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Impact of Management Practices on Coffee-Pine Agroforestry: Coffee Yield and Soil Respiration

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ABSTRACT

The coffee-pine agroforestry system offers a promising solution to enhance coffee yields and maintain soil health on degraded lands. This study aims to evaluate the impact of various agroforestry management practices on coffee yield and soil respiration. The experiment was conducted using a complete randomized block design across five management treatments: without management, without fertilization, organic fertilization, mixed fertilization, and recommended management by Perhutani. The observed parameters included coffee yield, soil respiration, soil moisture, soil temperature, litter biomass, canopy cover, and soil organic carbon (SOC) content. Results indicated that the recommended management (RM) plot achieved the highest coffee yield (834 kg ha^{-1}), attributed to wider planting spacing, which reduced resource competition between coffee and pine trees. The RM plot also displayed stable soil moisture and temperature, supporting coffee growth. Meanwhile, soil respiration showed no significant differences across treatments, though the mixed fertilization (MF) plot exhibited the highest respiration rate, indicating higher microbial activity due to combined fertilizer use. In conclusion, optimal management in agroforestry systems can enhance coffee productivity while preserving soil health.

1. INTRODUCTION

Perum Perhutani, a state-owned enterprise in Indonesia, manages forests that have experienced significant degradation due to deforestation, illegal logging, unsustainable agriculture, and socio-economic pressures (Rimbawan *et al*., 2021). In the period of 2014 to 2019, approximately 450 thousand hectares of forests managed by Perhutani in Java were lost, primarily due to land conversion for agriculture. This loss led to soil erosion, nutrient depletion, and disruption of the water cycle (Rudiarto *et al*., 2020; Sutarno *et al*., 2018). Economic pressures drive local communities to exploit forest resources unsustainably, further exacerbating forest degradation (Azhar *et al*., 2024).

Agroforestry, the integration of trees and crops, offers a sustainable solution by enhancing biodiversity, restoring degraded lands, and supporting livelihoods (Bhol *et al*., 2024). This system improves soil fertility, reduces erosion, and increases organic matter, supporting ecosystem restoration (Suchewaboripont *et al*., 2015). Economically, agroforestry provides multiple income sources from timber and non-timber products, reducing dependence on forest resources (Prajapati *et al*., 2024). Additionally, agroforestry sequesters carbon, contributing to climate change mitigation (Satish *et al*., 2024). Research has shown that agroforestry can enhance productivity, food security, and ecological balance in degraded areas managed by Perhutani (Afroz *et al*., 2024; Siagian *et al*., 2024).

In Malang, East Java, the coffee-pine agroforestry system managed by the community under Perhutani's supervision has been in place since 1974 (Mayrowani & Ashari, 2016). According to interviews with local coffee farmers, before

Perhutani collaborated with Universitas Brawijaya, farmers did not experience sustainable benefits from coffee yields under pine shade. Profits were only seen in the initial years, with harvests gradually declining. This decline was due to a lack of knowledge regarding coffee cultivation management under pine shade, making farmers less interested in continuing coffee cultivation within the agroforestry system. The primary benefits were gained by Perhutani, as they could maintain forest areas without deforestation (Triwanto *et al*., 2022).

In 2015, Perhutani and Universitas Brawijaya collaborated to develop a special-purpose forest area dedicated to research, forest development, forestry training, as well as cultural and religious activities (Kurniawan *et al*., 2024). Farmers received training in forest and coffee-pine agroforestry management, enabling them to continue coffee cultivation within this system. The management strategies in UB Forest include: (1) no management, (2) pruned coffee without fertilizer, (3) pruned coffee with organic and inorganic fertilizers, (4) pruned coffee with mixed fertilization under pine trees spaced at 3 × 2 meters, and (5) to enhance pine growth, Perhutani implemented thinning practices, removing one row of pine trees after 10 years (Suprayogo *et al*., 2020). These management strategies created a complex interaction between coffee and pine, aiming to balance agricultural productivity with environmental conservation.

Coffee yield reflects agricultural productivity and impacts the economic well-being of local communities. Higher yields can increase income, reduce poverty, and create job opportunities, facilitating investments in infrastructure, education, and healthcare (Purwowibowo, 2023; Suárez *et al*., 2022). Improved yields also encourage value-added activities like processing and marketing, enhancing market access and economic returns (Podong *et al*., 2024). Soil respiration is a key indicator of ecosystem health, reflecting carbon cycling and microbial activiity involved in nutrient cycling and organic matter decomposition. High soil respiration rates indicate active microbial communities that enhance nutrient availability (Majumdar *et al*., 2024). Soil respiration plays a critical role in the carbon cycle, linking soil organic carbon with atmospheric CO_2 and providing insights into carbon sequestration and ecosystem responses to climate change (Sukhoveeva *et al*., 2023). Factors like canopy cover, litter biomass, and soil moisture influence soil respiration, creating conditions for litter decomposition and maintaining a stable microclimate (Zhang *et al*., 2022; Badagliacca *et al*., 2024).

In an effort to balance agricultural productivity and ecosystem health in the coffee-pine agroforestry system, research is needed to assess the effects of different management practices on coffee yield and soil respiration, considering factors such as canopy cover, litter biomass, soil organic carbon, moisture, and temperature. Understanding these dynamics will help balance economic benefits with ecosystem services, thereby enhancing the sustainability of the coffee-pine agroforestry system.

2. METHODOLOGY

2.1. Study site

This research was conducted from August to December 2022, located in the Forest Area with Special Purpose of Universitas Brawijaya (KHDTK-UB) or UB Forest, Sumbersari, Tawangargo Village, Karangploso District, Malang Regency (Figure 1). The study area lies between 7°49’2” S – 7°51’26” S and 112°34’11” E – 112°36’37” E, with an elevation ranging from 700 to 1100 masl. Laboratory analyses were conducted at the Soil Physics and Soil Chemistry Laboratories of Universitas Brawijaya. The coffee-pine agroforestry system developed in the UB Forest was depicted in Figure 2.

