**Proceedings Academic Universitas Jambi**
Volume 2, Issue 2, Juli, 2026

# Comparative Analysis of Metal Composition in Ultisol Soil and Swallow Guano as Nutrient Sources for Liberica Coffee (*Coffea liberica*) Seedlings Based on XRF and Web-Based Cloud Machine Learning

**Madyawati Latief[1], Elis Kartika[2], Lizawati Lizawati[3], Yusnaidar Yusnaidar[4], Sutrisno Sutrisno[5], Indra Lasmana Tarigan[6], Samsidar Samsidar[7], Muhammad Irhash Shalihin[8], and Adzuan Handi Duansyah[9]**

[1,2,3,4,5,6,7,8,9]Universitas Jambi, Jambi, Indonesia.

*Coressponding Authors: madyawatilatief@unja.ac.id

## Abstract

Ultisol soils are widely used as planting media in humid tropical regions of Indonesia but are constrained by advanced weathering, high aluminum (Al) and iron (Fe) contents, and low natural fertility. These conditions limit nutrient availability during the nursery stage of Liberica coffee (*Coffea liberica*), which requires intensive nutrient supply for early growth. This study aimed to characterize the chemical properties of Ultisol using X-ray fluorescence (XRF) and to evaluate the potential of swiftlet manure as an organic nutrient source. XRF analysis showed that Ultisol was dominated by silicate minerals (Si 57.24%) with high Al (22.1%) and Fe (12.21%) and very low total nitrogen (0.08%). Swiftlet manure contained very high nitrogen (11.39%) and available phosphorus (210.71 ppm), indicating strong potential to alleviate nutrient deficiencies. However, it was low in base cations, particularly calcium (0%) and potassium (0.42%). Therefore, swiftlet manure is most effective when combined with inorganic fertilizers to achieve balanced nutrition. This study highlights the value of local organic resources for improving seedling quality on marginal soils.

**Keywords:** Ultisol; Liberica Coffee; Swiftlet Manure; XRF (X-ray Fluorescence); Soil Fertility

## Cite This Article

Madyawati Latief1, Elis Kartika, Lizawati Lizawati, Yusnaidar Yusnaidar, Sutrisno Sutrisno, Indra Lasmana Tarigan, Samsidar Samsidar, Muhammad Irhash Shalihin, Adzuan Handi Duansyah. (2026). Comparative Analysis of Metal Composition in Ultisol Soil and Swallow Guano as Nutrient Sources for Liberica Coffee (*Coffea liberica*) Seedlings Based on XRF and Web-Based Cloud Machine Learning. Proceedings Academic Universitas Jambi, 2(2): e55597. DOI: 10.22437/proca.v2i2.55597

## Editor

© 2026 The Author(s). Published with license by LPPM Universitas Jambi. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International (CC BY 4.0 International). This license enables reusers to distribute, remix, adapt, and build upon the material in any medium or format, so long as attribution is given to the creator.

**Proceedings Academic Universitas Jambi**
Volume 2, Issue 2, Juli, 2026

Kevin Waldo, M.Pd

## Article info

Received: Mei 15, 2026. Revised: Juli 06, 2026. Accepted: Juli 11, 2026

© 2026 The Author(s). Published with license by LPPM Universitas Jambi. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International (CC BY 4.0 International). This license enables reusers to distribute, remix, adapt, and build upon the material in any medium or format, so long as attribution is given to the creator.

## INTRODUCTION

Liberica coffee (*Coffea liberica*) is a strategic plantation commodity known for its remarkable adaptability to marginal environments, including peatlands and acidic lowland soils [1]. In Indonesia, particularly in Jambi Province, the development of Liberica coffee is largely concentrated on land dominated by Ultisol soils. Ultisols are highly weathered soils characterized by advanced mineral weathering, dominance of stable silicate minerals, and high accumulation of aluminum (Al) and iron (Fe) oxides [2]. These characteristics contribute to strong phosphorus (P) fixation and deficiencies in essential base cations such as potassium (K), calcium (Ca), and magnesium (Mg), thereby reducing soil fertility and limiting the quality of nursery growing media [3].

