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THE EFFECT OF COFFEE CANOPY PRUNING AND FERTILIZATION ON COFFEE GROWTH AND SOIL PHYSICAL PROPERTIES

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Abstract. *Arabica coffee is primarily cultivated in agroforestry systems in Indonesia, but limited local knowledge and technology adoption hinder its productivity due to insufficient practices in coffee pruning management. This study aims to analyze variations in coffee canopy pruning (Pruning+Bending) management and the impact on plant growth and soil physical characteristics.. The experiment employed a split-plot experimental design and utilized the Fisher test (5%) to assess the treatment effects. The primary plot focused on coffee canopy pruning using two management options: (1) Pruning (PR) and (2) Bending (BN). The subplots included various types and doses of fertilizer treatments: (1) Control (F0), (2) Chicken manure (F1), (3) Chicken manure+NPK fertilizer (F2), and (4) NPK fertilizer (F3). Each experimental plot covered an area of 20x20 m and contained 50 coffee plants. Bending techniques represent alternative pruning methods, and, in general, they have a significant impact on improving several coffee parameters compared to total pruning. Regarding the soil's physical properties, the bending technique exhibited a higher infiltration rate than pruning. The management approach of Bending+Chicken manure: NPK fertilizer (BNF2) enhanced various coffee parameters, resulting in an increased stem diameter of 4.79 cm, new shoot length of 471.20 cm, and chlorophyll content of 6.83 mg/g. Furthermore, this treatment increased soil organic carbon content by 7.51% and reduced bulk density to 0.58 g/cm. In conclusion, the bending technique wasproven to be more advantageous than pruning, especially when combined with chicken manure and NPK fertilizer for enhancing coffee management among farmers.*
Keywords: *land management; agroforestry; pruning; soil physical properties*

1. Introduction

Indonesia is one of the most important coffee suppliers in the world after Brazil, Vietnam, and Colombia (Waktola & Fekadu, 2021). Although most coffee production in Indonesia comes from smallholder plantations, many challenges currently hamper its growth and production. Coffee plants require a sunlight intensity of 40–50% (Sianturi & Wachjar, 2016). Deviations from the required light intensity at various stages of coffee plant growth and development can affect the growth, development, yield, and taste of coffee (Alemu, 2015). The main problem in coffee agroforestry systems is competition for light and nutrients. Sianturi & Wachjar (2016) showed above-ground competition for light or below-ground competition for water and nutrients. Shade plants that are too dense will affect the incoming irradiation (Amponsah *et al.,* 2013).

Several activities are often made by farmers to increase coffee productivity, one of which is pruning. Pruning branches in coffee is done so that the plant stays low to facilitate the maintenance

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of new branches and harvesting, as well as optimizing sunlight that enters the lowest crown for photosynthesis, increasing the fruit yield of coffee plants (Aerts *et al.,* 2011). The pruning technique is easy to do but has the disadvantage that it can cause low productivity at the beginning of growth due to the loss of leaves that play a role in photosynthesis (Suchocka *et al.,* 2021). The results showed that using pruning techniques involving the removal of entire branches resulted in coffee plants that did not produce any fruit or produced very limited fruit for two years (Rowe *et al.,* 2022).

The method of tucking coffee branches is a local innovation because it was started by several forest farmers who used local knowledge and available resources to overcome the challenge of decreasing coffee productivity owing to the shade of pine trees (Cahyono *et al.,* 2020). The results of a study showed that variations in pruning and fertilization practices within coffee agroforestry, especially the bending method, gave higher yields than the pruning treatment on microbial C biomass of 1447.62 μg/g and N and soil respiration of 89.78 C-CO_2.kg/ha/day (Azizah *et al.,* 2023). The pruning process that removes the entire top of the plant will affect the root system and dried and dead roots are a source of soil organic matter and can result in increasing or expanding soil pores to pass water into the soil (Jezeer *et al.,* 2018). In addition to crown pruning, perennial plants such as coffee need the addition of fertilizers to meet nutritional needs during the growth cycle (Khosa *et al.,* 2020). Suprayogo *et al.* (2019) explained that pruning during coffee plant development can reduce available water and nutrient resources within the soil, which can only be remedied through the periodic application of fertilizers. Nutrient sources can come from organic and inorganic fertilizers. The combination of organic and inorganic fertilizers can provide sufficient nutrients and reduce the cost of inorganic fertilizers (Wang *et al.,* 2016).

Agroforestry systems are considered an alternative approach for mitigating the adverse consequences of land conversion by preserving soil quality and fertility (Ishaq *et al.,* 2020). The UB Forest Area is a limited protected forest with minimal intensive agricultural activities within its boundaries (Prayogo *et al.,* 2019). The condition of coffee plants in UB Forest is generally that they are planted under dense stands of pine or mahogany. Coffee plants in the UB Forest that need to be maintained are towering, up to 2-3 meters tall, with small main trunks and many unproductive branches. In this research, the possibilities of enhancing agricultural practices within coffee-pine agroforestry systems were explored, particularly optimizing coffee pruning techniques and incorporating fertilization to enhance both plant growth and soil quality. It was hypothesized that improved farm management within coffee-pine agroforestry would enhance soil fertility, consequently affecting coffee yields. This research specifically investigated the enhancement of plant growth and the improvement of soil physical characteristics, as these factors play a pivotal role in soil fertility management within agroforestry systems.

