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Microbial Biomass and Soil Respiration Response to Pruning and Fertilization Practices in Coffee-Pine Agroforestry

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ABSTRACT

Pruning and fertilization practices plays an important role in coffee plantation, used to maintain soil quality and coffee productivity. However, the impact of pruning and fertilization practices on soil microbial activity under coffee-based agroforestry are poorly understood. The aimed of this study was to analyze the response of soil microbial properties (i.e., soil microbial biomass C (SMBC) and soil respiration rates (SR)) to pruning and fertilization management in coffee-based agroforestry in UB (Universitas Brawijaya) Forest. A split-plot design with eight treatments and three replications were used in this experiment. The main-plot factor consisted of two types of pruning (Pruning and Bending), and the sub-plot factor consisted of four types of fertilization (i.e., no fertilizer (NF), 100% chicken manure (MN), 50% chicken manure + 50% NPK-inorganic (MN+NPK), and 100% NPK-inorganic (NPK)). The result showed that there was a significantly different ($p<0.05$) in the soil microbial biomass C and soil respiration after the application of fertilizer. The addition of chicken manure (MN and MN+NPK treatment) could enhance the soil microbial biomass and soil respiration, compared to the NF treatment under different pruning practices. The level of soil pH in MN were highest and significantly different with NPK treatment, showed that the application of chicken manure had a potential to neutralize the soil acidity. Metabolic quotient (qCO_2) showed highest in the NF treatment as compared to the other treatments. The soil respiration had positive correlation ($p<0.05$) with SMBC, while SMBC had negative correlation ($p<0.01$) with qCO_2.

Keywords: coffee-based agroforestry, fertilization, microbial biomass, pruning, soil respiration.

INTRODUCTION

Coffee is one of the important export commodities for Indonesia's economy. In 2020, the coffee plants were grown in 1.2 million ha of land, producing 753,941 tons of beans for the country (Ditjenbun, 2021). East Java is the largest coffee producer in the island. From 91,788 ha of plantation in the same year, the total production was 49,157 tons (Ditjenbun, 2021). Coffee plantation in Indonesia is mostly smallholder plantations (96.09%); the rest is state plantations (1.83%) and private plantations (2.76%) (Sujatmiko and Ihsaniyati, 2018). Coffee in Indonesia is commonly planted using agroforestry system, which supports the socio-economic lives of small farmers and plays an important role in ecology through the preservation of soil microbial activity (Tridawati et al., 2020; Ayala-Montejo et al., 2022).

The productivity of coffee agroforestry can be improved by conducting pruning management. Pruning is believed to be the most important cultivation technique to keep the tree low enough for easier care, better development of new productive branches, and higher fruit quality and yield (Gokavi et al., 2021; Karim et al., 2021). The goal of pruning in coffee tree growing is to maintain the tree's productivity and sustainability (Tridawati et al., 2020). However, it reduces productivity for at least two years until the newly grown branches produce the berries since the plants lose some of its woody biomass and leaves, which are used for photosynthesis (Charbonnier et al., 2017; Acevedo et al., 2019).

Fertilizer addition from pruning can reduce the risk of water and nutrient shortage in the soil, and the growth of coffee plants can be improved (Suprayogo et al., 2020). Kurniawan et al. (2021) reported that such addition enhances the quantity of organic sources in the soil and increases soil microbial activities that involve nutrient cycles. The integration of management pruning and fertilization can lead to improving soil quality, especially in soil microbial properties. Soil microorganisms are generally very sensitive and respond much more quickly to changes in environmental conditions compared to physical and chemical properties such as soil C-organic content or total N (Giuditta et al., 2020). Soil microbes also have an important role in the ecosystem functioning, such as the dynamics of organic matter processes and nutrient cycles in the soil (Araujo et al., 2012; Teixeira et al., 2021). The soil microbial properties can be measured by estimating the size and activity of microbes in the soil, e.g soil microbial biomass and soil respiration (Kabiri et al., 2016). Soil microbial biomass are indicated the size of the decomposing of microbial biomass in the soil, and regarded as good indicators of the soil capacity for nutrient turnover (Xu et al., 2023), while soil respiration is represented as an indicator of C availability (Guillaume et al., 2016).

Several studies on coffee cultivation management systems have focused on measuring and comparing soil microbial biomass, nutrient availability, and coffee plants' productivity, and they were observed separately. Ayala-Montejo et al. (2022) reported that pruning practices in coffee-based agroforestry produce higher soil respiration and soil macrofauna biomass. SMBC is found higher in coffee cultivation after added fertilization and is related to higher coffee yields (Valdes et al., 2020). The practices of some management on coffee plantations have shown increased SMBC, soil nutrients, and productivity (Teixeira et al., 2021). Nonetheless, studies that combine several parameters as bioindicators for determining soil microbial activity from pruning and fertilization management in coffee plants are still relatively under-explored. In this research, the response of microbial activity particularly in microbial biomass and soil respiration after pruning and fertilization management on coffee-based agroforestry in UB Forest was measured.

MATERIALS AND METHODS

Study area

This study was conducted at UB Forest, an educational forest belonging to Universitas Brawijaya. It is located in Karangploso Sub-district of Malang Regency in East Java (7°49'464" S dan 112° 34'726" E). This special purpose forest was granted to the university in 2016 by the Ministry

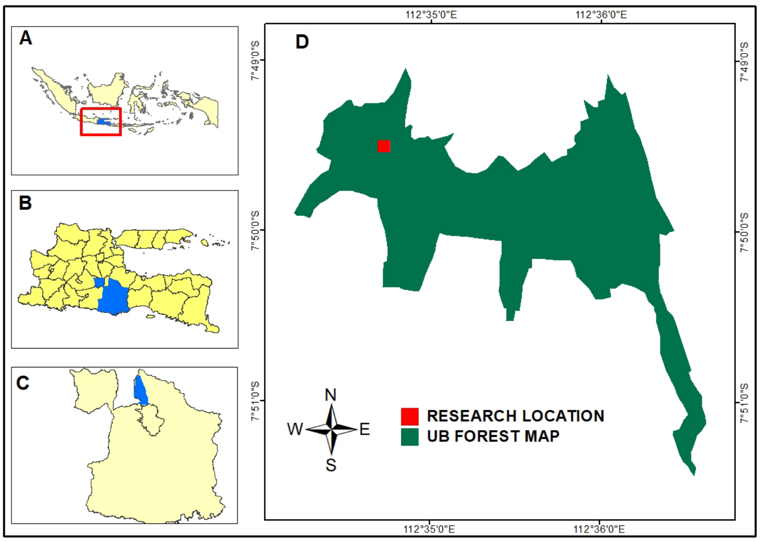

Figure 1. The research location at area of UB Forest (D), Sumbersari Hamlet, Tawangargo Village, Karangploso Sub-district, Malang District, East Java, Indonesia

of Environment and Forestry (KLHK). Situated in the elevation between 700–1300 m a.s.l (meters above sea level), it receives rain water from 1800 to 2400 mm/year (2017–2021), with the higher rain intensity during the rainy season (from November to April) (BMKG, 2021). The soil was classified as Inceptisols, derived from Arjuna-Welirang Mountain. The research site was a coffee-based agroforestry, with 9 years old coffee plant (*Coffea arabica* L.) and 40 years old pine trees (*Pinus merkusii*) as the shade tree.

The characterization of plot (e.g., fresh and dry weight organic matter (litter), basal area, tree population, and DBH of coffee and pine trees) were observed to all replicated plots. The dry weight organic matter (litter) was measured to determine the accumulation of total amount from aboveground litter. The samples were collected randomly from each replicated plot through a square frame with the size 0.5×0.5 m. Then, the collected samples (fresh weight organic matter) were dry-oven at 80°C for 48 h to determine the dry weight organic matter (litter) (g m^{-2}). The coffee bean yield was obtained from the harvested fruits (fresh cherries) from each coffee tree (g $tree^{-1}$) and converted to green beans (kg ha^{-1}).

Experimental design

The experiment was set up in a split-plot design and replicated three times. This research used two types of pruning, i.e., pruning and stem bending, as the main plots and uses four fertilization treatments, i.e., no fertilizer (NF), 100% chicken manure (MN), 50% chicken manure + 50% inorganic NPK (MN+NPK), and 100% inorganic NPK (NPK) as the subplots. Each plot consisted of 50 coffee plants, with each of treatment consisted of 10 coffee plants, totaling in 300 coffee plants. The coffee plants were pruned at 125 cm from the soil surface, known as regular pruning. Likewise, the bending was also set to 125 cm from the soil surface. The recommended fertilizer application for coffee plant as outlined by Puslitkoka (Indonesian Coffee and Cocoa Research Institute) is 10 kg of organic fertilizer per tree, 150 g of Urea per tree, 80 g of SP-36 per tree, and 100 g of KCl per tree. The fertilizer was applied twice per year, which in this research fertilizer was applied 6 months after pruned.

