BIO Web of Conferences **165**, 04001 (2025) https://doi.org/10.1051/bioconf/202516504001
ICGAB 2024

The Impact of the Chemical Characteristics of The Soil in an Agroforestry System on the Sensory Quality of Robusta Coffee

Rizky Prasetia[1], *Syahru*l Kurniawan[1], and *Kiki* Fibrianto[2*]

[1]Department of Soil Science, Faculty of Agriculture, Brawijaya University, Indonesia
[2]Brawijaya Senso-Gastrononomy Center, Department of Food Science and Biotechnology, Faculty of Agricultural Technology, Brawijaya Univeristy, Indonesia

Abstract. Traditionally, coffee farming in Indonesia has developed within an agroforestry system that involves non-homogenous shade that modish soil characteristics as well as coffee plantations in Malang regency, including traditional coffee plantations in Ampelgading village, Tirtoyudo, and Toyomarto village, Singosari. The cupping score showed that Ampelgading coffee tended to be more superior in terms of sensory quality than that of Toyomarto. While the soil chemical characteristics susc as organic carbon, total nitrogen, and phosphorus in Toyomarto flavorful coffee beans and better sensory quality.

1 Introduction

Indonesia is one of the largest coffee producing countries in the world, with various types of superior coffee originating from various regions. Two regions that have great potential in producing high-quality coffee are Toyomarto and Ampelgading, both of which are located in East Java. Coffee from these regions has distinctive taste characteristics, which are strongly suspected to be influenced by the chemical properties of the soil where the coffee is grown [1]. Soil chemical properties, such as pH, organic carbon content (C-organic), total nitrogen (N total), total phosphorus (P total), and total potassium (K total), play an important role in the growth of coffee plants and the formation of their flavor. Soil with the appropriate pH can affect the availability of nutrients for plants, while C-organic content contributes to soil structure and nutrient provision. Macronutrients such as N, P, and K are very important for plant physiological processes, such as photosynthesis, fruit formation, and metabolism of compounds that contribute to coffee flavor [2]. Toyomarto and Ampelgading have different geographical and climatic conditions, which have the potential to produce variations in soil chemical properties. These variations can affect coffee quality parameters such as fragrance, flavor, acidity, bitterness, mouthfeel, and balance. Previous studies have shown that coffee flavor is greatly influenced by the interaction between coffee plant genetics, growing environment, and land management [3]. However, specific studies on the relationship between soil chemical properties and coffee flavor in these two areas are still limited [4]. Research on the relationship between soil chemical properties and coffee flavor in Toyomarto and Ampelgading is important to provide a deeper understanding of the factors that influence

* Corresponding author: kiki.fibrianto@ub.ac.id

coffee quality. The results of this study are expected to be the basis for better land management, improving the quality of coffee products, and providing added value for local coffee farmers.

2 Research methods

The research location was conducted at two different locations in Malang Regency there are, Tirtoyudo district, Ampelgading village (600-700 masl with average slope of 22.4%) and Singosari district, Toyomarto village (800-900 masl with average slope 0.7%), East Java. Time of research conducted in May to June 2024. Materials used in this research were litter, robusta coffee beans, and soil sample. Meanwhile, the tools required for the study were Belgian drill type, phi band, canopy apps, ruler, and litter frame. The process of gathering data involves taking a sample of land by creating a 20 x 20 m^2 plot with a 5 x 5 m^2 subplot. All measurement was repeated three times (Fig. 1). Once sample collection is complete, the sample will be analyzed in soil chemistry laboratory at the Agriculture Faculty, Universitas Brawijaya. For coffee beans sensory quality, the analysis was conducted at PUSLITKOKA to further investigate the sensory profile of robusta coffee beans true standard cupping test (SCAA/ Specialty Coffee Association of America). Up to 300 grams of coffee beans were extracted from one site and processed naturally.