2. Methods

2.1 Study area

The research was conducted between October 2021 and November 2022 in the Brawijaya University Special Purpose Forest Area (KHDTK-UB), commonly known as the University of Brawijaya Forest (UB Forest). This forest is situated in Sumbersari, Tawangargo, Karangploso, Malang, East Java, Indonesia (Figure 1). Putri *et al.* (2019) confirmed that soils on UB Forest agroforestry land tend to have better chemical properties characterized by pH that tends to be slightly acidic to acidic (5.44), soil organic carbon (soil organic-C) of 5.16%, nitrogen total of 0.73%, P-available at 27.05%, and higher CEC with 43.1 cmol$^+$/kg.

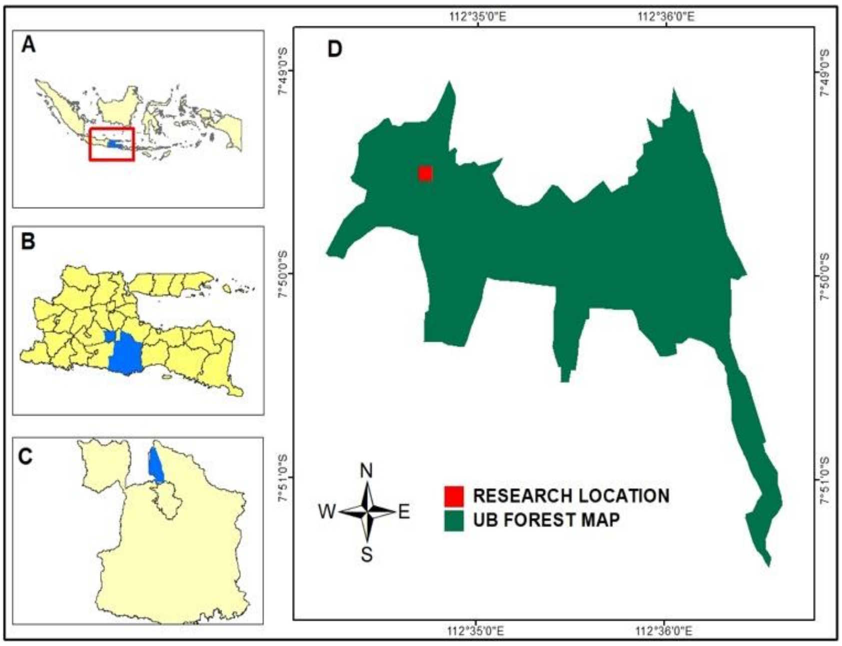

Figure 1. The positions of the Plot Points in the UB forest depict the sampling locations.

2.2 Experimental design

The research was conducted in a coffee-based agroforestry system, where the coffee plants were of the Lini-S variety and aged 10 years (*Coffea arabica* L.), while the shade trees were 41-year-old pine trees (*Pinus merkusii*). This study employed a split-plot design, which was replicated three times. In the primary plot, the focus was on pruning management conducted in June 2020, which impacted the growth and root systems of the coffee plants. Two specific pruning methods were implemented: regular pruning (PR), which involved cutting coffee plants at a height of 125 cm from the soil surface, and bending (BN), which also set the coffee plant height at 125 cm from the soil surface. Bending is one of the local knowledge some farmers use in cultivating coffee plants in UB Forest and pruning activities are kept from the field (Figure 2). Subplots are fertilizer treatments for coffee plants, which were divided into four treatments. Fertilization treatments carried out were (1) Control (without fertilizer) (F0), (2) Chicken manure 10 kg/tree, recommendation (F1), (3) Chicken manure + NPK (5 kg/tree+Compound NPK 90 g/tree; Urea

43.70 g/tree; KCl 26 g/tree) (F2), and (4) Compound NPK 180g/tree; Urea 87.39 g/tree; KCl 52 g/tree (F3). The fertilizer was applied twice per year, specifically six months after the pruning procedure. Fertilizer was applied to a circular groove 75 cm from the main stem with a 2-5 cm depth. One observation plot was divided into two observation plot blocks with different treatments of coffee pruning management. Each observation block had 50 coffee plants, and the sub-block had 10 plants, so there were 40 plants used and a total of 300 coffee plants. Each block was measured 20×20 m, and the spacing between coffee plants was 3×4 m. The data taken in this research includes plant growth, measurement of infiltration rates, and soil sampling to analyze soil physical properties on pine-coffee agroforestry land. Meanwhile for the analysis of plot characteristics, an analysis was conducted by examining the distribution of root density.