Soil sampling

The soil microbial activities were observed one month after the application of fertilizer. The soil samples were collected randomly around the fertilization zone (0–15 cm depth) to obtain the composite samples. Soil samples were replicated five times every rows of fertilization treatments to optimize the soil sampling. A total of 24 mixed soil samples were collected, from the three replications of the experimental design. All soil samples were separated from roots and plant residues, sieved to 2 mm mesh size and maintained at 4°C in the refrigerator until processed.

Microbial biomass measurement

The Chloroform Fumigation Extraction (CFE) method was used to estimated microbial biomass (Vance et al., 1987). The soil samples were collected randomly around the fertilization zone (0–15 cm depth) to obtain the composite samples. All soil samples were separated

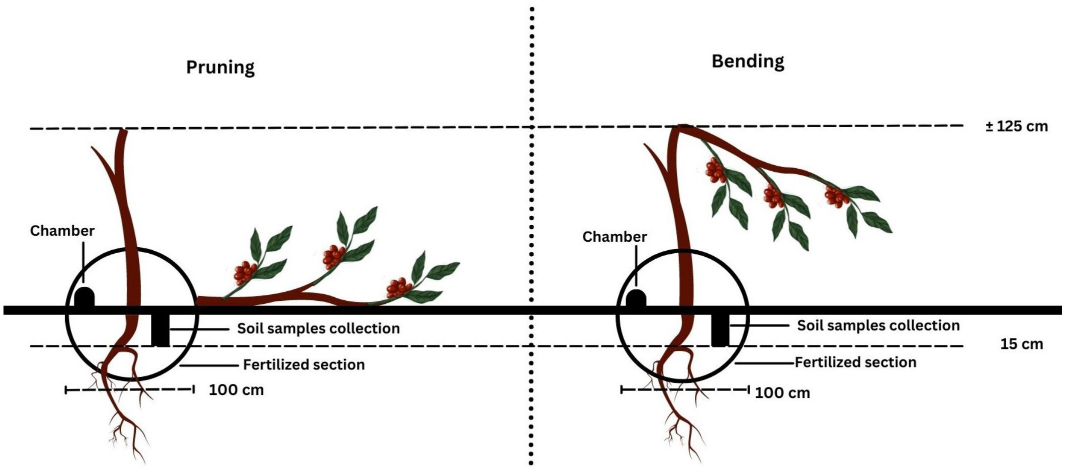

Figure 2. Coffee tree pruned, soil respiration, and soil samples collection schemes

from roots and plant residues, sieved to 2 mm mesh size and maintained at 4°C in the refrigerator until processed. In the laboratory, the 10 g of soil samples were placed in 50 ml beaker glasses and kept in a desiccator with 100 ml beaker glass containing 40 ml alcohol-free chloroform ($CHCl_3$), placed in the dark for 72 h at 24°C. Following the $CHCl_3$ removal, the soil samples added by 50 ml of 0.5 M K_2SO_4, then it was shaked for 30 min on a rotary shaker at 200 rpm. The extracts were filtered through a filter paper (Whatman No. 42), and the filtrates (10 ml) were distilled for organic-C analysis using Walkley-Black method. The soil microbial biomass carbon (SMBC) estimation was calculated using the following formula:

$$\text{SMBC} = \frac{C_{fumigated} - C_{nonfumigated}}{0.38}, (\mu g \cdot g^{-1}) \quad (1)$$

where: 0.38 was the extraction coefficient for carbon (K_{EC}) which showed the efficiency of the microbial C extraction (Vance et al., 1987).

Soil respiration measurement

The soil respiration was measured using a closed chamber method (Froment, 1972) with modification. The chamber was placed at the soil surface with a beaker glass containing 10 ml of 0.2 N KOH. Then chamber was closed tightly and incubated for two days. By the end of the incubation, the amount of produced CO_2 absorbed by KOH was analyzed using two-phase titration with HCl to determine the quantity of the CO_2. The KOH was titrated with 0.1 N HCl using phenolphthalein and methyl orange as the indicators. Then, the estimation of the respiration was calculated using the following formula:

$$R = \frac{(a-b) \cdot t \cdot 120}{n} \quad (2)$$

where: R – is the soil respiration ($kg_{C\text{-}CO_2} \cdot ha^{-1} \cdot day^{-1}$), a – is the HCl concentration in the soil-containing chamber (ml), b – is the HCl concentration in the soilless chamber (ml), t – is the HCl normality ($t = a$ mg/(381.42/2×ml titrant), and n – is day of incubation.

Statistical analysis

All of the data were collected and tested for normality using the Shapiro-Wilk's test, and the data transformation was checked when necessary. The data analysis was performed using two-way ANOVA (Analysis of Variance) to evaluate the main effect of pruning and fertilization on all parameters. The significant differences between pruning and fertilization were determined by the LSD test ($p<0.05$). All statistical analyses were performed with R statistical program.

RESULTS

Plot characterization

The plot characterization (e.g., fresh and dry weight organic matter (litter), basal area, tree population, DBH, and coffee bean yield) of study area are shown in Table 1. The result showed that the fresh weight organic matter (litter) in the Pruning plot has lower than Bending plot, but has higher of the dry weight organic matter (litter). Pruning plot showed higher basal area, tree population, and DBH of coffee and pine trees compared to Bending plot, due to the majority of big trees existence (tree with DBH > 30 cm). All the result shown that Pruning plot has higher number from all variable measurements (e.g., fresh and dry weight organic matter (litter), basal area, tree population, DBH, and coffee bean yield)

Table 1. Plot characteristics

Plot characteristics	Pruning	Bending
Fresh weight organic matter (litter) ($g \cdot m^{-2}$)	*500.07 ± 57.11	536.07 ± 62.38
Dry weight organic matter (litter) ($g \cdot m^{-2}$)	161.47 ± 27.01	140.67 ± 25.78
Basal area ($m^2 \cdot ha^{-1}$)	43.44 ± 8.64	40.70 ± 5.45
Tree population (ha^{-1})	1815 ± 175.29	1561 ± 163.58
Coffee DBH (cm)	3.96 ± 0.55	3.97 ± 0.33
Pine DBH (cm)	34.56 ± 1.06	34.41 ± 0.90
Coffee bean yield ($kg \cdot ha^{-1}$)	811.77 ± 123.87	744.23 ± 109.12

Note: * = mean ± SD (rep = 3); fresh and dry organic matter (litter) (n = 2); Basal Area (n = 67); tree population (n = 67); coffee DBH (n = 50); pine DBH (n = 17); coffee bean yield (n = 50).

compared to Bending plot. The basal area can be reflected the tree density, based on the diameter of trees and the trees population, which contribute to the litter input (Prayogo et al., 2021). The coffee bean production of Pruning plot (811.77 kg ha^{-1}) also showed higher yield than Bending plot (744.23 kg ha^{-1}). It is presumably because of the population of coffee tree shows higher in the Pruning, and affected to the coffee bean yield.

SOIL CHARACTERISTICS

The chemical and physical properties of the soil before fertilizer application in the research location are shown in Table 2. The soil has a low bulk density (0.65 g cm^{-3}) and low particle density (1.98 g cm^{-3}). It is classified as Inceptisols (considered as young soil) based on its parent material, that is volcanic ash from mount Arjuno-Welirang Mountain (Kurniawan et al., 2019). Its organic C is considered high (7.96%), indicating that the study location had a quite high amount of organic material. The organic material in the study location was presumably from the litterfall of coffee and pine trees due to low land maintenance, so the continuous addition of the residues contributes to the high production of organic material and soil's organic C (Yusuf et al., 2019; Kurniawan et al., 2019). The total N content is considered medium (0.39%), and the soil is slightly acidic with the pH of 5.33. The low pH might be caused by the high accumulation of organic materials in the soil (Singh et al., 2022).