Each subplot's litter sample was retrieved using a 50 cm x 50 cm frame, which was used to measure the litter's thickness in addition to the ruler litter sample that was used in the past. Afterwards, the sublot divided into 6 categories, including understory soils, leaves, twigs, fruits, seeds, and flowers (Fig. 2). The second steps analyze the vegetation that provides shade for the coffee in each research plot at each place where research has been conducted. The use of canopy applications is carried out while holding the device high in the air, in between shade and cover canopies. It proceeds to the canopy analysis until the application's results are displayed, along with the tools and materials listed in the above table. For the analysis in the laboratory each sample used C-Organic (Walkey-Black), N-Total (Kjeldahl method), then P-Total and K-Total (Olsen method) [5, 6]. Stastistical analysis in this research used software R-Studio and microsoft excel for the t-test

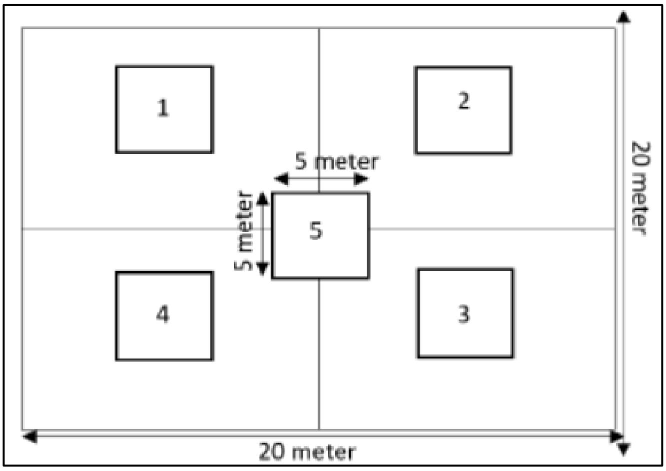

Fig. 1. Sample Plot Ilustration for soil

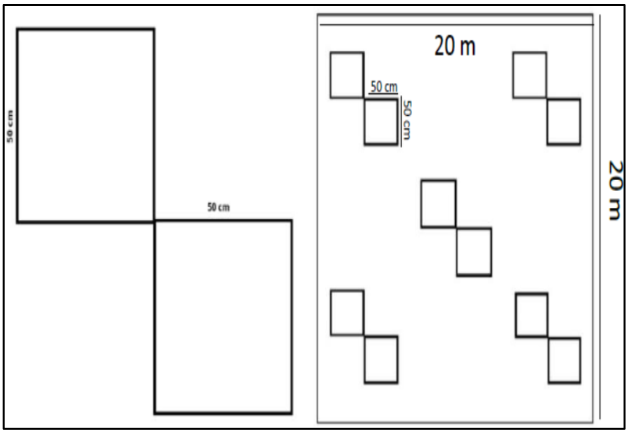

Fig. 2. Sample Plot Ilustration for litter

3 Results and discussion

Table 1. Chemical Properties and Nutrient Content of Ampelgading and Singosari Soils.

Parameters	Location	
	Ampelgading	**Toyomarto**
pH	**5.7 ± 0.2[a]**	**5.5 ± 0.4[a]**
C-Organic (%)	0.6 ± 0.5[a]	2.1 ± 0.6[b]
N-Total (%)	0.3 ± 0.02[a]	0.5 ± 0.02[b]
C/N	2.1 ± 1.9[a]	4.1 ± 1.1[a]
Organic matter (%)	1.0 ± 0.9[a]	3.6 ± 1.1[a]
P-Total (ppm)	1124.1 ± 11.6[a]	1300.9 ± 167.2[a]
K-Total (ppm)	1300.9 ± 167.2[a]	758.0 ± 155.4[a]
Bulk density (g/cm^3)	51.7 ± 5.2[a]	72.0 ± 4.7[a]
Total dry weight litter (gram)	20.5 ± 0.9[a]	28.8 ± 5.8[a]

