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Implications of Conventional and Organic Coffee Farming Systems on Soil Chemical Properties in West Lampung, Indonesia

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Abstract

The coffee cultivation system has important implications for soil quality, particularly soil chemical properties that play a role in supporting plant growth and productivity. This study aimed to analyze the implications of conventional and organic coffee cultivation systems on soil chemical properties in West Lampung Regency. The research was conducted from March to September 2025 using a comparative survey method. Soil samples (0–20 cm depth) were collected from conventional and organic coffee fields with three replications per system. Parameters analyzed included soil pH, organic carbon, total nitrogen, available phosphorus, available potassium, and cation exchange capacity (CEC). Data were evaluated using analysis of variance (ANOVA) followed by the LSD test at the 5% level. The results showed that the coffee cultivation system had a highly significant effect on soil pH, organic carbon content, and available phosphorus. The organic cultivation system exhibited higher soil pH (6.30), organic carbon (2.35%), and available phosphorus (19.00 mg kg^{-1}) compared to the conventional system. Meanwhile, total nitrogen, available potassium, and CEC did not show significant differences between cultivation systems. These findings indicate that organic coffee cultivation is more effective in improving soil chemical properties related to soil reaction and nutrient availability, thereby potentially supporting the sustainability of coffee agroecosystems.

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INTRODUCTION

Soil is a major component in the coffee production system because it functions as a provider of nutrients, water, and a growing medium for plants. Soil quality, particularly soil chemical properties, plays a crucial role in determining soil fertility and the sustainability of coffee plantation productivity. Soil chemical properties include soil pH, organic carbon content, nitrogen, phosphorus, and potassium, which directly influence the growth and yield of coffee plants (Angadi et al., 2025).

In coffee agroecosystems, soil chemical mechanisms are primarily reflected in the interaction among soil pH, organic carbon (C-organic), total nitrogen (N), available phosphorus (P), exchangeable potassium (K), and cation exchange capacity (CEC). Soil pH is a key controlling factor because it regulates nutrient solubility and ion availability. In acidic tropical soils, low pH can increase aluminum (Al^{3+}) solubility, which enhances phosphorus fixation by iron and aluminum oxides, thereby reducing available P for plant uptake (Brady & Weil, 2017). Soil pH also influences nitrogen transformation processes, particularly mineralization and nitrification, which determine the availability of plant-accessible N forms (Robertson & Groffman, 2015). Therefore, understanding these soil chemical mechanisms is fundamental to explaining how different cultivation systems may alter nutrient balance and long-term soil fertility in coffee plantations.

West Lampung Regency is recognized as one of the main centers of robusta coffee production in Indonesia. The coffee cultivation systems applied by farmers in this region are quite diverse, ranging from conventional systems that rely on inorganic fertilizers and synthetic pesticides to organic cultivation systems that utilize organic materials such as manure, compost, and crop residues. These differences in management systems have the potential to cause variations in soil chemical conditions, both in the short and long term.

The research site in West Lampung is characterized by tropical upland soils that are generally acidic and highly weathered. Such soils in humid tropical regions are commonly classified as Ultisols and Inceptisols, which typically exhibit low base saturation, moderate to low organic matter content, and high phosphorus fixation capacity due to the dominance of Fe and Al oxides. The initial soil pH at the study location ranged from acidic to moderately acidic conditions, reflecting the natural characteristics of highly weathered tropical soils. These inherent soil properties are important to describe because they determine baseline nutrient availability and influence how soils respond to fertilization and organic amendments (Soil Survey Staff, 2014; Sanchez, 2019).

Conventional coffee cultivation systems generally aim to increase productivity through the intensive application of chemical inputs. However, several studies have reported that the continuous use of inorganic fertilizers may lead to a decline in soil organic matter, changes in soil pH, and nutrient imbalance (Ning et al., 2020). Such conditions may reduce soil quality and threaten the sustainability of coffee agroecosystems.

In contrast, organic cultivation systems have been reported to improve soil quality through increased organic carbon content and improved nutrient availability. Recent studies in tropical coffee agroecosystems have shown that organic coffee fields possess higher levels of organic carbon, total nitrogen, available phosphorus, and potassium compared to conventional coffee fields (Angadi et al., 2025). In addition, organic systems contribute to greater chemical stability of the soil and enhanced microbial activity, which plays an important role in nutrient cycling.

