

Soil Chemical Fertility for Maize in Tibawa, Gorontalo, Indonesia

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Abstract

*This study evaluated the chemical status of soils under maize (*Zea mays* L.) cultivation in Tibawa Subdistrict, Gorontalo Regency, Indonesia, to identify fertility constraints and inform site-specific management. A field survey was conducted in May 2025 at three villages (Isimu Utara, Datahu, and Iloponu). At each site, ten subsamples from the 0–20 cm plough layer were composited and analysed for soil pH (H₂O and KCl), organic carbon, total nitrogen (Kjeldahl), available phosphorus (Bray I), exchangeable potassium (NH₄OAc), and cation exchange capacity (CEC). Results indicated slightly acidic to neutral soils (pH 6.3 - 6.9) with moderate CEC (16.72 - 22.32 cmol(+)/kg). Organic carbon ranged from low to moderate (1.42 - 2.51%). Available P was consistently moderate (12.04–14.72 ppm), whereas exchangeable K was low across all sites (0.19 - 0.24 cmol(+)/kg). Total N varied from low in Isimu Utara (0.13%) to moderate in Datahu and Iloponu (0.24 - 0.26%). The primary limitations for maize production were low K availability and, locally, low N and organic matter. Management should prioritize organic amendments, balanced NPK fertilization based on soil testing, and periodic liming where acidification trends emerge. These findings provide a baseline for future monitoring of soil quality and developing recommendations to sustain maize yields while reducing nutrient losses under intensive management in Tibawa.*

Keywords: maize; soil fertility; chemical soil properties; exchangeable potassium; Gorontalo Regency



INTRODUCTION

Soil is the primary growth medium that largely determines the efficiency of nutrient uptake by maize (*Zea mays*). Soil chemical properties - particularly pH, organic matter content (organic C), cation exchange capacity (CEC), and the availability of nitrogen (N), phosphorus (P), and potassium (K) - regulate nutrient solubility and availability, cation exchange dynamics, and soil biological activity that supports nutrient cycling (Nasreen et al., 2025). Under intensively managed cropping systems, inappropriate tillage and fertilization practices may degrade soil chemical quality, such as through soil acidification and declining organic matter, ultimately reducing fertilizer-use efficiency and land productivity (Al-Shammary et al., 2024).

Tibawa Subdistrict, Gorontalo Regency, is a major maize-producing area; however, detailed information on soil chemical status in several villages remains limited. Therefore, this study evaluated the soil chemical status of maize fields in Isimu Utara, Datahu, and Iloponu by measuring soil pH (H₂O and KCl), total N, available P, exchangeable K, CEC, and organic C. The evaluation is expected to identify key chemical constraints and provide a basis for more targeted soil fertility management recommendations.

Background

Maize productivity is strongly influenced by nutrient sufficiency and soil chemical conditions. Nitrogen is an essential element for the formation of key biomolecules (e.g., amino acids, proteins, and nucleic acids) and is closely linked to photosynthesis and plant growth (Amoah et al., 2026). Phosphorus is a macronutrient involved in cellular energy transfer, the formation of important structures, and various metabolic processes, thereby affecting root growth and nutrient-use efficiency (Wang, M. et al., 2026). In addition, balanced fertilization strategies have been associated with improved soil-plant nutrient status and enhanced growth components and maize yield (Syamsiyah et al., 2024).

Maize Intensification and Its Effects on Soil Chemical Status

Yield-oriented intensification often relies on increased inputs, particularly mineral fertilizers. However, excessive or unbalanced fertilization can alter soil chemical status, for example by accelerating soil acidification and degrading soil environmental quality (Zhang et al., 2022). Reviews of agronomic practices further indicate that suboptimal nutrient management may cause nutrient imbalances, reduce the availability of certain elements, and degrade soil health indicators (Al-Shammary et al., 2024).





Effects of Imbalanced Fertilization

Imbalanced fertilization may lead to the accumulation of certain nutrients while others become relatively deficient. One frequent consequence is a decline in soil pH, which affects cation exchange, base saturation, and chemical conditions that determine nutrient stability and soil biological functions (Liu, Y. et al., 2023). In high-input systems, pH decline is also often associated with elevated available N due to excessive N fertilization, which under certain conditions can worsen soil quality and disrupt soil ecosystem balance (Zhang et al., 2022).

Implications for Maize Productivity

Over the long term, soil chemical degradation resulting from nutrient imbalance may reduce yield sustainability. Evidence from long-term experiments shows that combining organic and inorganic fertilizers tends to be more effective in maintaining soil quality and sustaining yields than mineral fertilization alone, particularly when management aims to preserve nutrient balance and soil quality (Wang, J. et al., 2025). Other findings also highlight that balanced fertilization is correlated with improved soil–plant nutrient status and increased maize yield (Syamsiyah et al., 2024).

