Vol. 14, No. 5 (2025): 1857 - 1868 http://dx.doi.org/10.23960/jtep-l.v14i5.1857-1868

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Evaluation of Fertilizer Management Approaches in Maintaining Soil Fertility and Plant Nutrient Content in Coffee-Based Agroforestry Systems

Silvia Febiona[1], R Muhammad Yusuf Adi Pujo Nugroho[1,3], Sri Rahayu Utami[2], Syahrul Kurniawan[2,✉]

[1] Master Program of Soil and Water Management, Faculty of Agriculture, Universitas Brawijaya, Malang 65145, East Java, INDONESIA.

[2] Department of Soil, Faculty of Agriculture, Universitas Brawijaya, Malang 65145, East Java, INDONESIA.

[3] Departement of Agrotechnology, Faculty of Agriculture, Universitas Pembangunan Nasional Veteran Jawa Timur, Surabaya, INDONESIA.

Article History:

Received : 02 July 2025
Revised : 07 August 2025
Accepted : 30 August 2025

Keywords:

Coffee agroforestry,
Fertilizer management,
Organic matter,
Soil fertility,
Soil quality.

Corresponding Author:
✉ syahrul.fp@ub.ac.id
(Syahrul Kurniawan)

ABSTRACT

Application proper type and dose of fertilizer will maintain soil fertility and help coffee growing better in the agroforestry system. Mis-management in fertilization compromises soil quality, and therefore it is underscoring the imperative to ascertain proper type and dosage of fertilizer for maintaining soil properties and nutrient storage. The study aims to assess and evaluate the role of fertilizer management in influencing soil properties, nutrient stocks, and leaf nutrient content. The field experiment was conducted in smallholder coffee agroforestry systems East Java – Indonesia. A randomized block design including a control plot in the protected area and nine combinations of fertilizer types (i.e., organic, inorganic, and mixed) and doses (i.e., low, medium, and high), with three replications, was applied to coffee trees in an agroforestry system. This study proves that differences in fertilizer management did not significantly changes soil physical properties (i.e., soil bulk density and total porosity), indicated that changing in soil physical properties occurred in the long time. In addition, the reduced fertilizer dose (the low dose fertilizer application) had comparable soil available P, and higher soil exchangeable K and soil P stock as compared to those in the protected areas. The study revealed that applying low-dose mixed fertilizer management effectively improved soil fertility.

1. INTRODUCTION

Implementing agroforestry into coffee plantation represent a strategic approach to optimize coffee trees growth. The integration of shade trees into these systems has been demonstrated to provide numerous benefits, including the enhancement of soil fertility. Kaur *et al*. (2023) stated that agroforestry enhance soil structure, reduces erosion, and provide other environmental services. The presence of shade tree roots has been shown to bind soil particles, thereby increasing soil stability and reducing erosion (Fahad *et al*., 2022). Agroforestry also provides organic input from litter and root biomass, which contribute to nutrients and carbon, increasing water-holding capacity and nutrient retention in the soil (Solanki *et al*., 2024). Agroforestry is believed capable to create a climate that supports secondary crops, offering a cost-effective practice that can be implemented by smallholder farmers (Solanki *et al*., 2024). Managing agroforestry in appropriate way can give numerous benefits, both environment and economic for the farmers.

Fertilization has been identified as a crucial factor in the successful implementation of agroforestry in coffee plantations. Rowe *et al*. (2022) stated that the fertilizer type and dose can be influential factor of soil quality in coffee-pine agroforestry. Organic fertilizers have been shown to enhance the organic matter content of soil and improve its physical properties, while inorganic fertilizers have been shown to supply nutrients quickly (Brempong & Addo-Danso, 2022; Parveen *et al*., 2022). The integration of these two fertilizers has the potential to provide more optimal benefits (Ridwan *et al*., 2020). Kurniawan *et al*. (2024) reported that combination of organic and inorganic fertilizer increased nitrate and net ammonium concentration in coffee agroforestry systems. Nevertheless, the improper application of fertilizer type and dose has been demonstrated to exert deleterious effects on the systems and decreased the yield (Abdullah *et al*., 2024; Ugwuoke *et al*., 2024). Universitas Brawijaya (UB) forest, an area in the slope of Arjuna Mountain in East Java – Indonesia, contain the smallholder coffee-based agroforestry where farmers applied various fertilization management that may impact on soil fertility. Local reports indicate that coffee yields are extremely low (100-400 kg/ha/year) due to low soil fertility (Saraswati & Praptana, 2017). Appropriate fertilization is essential for providing available nutrient, which directly influence coffee growth.

Previous fertilization trials in UB Forest have provided valuable baseline data on soil and plant responses under different nutrient management strategies. The results showed that applied various fertilization management improve nutrient availability and soil health in coffee agroforestry systems. Nurcholis *et al*. (2024) demonstrated that combining organic and inorganic fertilizers in moderate doses could enhance soil nutrient status, whereas Rohani *et al*. (2024) emphasized that the incorporation of chicken manure and coffee tree management (e.g., bending) could enhance soil porosity and water infiltration rate, along with vegetative growth of coffee plants. These outcomes highlight the need for site-specific and balanced nutrient management approaches. The current study builds on these findings by further exploring optimal fertilizer types and doses to improve nutrient availability and soil health in coffee agroforestry systems. The study aims to assess and evaluate the role of fertilizer management in influencing soil properties, nutrient stocks, and leaf nutrient concentrations. The result is expected to advances the current knowledge by not only confirming the soil improvements under different fertilization strategies but also linking them to plant nutrient absorption, allowing for a more holistic evaluation of nutrient use efficiency. Finally, the study will be determined proper fertilizer management for smallholder coffee-based agroforestry systems, especially in maintaining soil fertility and sustainability of coffee agroforestry system.

2. MATERIALS AND METHODS

2.1. Location of Research and Experimental Design

The field research was conducted from September to December 2024, a period marking the transition from the late dry season to the beginning of the rainy season. In this period, the rainfall intensity is low, therefore reducing nutrient losses through leaching. In addition, during this phase, coffee plants typically start to flower and develop young fruit, processes that are highly sensitive to the availability of water and nutrients in the soil. The experimental plot was carried out 10-year-old Arabica coffee trees within an agroforestry system in UB Forest, Karangploso District, Malang Regency, East Java (Figure 1), with an altitude of 1,122 meters above sea level, with annual rainfall was 1970 mm/year and average daily temperature is 23.7^{0}C. The coordinates of the location are 7°49ˈ 300” - 7°51ˈ 363” S and 112°34ˈ 378” - 112°36ˈ 526” E. The soil is characterized with silty clay soil texture and are classified as Inceptisols (Kurniawan *et al*., 2019).