Table 2. Soil chemical and physical properties before fertilizer application

Soil characteristics	Value
Soil bulk density (g·cm^{-3})	0.65
Soil particle density (g·cm^{-3})	1.98
Soil organic carbon (%)	7.96
Total N (%)	0.39
pH H_2O	5.33
Soil water content (%)	57.22

Soil Microbial Biomass-C (SMBC)

The soil microbial biomass C (SMBC) under the Pruning and Bending treatments is consistently greater in the MN treatment and is significantly different ($p<0.05$) than the one with NF treatment, while the MN+NPK and NPK treatments have the values between them (Figure 3A and 3B). The difference between MN and NF treatment in SMBC values is about 139.16% under Pruning (1077.92 μg g^{-1} and 450.71 μg g^{-1}) and 81.18% under Bending (1003.01 μg g^{-1} and 553.59 μg g^{-1}).

SOIL RESPIRATION

The result of the variance analysis show that the fertilization treatments produce no significant differences on the soil respiration under the Pruning treatment, but they produce significant differences under the Bending treatment. The average of soil respiration levels under the Pruning and Bending treatments that involve chicken manure (MN and MN+NPK) is consistently higher than

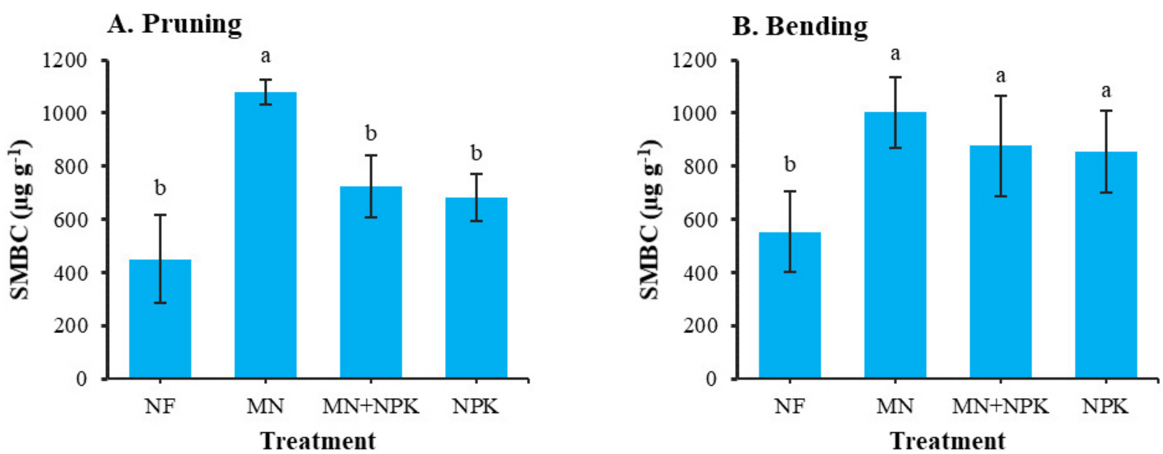

Figure 3. Soil microbial biomass C under different types of pruning (A) Pruning, (B) Bending and four fertilization treatments. NF: no fertilization; MN: Chicken manure; MN+NPK: Chicken manure and NPK-inorganic; NPK: NPK-inorganic. Means (± SD) denoted by different lowercase indicate significant differences according to LSD test at p <0.05.

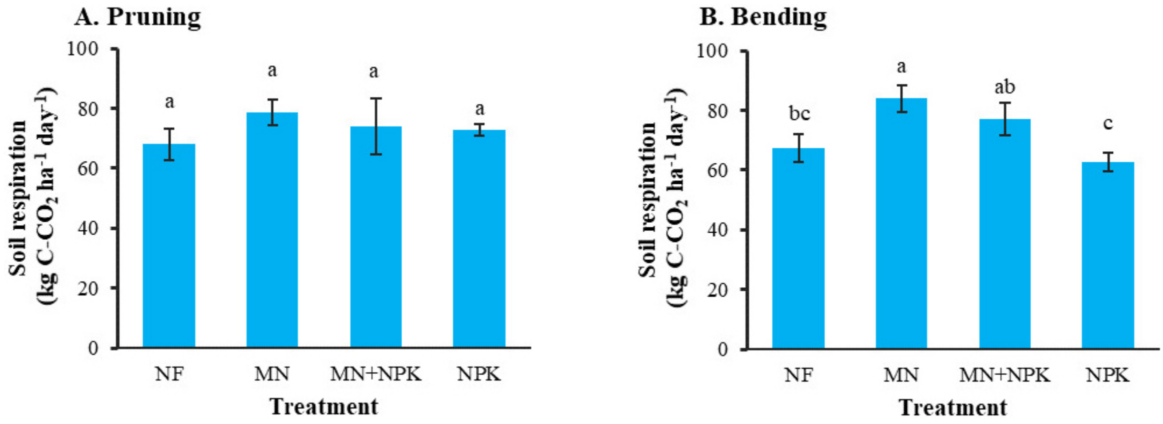

Figure 4. Soil respiration under different types of pruning (A) Pruning, (B) Bending and four fertilization treatment. NF: no fertilization; MN: Chicken manure; MN+NPK: Chicken manure and NPK-inorganic; NPK: NPK-inorganic. Means (± SD) denoted by different lowercase indicate significant differences according to LSD test at $p < 0.05$.

those involving NF and NPK treatment (Figure 4A and 4B). The highest soil respiration levels are in MN treatment (78.44 kg $C\text{-}CO_2$ ha^{-1} day^{-1}), but it has no significant difference ($p>0.05$) with the NF treatment (67.94 kg $C\text{-}CO_2$ ha^{-1} day^{-1}) that has the lowest soil respiration levels under the Pruning treatment (Figure 4A). The MN treatment (83.90 kg $C\text{-}CO_2$ ha^{-1} day^{-1}) under the Bending treatment has a significant difference ($p<0.05$) with the NF treatment (67.28 kg $C\text{-}CO_2$ ha^{-1} day^{-1}) (Figure 4B).

The result of the Pearson's analysis shows that the soil respiration has a strong and positive correlation with soil respiration under the two types of pruning (Figure 5A and 5B). The soil respiration and SMBC in the Pruning treatment have a very and strong positive correlation with $r = 0.76^{**}$ ($p<0.01$). Therefore, it results in a regression with the equation of $y = 0.0155x + 61.906$, and the R^2 value of 0.58 (Figure 5A). Meanwhile, in the Bending treatment, a strong and positive correlation with the value of $r = 0.50^{*}$ ($p<0.05$) was acquired, so the regression can be determined with the equation of $y = 0.0254x + 51.904$ and the $R^2 = 0.25$ (Figure 5B).

Soil organic C

The result of the variance analysis shows that the soil organic C under the Pruning treatment is greater in the MN treatment (6.80%), and significantly different with the NPK and NF treatment (6.01% and 5.81%) ($p<0.05$) that has the lowest soil organic C (Figure 6A). The MN+NPK treatment under the Bending treatment shows the greater soil organic C (7.51%) and has significantly different ($p<0.05$) with the NPK and NF treatment (6.93% and 6.52%) (Figure 6B). There

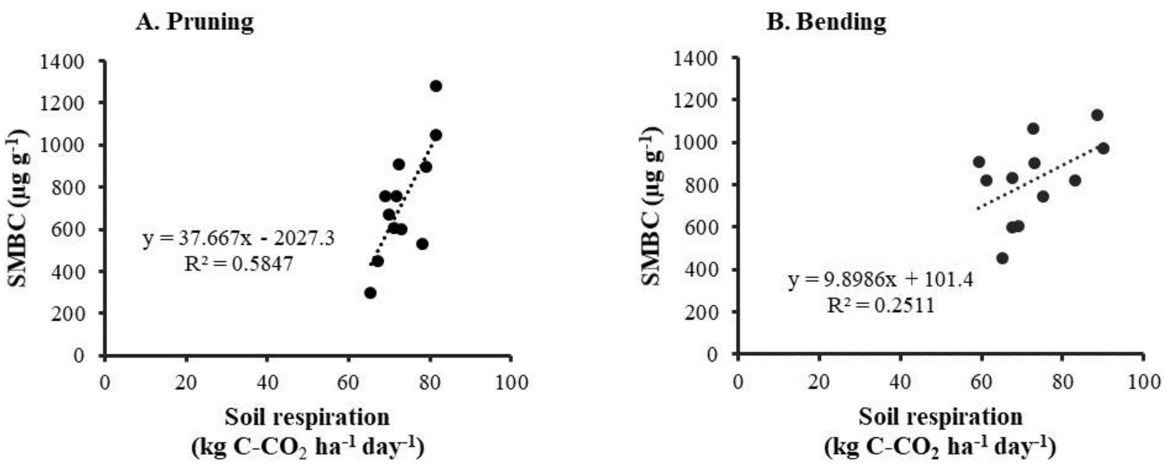

Figure 5. The correlation between soil microbial biomass and soil respiration responses to pruning: (A) Pruning; and (B) Bending; and fertilization practices on coffee plants