Limited Availability of Site-Specific Data

Gaps in site-specific information—such as pH, CEC, organic C, and nutrient availability—can hinder precise fertilizer recommendations. Studies in other regions indicate that monitoring soil fertility status is necessary to develop more appropriate management strategies because continuous nutrient extraction may induce nutrient imbalance and reduce land productivity (Mng'ong'o et al., 2021). Accordingly, providing site-specific soil chemical data is essential for more efficient and sustainable fertilization and soil improvement interventions.

Land Management Practices and Fertilization Effectiveness

Fertilizer effectiveness depends on the match between fertilizer type and rate and local soil conditions, as well as complementary management practices (e.g., tillage, crop rotation, and organic matter management). Comprehensive reviews show that integrating nutrient management with organic amendments and other agronomic practices can improve nutrient availability, maintain pH, and strengthen overall soil health (Al-Shammmary et al., 2024). Soil fertility management frameworks likewise emphasize understanding key soil chemical indicators (pH, CEC, available nutrients, and organic C) to design effective and environmentally sound nutrient management (Nasreen et al., 2025).



METHODS

This study was conducted in Tibawa Subdistrict, Gorontalo Regency, in May 2025 using a field survey followed by laboratory analyses. Soil sampling was carried out at three maize field locations: Point A (Isimu Utara Village), Point B (Datahu Village), and Point C (Iloponu Village) (coordinates are provided in the Appendix). At each site, ten subsamples were collected from the 0–20 cm plough layer using a soil auger and then homogenized into one composite sample representing each sampling point. Composite sampling was applied to reduce micro-spatial variability and improve sample representativeness within a field (USDA-NRCS, 2004).

Table 1. Coordinates of soil sampling sites

Pt.	Village	Subdistrict	Regency	Latitude (°)	Longitude (°)
A	Isimu Utara	Tibawa	Gorontalo	0.663964	122.863849
B	Datahu	Tibawa	Gorontalo	0.652486	122.843396
C	Iloponu	Tibawa	Gorontalo	0.690359	122.855898

Table 1 shows the distribution of sampling points representing maize fields in Tibawa Subdistrict. Point A is located in Isimu Utara Village (0.663964° N; 122.863849° E) in the central part of the area, Point B is located in Datahu Village (0.652486° N; 122.843396° E) toward the southwest, and Point C is located in Iloponu Village (0.690359° N; 122.855898° E) in the northern part of the study area. The three locations were purposively selected to capture variation in agroecosystem conditions and maize field management so that soil chemical status could be assessed across different field settings.

Sample Preparation and Laboratory Analysis

Collected soil samples were air-dried, cleared of roots and gravel, and sieved prior to analysis. Chemical parameters included soil pH (H₂O and KCl), total N, available P, exchangeable K, CEC, and organic C. Soil pH was measured in soil–solution suspensions (water and KCl) as a standard procedure for evaluating soil reaction (Thomas, 1996). Total N was determined using the Kjeldahl method (Bremner, 1996). Available P was measured using the Bray I method, which is commonly applied to acidic to slightly acidic soils (Bray & Kurtz, 1945). Exchangeable K was extracted using NH₄OAc, and CEC was measured as an indicator of the soil's capacity to retain and exchange nutrient cations; both procedures are widely used in soil fertility assessment (Sumner & Miller, 1996). Organic C was used as an indicator of soil organic matter and was analysed following standard laboratory procedures for soil carbon (Nelson & Sommers, 1996).

Data Processing and Interpretation

Laboratory results were processed descriptively to summarize values for each parameter at each sampling point. The results were then interpreted to determine soil chemical status and to identify potential fertility constraints. Sampling-point locations were also presented spatially through mapping to facilitate visualization of the observation sites.

Research Workflow

The research stages were arranged sequentially so that each step was connected and produced measurable data that can be scientifically accountable.