The seedling phase represents a critical stage in coffee cultivation because seedling vigor directly influences long-term field productivity and crop establishment success. Nutrient imbalance during this stage may lead to suboptimal vegetative growth and reduced plantation performance [4]. Therefore, improving the nutrient status of Ultisol-based growing media requires efficient organic amendments capable of supplying essential macro- and micronutrients.

Swallow guano has emerged as a promising organic fertilizer alternative due to its high nitrogen (N) and phosphorus (P) content compared to other animal wastes [5]. Nitrogen plays a central role in chlorophyll synthesis and vegetative canopy development, which are essential during early seedling growth [6]. However, despite its high N and P concentrations, guano generally contains relatively low levels of base cations, necessitating integrated nutrient management strategies to achieve balanced fertilization and avoid secondary nutrient deficiencies.

A major challenge in growing media management lies in the rapid and accurate assessment of metal and nutrient composition. Conventional laboratory analyses are often time-consuming and costly. The application of X-ray Fluorescence (XRF) technology provides a rapid, simultaneous, and non-destructive approach for determining macro- and micro-element composition in soils and organic materials [7]. Nevertheless, raw XRF data require complex multivariate interpretation to accurately assess fertility status and nutrient interactions.

In this context, Web-Based Cloud Machine Learning offers an advanced analytical framework for processing large-scale elemental datasets and predicting nutrient interactions with high precision. Cloud computing platforms enable scalable data processing, automated classification, and multivariate modeling without requiring extensive local computational infrastructure [8]. The integration of XRF-derived elemental data with machine learning algorithms enhances the ability to identify dominant nutrient factors, classify fertility characteristics, and generate predictive insights for sustainable growing media management.

Although the individual characteristics of Ultisol soils and swallow guano have been widely studied, comparative investigations integrating XRF analysis with cloud-based machine learning platforms remain limited. Therefore, this study aims to compare the metal composition of Ultisol soil and swallow guano and to evaluate their implications for Liberica coffee seedling media management using an integrated intelligent technology approach.

## METHODS

### *Study Site and Experimental Period*

This research was conducted from June to November at the Seedling Laboratory of PUI E2-KOLIM, Universitas Jambi. Chemical characterization of Ultisol soil and swallow guano was performed in the laboratory using X-ray Fluorescence (XRF) spectroscopy and complementary standard soil chemical analyses. The study focused on evaluating their potential as nutrient sources for *Coffea liberica* seedlings.

### *Materials and Instruments*

The materials used in this study consisted of (a) Ultisol soil collected from the experimental field area; (b) swallow guano obtained from local swallow nesting facilities; and (c) deionized water and standard reagents for supporting soil analysis. The primary analytical instrument used was an X-ray Fluorescence (XRF) spectrometer for elemental composition analysis. Supporting laboratory equipment included a drying oven, mortar and pestle, 100-mesh sieve, analytical balance (±0.0001 g accuracy), desiccator, and standard soil chemical analysis apparatus [8].

### *Sample Collection and Preparation*

Ultisol soil samples were collected using a composite sampling method from several random points at a depth of 0-20 cm (topsoil layer). The collected samples were air-dried at room temperature, manually cleaned from roots and coarse debris, ground using a mortar and pestle, and sieved through a 100-mesh sieve to obtain homogeneous fine powder. Swallow guano samples were air-dried until constant weight to reduce moisture content, ground, and sieved using a 100-mesh sieve. All prepared samples were stored in airtight polyethylene containers prior to analysis [8,9].

### *Elemental Analysis Using X-Ray Fluorescence (XRF)*

The elemental composition of Ultisol soil and swallow guano was determined using X-ray Fluorescence (XRF) spectroscopy. Approximately 5 g of finely homogenized powdered sample was placed into a sample holder and analyzed following the manufacturer's standard operating procedures. The XRF technique was selected due to its ability to provide rapid, simultaneous, and non-destructive multi-element detection with high analytical precision. The concentrations of major elements were reported in percentage (%) units, while trace elements were expressed in parts per million (ppm), according to the instrument output. The analyzed major elements included Mg, Al, Si, Fe, Ca, K, and S, whereas the trace elements comprised Zn, Mn, Ni, Cr, V, and Zr. Prior to analysis, the instrument was calibrated using certified reference materials to ensure measurement accuracy, precision, and reproducibility of the elemental data.

