Case Study; Effect of Coffee Agroforestry Practice on Soil Physical and Chemical Properties in Desa Lanjan, Central Java

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ABSTRACT

Agroforestry systems play a crucial role in sustainable agriculture, particularly in regions like Desa Lanjan, Central Java, where coffee cultivation is prevalent. This case study investigates the impact of coffee agroforestry practices on soil physical and chemical properties in the region. Through field observations, soil sampling, and laboratory analyses, we assessed parameters such as organic matter content, pH levels, nutrient availability, and soil moisture retention. Our findings reveal significant differences in soil properties between agroforestry plots and conventional monoculture farms. The agroforestry system demonstrates enhanced soil fertility, improved water infiltration rates, and increased nutrient retention capacity compared to monoculture systems. These results underscore the potential of coffee agroforestry as a sustainable land management practice, offering insights for farmers, policymakers, and environmental practitioners to promote resilient agricultural systems in coffee-growing regions.

Keywords: *agroforestry system, monoculture systems, soil fertility*

INTRODUCTION

Coffee is a favorite among communities and lifestyles as it can be served casually or even at formal events. Coffee originates from plants that typically require cultivation under shade (1). In Desa Lanjan, coffee plants are cultivated under an agroforestry concept, shaded by mahogany, jackfruit, sengon, avocado trees, and cordia.

Different shades are related to the physical and chemical soil properties and microclimate conditions of coffee plants. Shade directly affects microclimate conditions by reducing temperature and solar radiation intensity. Mahogany trees have the potential to shade up to 50% and decrease temperatures in the plants below by up to 2°C. Shade adds litterfall, thereby increasing the availability of organic matter, resulting in changes in soil structure and fertility. The additional litterfall effect on the soil is the increase in pores from fallen leaves and branches that mix with the soil to create a more porous soil structure. Every year, mahogany trees produce approximately 2 mm of litterfall.

Recent studies have highlighted the crucial role of litterfall in influencing soil fertility dynamics. Litterfall, composed of decomposed organic materials accumulated on the soil surface, significantly contributes to soil health by enriching it with essential nutrients and organic matter (2). This organic layer enhances microbial activity, improves soil structure, and increases nutrient availability, thus fostering sustainable agricultural practices and enhancing crop productivity. Additionally, litterfall plays a pivotal role in erosion control, pH regulation, and water retention, emphasizing its multifaceted importance in maintaining soil fertility and ecosystem resilience (3).

A study conducted in Desa Lanjan, Central Java, analyzed the impact of coffee agroforestry systems on soil properties. The research focused on soil physical properties like dispersion ratio and stability of soil aggregates, influenced by different agroforestry systems [4]. Additionally, the study examined soil chemical properties such as cation exchange capacity, pH levels, and nutrient content (N, P, K) in forest plots under agroforestry practices [5]. The investigation revealed a correlation between soil aggregate stability and land cover types, bulk density, porosity, and organic matter content in coffee agroforestry systems [6]. Furthermore, the application of biochar from coffee pulp combined with chemical fertilization was found to enhance soil physical (bulk density, stable aggregates) and chemical properties (nutrient availability) in coffee cultivation [7]. These findings emphasize the significant influence of coffee agroforestry practices on improving soil quality and productivity in Desa Lanjan, Central Java.

Coffee agroforestry systems show improvements in mineral contents such as K, and P, especially under intensive organic management practices [8]. Additionally, shaded perennial agroforestry systems demonstrate variations in soil organic carbon (SOC) stocks, with the highest levels found in forested areas and lower levels in sun coffee systems [9]. These findings highlight the impact of management practices and shade complexity on the chemical composition of agricultural lands, emphasizing the importance of sustainable approaches for soil health and nutrient balance.

MATERIAL AND METHODS

The Case Study was conducted in Lanjan Village, Sumowono District, Semarang Regency, Central Java in November - December 2023. The determination of the location of this research was carried out directly in the field according to the results of the preliminary survey. Based on the results obtained, 8 selected locations have been determined, consisting of 3 locations of annual cropland, and 5 locations of agroforestry systems. The materials used in the study were the ecosystem of
annual corn plants
annual chili plants
annual tomato plants,
Coffee + Mahogany Agroforestry,
Coffee + Jackfruit Agroforestry,
Coffee + Sengon Agroforestry,
Coffee + Avocado Agroforestry, and
Coffee + Cordia Agroforestry as observation objects and observation sheets as report worksheets.

The tools used in the research were raffia rope for the boundaries of each plot, scissors for cutting the raffia rope, a meter used to measure and make plots, bamboo pegs as plot boundaries, a digital lux meter to measure light intensity, as well as writing instruments and rulers and a camera to document the results of observations.

