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Nitrogen Balance in Coffee-Based Agroforestry System: An Impact of Fertilization Management

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ABSTRACT

Nitrogen (N) fertilization in coffee agroforestry system requires proper management to increase N use efficiency (NUE) and minimize N losses. This study investigated the impact of different fertilization management on N losses, N uptake, and N storage in a coffee-based agroforestry system. The study was conducted using three types of fertilizer (organic, inorganic, and mixture of organic-inorganic) with three doses (low, medium, and high), and a control treatment (no fertilization), with 3 replications. Soil leachate was collected using lysimeter at 50 cm depth (below coffee root zone) and gas emissions were collected monthly using chamber for 4 months. Soil sample at 0-20 cm depth and leaf sample were also collected. The variables included NH_4^+ *and* NO_3^- *concentration in the leachate and soil, soil N total, N uptake, N emission, N use efficiency (NUE) and partial N balance. Results showed no significant differences in N leaching or plant N uptake across treatments. However, the mixed fertilizer with high dose treatment significantly increased soil N availability while reducing* N_2O *emissions and improving the overall N balance. This suggests that a high dose mixed fertilizer application can enhance N utilization in coffee-based agroforestry systems, potentially improving productivity while minimizing environmental impacts.*

1. INTRODUCTION

Coffee is a leading commodity developed in Indonesia, especially in the East Java region, which has suitable topographic and climatic conditions for coffee cultivation (Oktasari, 2014). The amount of coffee production in East Java was 45,914 tons in 2021 and 45,812 tons in 2022 (Supriyati, 2023). Coffee cultivation is generally carried out using an agroforestry system where coffee is planted under the shade tree (i.e., pine, mahogany, etc.). Agroforestry that focuses on coffee plants provides various benefits, such as soil and water conservation, supporting biodiversity, increasing soil nutrients, and controlling pests and diseases (Supriadi & Pranowo, 2015; Kurniawan *et al*., 2024). Coffee plants require sufficient nutrients to support their growth and production, especially nitrogen. Nitrogen is the main nutrient required by coffee plants, with nitrate and ammonium being the most important inorganic sources for N uptake (Santos *et al*., 2017). Nitrogen availability has a pivotal role for coffee plants in their vegetative growth because it can stimulate flowering (Sitinjak *et al*., 2022).

However, the effect of fertilization management on N balance has not been studied further in the coffee agroforestry system at UB Forest. Fertilization management in Coffee-Pine agroforestry systems within Universitas Brawijaya (UB) Educational Forest affects production yields as reported by Sudharta *et al*. (2022), that coffee production can be increased by management in the form of additional nitrogen fertilizer because there is limited N in coffee agroforestry system plots that are not applied fertilizer treatment. Fertilization management in coffee agroforestry systems also shows larger N pools in the system compared to coffee agroforestry systems without fertilization management (Tully *et al*., 2013). Finding appropriate fertilizer management is essential for enhancing nutrient availability as a part of ecosystem services. Bruno *et al*. (2015) stated that determining the proper fertilizer dose can improve N availability due to enhancing N recoveries and decrease N losses, compared to the highest dose of N fertilizer. Further, the current research showed that fertilizer type and dose in coffee agroforestry systems impact on soil N concentration and N uptake. Such as finding by Kurniawan *et al*. (2021) shows that application of N fertilizer increased N availability in soil.

Managing coffee under agroforestry management based on N requirements could be beneficial for improving potential and actual yield. Kim & Isaac (2022) stated that agroforestry systems show complex N dynamics, where N inputs from fertilization and organic matter have a relationship with N losses through erosion, runoff, leaching, and gas emissions. Nutrients input (i.e., fertilization or other organic matter inputs, bulk precipitation) and output (i.e., leaching, emission, harvest export) can help determine nutrient requirements and management for coffee cultivation. Informing the current nutrient status through nutrient balance can be useful for determining appropriate fertilization management, helping to avoid imbalanced practices that may negatively affect nutrient balance (Gezie *et al*., 2024; Rawal *et al*., 2022). Therefore, this study was conducted to analyze the impact of fertilizer management on soil N available, N losses (i.e., leaching, emission), and N uptake in coffee agroforestry systems. Different fertilizer types and doses are assumed to have varying effects on N balance components, N losses (leaching and emissions), soil N content (total and available N), N uptake, and N use efficiency in the UB Forest coffee agroforestry system.

2. MATERIALS AND METHODS

2.1. Research Location

The research was conducted from February to June 2024 at the UB Forest located in Sumberwangi Hamlet, Tawangargo Village, Karangploso District, Malang Regency (Figure 1). The mineralization process of releasing N from inorganic fertilizer could take up weeks up to 4 months, the same for the decomposition of organic matter input (Chen *et al*., 2014). Therefore, we conducted a four-month study coinciding with the vegetative phase or seed formation of coffee plants, beginning at the end of the rainy season to assess the dissolution of applied fertilizers in the soil. The average rainfall during the research was 162.2 mm/month and average air temperature 24.6 ºC (BMKG, 2024). The research site is an upland area with a mean elevation of 1,122 m and soil type is Inceptisol (Kurniawan *et al*., 2019; Putri, 2019). Based on analysis results, the soil texture of the research site is classified as silty clay.

2.2. Research Method

The research was conducted using a Randomized Block Design, including 10 treatments and 3 replications. The allocation of treatments to plots within each block is determined randomly, typically using a random number generator or a physical randomization method like drawing lots (Akib, 2014). The replications provide a larger dataset, which enhances the statistical power of the analysis. This allows for more accurate estimates of the effects being studied (Akib, 2014). The control treatment was no fertilization, and the other 9 consisted of combination of fertilizer types (organic, inorganic, mixed organic-inorganic) and doses (low, medium, and high), as summarized in Table 1. The organic fertilizer was chicken manure containing 1.49% N, 2.91% P_2O_5, 2.57% K_2O (Nugroho *et al*., 2023). The inorganic fertilizers included Urea, SP-36 (36% P_2O_5), and KCl (60% K_2O) fertilizers, and mixed fertilizer consisted of 50% organic and 50% inorganic fertilizers. The low dose (D1) referred to nutrient loss from coffee bean harvest, medium dose (D2) referred to farmer, and high dose (D3) was based on the recommendation from Indonesian Coffee and Cacao Research Institute. The dose category was based on the N content in each fertilizer (Rowe *et al*., 2022).

2.3. Soil Sampling

Soil samples were collected before fertilizer application and four months after fertilizer application on coffee plants. Soil samples were taken in the rooting area of coffee plants according to the effective depth of coffee rooting 50 cm deep (Figure 2a). Sampling is done within 50 cm radius since it shows the result of nutritional management added to coffee plant (Schmidt *et al*., 2022). Analysis of soil sample observation parameters included N-Total by Kjeldahl method, soil ammonium by phenate method, and soil nitrate by brucine method (BPSI, 2023).