### *Web-Based Cloud Machine Learning Analysis*

The elemental composition data obtained from XRF analysis were compiled into a structured dataset in comma-separated values (CSV) format for computational analysis. Each data entry included elemental concentrations as independent variables (features), while the nutrient source category (Ultisol soil or swallow guano) was defined as the target variable for classification modelling [8]. Before model development, several preprocessing procedures were conducted to ensure data quality and analytical robustness. Missing values, if present,

were identified and appropriately handled. Outliers were detected using the interquartile range (IQR) method to minimize statistical bias. Subsequently, all numerical features were normalized using Min-Max Scaling to standardize the value range and improve algorithm performance. The dataset was then partitioned into training (80%) and testing (20%) subsets to evaluate predictive performance objectively. All preprocessing and modeling procedures were carried out within a cloud-based computational environment to ensure scalability, reproducibility, and efficient data handling.

### *Data Analysis*

The XRF analysis results and soil chemical properties are presented descriptively in tables. The discussion is qualitative, linking the chemical characteristics of Ultisol soil and swiftlet droppings to nutrient requirements during the Liberica coffee seedling phase, and is supported by relevant scientific literature.

## RESULTS AND DISCUSSION

The analysis results indicate that the Ultisol medium was dominated by Si (57.24%), followed by Al (22.1%) and Fe (12.21%). This composition reflects an advanced weathering stage typical of Ultisols in humid tropical regions. The dominance of silicate minerals suggests that the mineral fraction is relatively stable but poor in readily available nutrient reserves. This condition is commonly reported for Indonesian Ultisols that have undergone intensive base leaching and primary mineral weathering [10]. Based on the analysis of the Ultisol medium, nutrient contents were obtained as presented in Table 1.

**Table 1.** Results of analysis of nutrient content in Ultisol media.

| Metal Elements | Ultisol Sample (%) Sensor-Based | Ultisol Sample (%) XRF-Based | Swiftlet Manure Sample (%) Sensor-Based | Swiftlet Manure Sample (%) XRF-Based |
|---|---|---|---|---|
| Mg | 3.08 | 10.12 | 5.65 | 23.63 |
| Al | 22.10 | 14.66 | 20.59 | 0.72 |
| Si | 57.24 | 61.77 | 58.05 | 0.00 |
| Fe | 12.21 | 9.73 | 12.03 | 3.34 |
| S | 0.08 | 0.13 | 0.07 | 9.95 |
| Cl | 0.03 | 0.10 | 0.06 | 5.09 |
| K | 0.63 | 0.52 | 0.42 | 27.54 |
| Ca | 1.32 | 0.23 | 0.00 | 17.67 |
| Zn | 0.02 | 0.01 | 0.01 | 1.70 |
| Zr | 0.24 | 0.00 | 0.30 | 0.00 |
| Ni | 0.01 | 0.00 | 0.01 | 0.00 |
| Ta | 0.02 | 0.00 | 0.02 | 0.00 |
| V | 0.07 | 0.05 | 0.06 | 0.00 |
| Cr | 0.05 | 0.02 | - | 0.00 |
| Mn | 0.05 | 0.02 | - | 0.79 |
| C-Organic (W&B) | 2.13 | - | 5.40 | - |

| | | | | |
|---|---|---|---|---|
| P (Bray I) | 111.91 ppm | 0.00 | 210.71 ppm | 8.20 |
| N-Total (Kjeldahl) | 0.08 | - | 0.06 | - |
| pH | 6.70 | - | 5.60 | - |

### *Chemical Characteristics of Ultisol Soil*

High Al and Fe contents are key indicators of advanced weathering. Al-Fe oxides and hydroxides are known to have a strong capacity to fix phosphorus, thereby reducing P fertilization efficiency [11]. Under acidic conditions, Al may also induce root toxicity and inhibit root elongation in young plants [12]. Although the measured soil pH was 6.7 (slightly neutral), the presence of Al-Fe still influences phosphorus dynamics. These findings are consistent with reports by Pratamaningsih et al. [10], who noted that Ultisols in Sumatra and Kalimantan generally have low base saturation, high Al-Fe content, and high P fixation capacity. Other studies on coffee nurseries in acidic soils also indicate that the main limiting factor is not only soil pH but also the dominance of active Al-Fe oxides [13,20].