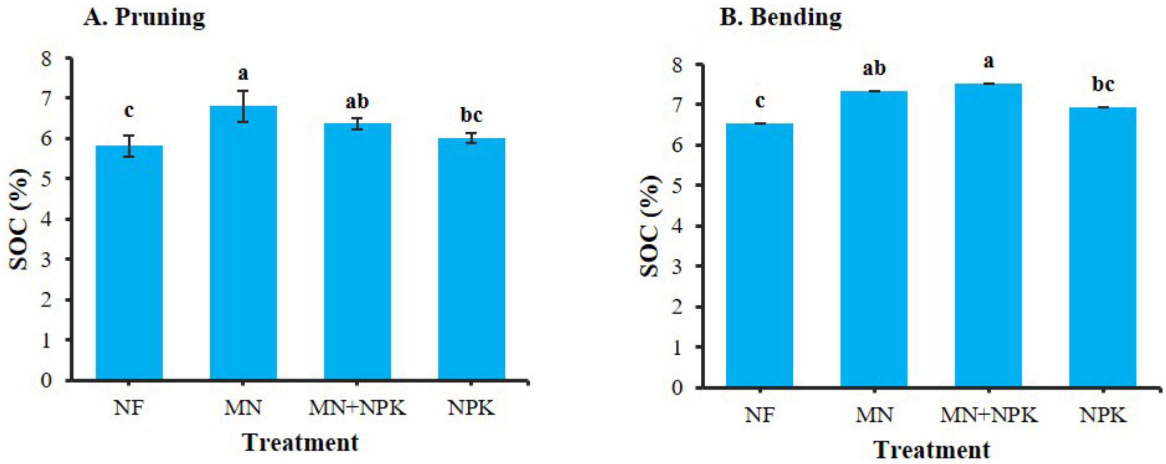

Figure 6. Soil organic C (SOC) under different types of pruning (A) Pruning, (B) Bending and four fertilization treatment. NF: no fertilization; MN: Chicken manure; MN+NPK: Chicken manure and NPK-inorganic; NPK: NPK-inorganic. Means (± SD) denoted by different lowercase indicate significant differences according to LSD test at p <0.05

is no significantly different among MN and MN-NPK treatments both under Pruning and Bending treatments.

The result of the Pearson's analysis shows that the soil organic C has a strong and positive correlation with SMBC (Figure 7) and soil respiration (Figure 8) under the two types of pruning. The relationship between soil organic C and SMBC shows under Pruning treatment with the value of r = 0.81** ($p<0.01$), the same result shows under the Bending treatment with the value of r = 0.61* ($p<0.05$), so the regression can be determined with the equation of $y = 449.4x – 2073.3$ and the $R^2 = 0.55$ under Pruning treatment, while the equation of $y = 283.68x – 1184.5$ with the $R^2=0.43$ under Bending treatment. The relationship between soil organic C and soil respiration shows under Pruning treatment with r = 0.74** ($p<0.01$), while under Bending treatment with r = 0.66* ($p<0.05$). Therefore, it results in a regression with the question of $y = 9.8675x + 11.643$ with the $R^2 = 0.65$ under Pruning treatment, while the equation of $y = 13.173x – 20.407$ with the $R^2 = 0.36$ is determined the regression under Bending treatment.

Soil pH

The result of the variance analysis shows that the soil pH under the Pruning treatment has no significant difference ($p>0.05$) (Figure 9A), while the one under the Bending treatment has significant differences ($p>0.05$) (Figure 9B). The highest soil pH levels were found in the MN treatment, and the lowest was found in NPK treatment, under both Pruning and Bending. The soil pH levels under the Pruning and Bending in the MN

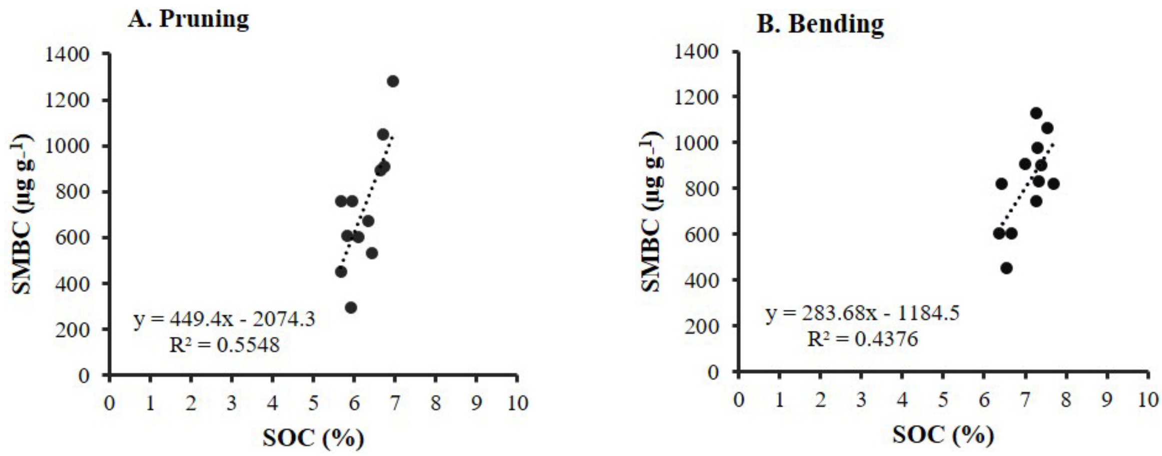

Figure 7. The correlation between soil microbial biomass and soil organic C responses to pruning: (A) Pruning; and (B) Bending; and fertilization practices on coffee plants

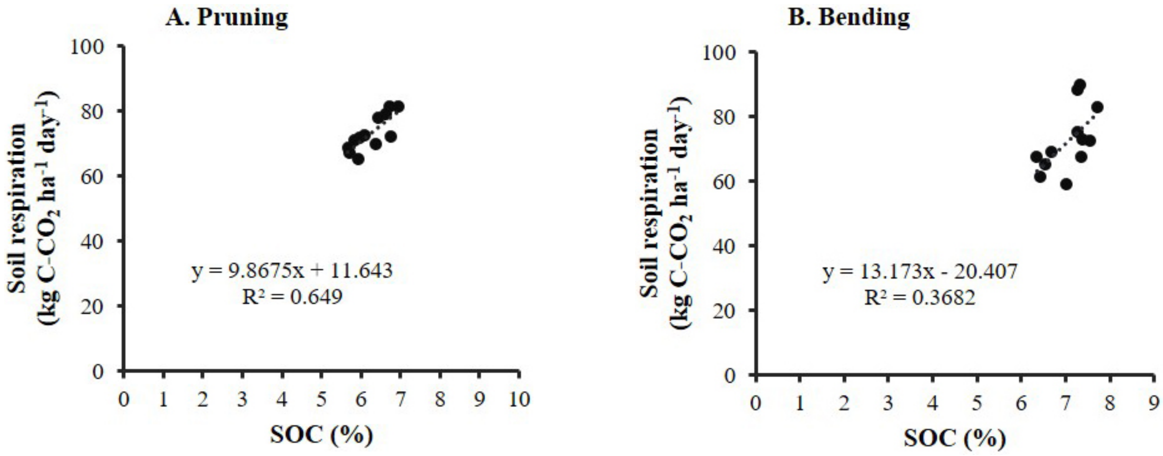

Figure 8. The correlation between soil respiration and soil organic C responses to pruning: (A) Pruning; and (B) Bending; and fertilization practices on coffee plants