Furthermore, research conducted in Indonesia has also emphasized the importance of cultivation systems in influencing soil chemical properties in coffee plantations. For example, a study in Bener Meriah Regency revealed that organically managed coffee fields had higher contents of organic carbon, total nitrogen, total phosphorus, and total potassium than fields managed under inorganic systems (Aygun et al., 2025). This provides local evidence that organic-based soil management can improve soil chemical quality in tropical coffee agroecosystems.

Other studies have reported that organic-based coffee management can improve soil quality indices and enhance nutrient balance, thereby supporting more sustainable coffee production compared to intensive conventional systems (Bongers et al., 2018). These findings further strengthen the view that cultivation systems have important implications for soil chemical conditions.

Although numerous international studies have examined the effects of coffee cultivation systems on soil quality, similar research in Indonesia—particularly in West Lampung—remains relatively limited. This is notable given that tropical soils in Indonesia are generally acidic and characterized by low organic matter content, requiring appropriate management to maintain long-term coffee productivity. Therefore, research on the implications of conventional and organic coffee cultivation systems on soil chemical properties in West Lampung is important to undertake.

MATERIALS AND METHODS

Time and Location of the Study

This study was conducted from March to September 2025. The research site was located in smallholder coffee plantations in West Lampung Regency, Lampung Province, which applied conventional and organic coffee cultivation systems. Analysis of soil chemical properties was carried out in the soil laboratory.

Research sites were selected through a preliminary survey to identify plantations that had consistently applied either management system. Soil sampling points were determined using a stratified random sampling method, with fields divided into relatively homogeneous units based on slope, plant age, and field condition to ensure representative samples.

Sampling was carried out during the dry season to minimize short-term rainfall effects on soil chemical properties. Both conventional and organic plantations had been managed under their respective systems for more than 10 years prior to sampling, allowing sufficient time for long-term management practices to influence soil pH, C-organic, total N, available P, available K, and CEC.

Tools and Materials

The tools and materials used in this study included a soil auger, hoe, sample bags, labels, balance, soil sieve, stationery, and laboratory chemicals required for the analysis of soil pH, organic carbon, total nitrogen, available phosphorus, available potassium, and cation exchange capacity (CEC).

Research Method

This study employed a survey method with a comparative approach by comparing soil chemical properties between coffee fields managed under conventional cultivation systems and those managed under organic cultivation systems. Soil sampling was conducted at a depth of 0–20 cm. Each cultivation system consisted of three replications, resulting in three soil samples for each system, which served as experimental units.

Analysis of Soil Chemical Properties

The analysis of soil chemical properties was conducted in the soil laboratory using standard soil analysis methods commonly applied in soil science research. The analytical methods included:

1. Soil pH was determined using the electrometric method with a pH meter at a soil-to-water ratio of 1:2.5.
2. Organic carbon (C-organic) was analyzed using the Walkley and Black method.
3. Total nitrogen (N-total) was determined using the Kjeldahl method.
4. Available phosphorus (P-available) was analyzed using the Bray I method, which is suitable for acidic soils.
5. Available potassium (K-available) was extracted using 1 N NH_4OAc at pH 7 and measured using a flame photometer or atomic absorption spectrophotometer (AAS).
6. Cation exchange capacity (CEC) was determined using the 1 N ammonium acetate (NH_4OAc) extraction method at pH 7.

To ensure data accuracy and reliability, laboratory instruments were calibrated prior to analysis following standard operating procedures. The pH meter was calibrated using standard buffer solutions at pH 4.0 and 7.0 before measurement. The spectrophotometer and flame photometer/AAS were calibrated using a series of standard solutions for phosphorus and potassium, respectively. Selected samples were analyzed in duplicate to verify analytical precision and consistency of results.

Data Analysis

Data obtained from the analysis of soil chemical properties were analyzed using analysis of variance (ANOVA) to determine the effect of differences between conventional and organic coffee cultivation systems on soil chemical properties. When significant differences were detected, the analysis was followed by the Least Significant Difference (LSD) test at the 5% significance level.