A randomized block design with 9 treatments of fertilizer management and 1 control plot (located in the protected area which did not receive fertilizer), replicated three times for each treatment, was carried out in this study. The fertilizer management consisted of three different fertilizer types (i.e., organic/O, inorganic/I, and mixed/M) and three dose levels (i.e., low, medium, and high, represented by numbers 1, 2, and 3, respectively) (Table 1). The fertilizer dose of each treatment was determined based on the amount of nitrogen incorporated into the soil from a previous study (Rowe *et al*., 2022). In addition, the study used the protected area (PA) as a control to compare fertilizer management in coffee agroforestry systems with the unmanaged forest located in UB Forest. Each plot measured 2 m × 2 m, with a 2-meter spacing between plots to prevent lateral flow of water, nutrients, or organic matter. This spatial arrangement ensured the independence of each plot and minimized potential cross-contamination or mass flow influence from adjacent plots.

The research applied chicken manure contain 1.49% N, 2.91% P_2O_5, and 2.57% K_2O, (Nugroho *et al*., 2023) as organic fertilizer, where inorganic fertilizer treatment was performed by applying urea (60% N), SP-36 (36% P_2O_5),

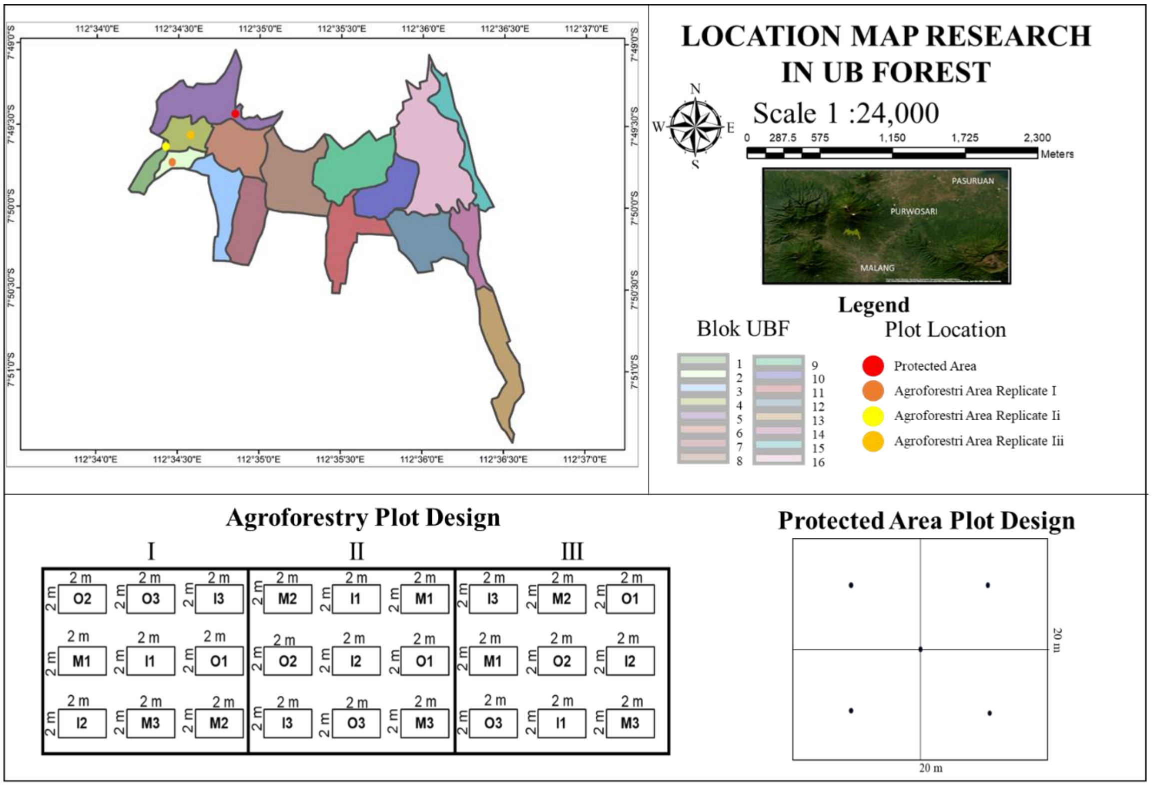

Figure 1. Research site and plot design

Table 1. Fertilizer dosage of each treatment

Code	Treatment type	Fertilizer Dosage (g/tree/year)			
		Manure	Urea	SP-36	KCl
PA	Protected area (no management)	-	-	-	-
O1	Organic Fertilizer, low dose	4322	-	-	-
O2	Organic Fertilizer, medium dose	4846	-	-	-
O3	Organic Fertilizer, high dose	9261	-	-	-
I1	Inorganic Fertilizer, low dose	-	140	72	157
I2	Inorganic Fertilizer, medium dose	-	157	59	42
I3	Inorganic Fertilizer, high dose	-	300	160	200
M1	Mixed Fertilizer, low dose	2161	70	36	78.5
M2	Mixed Fertilizer, medium dose	2423	78.5	29.5	21
M3	Mixed Fertilizer, high dose	4630	150	80	100

and KCl (60% K_2O). The fertilizer was applied at a depth of 5 centimeters and placed at a distance of 50 centimeters from the trunk of the coffee tree. The application site was subsequently covered with soil (Figure 2). The fertilizer doses used in this study refer to the total amount applied per years. The specific dosage levels for each treatment were determined based on the amount of nitrogen incorporated into the soil in a previous agroforestry fertilization study by Rowe *et al.* (2022), and adjusted to match local nutrient needs and site conditions.

2.2. Soil Sampling and Analysis

Undisturbed and disturbed soil samples were collected in the coffee active root zone, located at 30 cm from the trunk with 0-20 cm soil depth (Figure 2). Undisturbed soil samples were collected to determine soil bulk density which was measured using core method (Balai Penelitian Tanah, 2022). Subsequently, bulk density and soil porosity was calculated using formula (1 and 2) from Balai Penelitian Tanah (2022).

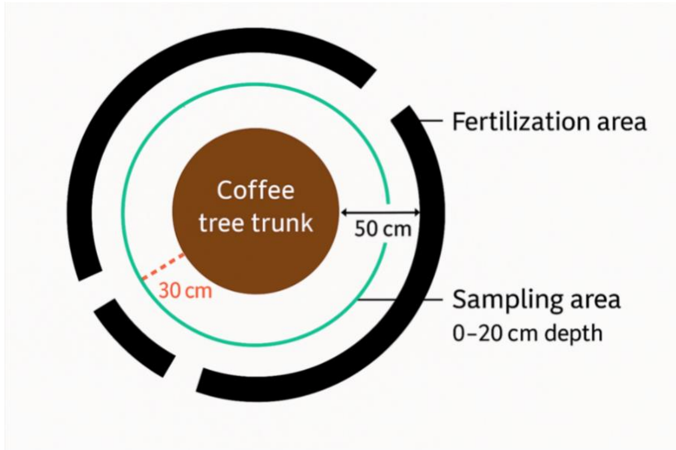

Figure 2. Ilustration for soil sampling method

$$Bulk\ Density = \frac{(Ms+Mr+Mc)-(Mr+Mc)}{\pi r^2 t} \quad (1)$$

where *Ms* is oven-dry weight of soil (g); *Mr* is weight of metal ring (g); *Mc* is weight of the container (g); *r* is inside radius of the ring (cm); *t* is height of the ring (cm).