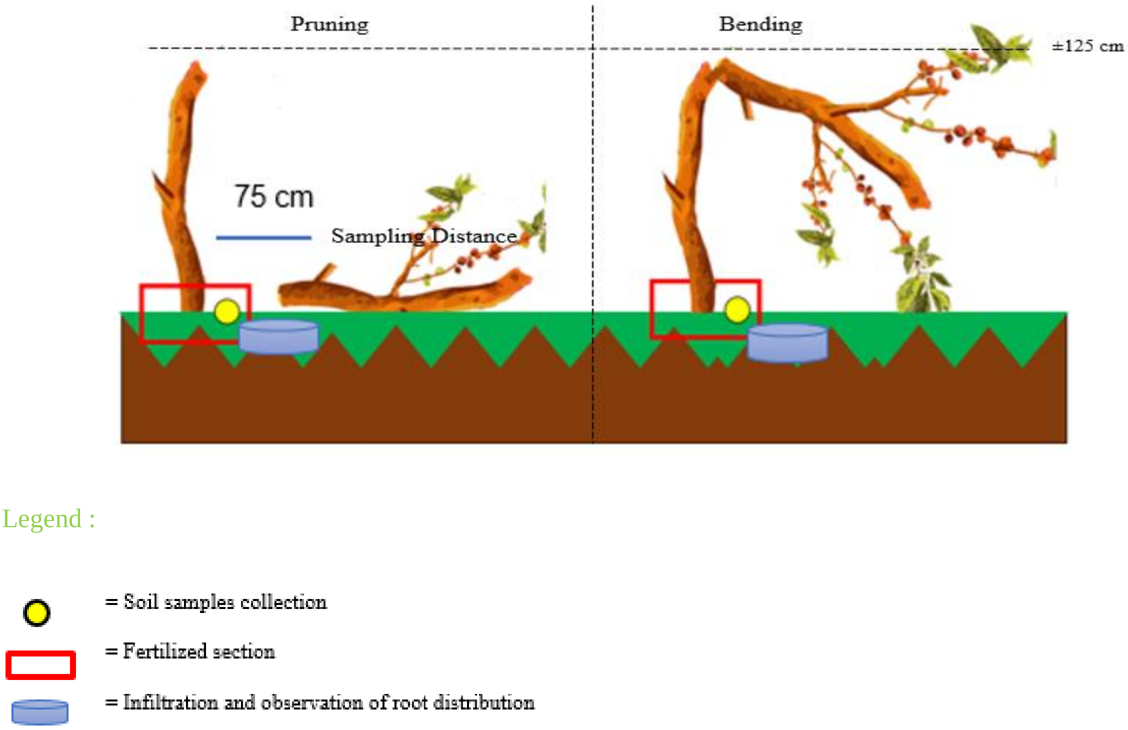

Figure 2. Schemes for coffee tree pruning, infiltration rate, and the collection of soil samples.

2.3 Research method

2.3.1 *Coffee growth measurement*

Measurement of growth parameters includescoffee stem diameter, new stem length, and chlorophyll. Measuring coffee stem diameter at 120 cm above ground level (DBH) was done using vernier calipers. The measurement of bud length used a meter by measuring from the initial point of growth to the highest point of growth (shoots). Chlorophyll observations were concentrated on the leaves, where five leaves from each plant were observed, and their average was determined. Leaf samples were positioned between two pre-calibrated SPAD-502 (Soil Plant Analysis

Development) sensors. The data readings from the SPAD device were subsequently transformed into chlorophyll values in units of µg/cm with the following (1) (Zhu *et al*., 2014) :

$$Chlorophyll = ((k \times SPADi) / (e - SPADi)) \quad (1)$$

Where : SPADi = Tool reading value to i; k = 117.1; e = 148.84

2.3.2 Soil sampling and analysis

Soil sampling was conducted at a 0–20 cm depth around the crop fertilization zone and was conducted compositely by taking soil samples at four different points. Soil and infiltration samples were collected 75 cm from the base of a coffee tree. Soil samples (100 g) were collected at each sampling location, yielding 400 g of fresh soil from each plot. Soil samples for the organic carbon test and soil physics (soil bulk density and porosity) were prepared by drying soil samples at room temperature before it continued to the process of grinding and sieving. The Walkley and Black (1934) method was used to determine soil organic carbon, soil bulk density by gravimetric method, and soil porosity by mathematical calculation using bulk density and particle density data, 1-Bulk Density/Particle Density. The constant infiltration rate, field measurement used the single-ring infiltrometer method, constant infiltration calculation used the Horton equation with the following (2) (Horton, 1933) :

$$F = fc + (f0-fc)e^{-kt} \quad (2)$$

Where : F = Infiltration rate (cm/hour); f0 = initial infiltration rate (cm/hour); fc = constant infiltration rate (cm/hour); e = 2.718; t = time under observation (hour); k = -1/(0.4343 x m)

2.3.3 Total root length measurement

Root observation in this study used the root trenching method (Smucker, 1987). This observation was conducted to determine differences in the root density of coffee trees of various types and pruning heights. A mini-pit of land was made measuring 50×50 cm. The mini-pit walls of the land were divided into grids with a size of 10×10 cm. Furthermore, the walls of the soil mini-pit were cut according to the size of the grid, with a volume of 10×10×10 cm. Soil roots underwent cleaning using two methods: the dry sieve method, conducted in the field, and the wet sieve method, performed in the laboratory. These methods involved the use of two sieves, measuring 0.5 mm and 250 µm in size.

Root density was analyzed using the intersecting line technique described by Tennant (1975). A subsection of coffee roots was cut into approximately 2 cm pieces and distributed across grid paper with a 1 × 1 cm grid size. Subsequently, the points where the roots intersected the horizontal and vertical lines on the grid paper were manually counted. The calculation of Lrv was then performed using the following (3):

$$Lrv\ sub = [\pi\{(H+V)D\}/4]/Soil\ Volume \quad (3)$$

Where : D = size of the graph used (cm); H = number of intersections of roots with horizontal lines; V = number of intersections of roots with vertical lines.

2.3.4 Root dry weight measurement

Drv measurement of roots was done by measuring the wet weight and dry weight of the roots. Sub-samples of roots were measured for length, then dried and weighed for wet weight. The remaining roots that had been taken as sub-samples were also weighed for wet weight. The sub-sample and the rest of the roots were put into different envelopes and then dried at 80°C for 48 hours in the oven. After that, the root dry weight was measured. The determination of the root Drv value was carried out using the (4) by Tennant (1975):

$$Drv=[\{Total\ Weight/\ Wet\ Weight\ Sub\}x\ Dry\ Weight\ Sub]/Soil\ Volume \quad (4)$$

Where : Drv = dry weight of roots (g/cm^3); Total Weight = total fresh weight/remaining roots (g); wet weight sub = wet weight of root sub-samples (g); Dry weight sub = dry weight of root sub-samples (g).