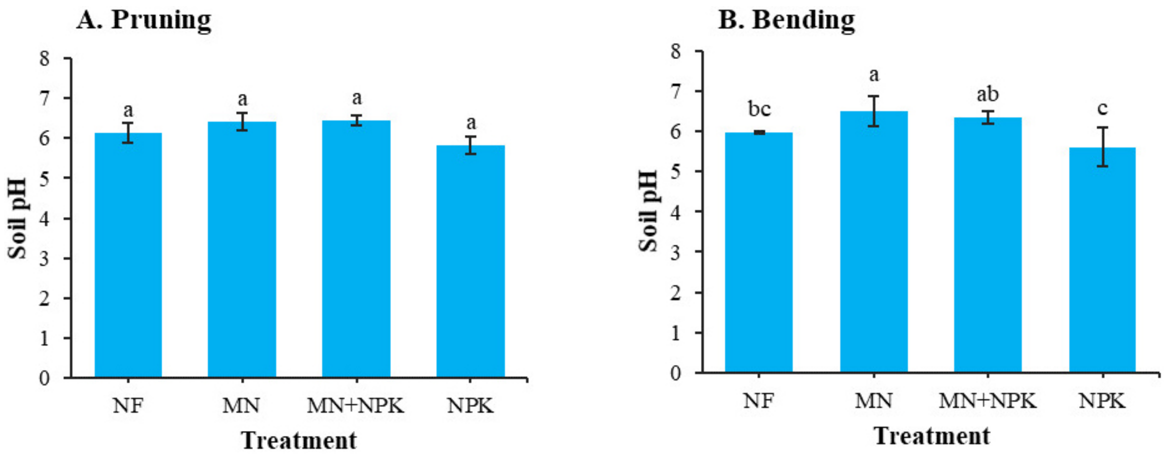

Figure 9. Soil pH under different types of pruning (A) Pruning, (B) Bending and four fertilization treatment. NF: no fertilization; MN: Chicken manure; MN+NPK: Chicken manure and NPK-inorganic; NPK: NPK-inorganic. Means (± SD) denoted by different lowercase indicate significant differences according to LSD test at p <0.05

treatment are 6.41 and 6.50 consecutively, while those in the NPK treatment are 5.82 and 5.61. The soil pH levels in all treatments are higher than the condition before the fertilizer application.

Metabolic quotient (qCO_2)

The results of the variance analysis show that the metabolic quotient (qCO_2) has no significant differences ($p>0.05$) under the Pruning treatment, but it has significant differences ($p<0.05$) under the Bending treatment. The highest qCO_2 values under the Pruning and Bending treatments were obtained in the NF treatment, i.e., 0.16 and 0.12, while the lowest qCO_2 value under the Pruning treatment was found in the MN treatment (0.07), and the same value under the bending treatment was found in the NPK treatment, i.e., 0.07 (Figure 10A and 10B).

The metabolic quotient (qCO_2) has a very strong and negative correlation ($p<0.01$) with SMBC under both types of pruning. The Pruning treatment has a negative correlation with the value of r = 0.89** ($p<0.01$), and the regression was determined by the equation of $y = -0.0001x + 0.2167$ and the coefficient of determination, i.e., $R^2= 0.79$ (Figure 11A). Similar to the Pruning treatment, the Bending treatment also produces a negative correlation with the value of r = 0.85** ($p<0.01$), and the regression equation was determined by $y = -1E^{-4}x + 0.1738$ and the R^2 of 0.72 (Figure 11B).

DISCUSSION

Changes in MBC reflect the processes of microbial growth, death, and the decomposition of organic matters (Zhang et al., 2014).

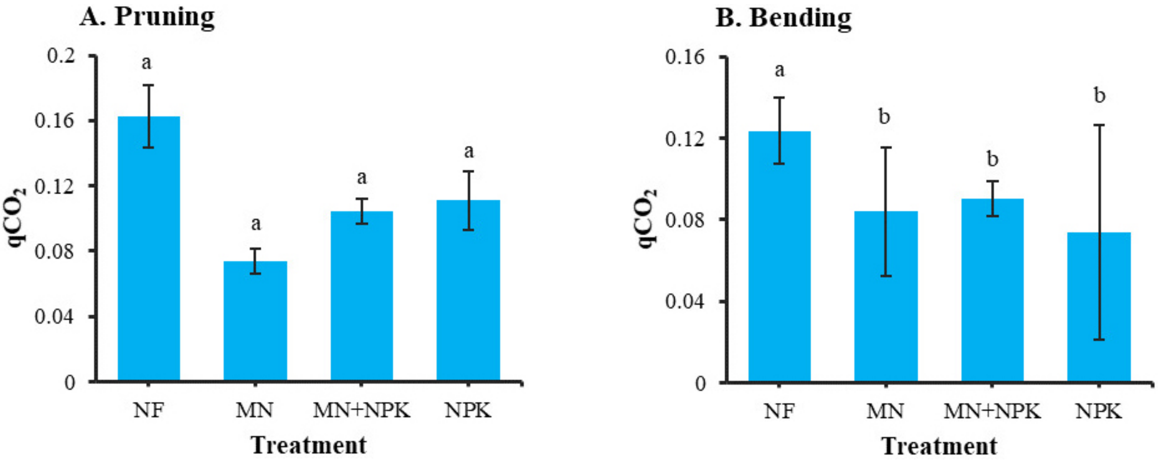

Figure 10. Metabolic quotient (qCO_2) under different types of pruning (A) Pruning, (B) Bending and four fertilization treatment. NF: no fertilization; MN: Chicken manure; MN+NPK: Chicken manure and NPK-inorganic; NPK: NPK-inorganic. Means (± SD) denoted by different lowercase indicate significant differences according to LSD test at p <0.05

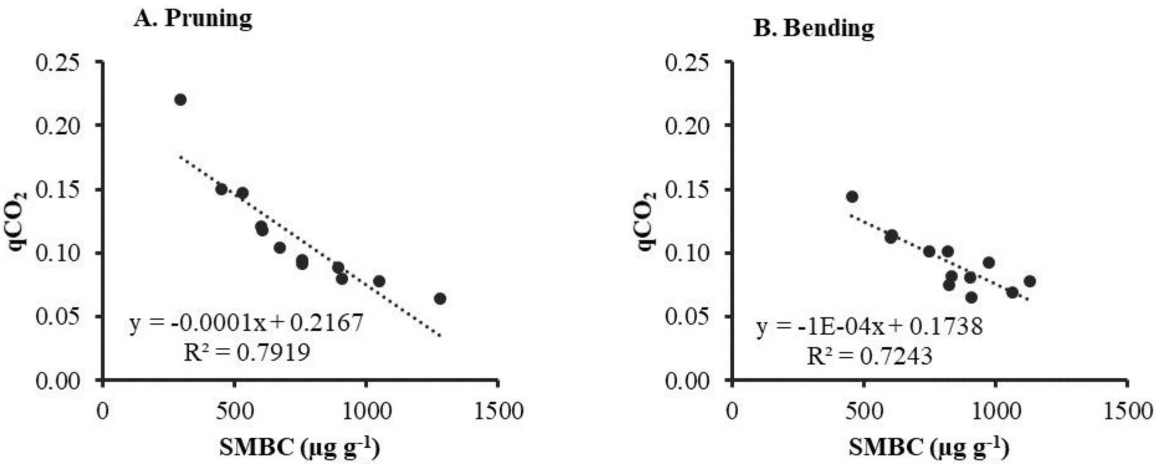

Figure 11. The correlation between metabolic quotient (qCO_2) and soil microbial biomass responses to pruning: (A) Pruning; and (B) Bending; and fertilization practices on coffee plants

The measurement of MBC is used to evaluate soil fertility, as its function of labile nutrient absorber or nutrient source for microbes (Li et al., 2018). This research finds that SMBC increases more highly with the application of chicken manure compared to the NF and NPK treatment, suggesting that chicken manure accelerates microbial growth (Figure 3). Several studies have found that the application of chicken manure or its combination with NPK fertilizer increases responses to SMBC (Abdalla et al., 2022) and that such application has a more significant result than the control or NPK-inorganic alone (Chen et al., 2022). Although the combination of chicken manure and inorganic fertilizer has lower responses than the application of chicken manure alone (Liu et al., 2020). The importance of organic matter in the growth and development of SMBC has been recognized. Microbial biomass has been identified to be related to the addition of organic sources which contributes to changes in soil's C availability (Luan et al., 2021). The high organic resources input enhances microbe's habitat by increasing nutrient availability and creates a suitable condition to promote microbial growth leading to higher SMBC (Yao et al., 2020; Luan et al., 2021). Thus, the increase of organic materials also increases SMBC in the soil (Singh et al., 2022). Labile C-sources is one of the factors that influence microbial activity in the soil. The labile C-sources is described as the active fraction of C-organic soil which can be decomposed easily by microorganisms (Qi et al., 2016). Soils with high C content will be more easily mineralized and fixed within the microbial biomass (Richter et al., 2018).