$$Soil\ Porosity = 1 - \left(\frac{Bulk\ Density}{Particle\ Density}\right) \times 100\% \quad (2)$$

The disturbed soil is used to determine the soil chemical properties. Soil pH was measured using Electrometric method (soil-to-water ratio 1:1), Organic C using Walkley-Black method, and total N using Kjeldahl method (Balai Pengujian Standar Instrument Tanah dan Pupuk, 2023). Soil available P was analyzed using Olsen method, where exchangeable K was determined using Ammonium Acetate (NH_4OAc) Extraction method (Balai Pengujian Standar Instrument Tanah dan Pupuk, 2023). The soil nutrient stocks were calculated using formula (3) from Fitria *et al.* (2021).

$$Nutrient\ stock\ (g.m^2) = \frac{Nutrient\ concentrate\ (g.kg^{-1}) \times Bulk\ Density\ (g.cm^{-3}) \times Depth\ Soil\ (cm) \times 10.000\ (cm^2.m^{-2})}{1000 (g.kg^{-1})} \quad (3)$$

2.3. Leaf Sampling

The nutrient uptake in coffee trees was determined by collecting coffee leaves from the third to fourth leaves from the top of the plagiotropic branch. Leaves were collected in the morning (08.00-10.00 WIB) to avoid bias due to transpiration (Sakiroh & Aunillah, 2020). The leaf nutrient content analysis was determined using wet combustion method.

2.4. Statistical Analysis

An analysis of variance (ANOVA) with 95% confidence level was performed to ascertain the effect of treatments. Duncan's Multiple Range Test (DMRT) was performed to determine the difference of each treatment if the result of ANOVA showed significant different (p-value ≤ 0.05). Correlation and regression analysis were conducted also to determine the relationship and effect of each parameter tested.

3. RESULTS AND DISCUSSION

3.1. Soil Physical Properties

The result demonstrated that fertilization management did not gave a significant impact (p-value ≥ 0.05) on soil bulk density and soil porosity (Figure 3). In addition, soil bulk density from all the fertilizer management practices (0.61–0.96 g/cm^3) was comparable to the measurement of Kurniawan *et al.* (2019) who reported that soil bulk density in agroforestry systems within UB Forest in 2017 (eight years ago) ranged from 0.6–0.9 g/cm^3, indicated that the changing of soil physical properties as an impact of fertilization occur in the long time. However, the findings revealed that soil porosity exhibited an increase of 1.51%, coinciding with a reduction in soil bulk density of 1.96%, as compared to the initial properties (58.50% and 0.86 g/cm³, respectively). The inherent low bulk density in this system is likely due to several factors: the presence of the A horizon within the 0–20 cm sampling depth, and typical of the andic properties of UB Forest soils, which naturally exhibit a friable and lightweight structure, and soil particle dominated by silt fraction.

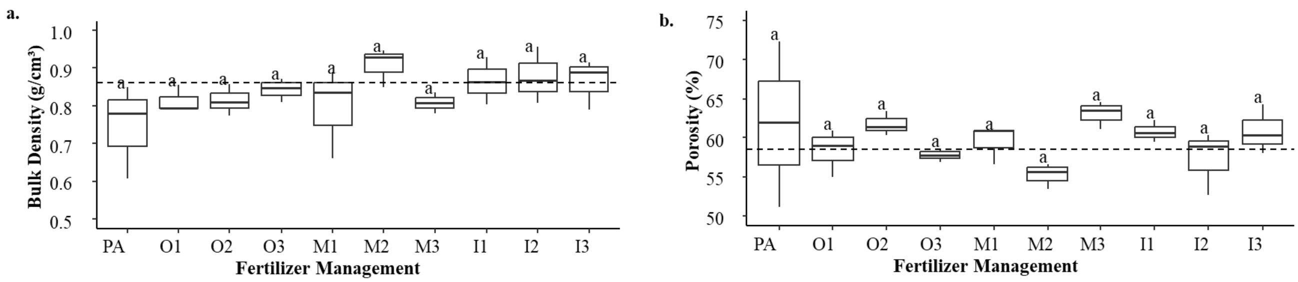

Figure 3. Fertilization management effect on soil bulk density (a) and soil porosity (b). The dash line refers to initial condition, and different notation show significant difference through DMRT test at 5% level

Soil bulk density in the organic fertilizer application at low to high doses tend to have lower soil bulk density as compared to the initial condition (Figure 3a). This was probably due to organic fertilizers improve soil physical properties through stabilizing soil aggregates, increase porosity and aeration that helps the improvement of soil structure (Brempong & Addo-Danso, 2022). Conversely, inorganic fertilizer did not enhance soil physical properties due to the absence of organic matter (Acar *et al*., 2025). Despite the fact that inorganic fertilizer did not contribute to the accumulation of organic matter, applying appropriate dose of inorganic fertilizer can enhance soil organic matter decomposition (Titirmare *et al*., 2023). The incorporation of both organic and inorganic fertilizers has been demonstrated to yield a synergistic effect; organic matter contributed to improved soil aggregation and porosity, while inorganic fertilizer provided immediate nutrient availability (Bashir *et al*., 2021). This finding is consistent with our finding that mixed fertilizer treatments mostly exhibited similar soil bulk density and porosity compared to the protected areas.

3.2. Soil Chemical Properties

The quantity of organic matter in each treatment is constitutes a pivotal factor of our findings. Fertilizer management had a significant effect on soil organic C, exchangeable K, and available P (p-value ≤ 0.05), but did not affect to soil total N, pH, and C/N ratio (p-value ≥ 0.05) (Figure 4). Soil organic C in the protected area (PA) was 90–250% higher than those in the coffee agroforestry system with different fertilizer management, except in the plot with application the high dose of organic fertilizer (O3). This was indicated that most of fertilizer management for coffee agroforestry in this study was not unable to improved soil organic C as compared to protected area. Further, application of organic fertilizer at the high dose (O3) exhibited 136% higher of soil organic C as compared to application the low dose of mixed fertilizer (M1, Figure 4a). The previous study reported that organic fertilizer in the soil can enhance lignocellulosic and organic complex such as humic content that helps to stabilize C fraction, also enhance soil microbial biomass that essential for carbon sequestration (Guo *et al*., 2019; Aytenew & Bore, 2020). Thus, organic fertilizer should be regularly applied to increase soil organic C and maintain the sustainability of soil organic matter.