The laboratory measurement found the variations in soil chemistry and nutrient concentration. Two study locations were used for the analysis C organic land range, which is classed as very low – medium criteria. Low soil organic matter content is caused by an imbalance between the addition and loss of organic matter from the soil, mainly through biological oxidation processes in the soil [7]. The t-test results show that C is organic land in the system coffee agroforestry in Ampelgading different significant (P = 0.03*) with system coffee agroforestry in Singosari. More furthermore organic C- content land on the system coffee agroforestry in Toyomarto compared to with Ampelgading. Soil total N content range between 0.24 – 0.53% which is classified as in criteria moderate [8]. The results of the t-test show that N is the total soil in the system coffee agroforestry in Ampelgading very significantly different (P = <0.01**) with system coffee agroforestry in Toyomarto. More further, the total N content of the soil in the system coffee agroforestry in Toyomarto is high compared to Ampelgading. That means, the agroforesty systems in Toyomarto have fertility soil than Ampelgading because the C-Organic and organic matter is higher.

Score on the table explain the range of coffee taste; 6.00–6.75= Good; 7.00–7.75= Very good; 8.00–8.75= Excellent; 9.00–9.75= Outstanding (no indicated)* Final score annotation**: Lowest possible value for (Lowest Possible Value) Specialty Rating: 80. Nutrients in soil, such as C- Organic, N-Total, P-Total, K-Total, and soil pH greatly affect the quality of coffee. A high C-organic content in the soil indicates an adequate level of organic material, which is crucial for providing nutrients to coffee plants. Organic matter enhances the soil's ability to retain water and nutrients, reducing plant stress that could otherwise lead to an increase in bitter compounds such as alkaloids. Soils rich in organic matter also exhibit good porosity and high water retention capacity, promoting root health and efficient nutrient uptake. This, in turn, results in coffee beans with a robust cell structure, contributing to a smoother and more satisfying texture when brewed [9].

Table 2. SCAA Cupping Test for Ampelgading (1) and Toyomarto (2) Robusta Coffee.

Parameters	Location	
	Ampelgading	**Toyomarto**
Fragrance	7.5	7.5
Flavor	7.5	7.5
Afterttase	7.5	7.5
Salt/acid	7.5	6.75
Bitter/sweet	7.5	6.75
Mouthfeel/body	7.5	6.75
Uniform cups	10	10
Balance	7.5	7
Clean cups	10	10
Overall	7.5	7
Taint-faults	0	0
Final score**	79.5	76.2
Notes	Chocolote, Spicy	

Nitrogen (N-Total) is required for growth vegetative, whereas phosphorus (P-Total) supports development roots and flowers. Potassium (K-Total) is important to Coffee quality is significantly influenced by soil nutrients, including C-Organic, N-Total, P-Total, K-Total, and soil pH, High C-Organic [10]. Sufficient nitrogen in the soil allows coffee plants to produce proteins and enzymes needed for the metabolism and synthesis of volatile compounds. These volatile compounds contribute to the distinctive aroma of coffee so that a lack of nitrogen can inhibit the synthesis of these compounds, reducing the intensity of the aroma [11]. Enough organic material is present in the earth, which is necessary to provide coffee plants nutrition. Phosphorus (P-Total) promotes the development of roots and blooms, while nitrogen (N-Total) is necessary for vegetative growth. Potassium (K-Total) is necessary for resilient fruit and disease resistance.

Table 3. Correlation test on soil chemical properties with sensory attributes of coffee

No	Soil test	Acid	Bitter	Mouthfeel	Balance	Overall
1	pH	0.39	0.39	0.39	0.39	0.39
2	C-Org	-0.85	-0.85	-0.85	-0.85	-0.85
3	N-Total	-0.99	-0.99	-0.99	-0.99	-0.99
4	P-Total	-0.99	-0.99	-0.99	-0.99	-0.99
5	K-Total	-0.54	-0.54	-0.54	-0.54	-0.54

