.377**	.036	-.089	.368**	-.424**	-.403**
Root weight density	.328**	.249*	.289*	.219	-.226	.200	.620**

Note: **correlation is significant at $\alpha = 0.01$; *correlation is significant at $\alpha = 0.05$

stocks. Research by Ampong et al. (2022) disclosed that adding soil organic matter increased the soil fulvic acid content. Soil organic matter is the primary source of carbon, nitrogen and soil carbon stocks. The humic acid and fulvic acid fractions are constant carbons in the soil because they decompose slowly in nature. Research by Sible et al. (2021) concludes that the carbon content in fulvic acid is higher than in humic acid. This is in line with the results of this present study (Table 3). The high content of humic acid and fulvic acid in the bamboo vegetation is due to more litter in the bamboo vegetation. Litter is a source of organic carbon and humic-fulvic acid. This is in line with the research by Wei et al. (2020), reporting that adding plant litter increased the soil's humic and fulvic acid content. Humic material plays an essential role in providing soil nutrients; humic material mainly consists of humic acid and fulvic acid; humic material is a crucial part of soil organic matter because it is closely related to soil carbon and nitrogen (Kõlli and Rannik, 2018).

Nitrogen fraction

The results of the ANOVA analysis showed that the type of land cover significantly affected N POM (Sig. 0.000) and N Mic (Sig. 0.000). The N POM at sites 1, 2, 5 and 6 was significantly affected by the type of land cover (Table 5). However, sites 3 and 4 showed no significant difference between bamboo and non-bamboo vegetation. The N POM content at sites 3, 4, 5 and 6 was higher in the bamboo vegetation. Still, at sites 1 and 2, the N POM content was higher in the non-bamboo vegetation. The N POM values at the study sites ranged from 0.04 to 0.17 g kg^{-1} soil.

N POM has a significant positive correlation with C POM (r = 0.814), humic acid (r = 0.367), soil carbon stock (r = 0.587), SOC (r = 0.674) and total nitrogen (r = 0.682), and it is negatively correlated to bulk density (r = -0.424) and pH (r = -0.332) (Table 4). This research showed that the N POM in bamboo vegetation was higher than that in non-bamboo vegetation (Table 5). Correlation analysis showed that N POM was correlated to C POM, soil carbon stock, SOC and total nitrogen. This research is also in line with the study of Xing et al. (2022), stating that an increase in C POM, soil carbon stock, SOC and total nitrogen was followed by an increase in the N POM content. The increase in N POM was accompanied by increased soil carbon and nitrogen. Higher soil carbon and nitrogen come from litter decomposition, which results in higher N POM concentrations. This is in line with the research by Bu et al. (2015), reporting that concentrations of N POM were greater in land with high organic matter content. Bamboo vegetation land has a higher organic matter content than non-bamboo vegetation land. The N POM fraction is a dynamic available nitrogen pool that leads to greater soil nitrogen mineralization. Differences in N POM composition are related to the source of plant residues, and their decomposition affects the nature of N POM and soil nitrogen mineralization (Martínez et al., 2017).

There was no significant effect of the type of land cover on the N Mic at all locations (Table 5). The results showed that N Mic at sites 3, 4, 5 and 6 was higher in non-bamboo vegetation. However, the nitrogen content of microbial biomass at sites 1 and 2 was higher in bamboo vegetation. This study disclosed that low N POM content went hand in hand with high N Mic counts (Table 5). This means that N POM has been used by microorganisms as an energy source, so the amount in the soil is small. N Mic values at the study sites ranged from 1.84 to 5.76 μg kg^{-1} soil. N Mic was significantly correlated to fulvic acid (r = -0.313) and bulk density (r = 0.368) (Table 4). N Mic in non-bamboo vegetation land was higher than in bamboo vegetation land. One of the factors that affect the availability of N Mic is the availability of organic matter

Table 5. Composition of soil nitrogen fraction at soil depth of 0 to 40 cm

Site	Parameter of land cover vegetation	N POM (g kg^{-1})	N Mic (μg kg^{-1})
1	Bamboo age 10 years	0.10±0.03[b]	5.76±1.14[b]
2	Bulrush	0.14±0.06[cd]	4.85±3.25[b]
3	Bamboo age 30 years	0.07±0.04[a]	1.84±0.73[a]
4	Brushwood and bulrush	0.04±0.01[a]	2.17±0.97[a]
5	Bamboo age 50 years	0.17±0.06[d]	2.47±1.66[a]
6	*A. falcataria* and brushwood	0.12±0.03[bc]	3.22±2.08[a]

Note: means followed by the same lowercase letters in the same column are not significantly different according to DMRT 5%