2.4 Data analysis

Data analysis involved the use the ANOVA table at a 5% significance level. If significant results were observed in the processed data, the Fisher test (5%) was used to assess treatment differences. Additionally, correlation and regression tests were performed to explore the relationships between research variables. All analyses were performed using R-Studio statistical software.

3. Results and Discussion

3.1 Coffee growth parameters

The ANOVA results for stem diameter, new stem length, and chlorophyll content in coffee plants across different land-use scenarios are detailed in Table 1.

Table 1. ANOVA results of stem diameter, new stem length, and chlorophyll.

Management Type	Stem Diameter (cm)	New Stem Length (cm)	Chlorophyll (mg/g)
	Pruning		
PRF0	4.25 cd	183.08 b	60.78 d
PRF1	4.08 d	182.34 b	64.78 b
PRF2	4.30 bcd	266.85 b	63.80 bc
PRF3	4.52 abc	222.93 b	63.33 bc
	Bending		
BNF0	4.27 bcd	307.10 b	61.84 cd
BNF1	4.44 abc	293.77 b	64.73 b
BNF2	4.79 a	471.20 a	68.29 a
BNF3	4.61 ab	243.88 b	65.49 b

Note: Numbers followed by columns followed by the same notation show no significant difference through the LSD test at the 5% level.

3.1.1 Stem diameter

The bending technique had a higher value than pruning on the stem diameter parameter. The local bending technique, innovated by farmers, can influence the coffee stem diameter by enhancing light absorption due to stem bending. The results of the analysis of variance on the diameter of the coffee stem showed a significantly different effect ($p<0.05$). The highest coffee stem diameter in the BNF2 treatment was 4.79 cm, while the lowest diameter in the PRF1 treatment was 4.08 cm (Table 1). BNF2 management experienced an increase of 17% compared to PRF1 management. BNF2 management was significantly different from PRF0, PRF1, PRF2, and BNF0 management. Based on the results of research by Musa *et al.* (2020) on Arabica coffee of the Kartika 1 variety under various shade plants, the stem diameter was 4.7–5.3 cm.

The technique of bending coffee branches has more advantages compared to trimming coffee branches in general. This method creates gaps between branches to address the restricted sunlight conditions beneath the pine canopy (Cahyono *et al.,* 2023). Light availability promotes photosynthesis and biomass production (Desrochers *et al.,* 2015). This is because the bending branches continue photosynthesis and photoassimilate production. When pruning, the crown of the coffee tree is uprooted, some of the roots die, and the plant depletes it to form new roots and shoots. When a coffee tree is bent, upper photosynthesis continues and the plant's tubes are assimilated by new shoots stimulated by the exposure of light (Dufour *et al*., 2019). In addition, the use of a combination of NPK fertilizer and moderate doses of manure affects stem diameter. This is due to the expansion of the root absorption area to absorb nutrients through the addition of fertilizer. Ferry and RusliI (2020) showed that mycorrhizal biofertilizer + 40% NPK increased the growth and production of robusta coffee under oil palm stands. This is in accordance with research which shows that the best inorganic-organic fertilizer combination for coffee growth is 25% inorganic fertilizer + 75% organic fertilizer (Lin *et al*., 2019).

3.1.2 New stem length

The farmer's local innovation, namely bending had a higher value than pruning. The bending technique increased the length of new shoots by 53.87% compared to the pruning technique. ANOVA results on the new shoot length parameter showed that the management of crown pruning and fertilization had a significant effect ($P < 0.05$) (Table 1). The highest value of water bud length was in the management of BNF2 at 471.20 cm. In comparison, the management of PRF1 had the lowest value of 182.34 cm. The results of previous studies on coffee plants with different shades in agroforestry systems show that the height of new shoots ranged from 133.97 cm - 405 cm (Halpern *et al.,* 2012). Bending management results in longer shoot lengths, as shoots emerge promptly around the affected part of the branch. This is in contrast with the conventional pruning method, in which branches are completely severed, causing the loss of some roots and utilization of the plant's reserves for new root and shoot growth. Pruning removes part of the plant structure, so the roots will spread out looking for food, and growth will be more focused on the root system (Cerda *et al.,* 2017).

The results of the correlation analysis between stem diameter and new shoot length showed a positive relationship (R^2 = 0.25). Figure 3 shows that the higher the tiller, the larger the stem diameter and the longer the new shoots grow. Stem growth will require quite a large amount of assimilate in this case. If the connection links are not perfect then the assimilate translocation process will not run smoothly, so it will cause growth disorders (Nguyen & Yen, 2018). The length of the joint shoot itself causes the length of the stem shoot to grow slowly. The highest stem diameter and shoot length in BNF2 management were also influenced by the element nitrogen. Nitrogen plays a role in plants by stimulating plant growth (stems, branches, and leaves) (Sauvadet *et al.,* 2019). According to Andivia *et al.* (2013), nitrogen found in manure enhances the vegetative growth of plants by participating in the development of cells, tissues, and plant organs. Optimal nutrient absorption relies on balanced fertilizers, which can be solid or liquid and contain both inorganic and organic components (Khayati *et al.,* 2020). NPK inorganic fertilizers can support the macronutrient needs of plants and are complemented by microelements (Lian *et al.,* 2022). If soil fertility can be maintained, the addition of inorganic fertilizers can be reduced and can be made available to plants. Thus, the combination treatment of manure and NPK is an alternative to meet nutrient needs.