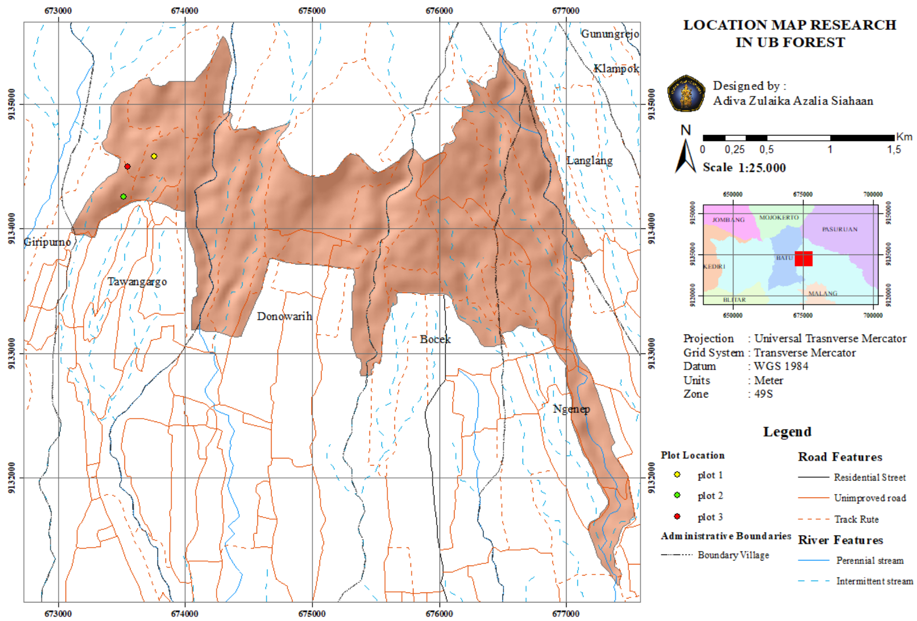

Figure 1. Research location map of UB Forest

Table 1. Combination treatment of fertilizer types and doses (g/tree)

	Fertilization Management									
Code	K	OD1	OD2	OD3	AD1	AD2	AD3	MD1	MD2	MD3
Description	Control	Organic low	Organic medium	Organic high	Inorganic low	Inorganic medium	Inorganic high	Mixed low	Mixed medium	Mixed high
Chicken manure	--	4322	4846	9261	--	--	--	2161	2423	4630
Urea	--	--	--	--	140	157	300	70	78.5	150
SP-36	--	--	--	--	72	59	160	36	29.5	80
KCl	--	--	--	--	157	42	200	78.5	21	100

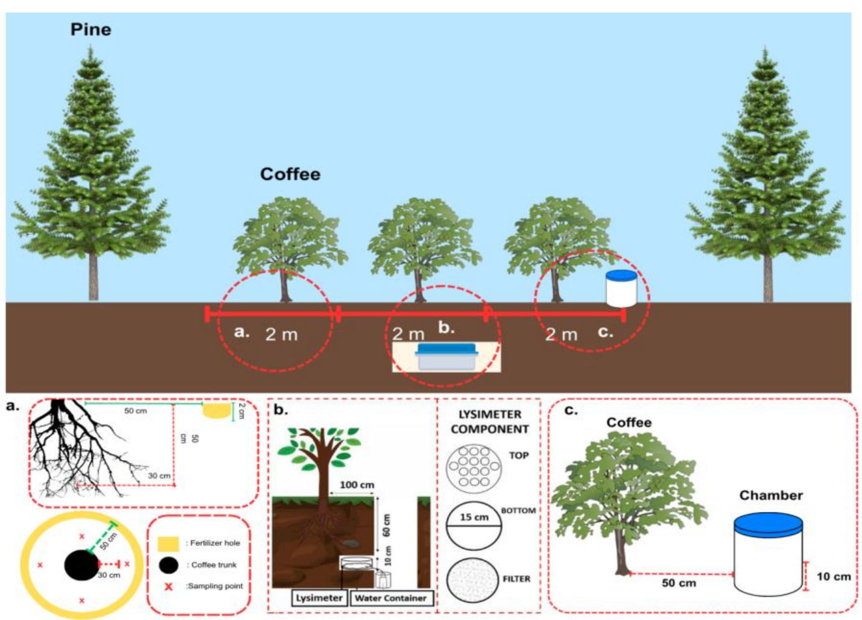

Figure 2. Illustration for: (a) Soil sampling, (b) Lysimeter, and (c) Gas sampling

2.4. Nitrogen Leaching Measurement

Nitrogen loss through leaching was measured by collecting soil solution samples using lysimeter. The lysimeter was made from pipe with a diameter of 15 cm and a height of 10 cm. The lysimeter was placed at a depth of 50 cm and a hose was attached to connect it with container (Figure 2b). Soil solution was collected once per month for a period of four months of observation. Analysis of observational parameters of soil solution samples including ammonium content using the indophenol blue method and nitrate concentration using the UV method. The results of the ammonium and nitrate concentration measurements were then used to calculate N leaching (*NL*) to assume the leached N in the area within UB Forest using the equation (1) by Naik *et al*. (2021):

$$NL = \frac{NC \times WV}{LS} \times 10^{-2} \tag{1}$$

where *NC* is N content in leachate (mg/L), *LS* is lysimeter surface area (m²), and *WV* is water volume in the lysimeter (L).

2.5. Nitrogen Emission Measurement

Gas emission samples were taken using a chamber. The gas chamber size is 25 cm x 25 cm x 15 cm and placed flat about 10 cm in the ground with 50 cm distance from the coffee trunk (Figure 2c). Gas emission sampling was conducted once per month during the four-month observation period. N_2O gas measurements were carried out using the gas chromatography method. The gas measurement results were then used to measure the flux F ($mg.m^{-2}.min^{-1}$) in order to predict the N loss from emission using the following equation (Shang *et al*. (2016).

$$F = \frac{dc}{dt} \times \frac{M}{V_0} \times \frac{P}{V_0} \times \frac{T_0}{T} \times \frac{Vch}{Ach} \tag{2}$$

where *dc* is gas concentration (ppm), *dt* is measurement duration (h), *M* is gas molecular weight (kg), V_0 is gas molecular volume (m^3), *P* is actual pressure (kPa), P_0 is standard pressure (kPa), T_0 is standard gas temperature (273 K), *T* is actual temperature (K), *Vch* is chamber volume (m^3), and *Ach* is chamber surface area (m²).