Soil available P at all fertilizer plot and the protected area in the end of study was lower than those in the initial condition (Figure 4c). Surprisingly, application of inorganic fertilizer (i.e., SP-36) at the low, medium, and high doses tended to have lower soil available P as compared to application the mixed fertilizer. This result indicated that the P released from inorganic fertilizer was probably bind in the complex absorption, losses through leaching, and/or uptake by plant, resulted in decreased soil available P. In contrast, application of organic fertilizer sole or combined with inorganic fertilizer can maintain soil available P, possibly due to application of organic fertilizer can enhance soil

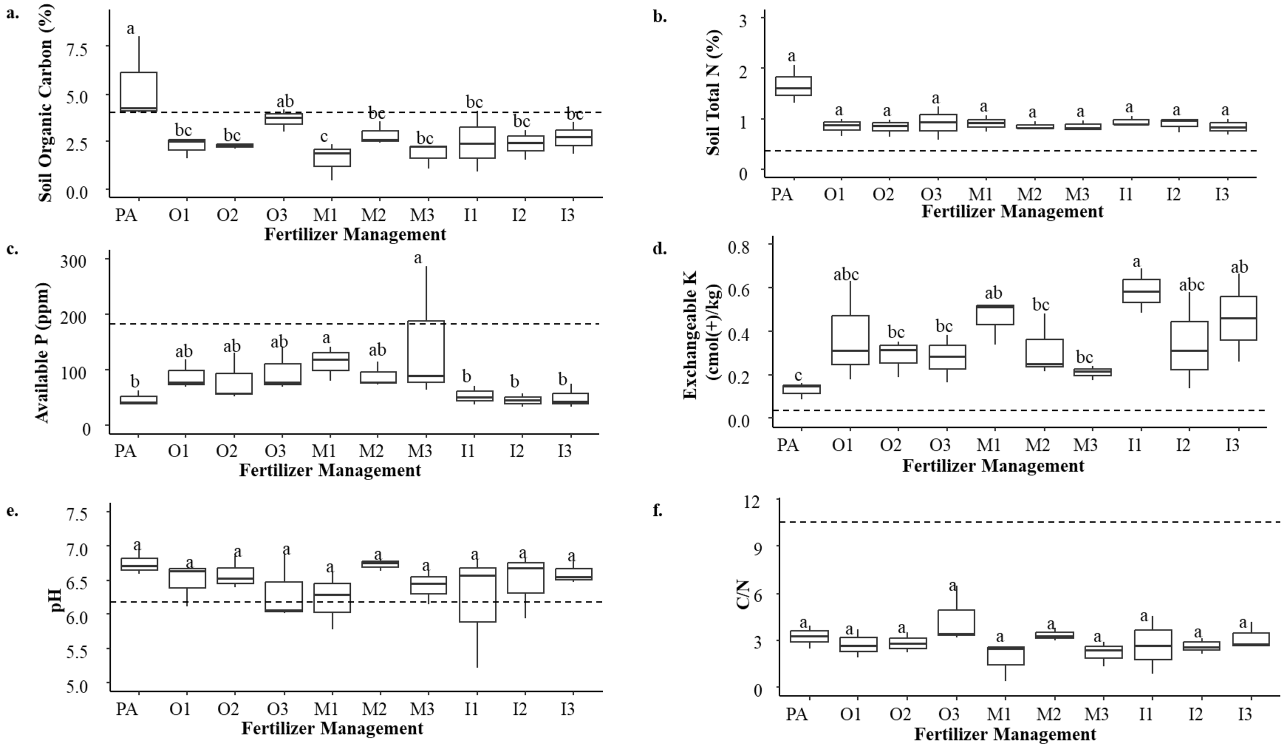

Figure 4. Fertilization management effect on soil organic carbon (a), soil total N (b), Available P (c), exchangeable K (d), pH (e), and C/N ratio (f). The dash line refers to initial condition, and different notation show significant difference through DMRT test at 5% level

microbial activity and the production of P-mineralizing enzymes (i.e., phosphatase and phytase), facilitating the transformation of organic P into plant-available forms (Luo *et al*., 2024). Organic complex from organic fertilizer also can inhibit P fixation, provide more P availability when combined with inorganic fertilizer that has fast-release characteristics (Howe *et al*., 2024).

Application inorganic fertilizer at a low dose (I1) showed the highest exchangeable K in this study (0.587 cmol(+)/kg), indicated that reduced in fertilizer dose tend to more effective in maintaining soil exchangeable K within coffee agroforestry system (Figure 4b). In addition, application the low dose of organic and mixed fertilizers had comparable soil exchangeable K with application of inorganic fertilizer (i.e., KCl). Chen *et al.* (2020) stated that organic matter increased cation exchange capacity (CEC), provided a sustained K release through biomass decomposition, ensuring better medium-term nutrient availability. This led to highest nutrient availability that we found in this study. The treatment of mixed fertilizer with high doses resulted in improving soil chemical properties, which generally showed values close to optimal conditions as found in protected areas (PA). This indicates that the fertilization strategy has the potential to support sustainable soil quality recovery in agroforestry systems.

In addition to fertilizer treatments, environmental conditions particularly rainfall intensity, canopy cover, and microclimate probably influenced soil chemical properties during the study. High cumulative rainfall (733.4 mm during the study period) potentially increased nutrient leaching, especially phosphorus and potassium, leading to lower nutrient retention in open canopy agroforestry systems. However, the previous study by Siahaan *et al.* (2025) who measured N leaching losses during the rainy season reported that N leaching losses among fertilizer management in coffee agroforestry systems within UB Forest was not significant different, indicated that rainfall was not predominant factor affecting N leaching in the research site. The relatively low canopy cover (16–31%) increased surface runoff and erosion risk, reducing carbon input from litterfall and promoting the loss of soil organic carbon through oxidation and microbial respiration. Consequently, these environmental factors may contribute to the variation in soil pH, C-organic, available

P, and C/N ratio, independent of the fertilizer types and doses applied. Therefore, nutrient dynamics in agroforestry systems cannot be fully explained by fertilizer inputs alone, but must also consider ecological processes shaped by climate and vegetation structure.

3.3. Soil Nutrient Stock

Our study revealed that the fertilizer treatment in coffee agroforestry increased soil N and K stocks, but decreased soil P stocks as compared to the initial condition. Protected area had 48–77% higher of soil N stock as compared to all fertilizer management treatment in coffee agroforestry. Interestingly, our study found that coffee agroforestry system managed by application of organic and mixed fertilizer (O and M) had 95–279% higher of soil P stock as compared to those in the protected areas (Figure 5b). Kurniawan *et al.* (2019) reported that soil N stock in coffee agroforestry systems within UB Forest on 2017 was 5 tons/ha, lower than current study. This was indicated that fertilizer management with coffee agroforestry systems increased soil N stock. Nevertheless, the N stock from all fertilizer plot was lower than those reported by Tinoco-Jaramillo *et al.* (2024) that reported soil N and K stocks in coffee agroforestry system was ranged from 360.0–205.2 tons/ha under mid-level conventional management, and 300.1–186.3 tons/ha under mid-level organic management due to the duration of the applied management. However, Tinoco-Jaramillo *et al.* (2024) found that agroforestry had higher K retention compared to the monoculture. This highlights the importance of increasing crop diversity within the systems.