Soil respiration measurement is the most traditional and popular technique to estimate soil microbial activities (Khosa et al., 2020). The results of this research show that soil respiration resulting from chicken manure application is higher than that which uses no fertilization (Figure 4). The higher soil respiration after the application of chicken manure compared to the NF treatment could be due to the difference fertilization input, which may lead to an increased C input to the soil. This confirms the finding of Chen et al. (2018), that the application of organic fertilizer increases C source for microbial activity and SOC content, which thereby increases higher soil respiration as compared to the application of inorganic fertilizer or no fertilizer at all. Huang et al. (2021) also reported that application of organic fertilizer (composted rapeseed cake) alone or in combination with NPK fertilizer results in higher soil respiration than the application of NPK fertilizer alone. The greater impact of chicken manure can directly be linked to the additional amount of C and N contained in chicken manure as nutrient sources for microbial activities and soil respiration (Abdalla et al., 2022; He et al., (2022). Soil nutrient availability influences soil respiration by affecting plant growth and soil microbial activities (Ma et al., 2022). Fu et al., (2020) showed a strong correlation between soil respiration and SOC by accelerating C consumption because of higher microbial number in soil with organic matter input. Soil microorganisms decompose and recycle the organic material by releasing C in the form of CO_2 as sources of soil respiration (Bae et al., 2013; Spohn and Chodak, 2015).

The results of the data analysis show that soil respiration has a strong and positive correlation with SMBC (r=0,76**, $p<0.01$) in Pruning and (r=0.50*, $p<0.05$) in Bending (Figure 5), confirming the results of Singh et al. (2022). It is indicated that SMBC is an important factor for soil respiration (Yao et al., 2020). Soil respiration is associated with SMBC, where SMBC represents the supply of carbon in the soil, which is required for microbial community and diversity (Wei et al., 2020; Chandra et al., 2022). Bastida et al. (2021) confirmed that the diversity of soil microorganism (i.e., bacteria and fungi) was significantly correlated with soil microbial biomass and soil respiration. Soil that maintains high levels of microbial biomass can be associated with its higher respiration rates. Higher levels of soil microbial biomass can enhance organic matter decomposition rates through greater acceleration of soil respiration (Mgelwa et al., 2019). Thus, the application of chicken manure can create a suitable environment for the growth of microorganisms as one of the largest sources for higher microbial diversity and microbial communities (Lian et al., 2022). Soil microbial activities are related to some physicochemical properties such as organic material availability (OM), soil moisture, water holding capacity (WHC), N concentration, and soil pH (Velmourougane, 2017; Richter et al., 2018). Soil temperature also contributes in making stable environments for soil microbial growth (Ren et al., 2019).

The result of this research shows that the soil organic C has a higher value with the application of chicken manure, alone or its combination with NPK fertilizer, compared to the NF treatment. The study from Olaya et al. (2019) also shows the same results. The addition of organic matter can increase the soil organic C. It is because the organic C in the soil is a food source for the soil microorganisms (Prayogo et al., 2021). Thus, the application of chicken manure can create a suitable environment for the growth of microorganisms as one of the largest sources for higher microbial diversity and microbial communities (Lian et al. 2022). Ren et al. (2019) also reported that the application of manure can lead to maintain the soil moisture and relieve the changes in the soil, so that can provide a suitable environment to the growth of soil microorganisms. The soil organic C shows a strong and positive correlation with SMBC and soil respiration. It is indicated that an increase of SOC and organic matter input will follow an increase in SMBC (Prayogo et al., 2021). The addition of organic matter strongly influences the richness of soil microorganisms and lead the increasing of soil respiration (Liu et al., 2018).

Soil pH has been known as one of the indicators of soil fertility that influence the biogeochemical processes of the soil. Soil pH is described as the "master soil variable" that has a big impact on soil's physical, biological, and chemical properties (Neina, 2019). The results of this study indicate that soil pH had increased in all treatments after pruning and fertilization practices and is classified as slightly acidic. The

NPK treatment produced a lower soil pH than the chicken manure treatment. The low pH level is presumably due to the accumulation of litterfalls in the soil surface from the standing biomass (Prayogo et al., 2020). The role of organic fertilizer in influencing soil pH has been explained by Wei et al. (2017). The application of manure can increase soil pH in acidic soils and decrease soil pH in alkaline soils to a level close to neutral (pH 7). In this study, chicken manure has an alkaline effect on the soils. This is strengthened by soil pH, which has increased compared to the condition before the application of fertilizer or the soil pH after the application of NPK fertilizer. In line with previous research by Lin et al. (2019), the pH level of soil treated with organic fertilizer is significantly higher than the pH of soil treated with inorganic fertilizer in tea plantation. Soil pH has a positive correlation with soil respiration (r=021) in Pruning treatment, and (r=0.69) in Bending treatment, but it has a weak correlation with SMBC (r=0.09) in Pruning treatment, and (r=0.45) in Bending treatment. It shows that small changes in soil pH level (either an increase or a decrease) greatly affect the soil's biological activity (Yusuf et al., 2020).

Metabolic quotient (qCO_2) is represented by the CO_2 release per unit of biomass and can be used as a sensitive environmental stress indicator for microbial activities (Abdalla et al., 2022). The qCO_2 observed in this study does not show any significant difference in terms of interactions among treatments. The NF treatment was recorded to have the highest qCO_2 values of all treatments. Higher qCO_2 values represent energy inefficiency in soil microbial biomass (Wardle and Ghani, 2018). Hence, this indicates that treatments with a lower metabolic quotient (qCO_2) have a less disturbance and are more favorable to soil microbes. The qCO_2 has a strong relationship with C concentration in the soil and litters (Spohn and Chodak, 2015). Land use also affects qCO_2 to show the characterization of soil organic matter (Stevenson et al., 2016). Moreover, factors such as organic material quality or soil physical structure also influence the qCO_2 (Spohn and Chodak, 2015). In agroforestry systems, litterfalls are frequently ideal substrates for microbial activities (Surki et al., 2021). The soil microbes regulate C and N cycles in the soil, stimulated by accumulation of the litterfalls and organic materials (Li et al., 2020; Ma et al., 2022).

CONCLUSIONS

The application of chicken manure on coffee plant pruned with different techniques can enhance soil respiration, SMBC, and soil pH level. The management of pruning and the application of organic fertilizer promote coffee plant growth by enhancing soil's ability to hold more water and nutrient availability, as well as increasing soil microbe's growth and activity. The addition of organic fertilizer can increase soil's microbial activities, e.g., SMBC. Moreover, soil nutrient availability influences soil respiration by affecting plant growth indirectly and by affecting soil microbial activities related to the important role of enhancing fertility and productivity, as well as in nutrient cycling. The challenges in managing organic fertilizer input effect on soil microbial activities are related with soil properties, type of organic fertilizer, recommended doses, and fertilizer application period and method.

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REFERENCES

1. Abbasi Surki, A., Nazari, M., Fallah, S., and Iranipour, R. 2021. Improvement of the soil properties, nutrients, and carbon stocks in different cereal–legume agroforestry systems. International Journal of Environmental Science and Technology, 18, 123–130. https://doi.org/10.1007/s13762-020-02823-9.
2. Abdalla, K., Sun, Y., Zarebanadkouki, M., Gaiser, T., Seidel S., and Pausch J. 2022. Long-term continuous farmyard manure application increases soil carbon when combined with mineral fertilizers due to lower priming effects. Geoderma, 116216. https://doi.org/10.1016/j.geoderma.2022.116216.
3. Ayala-Montejo, D., Valdés-Velarde, E., Benedicto-Valdés, G.S., Escamilla-Prado, E., Sánchez-Hernández, R, Gallardo, J.F., and Martínez-Zurimendi, P. 2022. Soil biological activity, carbon and nitrogen dynamics in modified coffee agroforestry systems in Mexico. Agronomy, 12(8), 1–14. https://doi.org/10.3390/agronomy12081794.
4. Badan Meteorologi, Klimatologi, dan Geofisika. Kab. Malang, Indonesia. 2021. www.bmkg.go.id. (in Indonesian).