DISCUSSION

Differences between conventional and organic coffee cultivation systems resulted in variations in several soil chemical properties, as presented in Table 1. In general, the organic cultivation system tended to improve soil chemical quality compared to the conventional system, although not all parameters showed statistically significant differences.

These differences can be explained by underlying biochemical processes and microbial activity in the soil. The addition of organic amendments in organic systems increases soil organic carbon, which serves as an energy source for soil microorganisms and enhances microbial biomass and activity (Lori et al., 2017). Increased microbial activity stimulates organic matter decomposition and nutrient mineralization, thereby increasing the availability of nitrogen through processes such as ammonification and nitrification (Robertson & Groffman, 2015).

Microorganisms also play a key role in phosphorus dynamics by producing organic acids and phosphatase enzymes that help solubilize bound phosphorus in acidic tropical soils, thereby increasing available P (Hinsinger, 2001). Furthermore, higher organic matter inputs contribute to improved cation exchange capacity (CEC), enhancing the soil's ability to retain exchangeable potassium (K^+) and other base cations while reducing nutrient leaching losses (Brady & Weil, 2017).

In contrast, conventional systems that rely heavily on inorganic nitrogen fertilizers may accelerate soil acidification through nitrification processes that release hydrogen ions (H^+), potentially lowering soil pH and affecting nutrient balance over time (Guo et al., 2010). Therefore, variations in soil pH, C-organic, total N, available P, available K, and CEC between the two systems are closely linked to differences in biochemical cycling and microbial-mediated nutrient transformations.

Table 1. Differences between conventional and organic coffee cultivation systems

Parameter	Conventional (Mean)	Organic (Mean)	Description
Soil pH	4.9a	6.3b	**
Organic Carbon (%)	1.38a	2.35b	**
N-total (%)	0.2a	0.22a	ns
P-Available (mg kg^{-1})	17.53a	19b	**
K-Available (cmol(+)/kg)	0.39a	0.42a	ns
KTK (cmol(+)/kg)	21.47a	22.47a	ns

Description
ns = not significant (p > 0,05)
**** = significant (p ≤ 0,01)**

The results showed that soil pH, organic carbon content, and available phosphorus under the organic cultivation system were significantly higher and differed very significantly from those under the conventional system, as indicated by differences in letter notation and significance values (**). In contrast, total nitrogen, available potassium, and cation exchange capacity (CEC) did not show significant differences between cultivation systems, indicating that these parameters were relatively stable and less responsive to differences in management systems during the study period. In contrast, total nitrogen, available potassium, and cation exchange capacity (CEC) did not show significant differences between cultivation systems, indicating that these parameters were relatively stable and less responsive to management differences during the study period. This stability may be related to the long-term (>10 years) implementation of both cultivation systems, which can allow nutrient pools to reach a steady state under continuous input and removal cycles. In the context of long-term organic residue applications, research has documented that even after more than two decades of annual organic additions, available K levels did not increase substantially in tropical soils, likely because released K either becomes adsorbed onto soil constituents or is lost through leaching processes that are typical in weathered tropical sandy soils, thus moderating changes in K availability despite continued inputs (Tanabhat-Sakorn et al., 2020).

Similarly, total N pools in agricultural soils may be maintained by balanced cycling and stabilization within organic matter fractions, rather than showing large differences between management systems, especially under conditions of long-term cultivation and comparable organic matter inputs (Adekiya, 2023). CEC in highly weathered tropical soils is also influenced more by intrinsic soil mineralogy and organic matter content than short-term management effects, and changes in CEC due to management require sustained increases in soil organic matter that exceed typical seasonal or medium-term fluctuations (Adekiya, 2023).

The differing responses of soil chemical properties suggest that organic coffee cultivation is more effective in improving soil chemical characteristics directly related to soil reaction and nutrient availability. Meanwhile, chemical properties influenced by nutrient reserves and inherent soil mineral characteristics tend to require a longer management period to exhibit significant changes.