2.6. Nitrogen Uptake Measurement

Biomass sampling included litter, pruning residue, weeding residue, and coffee yield. Samples were taken at five points around the coffee plant using a 50 cm x 50 cm frame and then composited. Coffee plant biomass samples were taken before fertilizer application and four months after fertilizer application on coffee plants. Biomass samples were then used for N uptake analysis using the Kjeldahl method. Biomass sampling was followed by the measurement of coffee tree diameter at breast height (DBH) at around 120 cm above ground. The dry weigh of coffee tree biomass (*DW*) was calculated according to Suprayogo *et al*. (2020) as the following.

$$DW = 0.281 \times DBH^{2.06} \tag{3}$$

The biomass and nitrogen content in plant *NCp* (%) were then used to calculate the N uptake (*NUp*) as the following:

$$NUp = \left(\frac{NCp}{100}\right) \times DW \tag{4}$$

2.7. Calculation of Nitrogen Use Efficiency

Nitrogen use efficiency (NUE) was used to determine the efficiency of each fertilization management. NUE was measured using the data from plant N uptake. NUE was calculated according to Moll *et al*. (1982), as the following:

$$NUE = \left(\frac{Nf - Nc}{Ns}\right) \times 100 \tag{5}$$

where *Nf* and *Nc* is respectively N uptake (kg/ha) with fertilizer and control, *Ns* is N content in the fertilizer (kg/ha).

2.8. Calculation of Nitrogen Balance

Nitrogen balance was calculated by subtracting the amount of nitrogen lost from the soil through outputs and changes in storage from the amount of nitrogen added to the soil through inputs. N inputs comes from fertilization, irrigation, biological N fixation, soil N mineralization, atmospherical N deposition, crop seeds, and non-symbiotic N fixation, while the outputs by volatilization, crop grain N removal, denitrification, emission, leaching, runoff, and N loss during plant senescence (Sainju, 2019). Nitrogen balance (Nb) was calculated as the following (Sainju, 2017):

$$Nb = X - Y - Z \quad (6)$$

where X is N inputs (kg/ha), Y is N outputs (kg/ha), and Z is changes in soil total N (kg/ha). In this calculation, the amount of fertilizer applied are recognized as N input, meanwhile the N output is derived from N leaching, N emission, and N uptake. The changes in soil total N is the subtraction of soil total N after and before fertilization.

2.9. Data Analysis

The data that has been obtained is tested for normality of data distribution using the Shapiro-Wilk Test. Data that have been spread normally are then analyzed for diversity with Analysis of Variance (ANOVA) at the 5% level. The analysis was continued with the Duncan Multiple Range Test (DMRT) test to analyze differences between treatments. The relationship among different parameters was examined using principal component analysis (PCA).

3. RESULTS AND DISCUSSION

3.1. Nitrogen Leaching

Different fertilization management did not have significant effect on NH_4^+ and NO_3^- leaching during four months after fertilization (Figure 3), which is thought to be due to the soil texture. Similar result by Kurniawan *et al*. (2018) also show that soil texture is the main factor that regulates the loss of nutrients due to leaching. This study was conducted in UB Forest which had Inceptisol soil type with clay loam texture, causing the ability to retain soil moisture and nutrient. Silt and clay textured soil has the ability to regulate N leaching by reducing the number of soil macropores, increasing water retention, therefore it could ensure water availability and N supply in soil for plant growth (Zhang *et al*., 2017). Reduced leaching rate will affect the N availability, N content will be available within the crop root-zone and can be taken up by the plant (Lu *et al*., 2021). We propose that N loss was not occurred due to leaching. However, the N_2O emission contribute more to the N loss.

3.2. Nitrogen Emission

Our findings show that N_2O emission are significantly affected by fertilization management (Figure 4). Mixed fertilizer with high dose has 37.62% lower N_2O emission compared to organic fertilizer treatment with low dose (OD1) which is the highest emission in this study. This value indicates that fertilizer management (MD3) is able to withstand emissions compared to other fertilizer management. The combination use of organic and chemical fertilizers can reduce N_2O emissions compared to the use of chemical fertilizers alone (Yu *et al*., 2023). Changes in fertilization

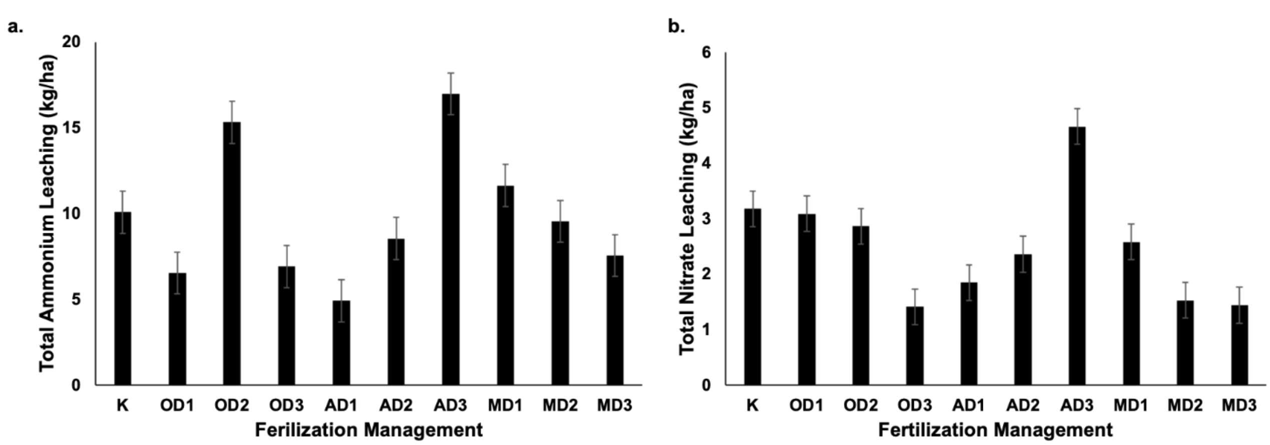

Figure 3. Total Ammonium (a) and Nitrate (b) Leaching (Note: Written codes are combinations of fertilizer type and dose. Treatment Factors: Fertilizer type (O: Organic, A: Inorganic, M: 50% organic+50% inorganic), and Fertilizer dose (D1: Low, D2: Medium, D3: High).