5. Bae, K., Lee, D.K., Fahey, T.J., Woo, S.Y., Quaye, A.K., and Lee, Y.K.. 2013. Seasonal variation of soil respiration rates in a secondary forest and agroforestry systems. Agroforestry Systems, 87(1), 131–139. https://doi.org/10.1007/s10457-012-9530-8.
6. Bastida, F., Eldridge, D.J., García, C., Kenny, Png.G., Bardgett, R.D., and Delgado-Baquerizo M. 2021. Soil microbial diversity–biomass relationships are driven by soil carbon content across global biomes. ISME Journal, 15(7), 2081–2091. https://doi.org/10.1038/s41396-021-00906-0.
7. Chandra, P., Gill, S.C., Prajapat, K., Barman, A., Chhokar, R.S., Tripathi, S.C., Singh, G., Kumar, R., Rai, A.K., Khobra, R., Jasrotia, P., and Singh, G.P. 2022. Response of wheat cultivars to organic and inorganic nutrition: Effect on the yield and soil biological properties. Sustainability, 14(15). https://doi.org/10.3390/su14159578.
8. Charbonnier, F., Roupsard, O., le Maire, G., Guillemot, J., Casanoves, F., Lacointe, A., Vaast, P., Allinne, C., Audebert L, Cambou A, Clément-Vidal A, Defrenet E, Duursma, R.A., Jarri, L., Jourdan, C., Khac, E., Leandro, P., Medlyn, B.E., Saint-André, L., … and Dreyer, E.. 2017. Increased light-use efficiency sustains net primary productivity of shaded coffee plants in agroforestry system. Plant Cell and Environment, 40(8), 1592–1608. https://doi.org/10.1111/pce.12964.
9. Chen, G., Yuan, J., Chen, H., Zhao, X., Wang, S., Zhu, Y., and Wang, Y. 2022. Animal manures promoted soil phosphorus transformation via affecting soil microbial community in paddy soil. Science of the Total Environment, 831. https://doi.org/10.1016/j.scitotenv.2022.154917.
10. Ditjenbun. 2021. Statistical of national leading estate crops commodity 2019-2021. Directorat General of Estate Crops. Ministry of Agriculture, Indonesia. (in Indonesian).
11. Fahad, S., Chavan, S.B., Chichaghare, A.R., Uthappa, A.R., Kumar, M., Kakade, V., Pradhan, A., Jinger, D., Rawale, G., Yadav, D.K., Kumar, V., Farooq, T.H., Ali, B., Sawant, A.V., Saud, S., Chen, S., and Poczai, P. 2022. Agroforestry systems for soil health improvement and maintenance. Sustainability, 14(22). https://doi.org/10.3390/su142214877.
12. Froment, A. 1972. Soil respiration in a mixed oak forest. Oikos, 23(2), 273-277. https://doi.org/10.2307/3543417.
13. Fu, X., Id, J.W., Xie, M., Zhao, F., and Id, R.D. 2020. Increasing temperature can modify the effect of straw mulching on soil C fractions, soil respiration, and microbial community composition. PLoS ONE, 15(8). https://doi.org/10.1371/journal.pone.0237245.
14. Giuditta, E., Marzaioli, R., Esposito, A., Ascoli, D., Stinca, A., Mazzoleni, S., and Rutigliano, F.A. 2019. Soil microbial diversity, biomass, and activity in two pine plantations of southern Italy treated with prescribed burning. Forests, 11(1). https://doi.org/10.3390/f11010019.
15. Gokavi, N., Mote, K., Jayakumar, M., Raghuramulu, Y., and Surendran, U. 2021. The effect of modified pruning and planting systems on growth, yield, labour use efficiency and economics of Arabica coffee. Scientia Horticulturae, 276. https://doi.org/10.1016/j.scienta.2020.109764.
16. Guillaume, T., Maranguit, D., Murtilaksono, K., and Kuzyakov, Y. 2016. Sensitivity and resistance of soil fertility indicators to land-use changes: New concept and examples from conversion of Indonesian rainforest to plantations. Ecological Indicators, 67, 49–57. https://doi.org/10.1016/j.ecolind.2016.02.039.
17. He, W., Ye, W., Sun, M., Li, Y., Chen, M., Wei, M., Hu, G., Yang, Q., Pan, H., Lou, Y., Wang, H., and Zhuge, Y. 2022. Soil phosphorus availability and stoichiometry determine microbial activity and functional diversity of fluvo-aquic soils under long-term fertilization regimes. *Journal of Soils and Sediments*, *22*(4), 1214–1227. https://doi.org/10.1007/s11368-021-03120-9.
18. Huang, K., Li, Y., Hu, J., Tang, C., Zhang, S., Fu, S., Jiang, P., Ge, T., Luo, Y., Song, X., Li, Y., and Cai, Y. 2021. Rates of soil respiration components in response to inorganic and organic fertilizers in an intensively-managed Moso bamboo forest. Geoderma, 403. https://doi.org/10.1016/j.geoderma.2021.115212.
19. Kabiri, V., Raiesi, F., and Ghazavi, M.A. 2016. Tillage effects on soil microbial biomass, SOM mineralization and enzyme activity in a semi-arid Calcixerepts. Agriculture, Ecosystems and Environment, 232, 73–84. https://doi.org/10.1016/j.agee.2016.07.022.
20. Karim, A., Hifnalisa, H, and Manfarizah, M. 2021. Analysis of arabica coffee productivity due to shading, pruning, and coffee pulp-husk organic fertilizers treatments. Coffee Science, 16. https://doi.org/10.25186/.v16i.1903.
21. Khosa, S.A., Khan, K.S., Akmal, M., and Qureshi, K.M. 2020. Effect of combined application of organic and inorganic phosphatic fertilizers on dynamic of microbial biomass in semi-arid soil. Soil Science Annual, 71(1), 47–54. https://doi.org/10.37501/soilsa/121491.
22. Kurniawan, S., Hariyanto, P., and Ishaq, R.M. 2021. Soil management practices in coffee-based agroforestry systems within Universitas Brawijaya Forest impact on maintaining soil carbon stock. IOP Conference Series: Earth and Environmental Science, 824. https://doi.org/10.1088/1755-1315/824/1/012010.
23. Kurniawan, S., Utami, S.R., Mukharomah, M., Navarette, I.A., and Prasetya, B. 2019. Land use

systems, soil texture, control carbon and nitrogen storages in the forest soil of UB Forest, Indonesia. Agrivita, 41(3), 416–427. https://doi.org/10.17503/agrivita.v41i3.2236.