2.2. Research design

The experiment was conducted using a Randomized Complete Block Design (RCBD) with five treatments (different management levels) and three replications. The five research plots are managed by farmers in the UB Forest area in accordance with traditional practices (Table 1), with a plot size of 20 x 20 m. This study will compare the effects of the five different management regimes on a range of key variables, including coffee bean yield, soil respiration, canopy cover, litter biomass, SOC, soil moisture, soil moisture, and soil temperature.

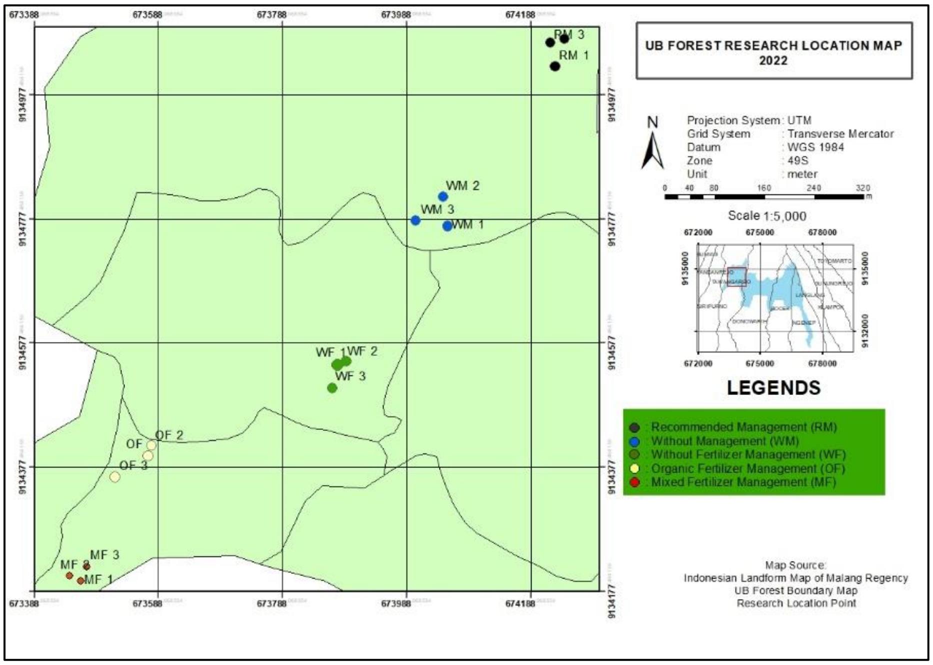

Figure 1. (a) Location of UB Forest (KHDTK-UB) in Sumbersari, Karangploso District, Malang (East Java).

Figure **2**. Coffee-pine agroforestry in UB Forest.

Table 1 Description of the five distinct management strategies employed by the farmers in the UB Forest as a plot of research location.

Plot	Management Practices
WM (No Management)	11 years old coffee and 41 years old pine with planting distance 3 x 2 m, no management effort.
WF (No Fertilizer)	11 years old coffee, once pruning, not fertilized with 41 years old pine with planting distance 3×2 m.
OF (Organic Fertilizer)	11 years old coffee, once pruning, input organic chicken manure applied twice a year with dose 1 kg/tree, 41 years old pine with planting distance 3×2 m.
MF (Mixed Fertilizer)	11 years old coffee, once pruning, input organic chicken manure applied twice a year with dose 1 kg/tree and nitrogen fertilizer applied once year with dose 250 kg/ha, 41 years old pine with planting distance 3×2 m.
RM (Recommended by Perhutani)	11 years old coffee, once pruning, input organic chicken manure applied twice a year with dose 1 kg/tree and nitrogen fertilizer applied once year with dose 250 kg/ha, 41 years old pine with planting distance 6×2 m.

2.3. Measured Parameters

The coffee bean yield was measured on three occasions between August and October 2022, with the objective of harvesting ripe red coffee cherries. Subsequently, the harvested beans were weighed (W_{wet_total}). A small subsample of the fresh beans (e.g., 100 grams) coffee plant samples (W_{wet_sample}) from each research plot were taken for the purpose of determining the dry weight after oven drying (W_{dry_sample}). The moisture content (%) of the fresh beans was calculated using gravimetric method with the following formula:

$$\text{Moisture Content (\%)} = \left(\frac{Wfresh\_sample - Wdry\_sample}{Wfresh\_sample}\right) \times 100 \quad (1)$$

We also determine the dry weight of the entire sample of fresh beans using the formula (Sudharta *et al*., 2022):

$$W_{dry\_total} = W_{wet\_total} \times \left(1 - \frac{Moisture\ Content\ (\%)}{100}\right) \quad (2)$$

The soil respiration and moisture was evaluated weekly, from September to December 2022. The soil respiration was determined using close incubation method (Van De Werf & Verstraete, 1987) using 1N KOH over two-day period, and soil moisture using gravimetric method. Initial canopy cover percentage was evaluated using digital photography at multiple points. Litter biomass was obtained by collecting surface litter within a 50 cm x 50 cm frame, then oven-dried (70°C) to determine the dry weight. The SOC was measured at two depths (0 - 20 cm and 20 - 40 cm) using the Walkley-Black method (Walkey & Black, 1934). The soil moisture content was determined by the gravimetric method, with measurements taken weekly from September to December 2022. The soil temperature was recorded using HOBO sensors on a daily basis from September to December 2022.

2.4. Data analyst

The data was visualized using box plots to assess the data distribution. Subsequently, an ANOVA with tukey test was conducted to determine the influence of the variables, followed by regression-correlation analysis to explore the relationships between them.

3. RESULTS AND DISCUSSION

3.1. Coffee bean yield

Significant variations in coffee bean yield were found among different agroforestry management practices (Figure 3). The plots with Recommended Management by Perhutani (RM) showed the highest average coffee bean yield, marked with the notation "d" (834 kg/ha), while the Without Management (WM) plots, which had no intervention, had the lowest yield, marked with the notation "a" (304 kg/ha). This finding highlights the critical impact of active management on coffee productivity in agroforestry systems. The RM plots showed a wider interquartile range in yield compared to other management types, indicating greater variability.