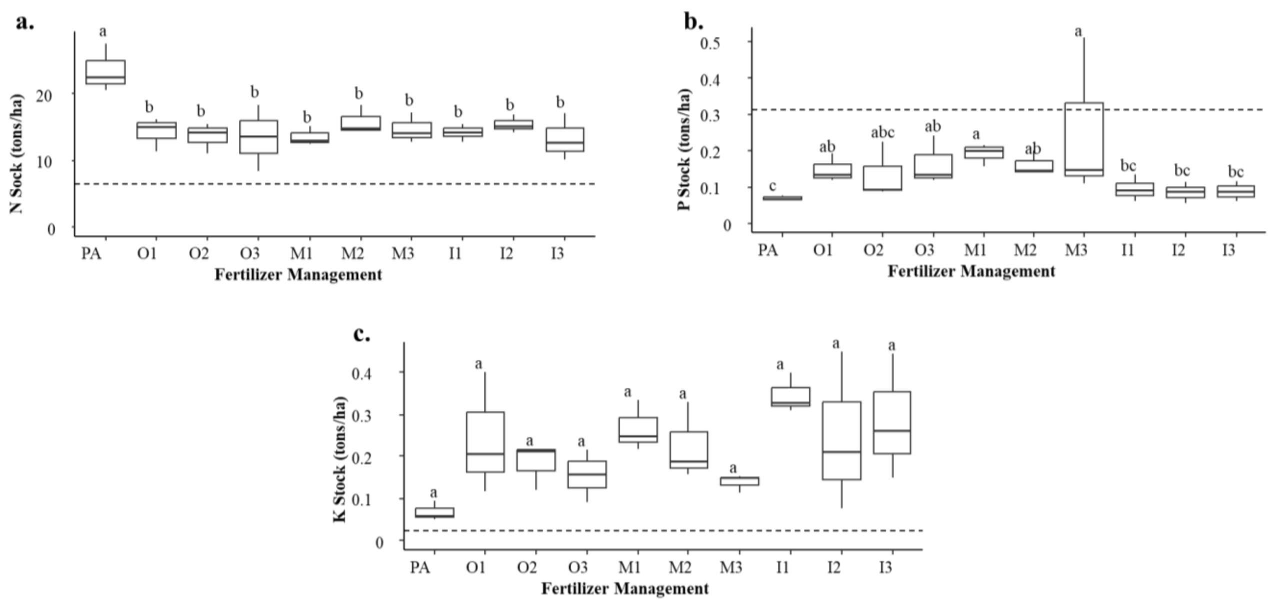

Figure 5. Fertilization management effect on N stock (a), P stock (b), K stock (c). The dash line refers to initial condition, and different notation show significant difference through DMRT test at 5% level

The incorporation of organic substances from fertilizers has been demonstrated to promote higher soil nutrient accumulation capacity, further amplified by the increased nutrient contribution from inorganic fertilizers. Organic matter improves soil structure and increases microbial activity. It also improves the soil's ability to retain nutrients by increasing its cation exchange capacity. This increase in nutrient storage occurs due to the improvement of soil structure, microbial activity, and nutrient retention through higher cation exchange capacity, which is affected by organic matter addition (Abdulraheem *et al.*, 2023). These effects allow nutrients to be stored in a more stable form, reducing nutrient losses and supporting long-term fertility. Inorganic nitrogen is readily available but susceptible to leaching, whereas organic nitrogen has a slow-release rate of mineralization that can be relied upon after application coupled with inorganic have enhanced plant uptake and reduced losses (Siahaan *et al.*, 2025).

The results showed that N, P and K nutrient stocks not only increased as a result of fertilization treatments, but were also able to match the level of nutrient stocks found in protected areas. This finding indicates that proper and balanced fertilizer management has great potential to improve soil fertility quality and increase nutrient availability in a sustainable manner. Thus, a fertilization strategy specifically designed according to the needs of the land and crop type can bring degraded soil conditions closer to a more stable and productive ecosystem condition, as reflected in areas with minimal intervention such as protected areas (PA).

3.4. Nutrient Concentration in the Coffee Leaf

Different fertilizer management tends to increase nutrient uptake by coffee trees, compared to the initial condition. Our study revealed that applying different fertilizer management significantly affect leaf N and K content (p-value ≥ 0.05). Application of inorganic fertilizer at the high doses (I3) showed a higher leaf N and K content (3.12 % and 0.22%, Figure 6) compared to the initial condition (0.16 % N and 0.00002 % K). However, reduce fertilizer dose application (O1 and M1) had comparable K concentration in the coffee leaf as compared to the high dose application of inorganic fertilizer (I3), indicated that reduced fertilizer dose effective to increase K uptake by plant.

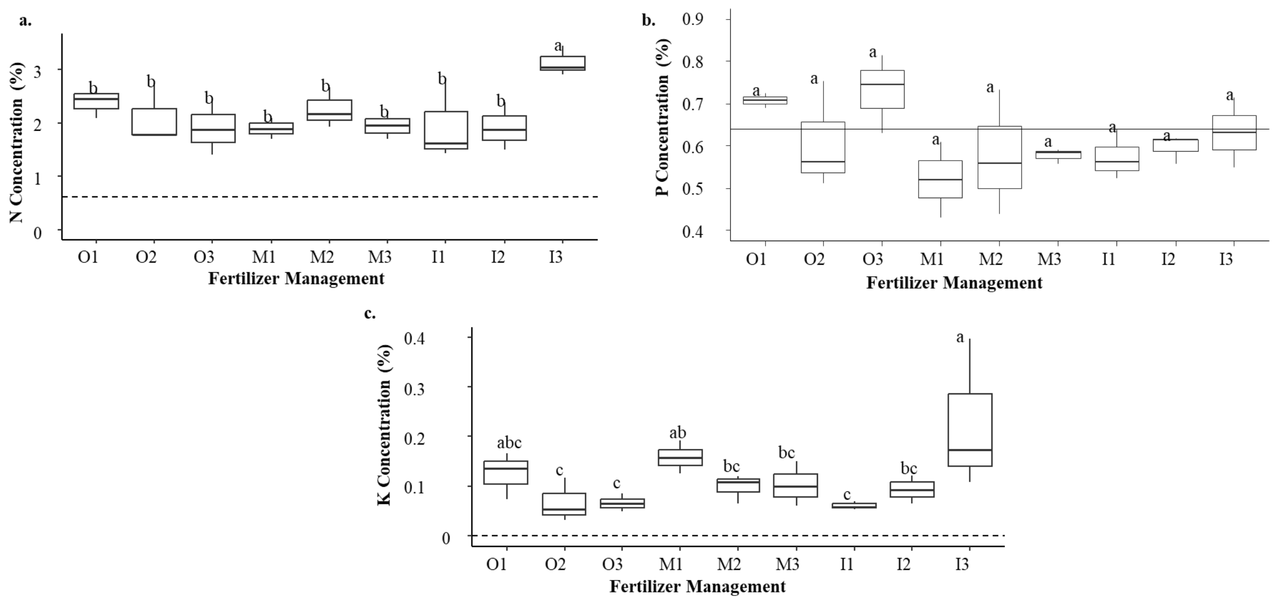

Figure 6. Fertilization management effect on N (a), P (b), and K (c) concentration in the leaf. The dash line refers to initial condition, and different notation show significant difference through DMRT test at 5% level