24. Li, X.A., Ge, T.D., Chen, Z., Wang, S.M., Ou, X.K., Wu, Y., Chen, H., and Wu, J. P. 2020. Enhancement of soil carbon and nitrogen stocks by abiotic and microbial pathways in three rubber-based agroforestry systems in Southwest China. Land Degradation and Development, 31(16), 2507–2515. https://doi.org/10.1002/ldr.3625.
25. Li, Y., Chang, S.X., Tian, L., and Zhang, Q. 2018. Conservation agriculture practices increase soil microbial biomass carbon and nitrogen in agricultural soils: A global meta-analysis. Soil Biology and Biochemistry, 121, 50–58. https://doi.org/10.1016/j.soilbio.2018.02.024.
26. Lian, J., Wang, H., Deng, Y., Xu, M., Liu, S., Zhou, B., Jangid, K., and Duan, Y. 2022. Impact of long-term application of manure and inorganic fertilizers on common soil bacteria in different soil types. Agriculture, Ecosystems and Environment, 337. https://doi.org/10.1016/j.agee.2022.108044.
27. Lin, W., Lin, M., Zhou, H., Wu, H., Li, Z., and Lin, W. 2019. The effects of chemical and organic fertilizer usage on rhizosphere soil in tea orchards. PLoS ONE, 14(5), 1–16. https://doi.org/10.1371/journal.pone.0217018.
28. Liu, S., Wang, J., Pu, S., Blagodatskaya, E., Kuzyakov, Y., and Razavi, B.S. 2020. Impact of manure on soil biochemical properties: A global synthesis. Science of the Total Environment, 745. https://doi.org/10.1016/j.scitotenv.2020.141003.
29. Liu, Y.R., Delgado-Baquerizo, M., Wang, J.T., Hu, H.W., Yang, Z., and He, J.Z. 2018. New insights into the role of microbial community composition in driving soil respiration rates. Soil Biology and Biochemistry, 118, 35–41. https://doi.org/10.1016/j.soilbio.2017.12.003.
30. Luan, H., Yuan, S., Gao, W., Tang, J., Li, R., Zhang, H., and Huang, S. 2021. Aggregate-related changes in living microbial biomass and microbial necromass associated with different fertilization patterns of greenhouse vegetable soils. European Journal of Soil Biology, 103. https://doi.org/10.1016/j.ejsobi.2021.103291.
31. Ma, S., Yu, Q., Chen, G., Su, H., Tang, W., Sun, Y., Zhou, Z., Jiang, L., Zhu, J., Chen, L., Zhu, B., and Fang, J. 2022. Aboveground net primary productivity mediates the responses of soil respiration to nutrient additions in two tropical montane rainforests. Agricultural and Forest Meteorology, 327. https://doi.org/10.1016/j.agrformet.2022.109200.
32. Mgelwa, A.S., Hu, Y.L., Xu, W.B., Ge, Z.Q., and Yu, T.W. 2019. Soil carbon and nitrogen availability are key determinants of soil microbial biomass and respiration in forests along urbanized rivers of southern China. Urban Forestry and Urban Greening, 43. https://doi.org/10.1016/j.ufug.2019.05.013.
33. Neina, D. 2019. The role of soil pH in plant nutrition and soil remediation. Applied and Environmental Soil Science, (3). https://doi.org/10.1155/2019/5794869.
34. Olaya, J.F.C., Ordoñez, M.C., and Salcedo, J.R. 2019. Impact of nutritional management on available mineral nitrogen and soil quality properties in coffee agroecosystems. Agriculture (Switzerland), 9(12). https://doi.org/10.3390/agriculture9120260.
35. Prayogo, C., Kusumawati, I.A., Qurana, Z., Kurniawan, S., and Arfarita, N. 2021. Does different management and organic inputs in agroforesty system impact the changes on soil respiration and microbial biomass carbon? *I*OP Conference Series: Earth and Environmental Science, 743(1). https://doi.org/10.1088/1755-1315/743/1/012005.
36. Prayogo, C., Prastyaji, D., Prasetya, B., and Arfarita, N. 2021. Structure and composition of major arbuscular mycorrhiza (MA) under different farmer management of coffee and pine agroforestry system. Agrivita, 43(1), 146–163. https://doi.org/10.17503/agrivita.v1i1.2639.
37. Qi, R., Li, J., Lin, Z., Li, Z., Li, Y., Yang, X., Zhang, J., and Zhao, B. 2016. Temperature effects on soil organic carbon, soil labile organic carbon fractions, and soil enzyme activities under long-term fertilization regimes. Applied Soil Ecology, 102, 36–45. https://doi.org/10.1016/j.apsoil.2016.02.004.
38. Ren, F., Sun, N., Xu, M., Zhang, X., Wu, L., and Xu, M. 2019. Changes in soil microbial biomass with manure application in cropping systems: A meta-analysis. Soil and Tillage Research, 194. https://doi.org/10.1016/j.still.2019.06.008.
39. Richter, A., Huallacháin, D., Doyle, E., Clipson, N., Van Leeuwen, J.P., Heuvelink, G.B., and Creamer, R.E. 2018. Linking diagnostic features to soil microbial biomass and respiration in agricultural grassland soil: A large-scale study in Ireland. European Journal of Soil Science, 69(3), 414–428. https://doi.org/10.1111/ejss.12551.
40. Singh, N.R., Kumar, D., Handa, A.K., Newaj, R., Prasad, M., Kamini, Kumar, N., Ram, A., Dev, I., Bhatt, B.P., Chaturvedi, O.P., Arunachalam, A., and Singh, L.N. 2022. Land use effect on soil organic carbon stocks, microbial biomass and basal respiration in Bundelkhand Region of Central India. Agricultural Research, 11(3), 454–464. https://doi.org/10.1007/s40003-021-00584-6.
41. Spohn, M., and Chodak, M. 2015. Microbial respiration per unit biomass increases with carbon-to-nutrient ratios in forest soils. Soil Biology and Biochemistry, 81, 128–133. https://doi.org/10.1016/j.soilbio.2014.11.008.
42. Stevenson, B.A., Sarmah, A.K., Smernik, R.,

Hunter, D.W.F., and Fraser, S. 2016. Soil carbon characterization and nutrient ratios across land uses on two contrasting soils: Their relationships to microbial biomass and function. Soil Biology and Biochemistry, 97, 50–62. https://doi.org/10.1016/j.soilbio.2016.02.009.

43. Sujatmiko, T., and Ihsaniyati, H. 2018. Implication of climate change on coffee farmers' welfare in Indonesia. IOP Conference Series: Earth and Environmental Science, 200. https://doi.org/10.1088/1755-1315/200/1/012054.
44. Suprayogo, D., Azmi, E.N., Ariesta, D.A., Sutejo, Y.A., Hakim, A.L., Prayogo, C., and McNamara, N.P. 2020. Tree and plant interactions in the agroforestry system: Does the management of coffee intensification disrupt the soil hydrological system and pine growth?. IOP Conference Series: Earth and Environmental Science, 449. https://doi.org/10.1088/1755-1315/449/1/012045.
45. Teixeira, H.M., Bianchi, F.J.J.A., Cardoso, I.M., Tittonell, P., and Peña-Claros, M. 2021. Impact of agroecological management on plant diversity and soil-based ecosystem services in pasture and coffee systems in the Atlantic forest of Brazil. Agriculture, Ecosystems and Environment, 305. https://doi.org/10.1016/j.agee.2020.107171.
46. Tridawati, A., Wikantika, K., Susantoro, T.M., Harto, A.B., Darmawan, S., Yayusman, L.F., and Ghazali, M.F. 2020. Mapping the distribution of coffee plantations from multi-resolution, multi-temporal, and multi-sensor data using a random forest algorithm. Remote Sensing, 12(23), 1–23. https://doi.org/10.3390/rs12233933.
47. Valdés, S.G.B., Montejo, D.A., Lancho, J.F.G, and Velarde, E.V. 2021. Soil respiration and distribution of aggregates in modified agroforestry systems of coffee and avocados in huatusco, Veracruz, Mexico. Soil and Environment, 40(1), 17–26. https://doi.org/10.25252/SE/2021/162291.
48. Vance, E.D., Brookes P.C., and Jenkinson, D.S. 1987. An extraction method for measuring soil microbial biomass C. Soil Biol Biochem, 19(6), 703–707. https://doi.org/10.1016/0038-0717(87)90052-6.
49. Velmourougane, K. 2017. Shade trees improve soil biological and microbial diversity in coffee based system in Western Ghats of India. Proceedings of the National Academy of Sciences India Section B - Biological Sciences, 87(2), 489–497. https://doi.org/10.1007/s40011-015-0598-6.
50. Wardle, D.A., and Ghani, A. 2018. A tale of two theories, a chronosequence and a bioindicator of soil quality. Soil Biology and Biochemistry, 121, A3–A7. https://doi.org/10.1016/j.soilbio.2018.01.005.
51. Wei, M., Hu, G., Wang, H., Bai, E., Lou, Y., Zhang, A., and Zhuge, Y. 2017. 35 years of manure and chemical fertilizer application alters soil microbial community composition in a Fluvo-aquic soil in Northern China. European Journal of Soil Biology, 82, 27–34. https://doi.org/10.1016/j.ejsobi.2017.08.002.
52. Widyati, E., Irianto, R.S.B., and Susilo, A. 2022. Rhizosphere upheaval after tree cutting: Soil sugar flux and microbial behavior. Communicative and Integrative Biology, 15(1), 105–114. https://doi.org/10.1080/19420889.2022.2068110.
53. Xu, W., Liu, W., Tang, S., Yang, Q., Meng, L., Wu, Y., Wang, J., Wu, L., Wu, M., Xue, X., Wang, W., and Luo, W. 2023. Long-term partial substitution of chemical nitrogen fertilizer with organic fertilizers increased SOC stability by mediating soil C mineralization and enzyme activities in a rubber plantation of Hainan Island, China. Applied Soil Ecology, 182. https://doi.org/10.1016/j.apsoil.2022.104691
54. Yao, X., Zeng, W., Zeng, H., and Wang, W. 2020. Soil microbial attributes along a chronosequence of Scots pine (Pinus sylvestris var. mongolica) plantations in northern China. Pedosphere. 30(4), 433–442. https://doi.org/10.1016/S1002-0160(17)60329-1.
55. Yusuf, M., Fernandes, A.A.R., Kurniawan, S., and Arisoesilaningsih, E. 2020. Initial soil properties of the restored degraded area under different vegetation cover in UB Forest, East Java, Indonesia. Journal of Physics: Conference Series, 1563. https://doi.org/10.1088/1742-6596/1563/1/012006.
56. Zhang, Q.Z., Dijkstra, F.A., Liu, X.R., Wang, Y.D., Huang, J., and Lu, N. 2014. Effects of biochar on soil microbial biomass after four years of consecutive application in the north China Plain. PLoS ONE, 9(7). https://doi.org/10.1371/journal.pone.0102062.