The influence of soil characteristics, particularly soil organic carbon (C-organic), total nitrogen (N-total), and total phosphorus (P-total), on the sensory attributes of coffee, including acidity, bitterness, mouthfeel, balance, and overall perception, can be detrimental under certain conditions. Understanding these negative impacts is crucial for optimizing coffee quality. High levels of C-organic can lead to increased soil pH, which may negatively affect coffee acidity. Research indicates that soils with elevated organic matter can exhibit a buffering effect, resulting in less fluctuation in pH levels [12]. When soil pH rises above optimal levels for coffee cultivation (typically between 5.0 and 6.0), it can lead to reduced acidity in the coffee beans, which is often a desirable trait for flavor complexity [13]. Furthermore, excessive organic matter can promote microbial activity that may deplete nitrogen levels, further impacting the flavor profile negatively by reducing the sweet and acidic notes that are essential for a balanced cup of coffee [14]. For coffee, a soil pH of 5.5 to 6.5 is optimum [15]. High or too low of a pH can interfere with nutrient absorption. Agroforestry multistate conditions generate an environment that is similar to coffee's natural home, which is beneath the shadow of large trees [16]. This helps maintain a constant temperature, lessen water evaporation from the land, and increase humidity. Furthermore, quality fruit and resilience to disease and the ideal soil pH for coffee ranges between 5.5-6.5 [15].

Total nitrogen content also plays a critical role in coffee quality. While nitrogen is essential for plant growth, an imbalance especially when nitrogen levels are too low—can lead to poor bean development and undesirable flavors. A low C/N ratio can indicate rapid decomposition of organic matter, which may not provide sufficient nitrogen for the coffee plants, leading to a deficiency that negatively impacts flavor attributes such as mouthfeel and overall balance [17]. Insufficient nitrogen can result in beans that lack the complexity and richness desired in high-quality coffee, often manifesting as increased bitterness and a flat mouthfeel [18].

Phosphorus levels in the soil can also adversely affect coffee quality. While phosphorus is necessary for root development and overall plant health, excessive phosphorus can lead to nutrient imbalances that may affect the sensory attributes of coffee. High phosphorus levels can interfere with the uptake of other essential nutrients, potentially leading to deficiencies that impact flavor [19]. Additionally, soils with high phosphorus content can contribute to increased bitterness in coffee, as the balance of flavor compounds is disrupted [20]. The relationship between phosphorus and other nutrients is complex; thus, managing phosphorus levels is critical to maintaining the desired flavor profile in coffee.

Table 4. Tree canopy cover on agroforestry systems

Location	**Name**	**Canopy (average)**
Ampelgading	*Swietenia mahagoni*	31.5%
	Falcataria moluccana	
	Persea americana	
	Tectona grandis	
Toyomarto	*Durio zibethinus*	38.9%
	Falcataria moluccana	
	Gmelina arborea	

The different tree canopy cover on agroforestry system in the location shows at (table 4). Ampelgading, there are *Swietenia mahagoni*, *Falcataria moluccana*, *persea americana,* and *Tectona grandis*. Mahogany, with one tree, functions as an important shade plant in the agroforestry system. This tree provides partial shade which is ideal for coffee growth, protecting coffee plants from direct sunlight and reducing soil temperature and Mahogany contributes to soil and water conservation and increases soil fertility through the decomposition of leaf litter [15]. Sengon is a legume plant that plays an important role in nitrogen fixation. increasing nitrogen content in the soil has benefits for coffee growth.

Toyomarto more diverse vegetation, including *Durio zibethinus*, *Falcataria moluccana*, and *Gmelina arborea*. The shade from durian helps regulate the microclimate such as providing shade that helps reduce temperature fluctuations, reducing soil moisture loss due to evaporation, and creating a more humid environment that supports coffee growth around the coffee plants [15]. White teak helps control erosion and improve soil health by increasing the availability of nitrogen and potassium, which are important for intercropping plant nutrition. In addition, its extensive canopy provides partial shade, which balances temperature and humidity levels, thus benefiting plants under the canopy by reducing stress and improving growth conditions [15].