Ensuring favorable condition in the soil is essential for enhancing nutrient uptake by plant. Applying organic and inorganic fertilizer provides adequate nutrients for the coffee vegetative stages and minimizes nutrient losses. Nitrogen is essential for develop cell division and chlorophyll formation during the vegetative stages of coffee trees (Fathi, 2022). Nitrogen is also required for flowering to fertilization phase at balanced levels, along with phosphorus and potassium. Appropriate nitrogen application at this stage fosters metabolic activities, fortifies the growth of flower and fruit tissues, and assists in the full maturation of coffee beans (Leghari *et al*., 2016). Phosphorus promotes early root formation and energy transfer processes that are essential for rapid vegetative expansion (Liu, 2021). Potassium contributes to cell turgor regulation, enzyme activation and assimilate transport, thereby strengthening overall plant resistance and stress tolerance (Wang *et al*., 2013). In addition, potassium plays crucial role in flower retention, fruit development and sugar translocation, which ultimately affects seed size and quality (Johnson *et al*., 2022).

3.5. Interaction Effects of Fertilizer Type and Dose on Soil Fertility

Our research confirmed that incorporating organic matter into fertilizer management improved soil fertility. The presence of organic fertilizer can improve soil fertility faster than litter because it has gone through a composting process, which breaks down organic matter and releases nutrients that can improve soil quality (Martínez-García *et al*., 2021). Applying organic fertilizer cause more readily nutrient source for microbial community, altering litter decomposition and nutrient mineralization (Dincă *et al*., 2022). Increasing soil organic carbon directly increase soil total N and N stocks (Figure 7). The presence of organic fertilizer accelerates the process of N mineralization in soil by providing a source of energy for microorganisms (Siahaan *et al*., 2025). Microorganisms, mainly heterotrophic bacteria and fungi, decompose complex organic compounds into ammonium (NH_4^+) through ammonification, which is then converted into the more plant-available form of nitrate NO_3^- (Kessel *et al*., 2015).

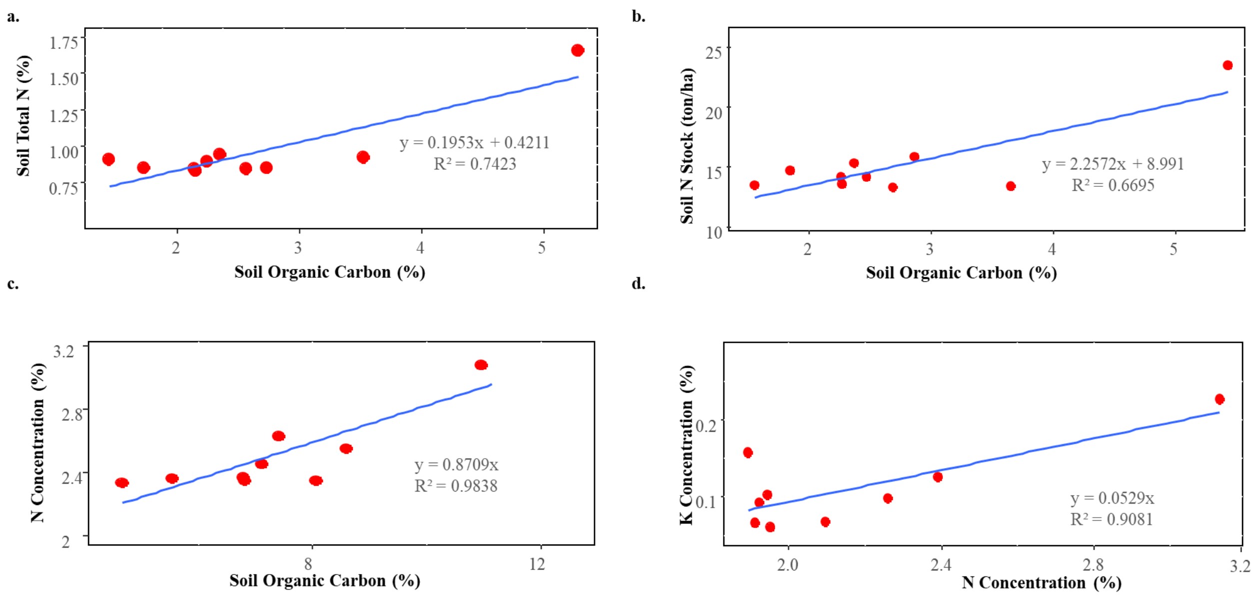

Figure 7. Correlation between soil Organic Carbon and soil Total N (a), Soil Organic Carbon and soil N Stock (b), Soil Organic Carbon and total N in the leaf (c), total N and total K in the leaf (d)

Our study also revealed that the condition of N in the soil directly impacts other nutrients. This study showed that increased leaf nitrogen (N) content increases protein synthesis and photosynthesis, thereby increasing the metabolic activity of the plant (Fathi, 2022). In response, potassium supports this demand by regulating stomatal function, enzyme activation, and transport of nitrogenous compounds (Wang *et al*., 2013). Consequently, higher N levels in leaves typically indicate increased K content to maintain physiological balance and nutrient efficiency.

Further, mixed fertilizer with medium dose (M2) produced comparable results to those of protected areas, making it the most effective and efficient management compared to the other fertilizer treatments. These treatments provide a balance between improving soil physical properties (bulk density & porosity), Organic Carbon content, and availability of key nutrients. Medium dose applications serve in avoiding the drawbacks of high dose applications, such as nutrient leaching and gas losses, while outperforming low dose treatments that may not be sufficient to support optimal plant growth (Du *et al*., 2021). The use of blended fertilizers (organic and inorganic fertilizer) offers synergistic benefits, ensuring a steady nutrient supply, enhancing soil health, and supporting sustainable productivity. Thus, applying a mixed fertilizer at a medium dose could be a proper management approach for general coffee agroforestry systems.

4. CONCLUSION

Different fertilizer management show significantly affected to soil physicochemical such as soil organic C, available P, exchangeable K, soil N stock and soil P stocks, also leaf N and K content. We also highlighting that the reduced fertilizer dose in the mixed fertilizer application (M1 = low-dose mixed) was effective in maintaining soil fertility, nutrient availability, and nutrient content. These results confirm that integrated fertilization offers the best strategy to sustain soil fertility, promote microbial activity, and support long-term agroecosystem productivity.