Effect of Coffee Cultivation Systems on Soil pH

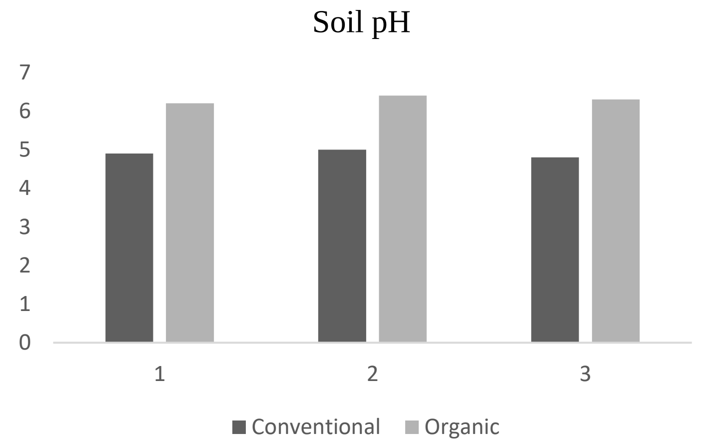

Figure 1. Effect of coffee cultivation systems on soil pH

The results of the analysis of variance indicated that the coffee cultivation system had a highly significant effect on soil pH. The average soil pH under the organic system (6.30) was higher than that under the conventional system (4.90) (Table 1). The increase in soil pH under the organic system is associated with the application of organic materials, which can enhance base cations and reduce aluminum saturation, a major cause of soil acidity.

In contrast, conventional systems that rely on inorganic fertilizers, particularly nitrogen fertilizers, tend to accelerate soil acidification due to the release of H^+ ions during the nitrification process. This condition commonly occurs in coffee fields subjected to long-term intensive management.

These findings are consistent with the study of Effendi et al. (2024), published in the Journal of Agriculture and Animal Science, which reported that coffee agroforestry systems with organic management exhibited improved soil physical and chemical properties, including higher organic matter content that supports better soil buffering capacity and pH stability.

Soil Organic Carbon Content

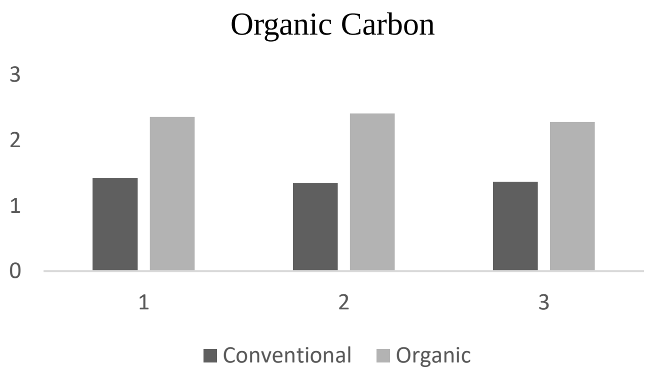

Figure 2. Effect of coffee cultivation systems on soil organic carbon content

Soil organic carbon content showed a highly significant difference between coffee cultivation systems. The organic system had an average organic carbon content of 2.35%, whereas the conventional system recorded only 1.38% (Table 1). The increase in organic carbon under the organic system was attributed to the high input of organic materials, which contributed to soil carbon accumulation and enhanced microbial activity.

Organic matter plays a crucial role in improving soil fertility by increasing cation exchange capacity, improving soil structure, and enhancing nutrient use efficiency. The low organic carbon content under the conventional system indicates a decline in soil quality due to the limited return of organic residues to the soil.

These findings are consistent with the study of Sukristiyonubowo et al. (2018), which reported that organic farming systems consistently increase soil organic carbon content.

Total Soil Nitrogen (N-total)