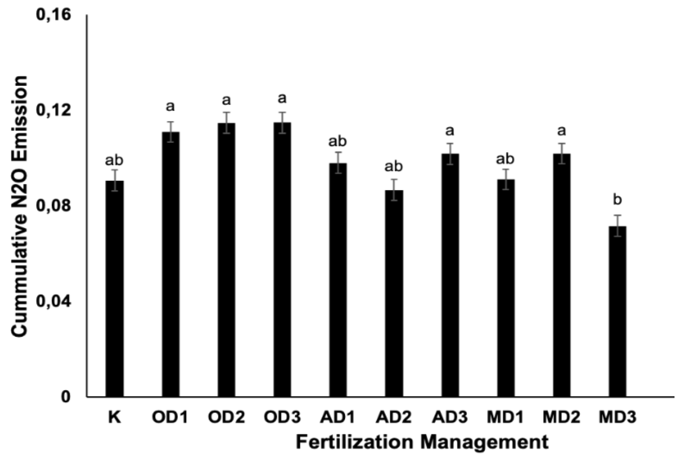

Figure 4. Gas emission as N_2O (Note: The data are significantly different based on DMRT. Codes are combinations of fertilizer type (O: Organic, A: Inorganic, M: 50% organic+50% inorganic), and dose (D1: Low, D2: Medium, D3: High).

management has an important effect on N_2O emissions. Wang *et al*. (2021) stated that fertilizers affect the mass of N_2O emissions mainly due to the different amounts of NH_4^+ and NO_3^- contained in them. Higher amounts of NH_4^+ and NO_3^- from fertilization enhance N_2O emissions as it is derived from the nitrification, denitrification, and dissimilatory nitrate reduction to ammonium (Yu *et al*., 2023). Applying organic fertilizer along with inorganic fertilizer in the management could help mitigate N loss. This is due to the organic fertilizer characteristics that can releasing organic acid, helps to prevent nutrient volatilization (Yang *et al*., 2020). Applying organic matter into the soil also decrease N loss by enhancing the N availability and transform the soil characteristic in order to improve nutrient retention (Liu *et al*., 2021). Therefore, it support our findings that mixed fertilizer with high dose could withstand emission better.

3.3. Soil N Total

Nitrogen pool in the soil (total N, NH_4^+, and NO_3^-) were significantly affected by fertilization management. The highest total N was found in the mixed fertilizer treatment with medium dose (MD2) (Figure 5). The soil N total is higher by 37.75% than the lowest value in organic fertilizer treatment with high dose (OD3). The use of inorganic fertilizers mixed with organic fertilizers affects the total N content in the soil. Total N in the soil comes from the mineralization of organic matter, so the addition of organic fertilizers together with inorganic fertilizers, especially with N content, can increase the total N content in the soil (Syamsiyah *et al*., 2023).

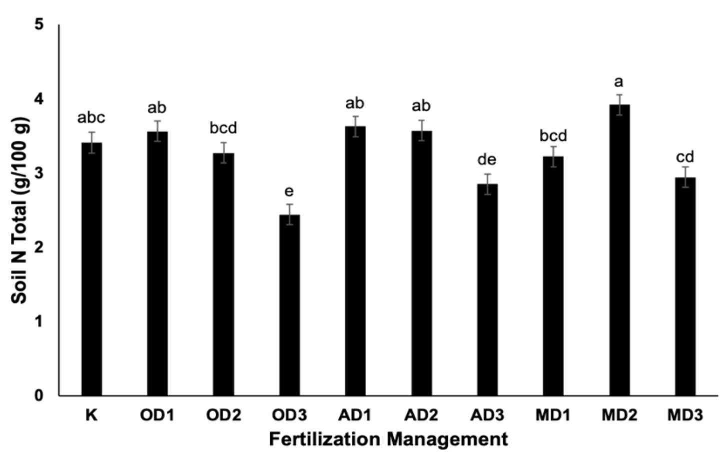

Figure 5. Soil N Total (Note: The data are significantly different based on DMRT. Codes are combinations of fertilizer type (O: Organic, A: Inorganic, M: 50% organic+50% inorganic), and dose (D1: Low, D2: Medium, D3: High).

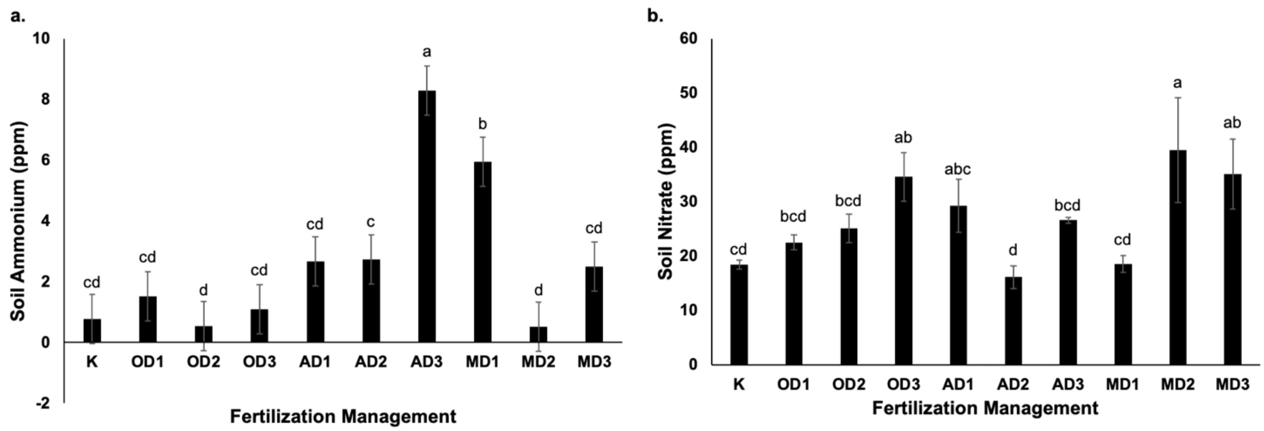

Figure 6. Soil N in form: (a) Ammonium, and (b) Nitrate (Note: The data are significantly different based on DMRT. Codes are combinations of fertilizer type (O: Organic, A: Inorganic, M: 50% organic+50% inorganic), and dose (D1: Low, D2: Medium, D3: High).

3.4. Soil N Availability

The ammonium and nitrate contents in the soil are directly proportional, a decrease in ammonium levels in the soil is followed by an increase in nitrate levels due to the change in the form of ammonium to nitrate through the nitrification process (Maulinda *et al*., 2017). It is aligned with our findings that the lowest ammonium value was found in the mixed fertilizer treatment with medium dose (MD2), where the treatment also had the highest nitrate content (Figure 6). The MD2 nitrate value is higher by 59.21% than the lowest value in inorganic fertilizer treatment with medium dose (AD2). The application of mixed chemical and organic fertilizers affects the available N in the soil. Chemical fertilizers combined with organic fertilizers can effectively increase the available N content (Bachtiar *et al*., 2020).

3.5. Nitrogen Uptake

The generative phase of coffee plants typically occurs from January to April (Unigarro *et al*., 2023). This further support our result that there is no significant difference between fertilizer management towards N uptake (Figure 7) because this study was conducted during the generative phase. Adequate N supply during the vegetative stage enhances biomass production, photosynthetic efficiency, and overall plant health, which are essential for subsequent stages of growth and yield (Bote *et al*., 2018). Nitrogen (N) uptake is influenced by the available N content in the soil. Balanced fertilization management aimed to meet the specific nutrient requirements of the plants, is essential for optimizing N uptake (Yuniarti *et al*., 2019).