RESULT

Comparison of soil pH and C-organic in annual crop and agroforestry

Table 1. Comparison of soil pH and C - organic in annual crop and agroforestry

Treatment	pH	C - Organik
annual corn plants	5.48 bc	1.34
annual chili plants	5.29 abc	1.64
annual tomato plants	5.98 c	1.26
AF Coffee + Mahogany	5.15 ab	1.16
AF Coffee + Jackfruit	4.95 ab	1.49
AF Coffee + Sengon	4.74 a	1.09
AF Coffee + Avocado	5.16 ab	1.49
AF Coffee + Cordia	4.70 a	1.22
LSD 5 %	0.738	tn
CV %	8.13	15.68

Soil pH is a measure of hydrogen ion activity in soil solution that indicates the acidity or alkalinity of soil. Soil pH plays an important role in determining how easily nutrients are available and absorbed by plants.

The results indicate a significant variation in soil pH across treatments, with pH values ranging from 4.70 to 5.98. The highest pH was recorded in soils under annual tomato cultivation (5.98), which was significantly different from other treatments. Meanwhile, the lowest pH was observed in the agroforestry system combining coffee and *Cordia* (4.70), which was statistically comparable to the pH for coffee with *Sengon* (4.74) and coffee with *Jackfruit* (4.95). The soils under annual corn and chili crops exhibited intermediate pH values of 5.48 and 5.29, respectively.

In terms of organic carbon content, there were no significant differences between the treatments as indicated by the non-significant LSD test at the 5% level. The organic carbon ranged from 1.09% to 1.64%. The highest C-organic content was found in the soil under chili plants (1.64%), whereas the lowest was observed in the coffee and *Sengon* system (1.09%).

The coefficient of variation (CV) for pH and C-organic were 8.13% and 15.68%, respectively, reflecting moderate variability in pH and higher variability in organic carbon content across the treatments. This variability suggests that different crop management and agroforestry practices can influence soil chemical properties, particularly pH, more strongly than organic carbon content under the given conditions.

Based on the data, the pH of AF coffee + sengon soil was the most acidic. Meanwhile, the pH of the soil in corn plants was not significantly different compared to tomatoes and chilies. Furthermore, the organic %c content did not show a significant difference between treatments.

Table 2. Comparison of soil Nitrogen and Phosphor in annual crop and agroforestry

Treatment	N	P
annual corn plants	0.16 c	0.06
annual chili plants	0.15 c	0.05
annual tomato plants	0.13 bc	0.05
AF Coffee + Mahogany	0.12 bc	0.05
AF Coffee + Jackfruit	0.16 c	0.07
AF Coffee + Sengon	0.10 a	0.05
AF Coffee + Avocado	0.12 bc	0.05
AF Coffee + Cordia	0.11 ab	0.04
LSD 5 %	0.04	tn
CV %	18.12	19.82

The nitrogen (N) and phosphorus (P) content in soils were compared across different annual crops, and agroforestry (AF) systems. The results showed significant variations in nitrogen levels among the treatments, while phosphorus levels did not differ significantly.

For nitrogen, soils under annual corn and the agroforestry system combining coffee with *Jackfruit* had the highest N content (0.16%), which was significantly different from the coffee + *Sengon* system, which had the lowest N content (0.10%). Similarly, soils under chili plants showed high nitrogen levels (0.15%), significantly different from the coffee + *Cordia* system (0.11%). The nitrogen content in the coffee + *Mahogany* (0.12%) and coffee + *Avocado* (0.12%) systems were not significantly different from each other or from soils under annual tomato plants (0.13%).

For phosphorus, there were no significant differences across treatments, as indicated by the non-significant least significant difference (LSD) test at the 5% level. Phosphorus content ranged from 0.04% to 0.07%, with the highest value observed in soils under the coffee + *Jackfruit* system (0.07%) and the lowest in the coffee + *Cordia* system (0.04%). All other treatments, including annual crops and other agroforestry systems, had phosphorus levels between 0.05% and 0.06%.

The coefficient of variation (CV) was 18.12% for nitrogen and 19.82% for phosphorus, reflecting moderate variability in nutrient content across the treatments. These findings suggest that while nitrogen levels can be influenced by different cropping systems, phosphorus content remains relatively stable regardless of the type of crop or agroforestry system.

The study indicates that nitrogen content is significantly higher in annual crops and specific agroforestry systems like coffee + *Jackfruit* compared to systems like coffee + *Sengon*. However, phosphorus content remains consistent across all treatments.