Agroforestry multistate conditions generate an environment that is similar to coffee's natural home, which is beneath the shadow of large trees. This helps maintain a constant temperature, lessen water evaporation from the land, and increase humidity. Additionally, the agroforestry system's trees can enhance the C- Organic content of the land by adding organic material through their fall leaves.

4 Conclusions

It can be concluded from the research that the land in the coffee agroforestry system located in Toyomarto is more fertile than the land in the system located in Ampelgading. This is reinforced by the soil's total soil N content and organic C content, which make the coffee agroforestry system in Toyomarto higher than it is in Ampelgading. The robusta coffee from Toyomarto have a taste that tends to be lower in acidity, bitterness, mouthfeel, and balance when compared to Ampelgading, which has more high characteristics at 7.50 and 7.5. This difference in content is purportedly related to the actual taste of the resulting coffee. In summary, while C-organic, N-total, and P-total are essential components of soil health, their excessive or imbalanced presence can negatively affect the sensory attributes of coffee. High organic matter can lead to increased pH and reduced acidity, low nitrogen can result in bitterness and poor mouthfeel, and excessive phosphorus can disrupt nutrient balance, further impacting flavor. Therefore, careful management of these soil characteristics is crucial for producing high-quality coffee. For farmers involved in land management, it is essential to prioritize planting trees and providing adequate shade to avoid hindering growth while ensuring sufficient organic material is available for coffee plants to thrive optimally.

References

1 S. Harum. Analysis Coffee Production in Indonesia 2015-2020 Using the Cobb-Douglass Method. J. Scntfc. Ecnmcs. Dvlpmt. **1**, 102–109 (2022). Https://Stiemmamuju.EJournal.Id/Gjiep/Article/View/107
2 Y. Muhammad, I. Ilyas, S. Sufardi. Soil Chemical Quality in Arabica Coffee Land Organic and Inorganic in the District Bebesen Central Aceh Regency. J. Scntfc. Stdnt. Agc. **7**, 449–462 (2022). Https://Doi.Org/10.17969/Jimfp.V7i3.20942
3 S. Ahmed, S. Brinkley, E. Smith, A. Sela, M. Theisen, C. Thibodeau, T. Warne, E. Anderson, N. Van Dusen, P. Giuliano, K.E. Ionescu, S.B. Cash. Climate Change and Coffee Quality: Systematic Review on the Effects of Environmental and Management Variation on Secondary Metabolites and Sensory Attributes of Coffea arabica and Coffea canephora. Plt. Scnc. **12**, 1–20 (2021). https://doi.org/10.3389/fpls.2021.708013
4 S. Darma, S. Ramayana, S. Sadaruddin. Investigation of Organic C, Nitrogen, P and K

Content, pH and C/N Ratio of Rainfed Rice Fields in Sarinadi Village, Kota Bangun District, Kutai Kertanegara Regency, East Kalimantan. J. Trpcl. Agrfd. **4**, 88–92 (2021). https://doi.org/10.35941/jatl.4.2.2022.6998.88-92

5 S.R. Olsen, C.V. Cole, F.S. Watanabe. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. (USDA Circular No. 939, US Government Printing Office, Washington DC, 1954).

6 B. Siswanto. Distribution Nutrients N, P, K and pH in Soil. B. Sains. **18**, 109 (2019). https://Doi.Org/10.33366/Bs.V18i2.1184

7 A. Wirayuda, W. Warkoyo, M. Mujianto. The Influence Size Robusta Coffee Beans on Quality Coffee Flavor. J. Agc. Plant. Indus. **11**, 1–14 (2023). Https://Doi.Org/10.25181/Jaip.V11i1.2602

8 Y.Y. Bolly, G.O. Apelabi, Analysis Rice Soil Organic Material Content as an Assessment Effort Soil Fertility in Magepanda Village Subdistrict Mage Panda Sikka Regency. Agrica. **15**, 26–32. https://Doi.Org/10.37478/Agr.V15i1.1919