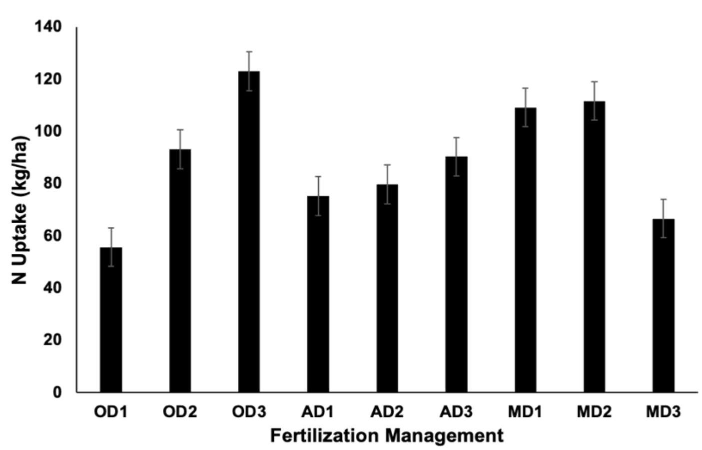

Figure 7. Nitrogen Uptake (Note: Written codes are combinations of fertilizer type and dose. Treatment Factors: Fertilizer type (O: Organic, A: Inorganic, M: 50% organic+50% inorganic), and Fertilizer dose (D1: Low, D2: Medium, D3: High).

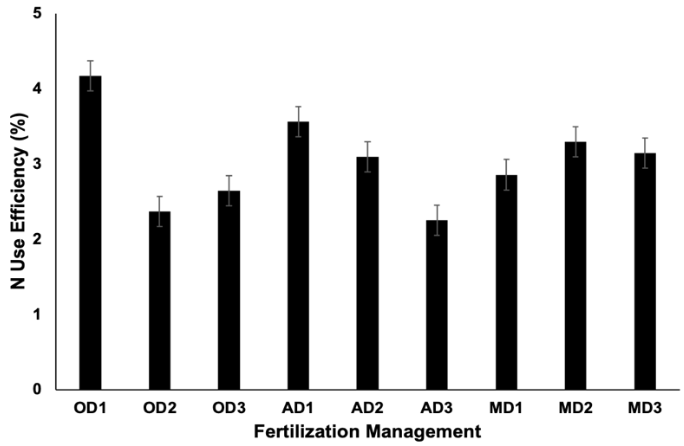

Figure 8. Nitrogen Use Efficiency (Note: Written codes are combinations of fertilizer type and dose. Treatment Factors: Fertilizer type (O: Organic, A: Inorganic, M: 50% organic+50% inorganic), and Fertilizer dose (D1: Low, D2: Medium, D3: High).

3.6. Nitrogen Use Efficiency

Fertilization management shows no different impact towards the Nitrogen Use Efficiency (NUE) (Figure 8). N fertilization only contributes less than 25% of N for coffee plants, which can occur because coffee plants have absorbed available N from fertilization residues in previous years (Bruno *et al*., 2020). It is also thought there is no significant impact in the result because the coffee agroforestry system has previously gone through fertilization and are going through the generative stage. Considering there is previous fertilization in the plot, the coffee plant already imbued with N resulting in lower NUE during the generative stage (Cannavo *et al*., 2013). Given that the coffee were undergoing their generative phase at the time of the study, available N was retained in the soil until the vegetative phase. N is crucial during coffee vegetative growth stage, so it is important to provide significant portion of N supply in the soil (Salamanca-Jimenez *et al*., 2017).

3.7. Nitrogen Balance

There is a significant impact on fertilization management towards N balance, indicate the importance of fertilization to enhancing the nutrient availability. The highest value of N balance was shown on the inorganic fertilizer treatment with the highest dose (AD3), but not significantly different compared to organic and mixed fertilizer application at highest dose (OD3 and MD3) (Table 2). Our findings show that substituting half of the inorganic fertilizer dose with organic fertilizer results in an equivalent nutrient balance, providing more environmental-friendly management. Organic fertilizer release N in a slow and gradual manner compared to inorganic fertilizer, thus reducing the rate of N loss and increasing the available N (Iqbal *et al*., 2019). The value of N balance could be used to determine the coffee N

Table 2. Nitrogen balance at different fertilizer management

Code	Fertilizer N Input (kg/ha)	N Outputs (kg/ha)				N Balance
		NH_4^+ Leaching	NO_3^- Leaching	N_2O Emission	N Uptake	
OD1	161	6.53 ± 1.76	3.09 ± 1.02	9.01 ± 0.11	35.48 ± 11.01	48.50 ± 36.99 b
OD2	180.5	15.31 ± 3.84	2.87 ± 0.59	8.76 ± 0.43	85.67 ± 31.03	125.95 ± 10.80 b
OD3	345	6.91 ± 2.56	1.41 ± 0.55	8.86 ± 0.86	94.83 ± 37.17	231.86 ± 30.92 a
AD1	161	4.91 ± 2.36	1.85 ± 0.73	11.65 ± 0.84	48.68 ± 12.31	48.51 ± 28.49 b
AD2	180.5	8.54 ± 4.06	2.36 ± 0.99	9.83 ± 0.19	79.63 ± 16.96	112.98 ± 8.68 b
AD3	345	16.97 ± 2.39	4.66 ± 1.16	10.40 ± 1.06	79.97 ± 26.50	244.14 ± 18.78 a
MD1	161	11.63 ± 2.80	2.58 ± 0.71	10.43 ± 1.94	109.15 ± 46.10	79.53 ± 15.38 b
MD2	180.5	9.54 ± 0.99	1.53 ± 0.51	14.05 ± 0.84	92.72 ± 33.21	46.27 ± 42.28 b
MD3	345	7.55 ± 2.47	1.44 ± 0.70	11.63 ± 1.92	60.35 ± 16.13	226.65 ± 31.96 a

Note: Means ± Standard Error of Difference (n=3), following different letters indicate significant difference based on DMRT at 5% level

N requirement to achieve optimal N supply. High N balance shows high excess of N remains in the soil, so it does not necessarily require numerous amount of N fertilizer applied for the next crop season (Quemada *et al*., 2016). Another study shows that inorganic fertilizer contain high amount of available N, therefore it shows better impact on the coffee growth compared to application of organic manure to coffee plant (Chemura, 2014).