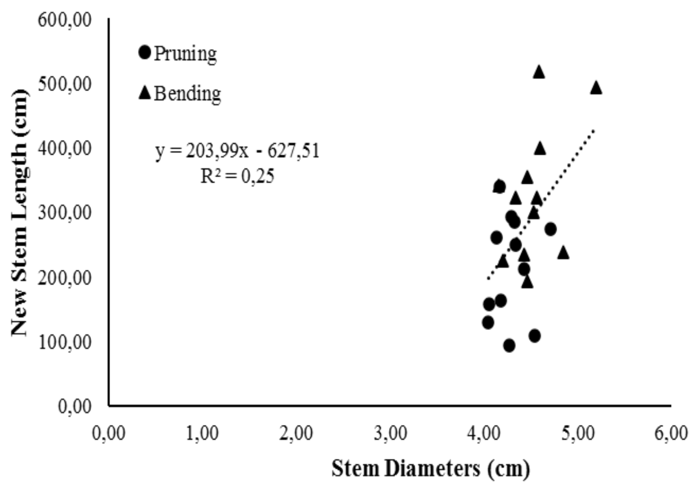

Figure 3. Relationship between Stem Diameter and New Stem Length

3.1.3 Chlorophyll

Sunlight affects chlorophyll levels, and one way to enhance light exposure to coffee branches is by bending the coffee trunk to create more space between the branches. This results in more intense and evenly distributed light reaching the coffee twigs. The results of the ANOVA analysis showed that the management of crown pruning and fertilization significantly affected the chlorophyll of coffee leaves (Table 1). BNF2 management was significantly different (p>0.05) from other managements. The highest chlorophyll value was found in BNF2 management at 68.29 mg/g, while the lowest chlorophyll was found in PRF0 treatment at 60.78 mg/g. This study showed that the chlorophyll index of coffee leaves in various land uses ranged from 68.88–75.17 µ/mL (Feng *et al.*, 2004).

This is in line with previous research showing that branch bending will open the canopy and increase leaf photosynthesis through changes in sunlight exposure on the leaves (Dufour *et al.*, 2019). The addition of chicken manure + NPK fertilizer can increase chlorophyll and reduce excessive doses of single inorganic NPK fertilizer (Maghfoer *et al.*, 2014). Chlorophyll production is influenced by several factors, including sufficient light, essential macronutrients such as NPK, and trace elements such as Mg and Fe, which serve as essential components and catalysts in chlorophyll synthesis (Fini *et al.*, 2015). Plants with sufficient N elements will have wider leaves and a higher chlorophyll content (Franck & Vaast, 2009).

3.2 Soil properties

The results obtained after analysis using ANOVA related to soil organic-C matter, soil bulk density, and soil porosity of coffee plants on various land uses are presented in Table 2.

Table 2. ANOVA results of soil organic-C matter, soil bulk density, and soil porosity.

Management Type	Soil Organic Carbon Matter (%)	Soil Bulk Density (g/cm^3)	Soil Porosity (%)
		Pruning	
PRF0	6.297 bc	0.72 ab	63.05 d
PRF1	6.142 c	0.70 b	64.02 c
PRF2	6.250 bc	0.70 ab	63.73 cd
PRF3	6.219 c	0.73 a	64.04 c
		Bending	
BNF0	7.152 ab	0.61 c	66.84 ab
BNF1	7.324 a	0.59 cd	67.53 a
BNF2	7.509 a	0.58 d	66.34 b
BNF3	6.927 abc	0.61 cd	66.52 b

Note: Numbers followed by columns followed by the same notation show no significant difference through the LSD test at the 5% level.

3.2.1 Soil organic Carbon matter

The equilibrium between the plant-derived litter input determines the quantity of soil organic carbon content. Bending management increased organic carbon content by 16.07% compared to pruning. ANOVA analysis showed that different management strategies of crown pruning and fertilization had a significant effect (P<0.05) on soil organic carbon (Table 2). Organic carbon content is an element that can determine soil fertility level. The highest soil organic carbon value was found in BNF2 management at 7.51% but it was not significantly different from BNF1, BNF2, and BNF3 management. Meanwhile, PRF1 management had the lowest organic carbon value of

6.14% and it was not significantly different from PRF0, PRF2, PRF3, and BNF3 management. The soil organic carbon measurements in this study align with those reported by Kurniawan *et al.* (2021), that the application of organic fertilizer alone or in combination with NPK fertilizer can increase soil organic carbon. The results of Olaya *et al.* (2019) also showed that organic fertilizers sourced from manure have the potential to boost the buildup of soil organic carbon, resulting in alterations in the microbial community structure and promotion of microbial biomass.