An interesting finding was observed in the MF and WF plots, which both had the same notation, "b," indicating no significant difference between these plots. However, in terms of management, the two plots were quite different, with the MF plot receiving chicken manure and nitrogen fertilizer, while the WF plot had no treatment at all. It is suspected that this lack of distinct difference is due to factors such as the effectiveness of fertilizer in the MF plot not showing immediate improvement and requiring a longer time to produce quality coffee yields. Research by Ben *et al*. (2023), shows that effective fertilization lasts for 18 months for vegetative and reproductive phases, also influenced by the type of fertilizer and environmental conditions.

The OF plots produced higher yields than the MF plots. This indicates that organic fertilizers significantly increase soil fertility, thereby enhancing coffee productivity, supporting previous studies that found that the type of fertilizer impacts coffee yields. Interestingly, the MF plots, which combined organic and inorganic fertilizers, did not perform as well as the RM plots. This may also result from the complex interaction between fertilizers and environmental conditions. RM had wider planting spacing, enabling more optimal nutrient absorption in each plant compared to MF. Optimally nourished plants can be observed by leaf number, plant height, and yield (Keerthi & Babu, 2017).

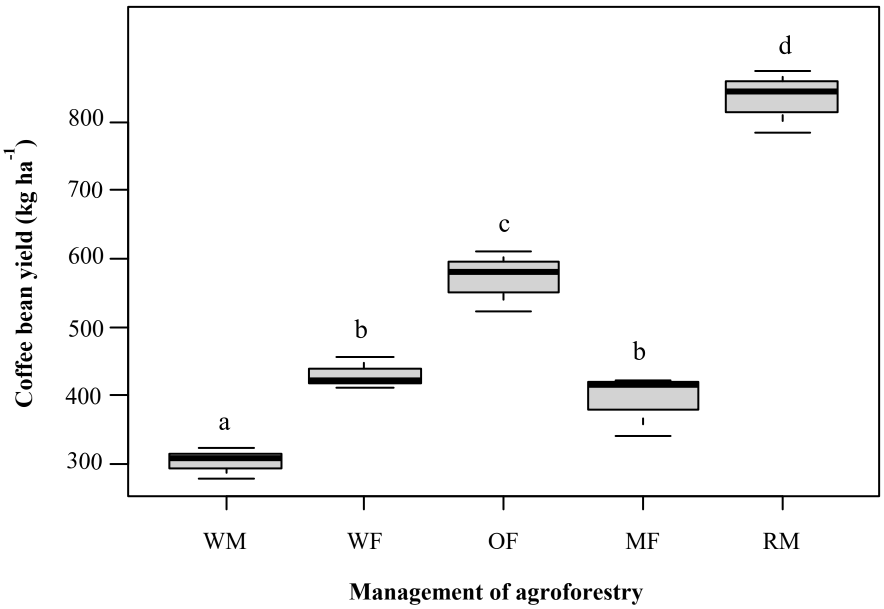

Figure 2. The coffee bean yield in five different agroforestry management system.

The RM plots, with wider spacing of pine trees, significantly outperformed other management types. The wider spacing reduced competition for light, water, and nutrients between coffee and pine trees, creating more favorable conditions for coffee growth. In contrast, tighter pine planting (such as in WM, WF, OF, and MF) increased competition and lowered yields. Shade tree thinning, a key management practice in the RM plots, significantly contributed to higher coffee bean yields. The integration of thinning, optimal fertilizer use, and adjusted pine spacing can increase coffee productivity by optimizing the agroforestry environment. Reduced competition for light and nutrients due to shade tree thinning directly improved coffee growth, consistent with previous studies (Méndez Rodríguez *et al*., 2022). The RM management practice, integrating holistic tree and fertilization management, proved to be the most effective strategy, underscoring the potential benefits of strategic management in enhancing coffee productivity in agroforestry landscapes.

3.2. Soil respiration

Various agroforestry management practices showed significant differences in soil respiration rates (Figure 4). The highest soil respiration rate was found in the Mixed Fertilizer (MF) plots (34.50-41.50 kg C-CO_2 ha^{-1} day^{-1}). This indicates that the combined use of organic and inorganic fertilizers enhances microbial activity, accelerates the decomposition of organic matter, and increases CO_2 release from the soil, consistent with previous studies (Iqbal *et al*., 2019). The Organic Fertilizer (OF) plots had slightly lower respiration rates (27.30-35.26 kg C-CO_2 ha^{-1} day^{-1}) compared to the MF plots, indicating that inorganic fertilizer can amplify the positive effect of organic fertilizer addition (such as soil organic matter and microbial activity). The RM plots exhibited lower soil respiration rates (29.70-32.67 kg C-CO_2 ha^{-1} day^{-1}). This finding suggests that tree spacing can significantly influence soil respiration by altering microclimatic conditions (light intensity, soil aeration), affecting nutrient availability and microbial activity (Liu *et al*., 2021). The WM plots had consistent but lower respiration rates, mainly due to the absence of fertilization or other management interventions. These plots maintained stable respiration rates, reflecting more natural soil heterogeneity rather than active management.

The variation in soil respiration across management practices highlights the complex interactions between management inputs and soil processes. The MF plots showed the highest variability, indicating that combined fertilizer inputs significantly alter microbial activity, while the RM plots had more stable rates, likely due to reduced competition and improved microclimatic conditions from wider tree spacing. In contrast, the WM plots had respiration rates that more closely reflected natural variability, with minimal influence from management-induced changes, consistent with the findings of Schmiege *et al*. (2023).