3.8. Relationship between Each Parameter

The PCA analysis show that there are different levels of sensitivity and significance between the parameters analysed in this study (Figure 9). We found that leaching were the most sensitive parameters, followed by N Balance and NUE. The result imply that leaching, N Balance, and NUE are sensitive to changes of fertilization management in coffee-based agroforestry systems. Furthermore, NH_4^+ and NO_3^- total leaching are closely correlated, revealed the importance of appropriate fertilizer management to suppress leaching rate. N input from fertilizer continuously promote higher N leaching over time (Wang *et al*., 2019). Applying inorganic N fertilizer lead to higher leaching loss compared to organic fertilizer (Fan *et al*., 2017). Applying organic fertilizer enhance soil characteristics that controlling N leaching in the systems. Organic fertilizer has the ability to increase water retention and capacity by improving the soil quality, therefore organic input could reduce N leaching rate (Wei *et al*., 2021). Moreover, we found that the increase of N uptake will also be followed by NUE. Increase of N uptake means that the majority of available N are used by plant, indicate the high efficiency of nitrogen used by plant. Similar result was reported by Salim *et al*. (2020), that NUE closely correlated to the utilization of N by the plant. N uptake also affected the overall N balance in the soil, as seen on the PCA results. N uptake is a component of N output that is used to determine nitrogen balance, therefore changes in nitrogen uptake can affect N balance (Sainju, 2017). Coffee plants require nitrogen for growth and metabolic processes, the uptake of N from the soil inevitably leads to a decrease in soil N availability, thus altering the N balance (Rocha *et al*., 2023).

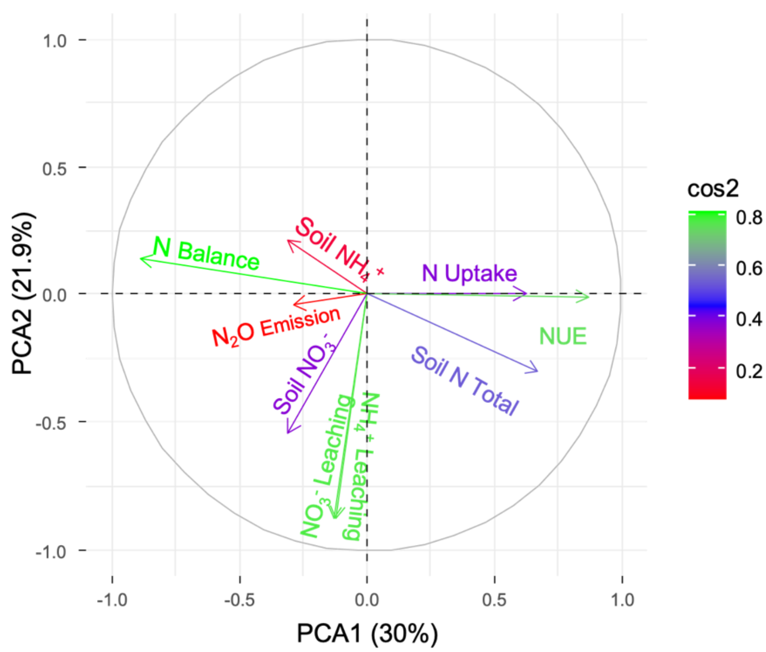

Figure 9. PCA Result

Nitrogen volatilization is one of the important factor that affect nitrogen storage in the soil. The PCA results show that N_2O emission negatively correlated with soil N total, indicating that total nitrogen in the soil mainly affected by N_2O emission rates. Nitrification and denitrification of N in the soil are the main biological processes that release N_2O gas into the atmosphere (Recio *et al*., 2020). N input from fertilizer also has an impact on N_2O emission. As stated by Gu *et al*. (2020), application of N fertilizer will be followed by N_2O emission caused by the available N in the soil from fertilizer input. In addition, both N_2O emission and soil N total are influenced by soil texture. We assume clay loam texture in the study plot affect the availability of N in the soil and emission. Result finding by Lang *et al*. (2021), shows that silt and clay loam textured soil resulting in lower N_2O emission compared to sandy soil because it has higher ability to conserve N in the soil which lower the nitrification rate that emitted N_2O. Our findings aligned with various study result in coffee-based agroforestry system, where N loss occurred by leaching and N_2O emission with N input from organic amendments and inorganic fertilizers (Kim & Isaac, 2022).

4. CONCLUSION

The results of this study show that fertilization management only had a significant effect on soil N content, emitted N_2O gas, and N balance. The not significantly different results on leaching, N uptake, and NUE could be due to the climatic condition during the study. Input of organic matter become the determining factor in measuring the amount of N loss in the soil. Mixed fertilizer treatment with high dose (MD3) show the lowest result of emission, with high NUE and N availability, thus making it potential to apply in coffee-based agroforestry and could be recommended for farmers. This study only occurs for short period of time, hence it would be better to do long-term study to further asses the impact of fertilization and the N balance in coffee-based agroforestry system.

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REFERENCES

Akib, M.A. (2014). *Prosedur Rancangan Percobaan: Aplication of The Model in Different Environmental Conditions* (1st ed.). Lampena Intimedia, Sengkang, South Sulawesi.

Bachtiar, T., Robifahmi, N., Flatian, A.N., Slamet, S., & Citraresmini, A. (2020). Pengaruh dan kontribusi pupuk kandang terhadap N total, serapan N, dan hasil padi sawah (*Oryzae sativa* L.) varietas MIRA-1. *Indonesian Journal of Nuclear Scence and Technology*, ***21***(1), 35-48. https://doi.org/10.17146/jstni.2020.21.1.5779

BMKG. (2024). *Data Online Pusat Database BMKG*. [Online]. https://dataonline.bmkg.go.id/home, [Accessed 15-09-2024].

Bruno, I., Reichardt, K., Bortolotto, R., Pinto, V., Bacchi, O., Dourado, D., & Unkovich, M. (2020). Nitrogen balance and fertigation use efficiency in a field coffee crop. *Journal of Plant Nutrition*, ***38***(13), 2055-2076. https://doi.org/10.1080/01904167.2014.958168

Bote, A., Žana, Ž., Ocho, F., & Vos, J. (2018). Analysis of coffee (*Coffea arabica* L.) performance in relation to radiation level and rate of nitrogen supply II. Uptake and distribution of nitrogen, leaf photosynthesis and first bean yields. *European Journal of Agronomy*, ***92***, 107-114. https://doi.org/10.1016/j.eja.2017.10.006

BPSI. (2023). *Analisis Kimia Tanah, Tanaman, Air dan Pupuk. 3rd ed*. Kementerian Pertanian Republik Indonesia.