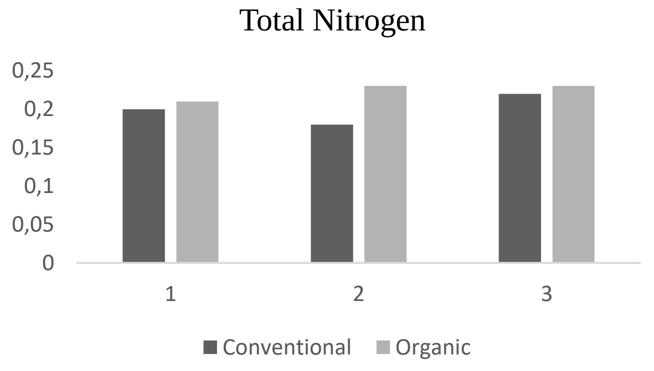

Figure 3. Effect of coffee cultivation systems on total soil nitrogen

The ANOVA results indicated that the coffee cultivation system did not have a significant effect on total soil nitrogen. The average total nitrogen content under the organic system (0.22%) and the conventional system (0.20%) was relatively similar (Table 1). This finding suggests that total soil nitrogen pools are relatively stable and not easily altered by differences in cultivation systems, particularly under long-term management (>10 years), where nitrogen inputs and outputs may approach equilibrium.

The insignificant difference in total N may also be influenced by the specific types of fertilizers applied in both systems. In conventional coffee systems, nitrogen is commonly supplied through inorganic fertilizers such as urea or ammonium-based fertilizers, which primarily increase mineral N (NH_4^+ and NO_3^-) in the short term but do not necessarily contribute substantially to long-term soil N reserves unless incorporated into stable organic fractions. Conversely, organic systems rely on compost, manure, or plant residues, where nitrogen is predominantly present in organic forms that require microbial mineralization before becoming plant-available. The transformation of organic N into ammonium (ammonification) and subsequently nitrate (nitrification) depends strongly on microbial activity, soil moisture, aeration, and temperature—factors that are characteristic of humid tropical environments (Zhang et al., 2018).

In highly weathered tropical soils, rapid nitrification and high rainfall can accelerate nitrate leaching, limiting the accumulation of nitrogen in stable soil pools despite continuous inputs (Han et al., 2021). As a result, both organic and conventional systems may exhibit similar total N levels, because added nitrogen is either taken up by plants, lost through leaching, or transformed into microbial biomass and labile organic fractions rather than significantly increasing the total soil nitrogen stock.

Available Phosphorus (P-available)

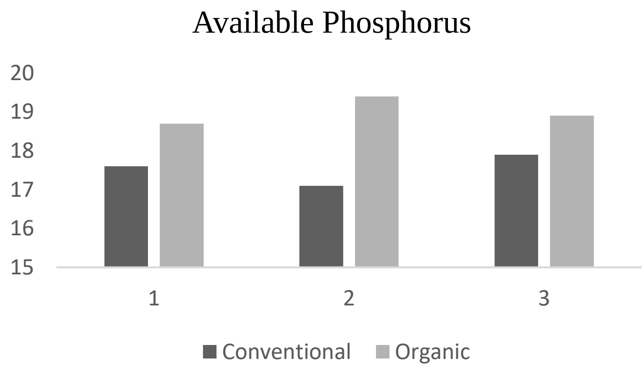

Figure 4. Effect of coffee cultivation systems on available phosphorus

Available phosphorus showed a highly significant effect of the coffee cultivation system The average available phosphorus under the organic system (19.00 mg kg^{-1}) was higher than that under the conventional system (17.53 mg kg^{-1}) (Table 1).

The increase in available phosphorus under the organic system was attributed to the role of organic matter in reducing phosphorus fixation by Fe and Al, as well as to enhanced activity of phosphate-solubilizing microorganisms. These conditions improve the efficiency of phosphorus uptake by coffee plants.

These results are consistent with the findings of Paramudita et al. (2025), published in the Journal of Agriculture and Animal Science, who reported that organic inputs significantly improve nutrient availability including phosphorus in tropical soils. This is further supported by Hinsinger et al. (2018), who reported that interactions among plant roots, microorganisms, and organic matter play an important role in increasing soil phosphorus availability.