The high value of organic carbon content indicates that the research location has relatively high levels of organic material. The soil organic carbon value can be influenced by several factors, one of which is the soil constituent material. The research location is known to have soil constituent materials derived from volcanic material from volcanic eruptions (andic material) and contains high organic matter (Kurniawan *et al.*, 2019). The type of soil in the research location is Andisol, which is formed because it is on the slopes of the active Arjuno volcano. This amorphous type of mineral can form very strong and stable bonds with organic matter, so the organic matter content in Andisol soil is high (Anda & Dahlgren, 2020). Apart from the materials that make up the soil, high organic matter can also come from the accumulation of organic material in the observation plot. The observation plot is agroforestry land with land cover in the form of coffee and pine plants with a history of low land management. Litter that falls and remains in agroforestry can contribute to producing a high source of organic material. Fallen litter and dead undergrowth will accumulate on the soil surface and become soil organic matter through decomposition. The primary source of soil organic matter in agroforestry systems is the input from fallen litter and dead roots, which can come from trees, shrubs, and undergrowth (Yusuf *et al.*, 2020). Additionally, adding fertilizer, especially organic fertilizer to the soil can increase organic carbon. The use of organic materials in the form of organic fertilizers can increase the soil's organic carbon content of the soil (Hairiah *et al.*, 2020).

3.2.2 Soil bulk density

The farmer's local innovation, the bending technique, reduced the soil content by 17.50% compared to the pruning technique. ANOVA results showed the effect of crown pruning and fertilization management on soil bulk density (Table 2). PRF3 management had the highest bulk density value and it was significantly different from PRF0 and PRF2. PRF3 management had the highest average content weight of 0.73 g/cm^3, while BNF2 management had the lowest bulk density of 0.58 g/cm^3. In line with Putri *et al.* (2019), the bulk density for each land use in UB Forest is classified as having a low value ranging from 0.50 – 0.73 g/cm^3.

The range of bulk density values, whether high or low, can serve as an indicator for assessing soil fertility. The unit weight of the soil is subject to various factors, one of which is the composition of the soil material. Soils formed from andic materials tend to have a low bulk density

(<1 g/cm^3) (Kurniawan *et al.*, 2019). Moreover, the variation in soil bulk density values is resulted from efforts to enhance the physical properties of soil through the incorporation of organic matter. The findings regarding soil unit weight in this study align with previous research conducted by Lin *et al.* (2019) that stated that the soil unit weight value due to the application of organic fertilizer is much lower compared to the treatment of inorganic fertilizer in tea gardens. The greater the concentration of organic matter in the soil, the lower the soil bulk density value (Lopes *et al.*, 2020). The quantity of organic matter in the soil affects variations in soil bulk density, with higher organic matter leading to reduced weight content than soil with lower organic matter (Abdalla *et al.*, 2022).

3.2.3 Soil porosity

The bending technique had a higher porosity value than the pruning technique. This local farmer's innovation was 4.86% higher than the pruning technique. The results of the ANOVA analysis showed that the management of crown pruning and fertilization had a significant effect on soil porosity content (P<0.05) (Table 2). The highest soil porosity content was found in BNF1 management at 67.53%, while PRF0 management had the lowest porosity content at 63.05%. Research result on coffee grounds of various shades show porosity values ranging from 44.88%-56.27% (Reswari & Prijono, 2020). BNF1 management was similar to BNF0 management.

The increase in soil porosity in BNF1 compared to PRF0 was likely caused by the addition organic material through fertilization. This shows that adding organic matter from chicken manure can increase the porosity in the soil. Karim *et al.* (2021) also stated that adding organic fertilizer alone or combined with NPK fertilizer increased soil porosity by 22.18% compared to treatment without fertilizer. Applying organic materials to the soil increased the community of soil microorganisms compared to other treatments, thus expanding the pore space in the soil (Singh *et al.*, 2022). The increase in soil pore space occurs because organic matter can push the formation of soil aggregates, which is indicated by a decrease in soil weight (Salamanca-Jimenez *et al.*, 2016). Furthermore, plant roots and soil microorganisms form aggregates that have enhanced soil porosity. This aggregation process starts with breaking down the soil into smaller units, subsequently bound together by root secretions, serving as both soil grain binders and stabilizers (Surya *et al.*, 2017).

3.3 Infiltration rate of measurement

To calculate the infiltration rate of the Horton model, model parameter values fc (constant infiltration), f0 (initial infiltration), and k (constant) were used. Analysis of variance showed that canopy pruning and fertilizer management significantly affected the infiltration rate (P<0.05). Horton infiltration model and parameter values are presented in Table 3. The results of Horton's infiltration parameter values showed that BNF0 management had the highest infiltration rate value with 804 mm/hour, meaning that within 1 hour, water could enter the soil by 804 cm, while the lowest was in 100% NPK pruning management with an average infiltration rate of 408 mm/hour. In line with research (Muñoz-Villers *et al.*, 2020), coffee plantations with mixed shade have a greater actual infiltration rate of 107.74 cm/hour.

Table 3. Horton method infiltration rate value

Management	f_0 (cm/second)	f_c (cm/second)	k	Mean (mm/hour)	Clasification
			Pruning		
PRF0	0.022	0.012	0.0017	432 ab	Very Fast
PRF1	0.024	0.014	0.0020	492 ab	Very Fast
PRF2	0.035	0.014	0.0042	504 ab	Very Fast
PRF3	0.022	0.012	0.0015	408 a	Very Fast
			Bending		
BNF0	0.035	0.022	0.0013	804 b	Very Fast
BNF1	0.031	0.014	0.0012	516 ab	Very Fast
BNF2	0.035	0.017	0.0041	576 ab	Very Fast
BNF3	0.028	0.019	0.0016	624 ab	Very Fast

Note: Numbers followed by columns followed by the same notation show no significant difference through the LSD test at the 5% level.