Bruno, I.P., Reichardt, K., Bortolotto, R.P., Pinto, V.M., Bacchi, O.O.S., Dourado-Neto, D., & Unkovich, M.J. (2015). Nitrogen balance and fertigation use efficiency in a field coffee crop. *Journal of Plant Nutrition*, ***38***(13), 2055–2076. https://doi.org/10.1080/01904167.2014.958168

Cannavo, P., Harmand, J.-M., Zeller, B., Vaast, P., Ramírez, J.E., & Dambrine, E. (2013). Low nitrogen use efficiency and high nitrate leaching in a highly fertilized *Coffea arabica-Inga densiflora* agroforestry system: A 15N labeled fertilizer study. *Nutrient Cycling in Agroecosystems*, ***95***, 377–394. https://doi.org/10.1007/s10705-013-9571-z

Chemura, A. (2014). The growth response of coffee (*Coffea arabica* L) plants to organic manure, inorganic fertilizers and integrated soil fertility management under different irrigation water supply levels. *International Journal of Recycling of Organic Waste in Agriculture*, ***3***(59). https://doi.org/10.1007/s40093-014-0059-x

Chen, B., Liu, E., Tian, Q., Yan, C., & Zhang, Y. (2014). Soil nitrogen dynamics and crop residues. A review. *Agronomy for Sustainable Development*, ***34***, 429-442. https://doi.org/10.1007/s13593-014-0207-8

Fan, J., Xiao, J., Liu, D., Ye, G., Luo, J., Houlbrooke, D., Laurenson, S., Yan, J., Chen, L., Tian, J., & Ding, W. (2017). Effect of application of dairy manure, effluent and inorganic fertilizer on nitrogen leaching in clayey fluvo-aquic soil: A lysimeter study. *The Science of the total environment*, ***592***, 206-214. https://doi.org/10.1016/j.scitotenv.2017.03.060

Gezie, M., Adgo, E., Assaye, H., Wassie, A. (2024). Nutrient balance in small catchments of the upland areas of the Gumara River, Northwestern Ethiopia, 30 January 2024, PREPRINT (Version 1). *Research Square*. https://doi.org/10.21203/rs.3.rs-3893338/v1

Gu, J., Wu, Y., Tian, Z., & Xu, H. (2020). Nitrogen use efficiency, crop water productivity and nitrous oxide emissions from Chinese greenhouse vegetables: A meta-analysis. *Science of the Total Environmen*t, ***743***, 140696. https://doi.org/10.1016/j.scitotenv.2020.140696

Iqbal, A., He, L., Khan, A., Wei, S., Akhtar, K., Ali, I., Ullah, S., Munsif, F., Zhao, Q. & Jiang, L. (2019). Organic manure coupled with inorganic fertilizer: An approach for the sustainable production of rice by improving soil properties and nitrogen use efficiency. *Agronomy*, ***9***(10), 651. https://doi.org/10.3390/agronomy9100651

Salamanca-Jimenez, A., Doane, T.A., & Horwarth, W.R. (2017). Nitrogen use efficiency of coffee at the vegetative stage as influenced by fertilizer application method. *Frontiers Plant Science*, ***8***(223). https://doi.org/10.3389/fpls.2017.00223

Kim, D-G., & Isaac, M.E. (2022). Nitrogen dynamics in agroforestry systems. A review. *Agronomy for Sustainable Developmen*t, ***42***(60). https://doi.org/10.1007/s13593-022-00791-7

Kurniawan, S., Corre, M.D., Matson, A.L., Schulte-Bisping, H., Utami, S.R., Straaten, O., & Veldkamp, E. (2018). Conversion of tropical forests to smallholder rubber and oil palm plantations impacts nutrient leaching losses and nutrient retention efficiency in highly weathered soils. *Biogeosciences*, ***15***(2), 5131–5154. https://doi.org/10.5194/bg-15-5131-2018

Kurniawan, S., Hariyanto, P., & Ishaq, R. (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***, 012010. https://doi.org/10.1088/1755-1315/824/1/012010

Kurniawan, S., Nugroho, R.M.Y.A.P., & Ustiatik, R. (2024). Soil nitrogen dynamics affected by coffee (*coffea arabica*) canopy and fertilizer management in coffee-based agroforestry. *Agroforestry System*, ***98***, 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), 416-427. http://doi.org/10.17503/agrivita.v41i3.2236

Lang, M., Li, P. & Wei, W. (2021). Gross nitrogen transformations and N_2O emission sources in sandy loam and silt loam soils. *Journal of Arid Land*, ***13***, 487–499. https://doi.org/10.1007/s40333-021-0098-x

Liu, L., Zhang, S., Chen, M., Cui, D., & Ding, X. (2021). Organic amendment increases wheat yield by improving soil N transformations and reducing N loss in North China Plain. *Archives of Agronomy and Soil Science*, ***68***(14), 1974–1987. https://doi.org/10.1080/03650340.2021.1946682

Lu, Y., Wang, E., Zhao, Z., Liu, X., Tian, A., & Zhang, X. (2021). Optimizing irrigation to reduce N leaching and maintain high crop productivity through the manipulation of soil water storage under summer monsoon climate. *Field Crops Research*, ***265***, 108110. https://doi.org/10.1016/j.fcr.2021.108110

Maulinda, R., Damayani, M., & Joy, B. (2017). Pengaruh pupuk kombinasi urea – zeolit - arang aktif (UZAA) terhadap ph, eh, amonium dan nitrat pada tanah SAWAH Rancaekek, Kabupaten Bandung. *Soilrens*, ***15***(2). https://doi.org/10.24198/soilrens.v15i2.21459

Moll, R.H., Kamprath, E.J., & Jackson, W.A. (1982). Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization 1. *Agronomy Journal*, ***74***(3), 562-564. https://doi.org/10.2134/agronj1982.00021962007400030037x

Naik, S.K., Mali, S.S., Kumar, O., Singh, A.K., & Bhatt, B.P. (2021). Assessing nutrient leaching loss using nonweighing lysimeters in acidic soils of eastern plateau and hill region of India. *Communications in Soil Science and Plant Analysis*, ***52***(9), 1023–1036. https://doi.org/10.1080/00103624.2021.1872601

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

Oktasari, I.N. (2014). perkebunan kopi rakyat di Jawa Timur 1920-1942. *Avatara: Jurnal Pendidikan Sejarah*, ***2***(1), 122-130. https://ejournal.unesa.ac.id/index.php/avatara/issue/view/359

Putri, D.A.L.P. (2019). Aplikasi pupuk organik dari residu sistem agroforestri kopi di UB Forest untuk perbaikan sifat kimia tanah inceptisol dan entisol. [*Thesis*]. Universitas Brawijaya. http://repository.ub.ac.id/id/eprint/173439

Quemada, M., Delgado, A., Mateos, L., & Villalobos, F.J. (2016). Nitrogen fertilization II: Fertilizer requirements. *Principles of Agronomy for Sustainable Agriculture*, 369–380. https://doi.org/10.1007/978-3-319-46116-8_25

Rawal, N., Pande, K.R., Shrestha, R., & Vista, S.P. (2022). Soil nutrient balance and soil fertility status under the influence of fertilization in maize-wheat cropping system in Nepal. *Applied and Environmental Soil Science*, ***2022***(1), 2607468. https://doi.org/10.1155/2022/2607468

Recio, J., Montoya, M., Gines, C., Cobena, A., Vallejo, A., & Alvarez, J. (2020). Joint mitigation of NH_3 and N_2O emissions by using two synthetic inhibitors in an irrigated cropping soil. *Geoderma*, 375, 114423. https://doi.org/10.1016/j.geoderma.2020.114423

Rocha, B., Martinez, H., Ribeiro, C., & Brito, D. (2023). Nitrogen metabolism in coffee plants subjected to water deficit and nitrate doses. *Brazilian Archives of Biology and Technology*, ***66***, e23210060.