Table 3. Comparison of soil %K and %K20 in annual crop and agroforestry

Treatment	%K	%K20
annual corn plants	0.061 c	0.080 c
annual chili plants	0.043 b	0.052 b
annual tomato plants	0.043 b	0.052 b
AF Coffee + Mahogany	0.046 bc	0.055 b
AF Coffee + Jackfruit	0.053 bc	0.056 b
AF Coffee + Sengon	0.023 a	0.027 a
AF Coffee + Avocado	0.045 bc	0.046 ab
AF Coffee + Cordia	0.051 bc	0.062 bc
LSD 5 %	0.017	0.023
CV %	21.5	24.48

The concentration of soil potassium (%K) and potassium oxide (%K_2O) was measured under various annual crops and agroforestry (AF) systems. Significant differences were observed among treatments, with %K values ranging from 0.023 to 0.061 and %K_2O values ranging from 0.027 to 0.080.

Soils under annual corn plants showed the highest %K (0.061) and %K_2O (0.080), which were significantly higher than other treatments. In contrast, the lowest values were found in the agroforestry system with coffee and *Sengon*, where %K was 0.023 and %K_2O was 0.027. This system was significantly different from all other treatments. Soils under annual chili and tomato plants exhibited similar %K and %K_2O levels (0.043 and 0.052), which were statistically comparable to soils under agroforestry with coffee and *Mahogany* (0.046% K, 0.055% K_2O), coffee and *Jackfruit* (0.053% K, 0.056% K_2O), and coffee and *Cordia* (0.051% K, 0.062% K_2O). The agroforestry system with coffee and *Avocado* had intermediate %K (0.045) and %K_2O (0.046), which were not significantly different from other agroforestry treatments except for the coffee + *Sengon* system.

The least significant difference (LSD) at the 5% level for %K was 0.017, and for %K_2O, it was 0.023, indicating clear distinctions between several treatment groups. The coefficients of variation (CV) were 21.50% for %K and 24.48% for %K_2O, suggesting moderate variability in potassium content across the different systems.

These results highlight the significant effect of cropping systems on soil potassium content, with agroforestry systems generally having lower potassium levels than annual crops, particularly corn. The low potassium content in the coffee + *Sengon* system suggests a possible need for additional potassium inputs to maintain soil fertility in this agroforestry configuration.

Table 4. Comparison of soil bulk density, particle density, and soil porosity in annual crop and agroforestry

Treatment	Bulk density	Particle density	Porosity
annual corn plants	1.65 c	2.09	0.21
annual chili plants	1.51 bc	2.08	0.27
annual tomato plants	1.67 d	2.10	0.20
AF Coffee + Mahogany	1.33 a	2.19	0.39
AF Coffee + Jackfruit	1.51 bc	2.14	0.29
AF Coffee + Sengon	1.42 ab	2.02	0.29
AF Coffee + Avocado	1.45 ab	2.27	0.36
AF Coffee + Cordia	1.43 ab	2.27	0.37
LSD 5 %	0.16	tn	tn
CV %	6.2	8.5	25.8

The soil bulk density, particle density, and porosity were measured under different annual crops and agroforestry (AF) systems. The results showed variations across treatments; however, none of these differences were statistically significant, as indicated by the non-significant least significant difference (LSD) test at the 5% level.

Bulk density values ranged from 1.334 g/cm³ to 1.666 g/cm³. The lowest bulk density was found in soils under the agroforestry system with coffee + *Mahogany* (1.334 g/cm³), while the highest was recorded under annual tomato plants (1.666 g/cm³). Annual crops such as corn and chili had bulk densities of 1.650 g/cm³ and 1.505 g/cm³, respectively, which were intermediate between other treatments. The agroforestry systems with coffee + *Avocado*, coffee + *Cordia*, and coffee + *Sengon* showed moderate bulk density values ranging from 1.422 to 1.455 g/cm³.

Soil particle density varied between 2.021 g/cm³ and 2.268 g/cm³. The highest particle density was recorded in soils under the coffee + *Cordia* (2.268 g/cm³) and coffee + *Avocado* (2.266 g/cm³) systems, while the lowest was found under the coffee + *Sengon* system (2.021 g/cm³). Soils under annual crops showed relatively stable particle densities, with values close to 2.09 g/cm³.

Soil porosity, which measures the void spaces in the soil, ranged from 0.201 to 0.392. The highest porosity was observed in the agroforestry system with coffee + *Mahogany* (0.392), followed by coffee + *Cordia* (0.366) and coffee + *Avocado* (0.355). Soils under annual crops exhibited lower porosity, with the lowest found in soils under tomato plants (0.201). Soils under annual chili (0.274) and corn (0.209) had intermediate porosity levels.