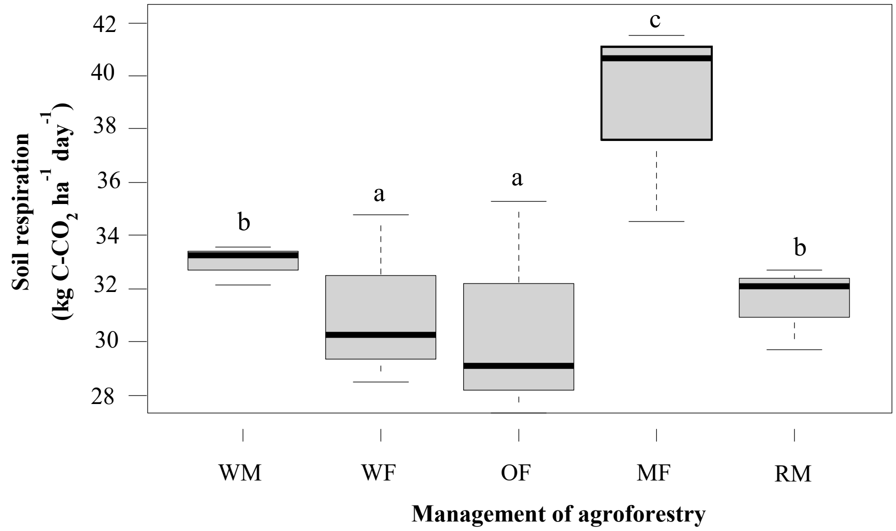

Figure 4. The soil respiration rate in five different agroforestry management system.

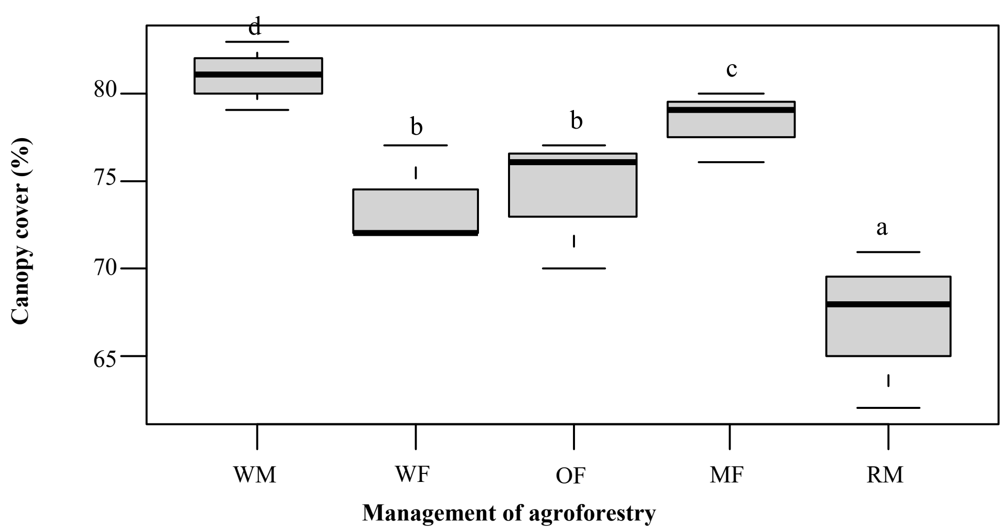

Figure 5. Canopy cover in five different agroforestry management systems.

3.3. Canopy cover

Various management practices show significant differences in the average values of canopy cover percentage (Figure 5). WM has a higher median value compared to the others. WM is a plot without management, so the pine canopy is denser, covering the land and limiting the sunlight received by the coffee plants below, which affects coffee productivity. The limitation of sunlight intensity in coffee agroforestry systems hinders the growth of coffee plants (Charbonnier *et al*., 2013). Shade above 70% is categorized as "high" shade and results in the lowest coffee bean yield for most coffee cultivars (Koutouleas *et al*., 2022). Meanwhile, RM has a lower median, meaning that the canopy cover in the RM plot is not dense, allowing more sunlight to penetrate and be utilized by the coffee plants. This results in higher photosynthetic efficiency in the coffee plants below, ultimately enhancing growth and yield (Hao *et al*., 2022). The height and density of canopy cover also influence soil respiration through their effects on light interception and the microclimate. This relationship is stronger for canopy complexity than for root complexity, indicating that canopy structure can be a spatial variation factor in soil respiration (Yang *et al*., 2023).

3.4. Litter biomass

The biomass litter showed statistical differences between the management types (Figure 6). The WM plots exhibited the lowest biomass of litter due to the absence of management practices (i.e., pruning and fertilization), with reliance solely on naturally occurring litter. In contrast, other plots, including MF, exhibited higher levels of litter biomass due to active management practices that returned pruned materials to the ground, enhanced SOM and nutrient cycling. These findings are consistent with previous studies indicating that fertilizer applications can enhance litter production by supporting vegetation growth and productivity (Amarille *et al*., 2023; Hairiah *et al*., 2006; Yu *et al*., 2019). In addition, both aboveground and belowground biomass positively correlate with soil respiration in forest areas (Riutta *et al*., 2021).

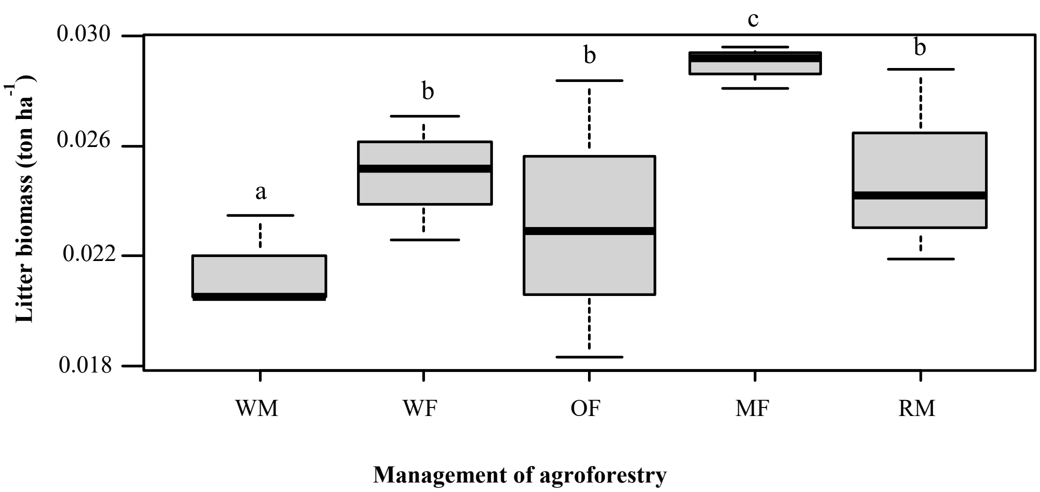

Figure 6. The litter biomass in five different agroforestry management systems.