The infiltration rate values that occured in all plots had varying values but are still in the very fast classification. Chemura (2014) states that the infiltration rate of agroforestry land is higher than the soil infiltration rate on dry land and seasonal crops. The organic matter content and ample macropores are key factors for the high infiltration rate in forest land compared with dry and agroforestry land. Generally, agroforestry land has the highest infiltration rate owing to its diverse tree cover and dense vegetation, leading to increased litter and biomass input. Higher ground cover percentages protect the soil surface and promote water absorption. In agroforestry systems with similar cover to forests, denser coverage enhances water absorption and preserves watershed hydrological functions. The results of research from Prakasa *et al.* (2021) stated that in an agroforestry system through a variety of inputs, litter and roots are able to maintain the activity and diversity of soil biota. The litter on the surface can increase soil biota activity to improve soil porosity. Based on the graphs obtained, which can be seen in Figure 4 and Figure 5, it can be seen that increasing cumulative time causes the infiltration capacity to decrease. In line with Horton's infiltration model, there was a decline in infiltration capacity over time, which was influenced by various factors, such as soil surface conditions, soil structure, vegetation, soil moisture, and air content. The infiltration rate curve displayed in the figure reveals distinct points at which the infiltration rate decreased. Generally, across all management scenarios, the infiltration rate decreased at approximately 1560 seconds, indicating a relatively constant infiltration rate. The curve above demonstrates that the infiltration rate remained consistent within the range of 0.007 cm/sec to 0.013 cm/sec.

The highest infiltration rate was in BNF0 management, and the lowest was in PRF3 management. The curve below shows that the infiltration rate decreased over time. This is because when infiltration occurs, the pore spaces in the soil are increasingly filled with water, which causes a decrease in the infiltration rate. In line with previous research, time has a very big influence on rate soil infiltration rate, where the longer the time to enter or pass water into the soil, the smaller the infiltration rate that occurs (Tang *et al.*, 2019). A long time will cause the soil to be more saturated, causing some soil cavities to be filled with fine soil, reducing the space for water movement.

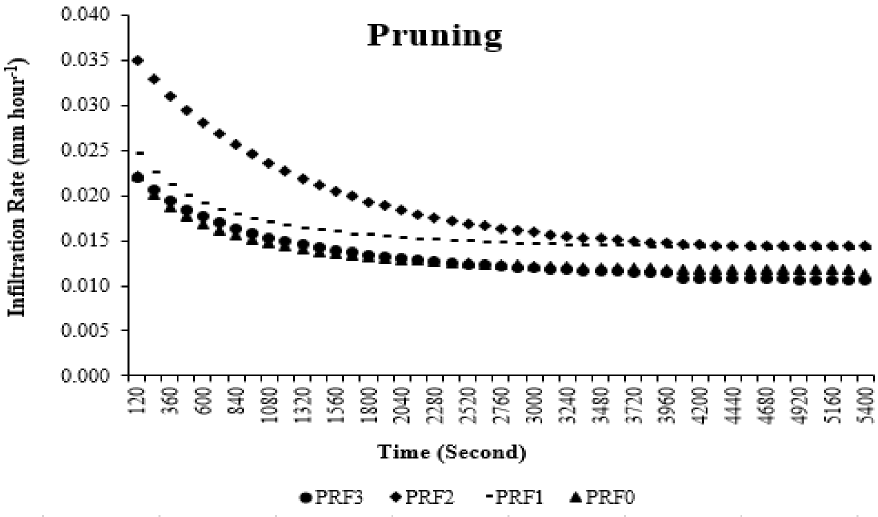

Figure 4. Measurement of Infiltration Rate on Pruning Management

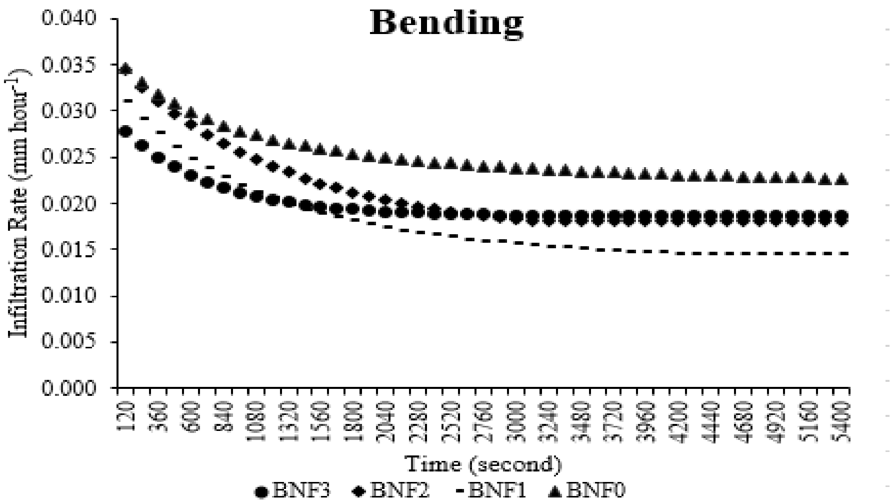

Figure 5. Measurement of Infiltration Rate on Bending Management

The infiltration rate values on all coffee lands vary, which can occur due to different pruning management on the land. The Horton equation describes the state of infiltration when the rain stops, and the improvement of infiltration capacity begins. The infiltration rate in bending had a higher value than pruning. The bulk density of each management area within the UB Forest fell within the low range, with values spanning from 0.58 to 0.73 g/cm^3. The analysis indicates that soil density at the study site remained relatively favorable. This shows that in soil with a low weight content, the infiltration rate will be high; the lower the soil density, the faster the soil will absorb water. Porous soil refers to soil with ample pore space, facilitating the movement of water and air in both directions within the soil (Fang *et al.,* 2014; Lihui *et al.,* 2019). Carducci *et al.* (2015) added that soil porosity will determine the storage capacity of infiltration water and the resistance to flow. Increasing levels of organic matter in the soil will increase the activity of soil microorganisms, thereby increasing soil porosity and aggregate stability. This facilitated the rapid entry of water into the soil (Cardoso *et al.,* 2013). High organic matter content causes the soil to have the ability to absorb water quickly, so it can affect the soil infiltration rate (Archer *et al.,* 2016). In addition, the infiltration rate can decrease with time. The longer the time, the lower the infiltration rate. This occurred because of the growing saturation of the soil, with certain voids being occupied by loose soil, thereby reducing the available space for water movement.