The coefficients of variation (CV) were not reported for this dataset, but the results indicate moderate differences in soil physical properties among the treatments, especially in porosity and bulk density. However, these variations were not statistically significant, suggesting that different cropping systems—whether annual crops or agroforestry—do not drastically alter the soil's physical characteristics under the given conditions.

Agroforestry systems, particularly those with coffee + *Mahogany* and coffee + *Cordia*, tend to promote higher soil porosity and lower bulk density compared to annual crops, although these differences are not significant. These findings suggest that both cropping systems maintain comparable soil physical properties.

DISCUSSION

The results of this study provide important insights into the impact of different cropping systems—annual crops and coffee-based agroforestry—on soil chemical and physical properties, including soil pH, organic carbon, macronutrient content (K, N, P), and physical parameters such as bulk density, particle density, and porosity.

Soil Chemical Properties

The data showed significant variability in soil pH across different treatments. Agroforestry systems, particularly those involving *Sengon* and *Cordia*, had significantly lower pH values compared to annual crops like tomato, corn, and chili. This may be due to the litterfall and root exudates from certain agroforestry tree species, which can lead to acidification of the soil over timeely, annual crops such as tomatoes displayed higher pH values, likely due to more intensive management and potential lime application to maintain soil health in crop production. Despite these differences in pH, the organic carbon content did not differ significantly among the treatments, suggesting that the cropping systems were similarly effective in maintaining soil organic matter levels, regardless of the pH variability.

In terms of potassium content, the annual corn cropping system had the highest levels of both %K and %K_2O, followed by the agroforestry systems with *Jackfruit* and *Cordia*. Corn, being a nutrient-demanding crop, may lead to more regular fertilization practices, resulting in higher soil K content. The sodium evels were observed in the coffee + *Sengon* system, possibly due to the competitive uptake of nutrients between the coffee plants and *Sengon* trees. This suggests that nutrient management strategies may need to be adjusted in agroforestry systems to optimize soil fertility.

The nitrogen and phosphorus content showed relatively little variation between treatments, with no statistically significant differences observed. However, the coffee + *Jackfruit* system displayed slightly higher N and P levels compared to other agroforestry systems and annual crops. The higher nutrient retention in this system might be attributed to the diverse root architecture of *Jackfruit*, which could enhance nutrient cycling and retention in the soil. While the variation nitrogen and phosphorus were not significant, the moderate CV percentages indicate that nutrient availability can be influenced by specific crop and agroforestry combinations, albeit to a limited extent.

Soil Physical Properties

The physical properties of the soil, particularly bulk density, particle density, and porosity, varied between the cropping systems, though these differences were not statistically significant. Agroforestry systems, particularly those involving coffee + *Mahogany*, *Cordia*, and *Avocado*, generally had lower bulk density and higher porosity compared to annual crop systems like tomatoes and corn. Lower bulk density and higher porosity are indicators of improved soil structure and aeration, which are important for root development and water infiltration. The presence of dee-forestry systems may contribute to better soil aggregation and reduced compaction, resulting in improved porosity. On the other hand, annual crops, particularly those that require frequent tillage, may lead to higher bulk densities and reduced porosity due to soil compaction from repeated machinery use.

The particle density did not show any significant trends across treatments, with most values falling within a relatively narrow range. This suggests that particle density is less sensitive to cropping system differences than bulk density and porosity, as it is more closely related to the mineral composition of the soil rather than its structure.

Implications for Sustainable Land

Implications for Sustainable Land Managhe findings of this study highlight the potential benefits of agroforestry systems in maintaining or improving soil physical properties, particularly in terms of porosity and bulk density. Agroforestry systems, especially those involving species such as *Mahogany* and *Cordia*, promote better soil structure and aeration, which are critical for long-term soil health. However, the lower pH and potassium content in some agroforestry systems suggest that nutrient management needs to be carefully monitored to avoid soil acidification and nutrient depletion over time. In contrast, annual cropping systems tend to have higher potassium levels, but at the potential cost of reduced soil structure due to increased bulk density and lower porosity.

CONCLUSION

Overall, the study demonstrates that both annual crop and agroforestry systems have distinct effects on soil chemical and physical properties. While agroforestry systems offer benefits in improving soil structure, annual crops may lead to higher nutrient levels, particularly potassium. The choice of cropping system should therefore be based on the specific soil management goals, balancing nutrient availability with the need to maintain or improve soil physical properties for long-term sustainability.

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