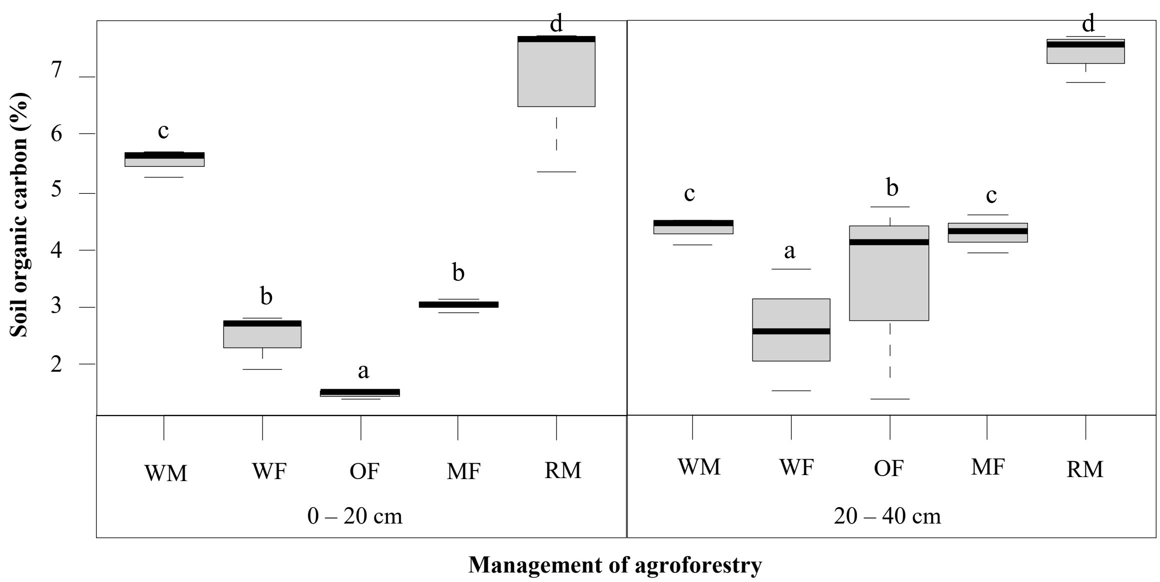

Figure 7. The soil carbon organic in five different management systems.

3.5. Soil Organic Carbon

The SOC levels exhibit significant variation among the various management practices considered (Figure 7). The RM plots show higher SOC levels compared to other plots (at both depths), indicating that integrated management practices (pruning, thinning, and fertilization) have a positive impact on SOC. The high levels of organic carbon suggest an improvement in soil structure, nutrient retention, and overall soil health. The OF at depth 0-20 cm had low C-organic content, although this plot received additional organic sources from organic fertilizer, the topsoil did not show high C-organic content. The possibility is that the quality of organic fertilizer is less supportive of stable carbon accumulation and even lost due to leaching. The C-organic content in WM (at both depths) was higher than WF, OF, and MF). Natural organic inputs such as debris tend to accumulate in the upper layers and slowly decompose towards the lower layers. OF showed moderate variation but remained lower than RM. This finding reflects suboptimal management in distributing organic matter to the lower layers. These practices contribute organic residues and facilitate soil microbial activity, thereby increasing organic carbon content throughout the soil profile (Nurcholis *et al*., 2024). The level of SOC is influenced by organic matter contribution, vegetation type, soil moisture, climate, and decomposition rate (Garcia-Franco *et al*., 2021; Han *et al*., 2018; Yu *et al*., 2019).

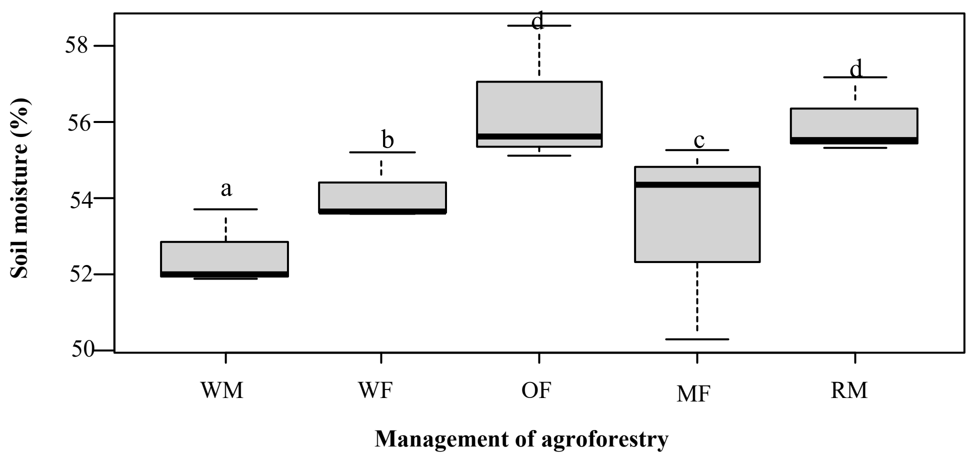

Figure 8. The soil moisture in five different agroforestry management systems

3.6. Soil Moisture

The soil temperature analysis revealed significant differences (Figure 8). The RM had the lowest temperature compared to other plots, the lower soil temperature in RM suggests that this plot has effective management practices in maintaining moisture and soil conditions rich in organic matter, which helps keep soil temperature stable. On the other hand, the wider spacing of pine trees in the RM plot also contributes to creating a balanced microclimate around coffee plants, emphasizing the role of canopy management in temperature regulation. Soil temperature stability is essential for maintaining plant growth and aligns with previous findings showing that integrated soil fertility management practices contribute to stable soil conditions (Devine *et al*., 2022). The WM had the highest temperature with an median value of 29.39°C, higher than the other plots. The low soil moisture in WM is one reason for the higher soil temperature in this plot. Soil temperature is a major driver of soil respiration rates, with higher temperatures generally increasing respiration rates due to enhanced microbial and root activity (Devine *et al*., 2022).