### *Macronutrient Status*

The contents of Ca (1.32%), Mg (3.08%), and K (0.63%) were classified as low to moderate, reflecting low exchangeable base cations. This condition limits structural and physiological nutrient support for seedlings, particularly in cell wall formation (Ca), enzyme activation (Mg), and osmotic regulation (K). The total N value (0.08%) indicates low nitrogen status. Nitrogen is a primary component of chlorophyll and proteins, making it a key limiting factor in vegetative growth of coffee seedlings. Nitrogen deficiency at the nursery stage typically results in slow growth and pale leaves [14]. These results are consistent with previous studies reporting that tropical Ultisols are generally poor in N and base cations due to intensive leaching. Studies in coffee nurseries on acidic soils also show that the most pronounced early seedling responses occur after the addition of organic N sources [15].

### *Availability of Phosphorus*

The available P value (111.91 ppm Bray I) was analytically classified as very high. However, in Ultisols with high Al-Fe content, this value does not always represent truly plant-available P. A large portion of phosphorus may exist in strongly adsorbed or precipitated forms. Yang et al. [16] emphasized that P efficiency in acidic soils is more strongly governed by rhizosphere processes than by total chemical values. Therefore, biological approaches such as arbuscular mycorrhizal utilization are relevant to enhance P uptake. Soti et al. [17] reported that mycorrhizal inoculation in acidic soils can increase P uptake in perennial crops by 30-60%, particularly in soils with high fixation capacity such as Ultisols.

### *Soil Organic Matter*

The organic C content of 2.13% was considered moderate but not yet ideal for nursery media. Organic matter plays an important role in improving cation exchange capacity, aggregate stability, water retention, and soil microbial activity. Stevenson [18] emphasized that increasing organic matter in acidic soils not only improves physical properties but also reduces Al activity through organo-metal complex formation. Swiftlet manure showed very high N (±11.39%) and available P (210.71 ppm) contents, indicating its potential as a readily available nutrient source. Organic nitrogen from animal manure is relatively easily

mineralized and supports early vegetative growth [19]. However, the low Ca and K contents indicate that swiftlet manure is not a major source of base cations. Thus, it functions more as an N-P supplier than as a base-balance amendment. Studies on various animal manures show a similar pattern, with dominance in N and P supply but relatively low K and Ca [13,20]. Positive responses of coffee seedlings to N-rich organic fertilizers have also been reported in nursery systems on acidic soils [3,4].

### *Agronomic Implications for Liberica Coffee Nurseries*

Overall, Ultisol is suitable as a growth medium for Liberica coffee seedlings but has major limitations in N, base cations, and organic matter. The application of swiftlet manure is effective in correcting N deficiency and partially addressing P needs, thereby supporting early leaf and canopy development. However, because it does not provide sufficient K, Ca, and Mg, swiftlet manure cannot be used as the sole nutrient source. Combination with inorganic fertilizers is required to achieve nutrient balance.

An integrated fertilization approach (organic + inorganic) offers several advantages: improving nutrient uptake efficiency, reducing nutrient losses, enhancing the rhizosphere environment, and supporting more uniform seedling growth. These findings align with the balanced fertilization concept for tropical acidic soils, which emphasizes the integration of organic and inorganic nutrient sources [13,20].

### *Chemical Characteristics of Ultisol Media and the Strategic Role of Swiftlet Manure*

Analysis of the Ultisol medium showed dominance of silicate minerals (Si 57.24%) and high concentrations of metal oxides such as Al (22.1%) and Fe (12.21%). These conditions confirm the profile of Ultisol as a highly weathered soil, where the accumulation of Al and Fe poses a risk of fixing phosphorus (P) into forms unavailable to plants [21]. The low total N content (0.08%) and low base cations (K, Ca, Mg) in Ultisol are major limiting factors for Liberica coffee seedling growth. The application of swiftlet manure provides a significant solution to nitrogen deficiency due to its high N content (11.39%). However, the finding that swiftlet manure contains no calcium (Ca 0%) and low potassium (K 0.42%) confirms that this organic material cannot function as a sole nutrient source. Synergy between swiftlet manure and inorganic fertilizers is therefore required to ensure balanced macronutrient availability during the nursery phase [21].