Rowe, R.L., Prayogo, C., Oakley, S., Hairiah, K., Noordwijk, M., Wicaksono, K.P., Kurniawan, S., Fitch, A., Cahyono, E.D., Suprayogo, D., & McNamara, N. (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

Sainju, U. (2017). Determination of nitrogen balance in agroecosystems. *MethodsX*, ***4***, 199–208. https://doi.org/10.1016/j.mex.2017.06.001

Sainju, U.M. (2019). Improving nitrogen balance with irrigation practice and cropping system. *Journal of Soil and Water Conservation*, ***74***, 622–631. https://doi.org/10.2489/jswc.74.6.622

Salim, N., & Raza, A. (2019). Nutrient use efficiency (NUE) for sustainable wheat production: a review. *Journal of Plant Nutrition*, ***43***(2), 297–315. https://doi.org/10.1080/01904167.2019.1676907

Santos, T.B.D., Lima, J.E., Felicio, M.S., Soares, J.D.M., & Domingues, D.S. (2017). Genome-wide identification, classification and transcriptional analysis of nitrate and ammonium transporters in coffea. *Genetics and Molecular Biology*, ***40***, 346–359. https://doi.org/10.1590/1678-4685-gmb-2016-0041

Schmidt, R., Silva, L.O.E., Ferreira, A., Gontijo, I., Guimarães, R.J., Ramalho, J.C., & Partelli, F.L. (2022). Variability of root system size and distribution among *Coffea canephora* genotypes. *Agronomy*, ***12***(3), 647. https://doi.org/10.3390/agronomy12030647

Shang, F., Ren, S., Yang, P., Chi, Y., & Xue, Y. (2016). Effects of different irrigation water types, N fertilizer types, and soil moisture contents on N_2O emissions and N fertilizer transformations in soils. *Water, Air, & Soil Pollution*, ***227***, 225. https://doi.org/10.1007/s11270-016-2920-1

Sitinjak, R., Siregar, R. & Nainggolan, T. (2022). Respon lama perendaman zat pengatur tumbuh gibberelin dan pupuk NPK terhadap pertumbuhan bibit kopi arabika (*Coffea Arabica* L). *Fruitset Sains: Jurnal Pertanian Agroteknologi*, ***10***(5), 301-310. https://doi.org/10.13057/biodiv/d231142

Sudharta, K.A., Hakim, A.L., Fadhilah, M.A., Fadzil, M.N., Prayogo, C., Kusuma, Z., & Suprayogo, D. (2022). Soil organic matter and nitrogen in varying management types of coffee-pine agroforestry systems and their effect on coffee bean yield. *Biodiversitas Journal of Biological Diversity*, ***23***(11), 5884-5891. https://doi.org/10.13057/biodiv/d231142

Suprayogo, D., Azmi, E.N., Ariesta, D.A., Sutejo, Y.A., Hakim, A.L., Prayogo, C., & 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 Conf. Series: Earth and Environmental Science*, ***449***, 012045. https://doi.org/10.1088/1755-1315/449/1/012045

Supriadi, H. & Pranowo, B. (2015). Prospek pengembangan agroforestri berbasis kopi di Indonesia. *Perspektif: Review Penelitian Tanaman Industri*, ***14***(2), 135–150. https://doi.org/10.21082/p.v14n2.2015.135-150

Supriyati, Y. (2023). *Analisis Kinerja Perdagangan Kopi*. Pusat Data dan Sistem Informasi Pertanian Kementerian Pertanian, Sekretariat Jenderal, Kementerian Pertanian 2023.

Syamsiyah, J., Herdiyansyah, G., Hartati, S., Suntoro., Widijanto, H., Larasati, I., & Aisyah, N. (2023). Pengaruh substitusi pupuk kimia dengan pupuk organik terhadap sifat kimia dan produktivitas jagung di Alfisol Jumantono. *Jurnal Tanah dan Sumberdaya Lahan*, ***10***(1), 57-64. https://doi.org/10.21776/ub.jtsl.2023.010.1.6

Tully, K.L., Lawrence, D., & Wood, S.A. (2013). Organically managed coffee agroforests have larger soil phosphorus but smaller soil nitrogen pools than conventionally managed agroforests. *Biogeochemistry*, ***115***(3), 385–397. https://doi.org/10.1007/s10533-013-9842-4

Unigarro, C.A., Imbachi, L.C., Darghan, A.E., & Flórez-Ramos, C.P. (2023). Quantification and qualification of floral patterns of *Coffea arabica* L. *Plants*, ***12***(18), 3332. https://doi.org/10.3390/plants12183332

Wang, C., Amon, B., Schulz, K., & Mehdi, B. (2021). Factors that influence nitrous oxide emissions from agricultural soils as well as their representation in simulation models: A review. *Agronomy*, ***11***(4), 770. https://doi.org/10.3390/agronomy11040770

Wang, Y., Ying, H., Yin, Y., Zheng, H., & Cui, Z. (2019). Estimating soil nitrate leaching of nitrogen fertilizer from global meta-analysis. *Science of The Total Environment*, ***657***, 96–102. https://doi.org/ 10.1016/j.scitotenv.2018.12.029

Wei, W., Lang, M., & Li, P. 2021. Gross nitrogen transformations and N_2O emission sources in sandy loam and silt loam soils. *Journal of Arid Land*, ***13***, 487–499. https://doi.org/10.1007/s40333-021-0098-x

Yang, Q., Liu, P., Dong, S., Zhang, J., & Zhao, B. (2020). Combined application of organic and inorganic fertilizers mitigates ammonia and nitrous oxide emissions in a maize field. *Nutrient Cycling in Agroecosystems*, ***117***, 13–27. https://doi.org/10.1007/s10705-020-10060-2

Yu, H., Han, X., Zhang, X., Meng, X., Yue, Z., Liu, X., Zheng, N., Li, Y., Yu, Y., & Yao, H. (2023). Fertilizer induced N_2O and NO emissions in tea gardens and the main controlling factors : A recent three-decade data synthesis. *Science of The Total Environment*, ***871***, 162054. https://doi.org/10.1016/j.scitotenv.2023.162054

Yuniarti, A., Damayani, M. & Nur, D. (2019). Efek pupuk organik dan pupuk N,P,K terhadap C-Organik, N-Total, C/N, Serapan N, serta hasil padi hitam dalam inceptisols. *Journal of Precision Agriculture*, ***3***(2). http://dx.doi.org/10.35760/jpp.2019.v3i2.2205

Zhang, Y.Y., Zhao, W.Z., & Fu, L. (2017). Soil macropore characteristics following conversion of native desert soils to irrigated croplands in a desert-oasis ecotone, Northwest China. *Soil and Tillage Research*, ***168***, 176–186. https:///doi.org/10.1016/j.still.2017.01.004