3.7. Soil Temperature

The soil temperature analysis revealed significant differences (Figure 9), where WM, WF, OF, and MF have the same notation, indicating no significant difference, while RM has a distinct notation "e" from the other four plots, indicating its significant difference. The lower soil temperature in RM suggests that this plot has effective management practices in maintaining moisture and soil conditions rich in organic matter, which helps keep soil temperature stable. On the other hand, the wider spacing of pine trees in the RM plot also contributes to creating a balanced microclimate around coffee plants, emphasizing the role of canopy management in temperature regulation. Soil temperature stability is essential for maintaining plant growth and aligns with previous findings showing that integrated soil fertility management practices contribute to stable soil conditions (Devine *et al*., 2022). Although not significant, WM, WF, OF, and MF still exhibit slight differences among them, such as WM, which has a median value of 29.39°C, higher than the other plots. The low soil moisture in WM is one reason for the higher soil temperature in this plot. Soil temperature is a major driver of soil respiration rates, with higher temperatures generally increasing respiration rates due to enhanced microbial and root activity (Devine *et al*., 2022).

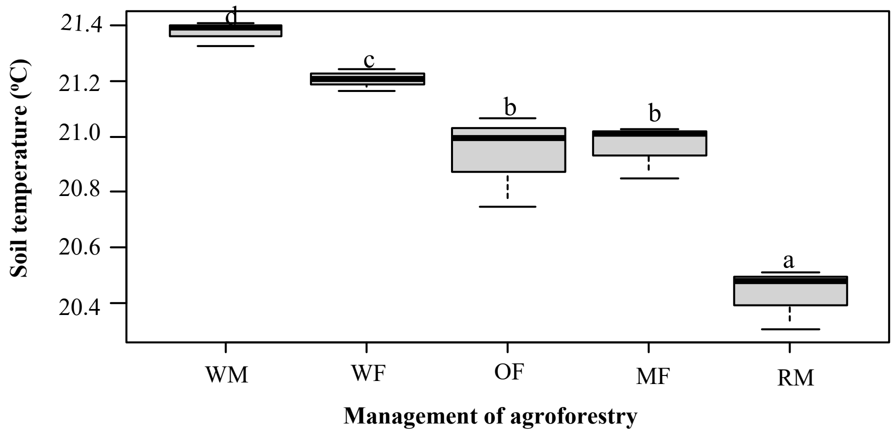

Figure 9. The soil temperature in five different agroforestry management systems.

3.8. Factors Influencing Coffee Bean Yield

The coffee bean yield is affected by various environmental influences, including SOM, soil temperature, soil moisture, litter biomass, and canopy cover (Figure 10). Increase in SOM can improve soil fertility and water retention capacity, which in turn supports plant growth and enhances yield production (King *et al*., 2020). This study found no significant correlation between SOM and coffee bean yield (a), suggesting that SOM is not the only determining factor. Soil temperature showes a strong negative correlation with coffee bean yield (b), where an increase in soil temperature was associated with a decrease in coffee bean yield. Coffee plants are unable to flourish at elevated temperatures due to the reduction in photosynthetic efficiency and the subsequent stress on the plants (Pimentel, 2022). An optimal soil temperature can enhance enzymatic activity and plant metabolism, which is conducive to coffee growth and productivity (Souza & Billings, 2021).

In contrast, soil moisture has a positive effect on coffee bean production (c). Optimal moisture is essential for coffee plant growth and productivity due to water role in photosynthesis and transpiration processes that are essential for coffee fruit development (Castanheira et al., 2022). However, no significant correlation was observed between soil moisture and coffee bean production. The correlation between litter biomass and coffee bean yield was not statistically significant (d). Litter biomass that affects coffee bean yield is that which decomposes readily and is thus readily absorbed by plants for production. Litter biomass that decomposes slowly can inhibit plant growth by reducing light penetration and disrupting soil aeration (de Oliveira *et al*., 2020). A strong negative relationship was observed between canopy cover (e) and coffee bean yield. An increase in canopy cover has been observed to result in a reduction in coffee bean yield. Optimal conditions for coffee plants are temperatures between 18 - 24°C with a relative humidity of 60 - 70% (Chen *et al*., 2020). This was also demonstrated by the elevated coffee bean yield observed in the RM plot, which exhibited a 6 x 2 m shade tree spacing, in comparison to the other plots, which had a 3 x 2 m shade tree spacing.