Research Flowchart

Evaluation of Soil Chemical Status on Maize Fields in Tibawa Subdistrict, Gorontalo Regency

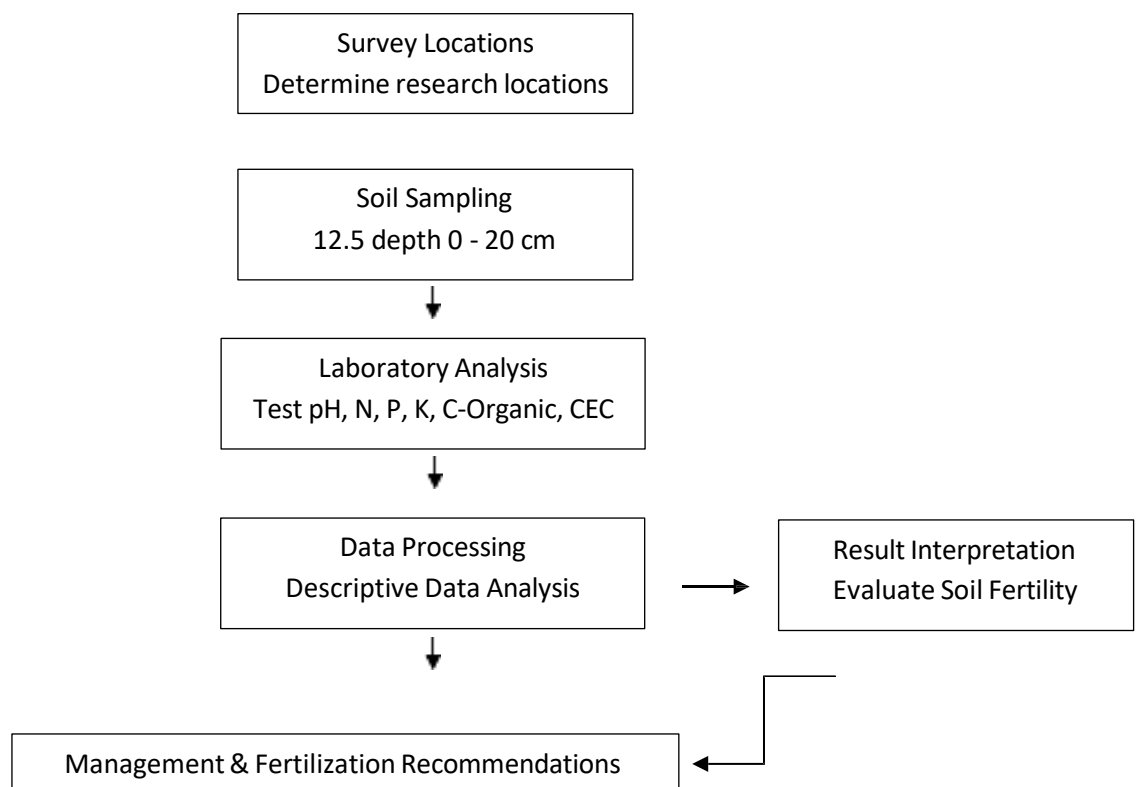


Figure 1. Research flowchart

The workflow (Figure 1) begins with a location survey to determine study sites that represent maize fields in the area. The next stage is soil sampling at 0–20 cm, corresponding to the

plough layer where root–soil interactions and nutrient dynamics are most active. Samples were then prepared and analysed in the laboratory for pH (H₂O and KCl), organic C, total N (Kjeldahl), available P (Bray I), exchangeable K (NH₄OAc), and CEC using standard procedures (Bray & Kurtz, 1945; Bremner, 1996; Nelson & Sommers, 1996; Sumner & Miller, 1996; Thomas, 1996). The analytical results were subsequently processed descriptively and interpreted to determine soil chemical status, identify limiting factors, and support site-specific recommendations for soil fertility management and fertilization.

RESULTS AND DISCUSSION

Table 2. Summary of soil chemical properties (0–20 cm) at three maize field locations in Tibawa Subdistrict

Parameter	Unit	Point A (Isimu Utara)	Point B (Datahu)	Point C (Iloponu)
CEC	cmol(+) kg ⁻¹	16.72 (Moderate)	22.32 (Moderate)	20.54 (Moderate)
pH (H ₂ O)	–	6.9 (Neutral)	6.5 (Neutral)	6.3 (Slightly acidic)
Organic C	%	1.42 (Low)	2.40 (Moderate)	2.51 (Moderate)
Available P (Bray I)	ppm	12.04 (Moderate)	14.72 (Moderate)	13.79 (Moderate)
Total N (Kjeldahl)	%	0.13 (Low)	0.24 (Moderate)	0.26 (Moderate)
Exchangeable K (NH ₄ OAc)	cmol(+) kg ⁻¹	0.19 (Low)	0.24 (Low)	0.21 (Low)

Overall, CEC was moderate (16.72–22.32 cmol(+) kg⁻¹), soil pH (H₂O) ranged from slightly acidic to neutral (6.3–6.9), organic C was low to moderate (1.42–2.51%), total N was low to moderate (0.13–0.26%), available P was moderate (12.04–14.72 ppm), whereas exchangeable K was low across all sites (0.19–0.24 cmol(+) kg⁻¹).