ACKNOWLEDGEMENT

This research was partially funded by Doctoral research grant 2024 (No. 03644.1/UN1.F0401/B/KS/2024). The author thanks to UB forest management for providing research site and technician of Soil Chemical Laboratory, Soil Science Department, Faculty of Agriculture, Universitas Brawijaya for laboratory analysis.

REFERENCES

Abdullah, N., Inayah, A.N., & Ramadan, L.O.M.A. (2024). Pemupukan Presisi berbasis peta nutrisi: analisis sebaran N, P, dan K pada lahan kopi di Kabupaten Gowa. *Plantklopedia: Jurnal Sains dan Teknologi Pertanian*, ***4***(2), 1–15. https://doi.org/10.55678/plantklopedia.v4i2.1604

Abdulraheem, M.I., Hu, J., Ahmed, S., Li, L., & Naqvi, S.M.Z.A. (2023). Advances in the use of organic and organomineral fertilizers in sustainable agricultural production. In *Organic Fertilizers - New Advances and Applications [Working Title]*. IntechOpen. https://doi.org/10.5772/intechopen.1001465

Acar, M., Wahab, T.S., Kaya Karaca, Ö., Işık, M., Sariyev, A., & Ortaş, İ. (2025). Exposing how long-term organic and inorganic fertilizers affect the physical characteristics of soil. *Journal of Soil Science and Plant Nutrition*, ***25***, 5187–5201 https://doi.org/10.1007/s42729-025-02457-1

Aytenew, M., & Bore, G. (2020). Effects of organic amendments on soil fertility and environmental quality: A review. *Journal of Plant Sciences*, ***8***(5), 112. https://doi.org/10.11648/j.jps.20200805.12

Balai Penelitian Tanah. (2022). Sifat Fisik Tanah dan Metode Analisisnya. In Irawan, Maswar, R.D. Yustika, & R. Ariani (Eds.), *Balai Penelitian Tanah Balai Besar LITBANG Sumberdaya Lahan Pertanian Badan Penelitian dan Pengembangan Pertanian Kementrian Pertanian* (2nd ed.).

Balai Pengujian Standar Instrument Tanah dan Pupuk. (2023). Analisis Kimia Tanah, Tanaman, Air, dan Pupuk. In *Balai Besar Pengujian Standar Instrumen Sumberdaya Lahan Pertanian Kementrian Pertanian* (3rd ed.).

Bashir, O., Ali, T., Baba, Z.A., Rather, G.H., Bangroo, S.A., Mukhtar, S.D., Naik, N., Mohiuddin, R., Bharati, V., & Bhat, R.A. (2021). Soil organic matter and its impact on soil properties and nutrient status. *Microbiota and Biofertilizers,* ***2***, 129–159. Springer International Publishing. https://doi.org/10.1007/978-3-030-61010-4_7

BPS Kabupaten Malang. (2025). Kabupaten Malang Dalam Angka. In E.F. Setyoharini (Ed.), *Badan Pusat Statistik Kabupaten Malang* (Vol. 46). BPS Kabupaten Malang.

Brempong, M.B., & Addo-Danso, A. (2022). Improving soil fertility with organic fertilizers. In *New Generation of Organic Fertilizers,* ***1***(15). IntechOpen. https://doi.org/10.5772/intechopen.103944

Chen, S., Yan, Z., Ha, X., Qin, W., & Chen, Q. (2020). Combining application of chemical fertilizer with manure significantly increased potassium availability in an alkaline soil. *Nutrient Cycling in Agroecosystems*, ***116***(3), 285–298. https://doi.org/10.1007/s10705-019-10044-x

Dincă, L.C., Grenni, P., Onet, C., & Onet, A. (2022). Fertilization and soil microbial community: A review. *Applied Sciences*, ***12***(3), 1198. https://doi.org/10.3390/app12031198

Du, Q.-J., Xiao, H.-J., Li, J.-Q., Zhang, J.-X., Zhou, L.-Y., & Wang, J.-Q. (2021). Effects of different fertilization rates on growth, yield, quality and partial factor productivity of tomato under non-pressure gravity irrigation. *PLoS ONE*, ***16***(3), 1–10. https://doi.org/10.1371/journal.pone.0247578

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., & Poczai, P. (2022). Agroforestry systems for soil health improvement and maintenance. *Sustainability (Switzerland)*, ***14***(22), 14877. https://doi.org/10.3390/su142214877

Fathi, A. (2022). Role of Nitrogen (N) in plant growth, photosynthesis pigments, and N use efficiency: A review. *Agrisost*, ***28***, 1-8. https://doi.org/10.5281/zenodo.7143588

Fitria, A.D., Sudarto, S., & Kurniawan, S. (2021). Land-use changes and slope positions impact on the degradation of soil functions in nutrient stock within the Kalikungkuk Micro Watershed, East Java, Indonesia. *Journal of Degraded and Mining Lands Management*, ***8***(2), 2689–2702. https://doi.org/10.15243/jdmlm.2021.082.2689

Guo, Z., Han, J., Li, J., Xu, Y., & Wang, X. (2019). Effects of long-term fertilization on soil organic carbon mineralization and microbial community structure. *PLOS ONE*, ***14***(4), e0211163. https://doi.org/10.1371/journal.pone.0211163

Howe, J.A., McDonald, M.D., Burke, J., Robertson, I., Coker, H., Gentry, T.J., & Lewis, K.L. (2024). Influence of fertilizer and manure inputs on soil health: A review. *Soil Security*, ***16***, 100155. https://doi.org/10.1016/j.soisec.2024.100155

Johnson, R., Vishwakarma, K., Hossen, M.S., Kumar, V., Shackira, A.M., Puthur, J.T., Abdi, G., Sarraf, M., & Hasanuzzaman, M. (2022). Potassium in plants: Growth regulation, signaling, and environmental stress tolerance. *Plant Physiology and Biochemistry*, ***172***, 56–69. https://doi.org/10.1016/j.plaphy.2022.01.001

Kaur, A., Paruchuri, R. G., Nayak, P., Devi, K.B., Upadhyay, L., Kumar, A., Pancholi, R., & Yousuf, M. (2023). The role of agroforestry in soil conservation and sustainable crop production: A comprehensive review. *International Journal of Environment and Climate Change*, ***13***(11), 3089–3095. https://doi.org/10.9734/ijecc/2023/v13i113478

Kessel, M.A.H.J.van, Speth, D.R., Albertsen, M., Nielsen, P.H., Camp, H.J.M.O.den, Kartal, B., Jetten, M.S.M., & Lücker, S. (2015). Complete nitrification by a single microorganism. *Nature*, ***528***(7583), 555–559. https://doi.org/10.1038/nature16459