3.9. Factors Influencing Soil Respiration

Soil respiration is a significant indicator of soil health within an ecosystem, with high and low soil respiration rates exerting a pronounced influence on land productivity. Various environmental factors can influence soil respiration rates, including organic carbon content, soil temperature, soil moisture, the presence of litter biomass, and canopy cover. Each factor interacts in complex ways (Figure 11), collectively determining the land sustainability. However, our study revealed that the correlation between SOM and soil respiration was not particularly robust (a). Based on previous study,

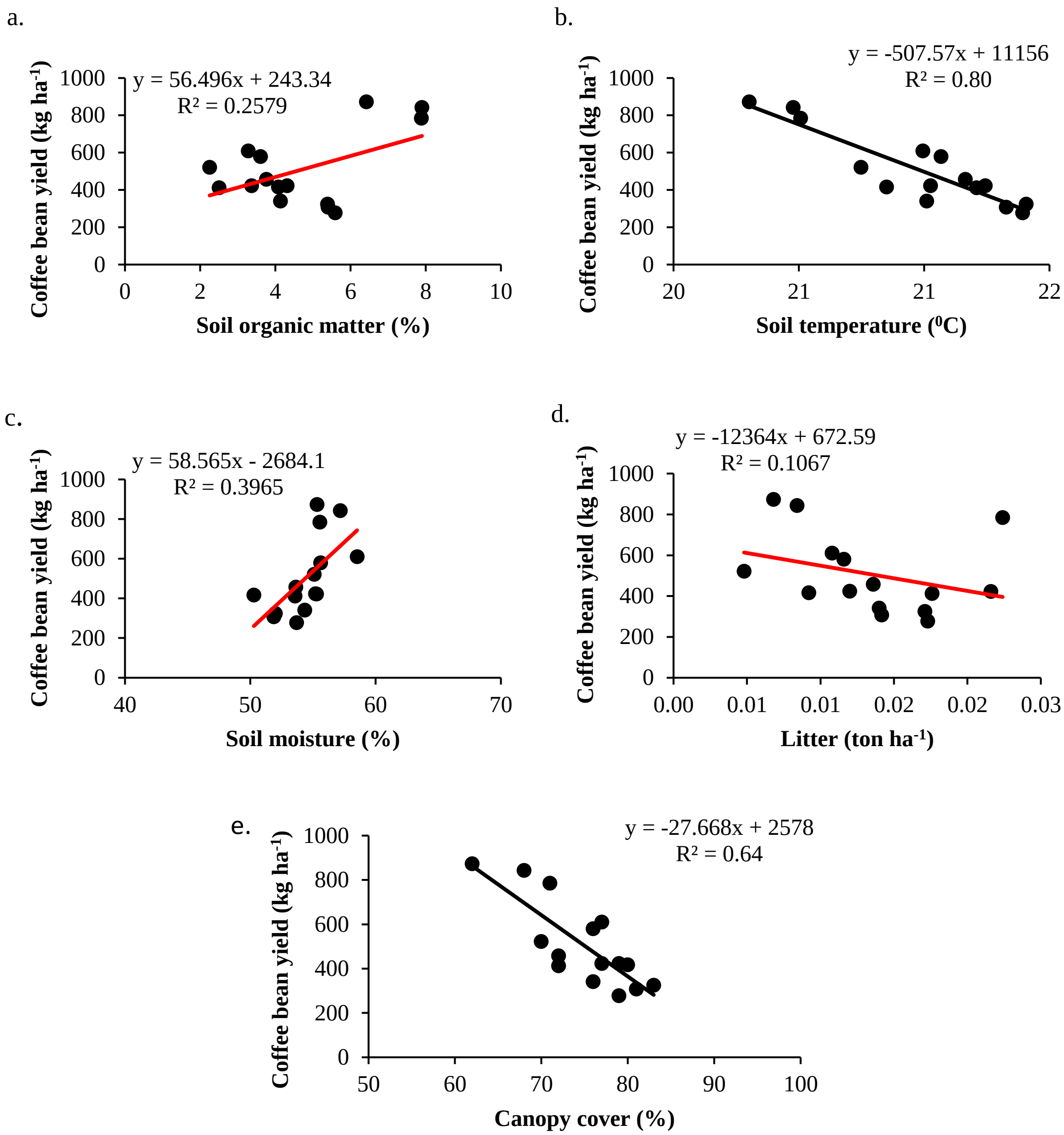

Figure 3. The correlation between coffee bean yield and 5 influencing factors: (a) soil organic matter (SOM), (b) soil temperature, (c) soil moisture, (d) biomass litter, and (e) canopy cover.

it can be concluded that SOC and microbial activity impact can only be considered as indicators of soil health in long-term dynamics (Mabuhay-Omar *et al*., 2018). Furthermore, there is a weak correlation between soil temperature and soil respiration (b). An elevated soil temperature can stimulate microbial activity, which in turn elevates soil respiration rates. However, the impact of temperature on respiration may vary contingent on other environmental conditions (Hawkes & Keitt, 2015). In addition to the impact of soil temperature on microbial activity, other factors, such as soil moisture, also influence microbial activity and, in turn, affect soil respiration (c). The graph illustrates a robust correlation between the two variables indicating that elevated moisture levels markedly enhance soil respiration. Optimal soil moisture levels facilitate the aeration required by microorganisms and plants, thereby increasing respiration rates (Zhou *et al*., 2023). Litter serves as a substrate provider, offering a rich source of organic matter for soil microorganisms to enhance the decomposition process, which in turn increases the soil respiration rate. This relationship is positively correlated (d). Coffee-pine leaves, which have a high lignin content, support microbial activity over time by providing a stable substrate for continued decomposition (Wang *et al*., 2015). The decomposition of this litter releases carbon and nutrients that support soil respiration (Dacal *et al*., 2021). No significant correlation was observed between canopy cover and soil respiration (e). The presence of a canopy cover has been demonstrated to reserve soil moisture and provide litter biomass that supports microbial activity and soil respiration.