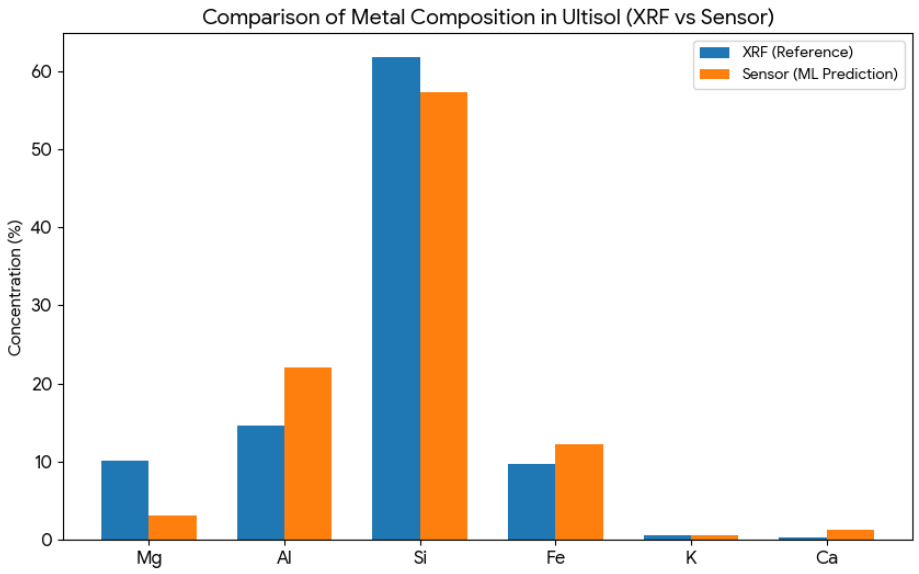


**Figure 1.** Comparison of metal composition in Ultisol measured by XRF reference and predicted by sensor-based machine learning.

**Table 2.** Scatter plot comparison of Ultisol and swiftlet manure.

| Metal Element | XRF Value (X - Reference) (%) | Sensor Value (Y - Predicted) (%) | Relative Error | Remarks |
|---|---|---|---|---|
| Scatter Plot Comparison (Ultisol Sample) | | | | |
| Mg | 10.12 | 3.08 | -69.56% | Strong underestimation |
| Al | 14.66 | 22.10 | +50.75% | Overestimation |
| Si | 61.77 | 57.24 | -7.33% | High accuracy |
| Fe | 9.73 | 12.21 | +25.48% | Overestimation |
| K | 0.52 | 0.63 | +21.15% | Overestimation |
| Ca | 0.23 | 1.32 | +473.91% | Extreme overestimation |
| Scatter Plot Comparison (Swiftlet Manure) | | | | |
| Mg | 23.63 | 5.65 | -76.09% | Strong underestimation |
| Al | 0.72 | 20.59 | +2759.7% | Extreme overestimation |
| Fe | 3.34 | 12.03 | +260% | Extreme overestimation |

| | | | | |
|---|---|---|---|---|
| K | 27.54 | 0.42 | -98.47% | Sensor detection failure |
| Ca | 17.67 | 0.00 | -100% | Sensor detection failure |
| Zn | 1.70 | 0.01 | -99.41% | Strong underestimation |

**Table 3.** Side-by-side bar chart of Ultisol sample and swiftlet manure.

| Metal Element | Sensor (%) | XRF (%) | Bias |
|---|---|---|---|
| Ultisol Sample | | | |
| Si | 57.24 | 61.77 | -4.53 (consistent) |
| Al | 22.10 | 14.66 | +7.44 (overestimate) |
| Fe | 12.21 | 9.73 | +2.48 (overestimate) |
| Mg | 3.08 | 10.12 | -7.04 (underestimate) |
| Swiftlet Manure | | | |
| K | 0.42 | 27.54 | -27.12 (extreme bias) |
| Mg | 5.65 | 23.63 | -17.98 (strong bias) |
| Ca | 0.00 | 17.67 | -17.67 (failure of detection) |
| Al | 20.59 | 0.72 | +19.87 (interference) |