3.4 Plot characteristics based on coffee root distribution after pruning (Pruning and Bending)

Total root length (lrv) decreased with increasing soil depth in both bending and control management. The analysis of variance results indicates that varying crown pruning techniques had a notable impact on the overall root length. The distribution of coffee roots throughout management was concentrated in the topsoil, in the top layer (0–20 cm), with an lrv value of 6.23 times higher than the layer below (30–50 cm) in the bending treatment. Meanwhile, in the control and pruning treatments, the root distribution was in the upper layers (0–20 cm), showing lrv values of 3.50 and 1.46 times higher than the layers below (Figure 6). The distribution of coffee roots consists of fine roots that dominate the layer 10–20 cm from the soil surface, while lateral roots are spread near the surface up to 2.40 m deeper than the coffee stems (van Kanten *et al.,* 2005).

Root dry weight shows the amount of carbon stored in the root system. The analysis of variance findings demonstrated significant disparities in pruning management concerning root density (drv). The drv values for the bending and control management at various depths showed significantly different results, while those for the pruning treatment were not significantly different. At 0–20 cm depth, the highest dry weight was in bending management, and the lowest was in pruning (Figure 7). This shows that coffee roots are widely distributed on the soil surface. This aligns with the findings of (Schmidt *et al.,* 2022), who reported that coffee root systems predominantly extend within 0–30 cm depth and encompass approximately 70% of the root surface area.

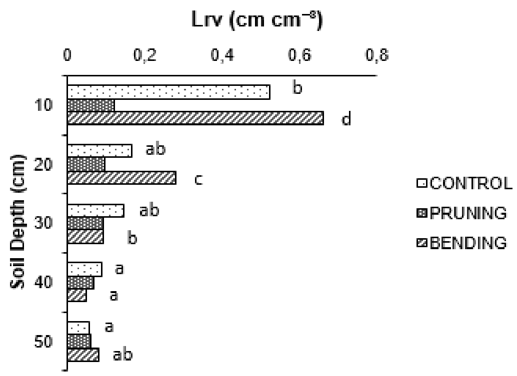

Figure 6. Average total length density (cm/cm^3).

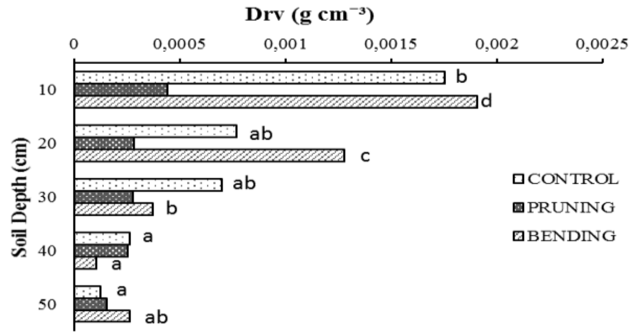

Figure 7. Average root dry weight (g/cm^3).

The highest score of Lrv and Drv was on bending management. This is because bending management had a high value for organic matter and porosity. Increasing soil organic matter can increase the root length density value. Soil organic matter contributes to enhancing the physical characteristics of soil, including soil aggregation, pore size distribution (which promotes increased soil organism activity, particularly in the vicinity of root zones, thereby influencing the creation of new soil pores), bulk density, and porosity (Guhra *et al.*, 2023). Lrv and Drv values in bending and control management showed decreasing values in each soil depth.

Meanwhile, in pruning management, the Lrv and Drv values did not decrease too much. A low Lrv value indicates that the roots are thickened and short. Conversely, a high Lrv value indicates that the roots and smooth are elongated (Dunbabin *et al.*, 2013). Greater root length and dry weight densities result in increased water and nutrient absorption by the roots, thereby exerting an influence on plant productivity (Zhou *et al.*, 2022).

4. Conclusion

In conclusion, local innovations, specifically farmers' bending techniques, were found to have positive impacts on coffee growth and soil physical characteristics. The combination of the bending technique with chicken manure and NPK fertilizer (BNF2) demonstrated improvements in coffee stem diameter, new shoot length, chlorophyll levels, soil organic carbon content, and a reduction in soil bulk density. Conversely, using the bending technique with chicken manure alone (BNF1) increased soil porosity. Moreover, the soil infiltration rate under bending management (BNF0) surpassed that of other approaches, highlighting the advantages of this technique, especially when coupled with chicken manure and NPK, for enhancing coffee farm management. While valuable practical insights were gained from this study, it is essential to emphasize that further research is needed to explore the effects of coffee pruning management, incorporating both pruning and bending techniques with fertilizers on coffee growth and soil fertility. This extended research should cover a broader range of parameters, including chemical, physical, and biological properties of the soil.

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