Table 6. Composition of soil carbon stock at soil depth of 0 to 40 cm

Site	Parameter of land cover vegetation	Soil carbon stock (g g^{-1} soil)	Root carbon stock (g g^{-1} soil)	Total soil carbon stock (g g^{-1} soil)
1	Bamboo age 10 years	0.016±0.006^{b}	0.007±0.002^{c}	0.023±0.007^{cd}
2	Bulrush	0.015±0.008^{b}	0.002±0.001^{a}	0.017±0.007^{ab}
3	Bamboo age 30 years	0.011±0.005^{a}	0.010±0.003^{d}	0.021±0.008^{bc}
4	Brushwood and bulrush	0.010±0.002^{a}	0.005±0.002^{b}	0.015±0.002^{a}
5	Bamboo age 50 years	0.019±0.002^{b}	0.010±0.003^{d}	0.029±0.005^{d}
6	*A. falcataria* and brushwood	0.017±0.003^{b}	0.002±0.001^{a}	0.019±0.004^{ab}

Note: means followed by the same lowercase letters in the same column are not significantly different according to DMRT 5%

substrates. Abundant organic matter will cause soil microbes to develop appropriately (Babur et al., 2021). Differences in N Mic content are caused by environmental factors in the soil, one of which is soil pH. This study showed an increase in N Mic followed by an increase in pH (Table 2 and Table 5). In line with the results of research by Xing et al. (2022), an increase in N Mic was followed by an increase in soil pH. The pH will affect the activity of microorganisms, thereby affecting soil microbial biomass. The N Mic is a small fraction of the total fraction of soil nitrogen, which is unstable or easily changed. Soil microbial biomass's amount, activity and quality are vital factors in controlling the amount of N mineralized (Bargali et al., 2018).

Soil carbon stock

Soil carbon stocks are organic carbon stores in the soil (Buraka et al., 2022). Carbon is stored in four carbon pools: aboveground biomass (tree), SOC, underground biomass (root) and dead organic matter. Three carbon pockets are stored in the soil, while one carbon pool is stored in trees. Soil carbon stock is organic carbon stored in the soil, with calculations in the methods chapter. Root carbon stock is carbon in underground biomass, especially plant roots, with calculations in the methods chapter. Total soil carbon stock is the sum of the total carbon stored in soil and roots. The results of the ANOVA analysis showed that the type of land cover significantly affected carbon stock (Sig. 0.000). The soil carbon stock at all sites demonstrated that the land cover of bamboo and non-bamboo had significantly different effect (Table 6). Soil carbon stock values at the study sites ranged from 0.015 to 0.029 g g^{-1} soil.

Soil carbon stock had a significant positive correlation with C POM (r = 0.662), humic acid (r = 0.636), fulvic acid (r = 0.545), N POM (r = 0.587), SOC (r = 0.835), total nitrogen (r = 0.676) and root weight density (r = 0.620), and it was significantly and negatively correlated to bulk density (r = -0.403) and pH (r = -0.372) (Table 4). The results showed that soil carbon stock at all sites was higher in bamboo vegetation. Soil carbon stock was affected by SOC and bulk density (FAO, 2018). This is in line with this research, in which an increase in soil carbon stock was followed by an increase in SOC and a decrease in bulk density (Table 2 and Table 5). This study showed that soil carbon stock was positively related to SOC, total nitrogen and root weight density. The SOC (Table 2) was found the highest at site 5, in line with the results of soil carbon stock (Table 6). Soil carbon stock comes from SOC, including subsurface biomass and dead organic matter (Shapkota and Kafle, 2021). The highest soil carbon stock results were at site 5, followed by the highest root weight density (Table 2). Research by Lal (2005) explains that differences in the diversity of soil carbon stocks occur because each vegetation type has a different distribution of roots.

CONCLUSIONS

The highest carbon storage is found in bamboo vegetation land compared to non-bamboo vegetation land. The composition of the carbon fraction, nitrogen fraction and soil carbon stock is influenced by the physical-chemical properties of the soil, including root weight density, bulk density, pH H_2O, SOC and total nitrogen. Soil carbon stock and stable carbon composition (humic acid and fulvic acid) are the highest in 50-year-old bamboo vegetation, meaning carbon is stored in the soil but in a slowly degraded form. Therefore, the potential for long-term carbon storage is found in bamboo vegetation. The increase in atmospheric CO_2 can be reduced by transferring/sequestering carbon into the soil (soil carbon sequestration). The amount of carbon stored in the soil represents the carbon removed from the atmosphere. Soil carbon stock and stable carbon content (humic acid and fulvic acid) were highest in 50-year-old bamboo vegetation, meaning carbon is stored for an extended period in the soil in a slowly degraded form.

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