### *Sensor Bias Analysis and XRF-Based Validation with Cloud Machine Learning*

The use of sensor methods integrated with web-based cloud machine learning showed variable performance depending on the sample matrix. In the Ultisol medium, the algorithm demonstrated high accuracy in predicting Si, with an error of only -7.33%. However, significant overestimation occurred for Al (+50.75%) and Fe (+25.48%), with extreme bias observed for Ca (+473.91%). Even more extreme bias was found in swiftlet manure samples, where the sensor completely failed to detect Ca (17.67% vs. 0%) and showed strong negative bias for K (-98.47%). These anomalies are most likely caused by the density and organic matrix of guano affecting sensor spectral reflectance, which differs from the mineral matrix of soil. This inconsistency indicates that the machine learning model requires more specific training datasets for organic materials to improve the precision of real-time, cloud-based nutrient prediction.

**Table 4.** Statistical performance of web-based cloud machine learning.

| Sample Matrix | Coefficient of Determination ($R^2$) | RMSE (%) | Prediction Quality |
|---|---|---|---|
| Ultisol Soil | 0.941 | 4.21 | High accuracy |
| Swiftlet Manure | 0.182 | 15.84 | Low accuracy / bias |

The statistical analysis reveals a stark contrast in the predictive performance of the Web-Based Cloud Machine Learning model between the two matrices. In Ultisol soil, the model achieved a high $R^2$ of 0.941, indicating that the algorithm effectively recognizes mineral patterns in inorganic soil structures. The relatively low RMSE (4.21%) suggests that the sensor-cloud integration is reliable for rapid soil nutrient screening. In contrast, the model performance significantly degraded when processing swallow guano ($R^2$ = 0.182). The high RMSE (15.84%) is primarily driven by the sensor's inability to detect basic cations (Ca and K)

within the complex organic matrix. This low correlation proves that organic guano requires a dedicated calibration model, as the spectral signatures of nutrients in organic matter differ fundamentally from those in mineral soils. This finding justifies the need for more diverse training datasets to refine the cloud-based prediction engine.

## CONCLUSIONS

The Ultisol used as a nursery medium for Liberica coffee was highly weathered, characterized by silicate mineral dominance, high Al and Fe contents, and low nitrogen and base cations. Although the soil pH was slightly neutral, N deficiency and low exchangeable bases remained key constraints for seedling growth. Swiftlet manure contained very high N and P, making it an effective organic nutrient source to support early vegetative development and to improve the low N status of Ultisol. However, high Al-Fe levels in Ultisol may still limit P use efficiency through fixation. The low Ca, Mg, and K contents of swiftlet manure indicate that it cannot serve as a sole fertilizer. Therefore, combining swiftlet manure with inorganic fertilizers supplying base cations is the most effective strategy to achieve nutrient balance, improve nutrient use efficiency, and produce more vigorous and uniform Liberica coffee seedlings.

## CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## FUNDING

Funding information was not specified in the manuscript.

## DECLARATION OF ARTIFICIAL INTELLIGENCE USE

AI-based language tools were used only for manuscript formatting support, language refinement, and reference-style adjustment during editorial preparation. We confirm that all AI-assisted processes were critically reviewed to ensure the integrity and reliability of the manuscript. The final decisions and interpretations presented in this article remain the sole responsibility of the authors.

## REFERENCES

1. Rosmaiti, Iswahyudi. Land suitability evaluation of Liberika coffee on sub optimal land, Langsa Timur Sub District, Langsa, Aceh. International Conference on Agriculture and Applied Science (ICoAAS) 2022. 2022;23:111-119.
2. Mukundan D, R MR, I V, V B, L A, S PP. Assessing iron fractions and their availability in lateritic soils of Kerala using structural equation modelling. International Journal of Plant & Soil Science. 2025;37(5):290-303. doi:10.9734/ijpss/2025/v37i55453.
3. Chang YY, Razak MFA, Sim CC. Effects of different growing media under soilless culture on the growth and nutrient uptake of oil palm seedlings in the pre-nursery stage. Science and Technology Asia. 2023;28(4):256-263.
4. Martín-Cardoso H, San Segundo B. Impact of nutrient stress on plant disease resistance. International Journal of Molecular Sciences. 2025;26(4):1-33. doi:10.3390/ijms26041780.
5. Lubis FA, Kusbiantoro D, Asbur Y, Purwaningrum Y, Indra D, Kurniawan S. Analysis study of soil phosphorus availability on the growth of oil palm seedlings with the application of liquid fertilizer

and guano fertilizer. Contributions of Central Research Institute for Agriculture. 2024;18(2):58-66. doi:10.59651/ccria.