Kurniawan, S., Nugroho, R.M.Y.A.P., Ustiatik, R., Nita, I., Nugroho, G.A., Prayogo, C., & Anderson, C.W.N. (2024). Soil nitrogen dynamics affected by coffee (*Coffea arabica*) canopy and fertilizer management in coffee-based agroforestry. *Agroforestry Systems*, ***98***(6), 1323–1341. https://doi.org/10.1007/s10457-024-01004-8

Kurniawan, S., Utami, S.R., Mukharomah, M., Navarette, I.A., & Prasetya, B. (2019). Land use systems, soil texture, control carbon, and nitrogen storages in the forest soil of UB Forest, Indonesia. *AGRIVITA Journal of Agricultural Science*, ***41***(3), 1–2. https://doi.org/10.17503/agrivita.v41i3.2236

Leghari, S.J., Wahocho, N.A., Laghari, G.M., Laghari, A.H., Bhabhan, G.M., Talpur, K.H., Bhutto, T.A., Wahocho, S.A., & Lashari, A.A. (2016). Role of nitrogen for plant growth and development: A Review. *Advances in Environmental Biology*, ***10***(9), 209–218.

Liu, D. (2021). Root developmental responses to phosphorus nutrition. *Journal of Integrative Plant Biology*, ***63***(6), 1065–1090. https://doi.org/10.1111/jipb.13090

Luo, X., Elrys, A.S., Zhang, L., Ibrahim, M.M., Liu, Y., Fu, S., Yan, J., Ye, Q., Wen, D., & Hou, E. (2024). The global fate of inorganic phosphorus fertilizers added to terrestrial ecosystems. *One Earth*, ***7***(8), 1402–1413. https://doi.org/10.1016/j.oneear.2024.07.002

Martínez-García, L.B., Korthals, G.W., Brussaard, L., Mainardi, G., & De Deyn, G.B. (2021). Litter quality drives nitrogen release, and agricultural management (organic vs. conventional) drives carbon loss during litter decomposition in agro-ecosystems. *Soil Biology and Biochemistry*, ***153***, 108115. https://doi.org/10.1016/j.soilbio.2020.108115

Nugroho, R.M.Y.A.P., Ustiatik, R., Prasetya, B., & Kurniawan, S. (2023). Response of different coffee-based agroforestry management on microbial respiration and density. *Journal of Ecological Engineering*, ***24***(9), 158-170. https://doi.org/10.12911/22998993/169179

Nurcholis, O., Nugroho, G.A., Nugroho, R.M.Y.A.P., Prayogo, C., & Kurniawan, S. (2024). Trees and soil management impacts on soil nutrient and coffee production in coffee-based agroforestry. *IOP Conference Series: Earth and Environmental Science*, ***1299***(1), 0–9. https://doi.org/10.1088/1755-1315/1299/1/012003

Parveen, A., Ashraf, M.A., Hussain, I., Perveen, S., Rasheed, R., Ebadi, A.G., & Thind, S. (2022). Potential of inorganic fertilizers for sustainable development in agriculture. In Q. Mahmood (Ed.), *Sustainable plant nutrition under contaminated environments* (pp. 41–55). Springer https://doi.org/10.1007/978-3-030-91499-8_3

Ridwan, Wardah, & Ariani, D. (2020). Kombinasi Pupuk organik dan anorganik untuk optimalisasi produksi dan kandungan nutrisi umbi taka. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy)*, ***48***(2), 150–156.

Rohani, R.T.S., Prayogo, C., Suprayogo, D., & Wicaksono, K.S. (2024). The effect of coffee canopy pruning and fertilization on coffee growth and soil physical properties. *Journal of Applied Agricultural Science and Technology*. ***8***(1), 29-49. https://doi.org/10.55043/jaast.v8i1.208

Rowe, R.L., Prayogo, C., Oakley, S., Hairiah, K., van Noordwijk, M., Wicaksono, K.P., Kurniawan, S., Fitch, A., Cahyono, E.D., Suprayogo, D., & McNamara, N.P. (2022). Improved coffee management by farmers in state forest plantations in Indonesia: An experimental platform. *Land*, ***11***(5), 671. https://doi.org/10.3390/land11050671

Sakiroh, S., & Aunillah, A. (2020). Shape, size and density of five leaves stomata of the arabica variety coffee (*Coffea arabica* L.). In S. Herlinda et al. (Eds.), *Prosiding Seminar Nasional Lahan Suboptimal ke-8 Tahun 2020, Palembang, 20 Oktober 2020* (pp. 940-947). Palembang: Penerbit & Percetakan Universitas Sriwijaya (UNSRI).

Saraswati, R., & Praptana, R.H. (2017). Percepatan proses pengomposan aerobik menggunakan biodekomposer. *Perspektif,* ***16***(1), 44–57.

Siahaan, A.Z.A., Prasetya, B., Nugroho, R.M.Y.A.P., & Kurniawan, S. (2025). Nitrogen balance in coffee-based agroforestry system: an impact of fertilization management. *Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering)*, ***14***(1), 283-295. https://doi.org/10.23960/jtep-l.v14i1.283-295

Solanki, V.K., Meena, R.K., Parte, V., & Kumari, T. (2024). Nutrient acquisition in agroforestry ecosystem services and soil health. In H.S. Jatav, V.D. Rajput, T. Minkina, E.D. Van Hullebusch, & A. Dutta (Eds.), *Agroforestry to combat global challenges* (Sustainable Development and Biodiversity, Vol. 36). Springer. https://doi.org/10.1007/978-981-99-7282-1_9

Tinoco-Jaramillo, L., Vargas-Tierras, Y., Paredes-Arcos, F., Viera, W., Suárez-Tapia, A., Vargas-Tierras, T., Suárez-Cedillo, S., Morales-León, V., & Vásquez-Castillo, W. (2024). Nutrient contribution and carbon sequestration of an agroforestry system of *Coffea canephora* cultivated by conventional and organic management in the Ecuadorian Amazon. *Forests*, ***15***(5), 807. https://doi.org/10.3390/f15050807

Titirmare, N.S., Ranshur, N.J., Patil, A.H., Patil, S.R., & Margal, P.B. (2023). Effect of inorganic fertilizers and organic manures on physical properties of soil: A Review. *International Journal of Plant & Soil Science*, ***35***(19), 1015–1023. https://doi.org/10.9734/ijpss/2023/v35i193638

Ugwuoke, C.U., Omeje, B.A., & Eze, G.E. (2024). Consequences of excessive application of agricultural chemicals on the sustainable environment and food security. *International Journal of Agriculture and Environmental Research*, ***2***(1), 100–108.

Wang, M., Zheng, Q., Shen, Q., & Guo, S. (2013). The critical role of potassium in plant stress response. *International Journal of Molecular Sciences*, ***14***(4), 7370–7390. https://doi.org/10.3390/ijms14047370