9 Y. Abebe, B. Juergen, B. Endashaw, H. Kitessa, G. Heiner. The role of soil nutrient ratios in coffee quality: Their influence on bean size and cup quality in the natural coffee forest ecosystems of Ethiopia. Afr. J. Agc Rsrch. **14**, 2090–2103 (2019). https://doi.org/10.5897/ajar2019.14332

10 K. Piato, F. Lefort, C. Subía, C. Caicedo, D. Calderón, J. Pico, L. Norgrove. Effects of shade trees on robusta coffee growth, yield and quality. A meta-analysis. Agronomy of Sustainable Development. **40** (2020). doi: https://doi.org/10.1007/s13593-020-00642-3

11 R. Kasongo, A. Verdoodt, P. Kanyankogote, G. Baert, É. Ranst, Response of italian ryegrass (lolium multiflorum lam.) to coffee waste application on a humid tropical sandy soil. Sl. Us. Mngmnt. **29**, 22-29 (2012).

12 K. Sudharta, A. Hakim, M. Fadhilah, M. Fadzil, C. Prayogo, Z. Kusuma, D. Suprayogo, Soil organic matter and nitrogen in varying management types of coffee-pine agroforestry systems and their effect on coffee bean yield. Biodiversitas J.Bio. Dvsty. **23**, (2022). https://doi.org/10.13057/biodiv/d231142

13 E. Eponon, K. Kassi, K. Kouame, D. Snoeck, T. Ouattara, M. Camara, D. Koné, The soil diagnostic method to formulate fertilizer requirements for coffee trees in côte d'ivoire. Arc. Crrnt. Rsrch Int. **23**, 51-59 (2023). https://doi.org/10.9734/acri/2023/v23i4569

14 R. Hadjikinova. Effect of sucrose replacement on physicochemical parameters and sensory characteristics of instant coffee drinks. Bio Web of Conferences. **102** (2024). https://doi.org/10.1051/bioconf/202410201013

15 T. Sarzynski, B. Bertrand, C. Rigal, P. Marraccini, P. Vaast, F. Georget, C. Campa, C. Abdallah, C.T.Q. Nguyen, H.P. Nguyen, H.T.T. Nguyen, Q.L. Ngoc, G.K. Ngan, T.V. Viet, L. Navarini, V. Lonzarich, L. Bossolasco, H. Etienne. Genetic-environment interactions and climatic variables effect on bean physical characteristics and chemical composition of Coffea arabica. J. Scnc. Food and Agc. **103**, 4692–4703 (2023). https://doi.org/10.1002/jsfa.12544

16 G. Voltolini, L., Silva, A. Alecrim, D. Castanheira, L. Resende, T. Rezende, R. Guimarães, Soil chemical attributes in coffee growing with different agronomic techniques. Coff. Scnc. **15**, 1-11 (2020). https://doi.org/10.25186/.v15i.1689

17 S. Jurburg, K. Shek, K. Mcguire, Soil microbial composition varies in response to coffee agroecosystem management (2020). https://doi.org/10.1101/2020.07.10.197202

18 S. Al-Dalain, M. Haddad, S. Parisi, M. Al-Tarawneh, H. Qaralleh, Determination of macroelements, transition elements, and anionic contents of commercial roasted ground coffee available in jordanian markets. Bvrgs. **6**, 16 (2020).. https://doi.org/10.3390/beverages6010016

19 A. Fathi, Role of nitrogen (N) in plant growth, photosynthesis pigments, and N use efficiency: Agr. **28**, (2022). https://doi.org/10.5281/zenodo.7143588

20 V. Jílková, P. Straková, J. Frouz, Foliage C/N Ratio, Stage Of Organic Matter Decomposition And Interaction With Soil Affect Microbial Respiration And Its Response To C And N Addition More Than C:N Changes During Decomposition. Appld. Sl. Eclg. **152** (2022). https://Doi.Org/10.1016/J.Apsoil.2020.103568