6. Ma J, Zhao J, Zhang J, Liu Q, Lei L, Hou J, et al. Effect of nitrogen application timing on the photosynthetic traits and essential oil yield of Cinnamomum camphora var. linalooliferum coppice stands. Horticulturae. 2026;12:1-19. doi:10.3390/horticulturae12020228.
7. Marguí E, Queralt I, de Almeida E. X-ray fluorescence spectrometry for environmental analysis: basic principles, instrumentation, applications and recent trends. Chemosphere. 2022;303(P1):135006. doi:10.1016/j.chemosphere.2022.135006.
8. Samsidar S, Maison M, Ermadani E, Latief M, Pebralia J, Riany H, et al. X-ray fluorescence monitoring metal content and nutrient elements for predicting soil fertility parameters based on pH in Ultisol soil. International Journal of Hydrological and Environmental for Sustainability. 2023;2(3):104-112. doi:10.58524/ijhes.v2i3.290.
9. Pratamaningsih MM, Hati DP, Erwinda E, Muslim RQ, Hikmat M, Purwanto S. Soil characteristics and management of Ultisols derived from claystones of Sumatra. Journal of Tropical Soils. 2023;29(3):115-125. doi:10.5400/jts.2024.v29i3.115-125.
10. Pratamaningsih MM, Hati DP, Erwinda E, Muslim RQ, Hikmat M, Purwanto S. Soil characteristics and management of Ultisols derived from claystones of Sumatra. Journal of Tropical Soil. 2024;29(3):115-125. doi:10.5400/jts.2024.v29i3.115-125.
11. Hinsinger P. Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. Plant and Soil. 2001;237:173-195. doi:10.1023/A:1013351617532.
12. Foth HD. Fundamentals of Soil Science. 8th ed. New York: Wiley; 1990.
13. Nuryani S, Utami H, Maas A, Nurudin M. Effects of manure and chemical fertilizers on maize performance in the steep hillside with and without terraces in North Halmahera, Indonesia. Ilmu Pertanian (Agricultural Science). 2022;7(1):56-67.
14. Regni L, Proietti P. Effects of nitrogen foliar fertilization on the vegetative and productive performance of the olive tree and on oil quality. Agriculture. 2019;9(12). doi:10.3390/agriculture9120252.
15. Cristancho JA, Hanafi MM, Omar SRS, Rafii MY. Alleviation of soil acidity improves the performance of oil palm progenies planted on an acid Ultisol. Acta Agriculturae Scandinavica Section B: Soil and Plant Science. 2011;61(6):487-498. doi:10.1080/09064710.2010.506448.
16. Yang M, Su J, Lv H, Jia H, Yun W, Liu J, et al. Biostimulant-induced phosphorus activation in soils: mechanisms and efficacy of polyglutamic and humic acids. Applied Soil Ecology. 2026;218:106713. doi:10.1016/j.apsoil.2025.106713.
17. Soti PG, Jayachandran K, Koptur S, Volin JC. Effect of soil pH on growth, nutrient uptake, and mycorrhizal colonization in exotic invasive Lygodium microphyllum. Plant Ecology. 2015;216(7):989-998. doi:10.1007/s11258-015-0484-6.
18. Stevenson FJ. Humus Chemistry: Genesis, Composition, Reactions. 2nd ed. New York: Wiley; 1994.
19. Marschner P, editor. Marschner's Mineral Nutrition of Higher Plants. 3rd ed. London: Academic Press; 2012.
20. Howe JA, McDonald MD, Burke J, Robertson I, Coker H, Gentry TJ, et al. Influence of fertilizer and manure inputs on soil health: a review. Soil Security. 2024;16:100155. doi:10.1016/j.soisec.2024.100155.
21. Tampus DS, Escasinas RO. Effects of swiftlet (Aerodramus fuciphagus) manure and methods of crop establishment on the growth and yield of sweet corn (Zea mays var. saccharata) in Western Leyte, Philippines. Advances in Crop Science and Technology. 2019;7:1-7.