Available Potassium (K-available)

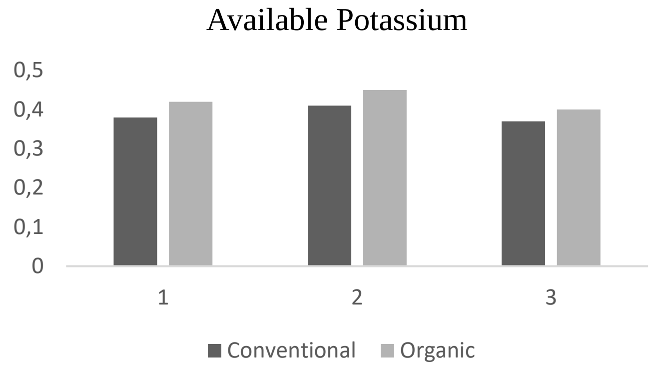

Figure 5. Effect of coffee cultivation systems on available soil potassium

The results of the analysis of variance indicated that the coffee cultivation system did not have a significant effect on soil available potassium. The available potassium content under both cultivation systems was relatively similar (Table 1).

Potassium is a nutrient that is largely derived from the weathering of soil minerals; therefore, its variation is more strongly influenced by soil parent material than by short-term management practices. As a result, differences in cultivation systems were not sufficient to produce a significant effect on available potassium.

These findings are consistent with the study of Bongers et al. (2018), who reported that differences in coffee management systems did not consistently result in significant changes in available potassium, as this nutrient is largely governed by soil mineral weathering and is less sensitive to short-term management changes.

Cation Exchange Capacity (CEC)

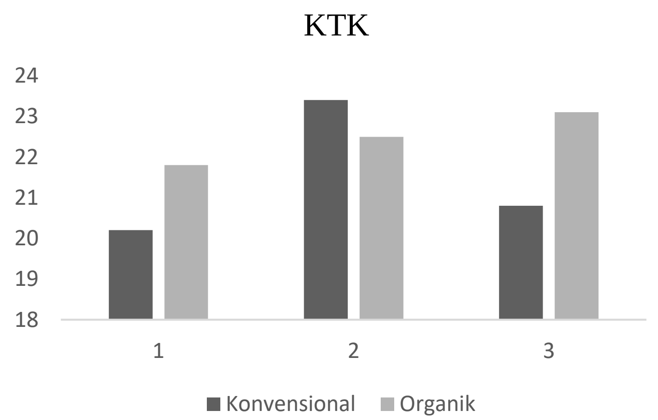

Figure 6. Effect of coffee cultivation systems on soil cation exchange capacity (CEC)

The ANOVA results indicated that the coffee cultivation system did not have a significant effect on soil cation exchange capacity (CEC) (F calculated = 0.9). Nevertheless, the CEC value under the organic system tended to be higher than that under the conventional system (Table 1).

Soil CEC is influenced by clay content and organic matter. Although organic management increased soil organic matter content, its effect on CEC was not statistically significant because CEC is largely determined by soil texture and clay mineral composition, which are relatively stable properties.

These findings are consistent with the study of Sutanto (2019) and are further supported by Angadi et al. (2025), who confirmed that soil CEC values in organically managed coffee fields tended to be higher than in conventionally managed ones, but the differences were not always statistically significant due to the dominant influence of soil texture and clay mineral composition.

Implications for Coffee Plantation Soil Management

Based on the results of this study, the organic coffee cultivation system was proven to improve several key soil chemical properties, particularly soil pH, organic carbon content, and available phosphorus. These improvements have the potential to enhance fertilizer use efficiency, soil health, and the sustainability of coffee production.

In contrast, conventional cultivation systems tend to maintain short-term productivity but may lead to a decline in soil chemical quality if not accompanied by adequate organic matter management. Therefore, the integration of organic-based management principles into conventional coffee cultivation systems is recommended as a strategy to maintain the sustainability of coffee agroecosystems.

CONCLUSION

Based on the results and discussion of this study, it can be concluded that coffee cultivation systems exert different effects on soil chemical properties. The organic coffee cultivation system had a highly significant effect in increasing soil pH, organic carbon content, and available phosphorus compared to the conventional coffee cultivation system. Improvements in these parameters indicate enhanced soil chemical quality in organically managed coffee plantations.

In contrast, conventional and organic coffee cultivation systems did not show significant differences in total nitrogen, available potassium, and soil cation exchange capacity. This indicates that soil chemical properties related to nutrient reserves and soil mineral characteristics require a longer management period to exhibit significant changes.

Overall, organic coffee cultivation systems have positive implications for improving soil chemical quality and show strong potential for supporting sustainable coffee plantation management.

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