Soil reaction (pH) and its implications

Soil pH (H₂O) values of 6.3–6.9 indicate conditions that generally support nutrient



availability because most macronutrients are more soluble and available in slightly acidic to near-neutral soils. Nevertheless, locations with lower pH (e.g., 6.3) should be monitored because continued acidification may increase the risk of reduced P availability and shifts in soil nutrient balance (Brady & Weil, 2016; Havlin et al., 2013). Differences between pH measured in H₂O and KCl (when available) can also be used as an indicator of exchangeable acidity relevant to assessing hidden acidity potential in soils (Thomas, 1996).

Organic matter and total nitrogen

Organic C ranged from low to moderate, with the lowest value at Point A (1.42%) and higher values at Points B–C (2.40–2.51%). Organic matter contributes to colloid charge, improves aggregation, enhances water retention, and serves as an energy source for soil microorganisms. This is closely linked to N dynamics because most soil N is stored in organic forms and becomes available through microbial mineralization (Brady & Weil, 2016; Havlin et al., 2013). The pattern observed in this study is consistent: Point A, with lower organic C, had low total N (0.13%), whereas Points B–C had moderate total N (0.24–0.26%). These results suggest the need to strengthen organic matter inputs and to apply N fertilization strategies that consider soil N reserves and risks of N loss (e.g., leaching and volatilization) (Bremner, 1996; Havlin et al., 2013).

Available phosphorus

Available P (Bray I) was moderate at all sites. Phosphorus availability is strongly influenced by soil reaction and fixation mechanisms, particularly as soils become more acidic, because P can be bound by Al/Fe and thereby reduce the fraction available for plant uptake. Given that soil pH remained in the slightly acidic–neutral range, the moderate P status likely reflects relatively favourable conditions; however, P-use efficiency still depends on fertilizer placement, application rate, and pH and organic matter management (Havlin et al., 2013; Brady & Weil, 2016).

Exchangeable potassium and CEC

Exchangeable K was low at all sites (0.19–0.24 cmol(+) kg⁻¹), indicating a potential constraint on maize production, especially under intensive systems that remove substantial K through harvest. Improving K status therefore requires more targeted and efficient K fertilization, for example by splitting applications across growth stages to reduce losses and improve uptake opportunities (Havlin et al., 2013). Meanwhile, moderate CEC suggests a medium capacity to retain cations, which can still be improved—particularly through organic amendments that increase colloid charge and enhance nutrient retention (Sumner & Miller, 1996; Brady & Weil, 2016).





Implications and management directions

Based on the combined soil chemical indicators, the most prominent issues were low exchangeable K at all sites and low organic C and total N at Point A. Accordingly, recommended soil fertility management includes: (i) maintaining soil pH within a productive range (and correcting pH if acidification trends occur), (ii) increasing organic matter inputs to strengthen CEC and medium-term N supply, and (iii) implementing soil test-based balanced NPK fertilization with particular attention to K deficiency across the study area (Brady & Weil, 2016; Havlin et al., 2013).

CONCLUSION

This study assessed the soil chemical status of maize (*Zea mays* L.) fields in Tibawa Subdistrict, Gorontalo Regency, to determine fertility status and identify constraints to productivity. Across the three locations (Isimu Utara, Datahu, and Iloponu), soils generally had slightly acidic to neutral pH (H₂O 6.3–6.9), moderate CEC (approximately 16–22 cmol(+) kg⁻¹), and low to moderate organic C (approximately 1.4–2.5%). These pH conditions are broadly favourable for macronutrient availability, while moderate CEC indicates a medium cation-retention capacity that can be improved through better organic matter quality (Brady & Weil, 2016; Sumner & Miller, 1996).

In terms of nutrient status, nitrogen (N) and potassium (K) were identified as the most limiting elements because they tended to be low in part of the study area, whereas phosphorus (P) was moderate. Limitations in N and K are closely related to low organic matter, which supplies N through mineralization and contributes to the soil's capacity to retain cations, including K, thereby influencing fertilizer-use efficiency (Bremner, 1996; Havlin et al., 2013). Although soil pH was generally beneficial for P availability, pH management and fertilization strategies remain important to reduce the risk of declining P-use efficiency due to soil reactions and P retention (Havlin et al., 2013; Thomas, 1996).

Therefore, the main fertility constraints in Tibawa maize fields are low N, low K, and low organic matter. Recommended management focuses on increasing organic amendments to improve soil quality and nutrient retention, applying balanced soil test-based NPK fertilization (site-specific rates), and managing soil pH through liming/dolomite when needed. This evidence-based evaluation provides a scientific basis for location-specific soil fertility decisions to support sustainable maize production in the region (Brady & Weil, 2016; Havlin et al., 2013).

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