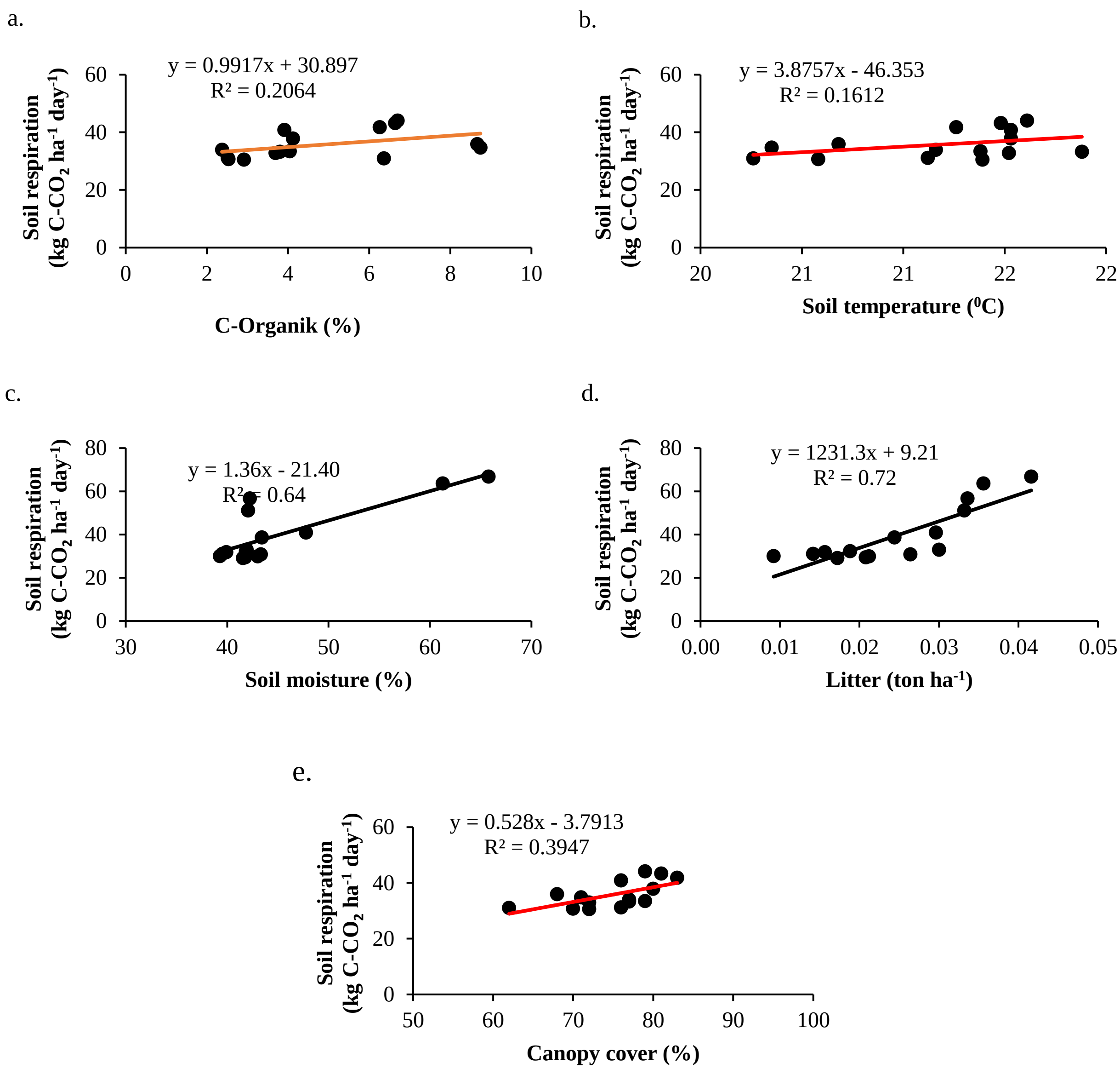

Figure 4. The correlation between soil respiration and 5 influencing factors: (a) soil organic matter (SOM), (b) soil temperature, (c) soil moisture, (d) biomass litter, and (e) canopy cover.

3.10. Correlation of Soil Respiration and Coffee Bean Yield

Soil respiration is an important indicator of soil health, but the graph demonstrating the relationship between soil respiration and coffee bean production indicates that soil respiration has no significant impact on coffee bean production (Figure 12). This is due to the intricate interrelationships between the various factors that influence crop production, including water availability, temperature, and land management practices. Other research related to soil respiration in the last decade has also demonstrated that climatic factors, vegetation composition, and soil management practices exert a significant influence on the variability of soil respiration and crop productivity (Barneze *et al*., 2024). Moreover, the quality of organic matter and soil moisture have been demonstrated to exert a considerable influence on soil respiration and crop productivity (Azembouh *et al*., 2021). Although soil respiration reflects microbial activity that decomposes organic matter, this activity does not always contribute significantly to increased crop production if essential nutrients are not available or if environmental conditions are unfavorable. The essential nutrients required by coffee plants are a combination of organic and inorganic fertilizers (Fitra *et al*., 2024). The results of this study support the conclusion that while soil respiration is a valuable indicator of soil health, enhancing crop productivity necessitates a more holistic approach that takes into account a range of environmental and management variables.

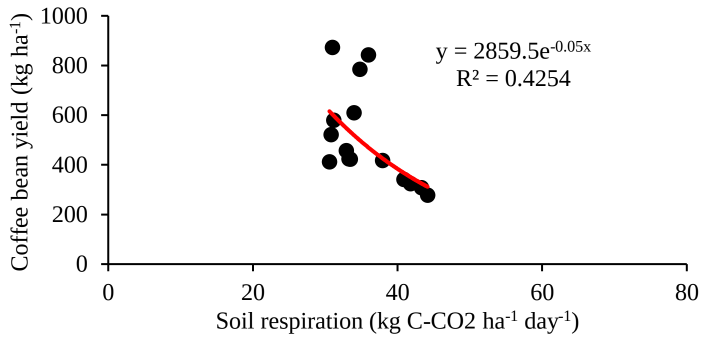

Figure 12. The correlation between coffee bean yield and soil respiration.

4. CONCLUSION

The research shows that a balanced agroforestry management approach between land productivity and environmental conservation, as applied in the RM plots, yields the best results. Environmental conditions with lower soil temperature and higher soil moisture support increased coffee yields. Although soil respiration does not have a significant correlation with coffee production, other factors, such as microclimate, more strongly influence coffee productivity. The varying soil respiration levels indicate microbial activity that supports nutrient cycling in the soil. The MF plots were found to have higher respiration rates compared to other plots, although not significantly. However, this also indicates that intensive management practices, as applied in RM and MF, tend to increase litter biomass and retain moisture, both essential for agroforestry ecosystems.

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