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Evaluation Status Hara Land and Leaf Plant Coconut Palm oil (*Elaeis guineensis*) Plantation People in Linggabayu District, Mandailing Natal Regency, North Sumatra Province, Indonesia

Noviantika Nasution[1,*], Mukhlis[1], Mariani Br Sembiring[1]

Abstract

Oil palm (*Elaeis guineensis* Jacq.) is one of the most important plantation crops in Indonesia, and requires effective soil and nutrient management to achieve optimal productivity. This survey aimed to evaluate soil and leaf nutrient status in oil palm plantations managed by smallholders in Linggabayu District, Mandailing Natal Regency, North Sumatra Province, Indonesia. Data were collected through field observations and soil and leaf sampling in Batuloting Village, Banjar Selamat, and Padang Silojongan, with 10 trees sampled at each location. All samples were analyzed at the PT Socfin Indonesia (SOCFINDO) Laboratory to determine the macronutrient content of nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg). The results showed that soil N, P, and K levels at most locations were low to very low, while Mg levels ranged from low to high. Leaf tissue analysis revealed that nitrogen content was generally within the optimal range at almost all locations, except in Banjar Selamat Village and Padang Silojongan, where deficiency symptoms were observed. Phosphorus content in leaves ranged from adequate to optimal, while potassium content varied from low to optimal across sampling locations. Magnesium levels in leaves were relatively adequate, although a small percentage of samples still indicated deficiencies. These findings suggest that, despite generally limited soil fertility, oil palm plants can effectively absorb nutrients. This condition is supported by current fertilization practices and the physiological adaptability of oil palm plants to efficiently utilize soil nutrients. Therefore, site-specific nutrient management, particularly for N, P, and K, is recommended to improve soil fertility and maintain oil palm productivity in smallholder plantations.

Keywords: Leaf Analysis, Location-Specific Nutrient Management, Nutrient Status, Smallholder Plantations, Soil Fertility

1. Introduction

Oil palm (*Elaeis guineensis* Jacq.) is a key commodity in Indonesia, contributing significantly to various aspects of the national economy. This observation is evidenced by the expanding plantation area and its capacity to employ approximately 16.2 million workers, both directly and indirectly. In addition to being a major contributor to exports and foreign exchange earnings, the palm oil industry also supports the provision of New and Renewable Energy (NRE), which is more environmentally friendly and produces lower emissions than fossil fuels. The implementation of a palm oil-based biodiesel program has helped reduce dependence on fuel imports, thereby strengthening the trade balance and promoting national energy independence (Ahmad, 2019). Mandailing Natal Regency in North Sumatra Province covers an area of 662,070 hectares, approximately 9.23% of the province's total area. The existing plantation area totals 111,778.5 hectares, comprising 96,280.2 hectares of smallholder plantations and 15,498.3 hectares of private plantations. The productivity of smallholder oil palm plantations remains relatively low compared to large state-owned and

*Correspondence: noviantikanasution99@gmail.com
1) Universitas Sumatra Utara - Jl. Prof A Sofyan No. 3. Kampus USU, Medan, Sumatera Utara, Indonesia

private plantations. In 2023, smallholder plantation production reached only 3,264 kg/ha, compared to 4,442 kg/ha for state-owned plantations and 3,819 kg/ha for private plantations (Directorate General of Agricultural Plantations, 2024). High productivity in large plantations is influenced by the use of superior seeds and intensive cultivation techniques, whereas smallholder plantations generally still use substandard seeds and are not managed optimally. Inappropriate fertilization practices, irregular pruning, and inadequate harvesting and post-harvest techniques further exacerbate this situation. (Rankine & Fairhurst, 1998).

One of the main factors contributing to the low productivity of smallholder plantations is the inaccuracy of fertilizer dosing, as different soil types, plant ages, and growing conditions require different rates. Furthermore, fertilizer application must be tailored to land conditions and plant nutrient requirements (Pradiko et al., 2021). Ideally, fertilization should be site-specific based on soil and leaf analysis. A 2021 study at PT SAL I showed that calculating fertilizer dosages using specific analysis data can produce more accurate recommendations (Simatupang, 2010).

However, the relatively high cost of analysis and limited expertise make it difficult to implement this method on smallholder plantations. Several studies have previously examined oil palm nutrient status. Pradiko et al. (2021) reported that determining fertilizer dosages based on soil and leaf analysis can produce more accurate fertilizer recommendations. Simatupang (2010) also stated that site-specific fertilization can increase the efficiency of nutrient utilization by plants. However, most of these studies were conducted on large plantations or companies, while studies on smallholder plantations, particularly in Linggabayu District, Mandailing Natal Regency, are still limited. Therefore, this study is novel because it directly evaluates the nutrient status of oil palm soil and leaves on smallholder plantations in Linggabayu and provides site-specific nutrient management recommendations. The results of this study are expected to serve as a basis for improving fertilization practices to increase oil palm productivity at the farmer level.

2. Material and Methods

This research was conducted on a smallholder oil palm plantation in Linggabayu District, Mandailing Natal Regency, North Sumatra Province. The coordinates of the research location are 1°59'34.5 North latitude and 99°3'21.2 East longitude, with an altitude of ±145 meters above sea level. Soil and leaf analysis was conducted at the laboratory of PT. Socfin Indonesia (SOCFINDO). This research began in February and lasted until May 2025.

The tools used in this research are *Global Position System* (GPS) to determine coordinate points, cameras, rubber bands, plastic bags, clear plastic, machetes, perforated envelopes, egrek used to cut branches/palm fronds on old plants, soil drills used to take soil samples, plates, plastic buckets, label paper, knives and ovens.

The materials used were soil samples and leaf samples from smallholder oil palm plantations in Mandailing Natal Regency as samples to be observed, cotton and distilled water were used to clean the leaf samples from fungi and other things, chemicals as materials used for analysis, and laboratory coats as protective equipment in analyzing in the laboratory.

2.1. Determination of Research Area.

The research area was determined in 3 (three people's plantation areas of (1) Batuloting Village, (2) Banjar Selamat Village, and (3) Padang Silojongan Village. The planting age varied across villages. Batuloting Village was 8 years old, Banjar Selamat Village was 16 years old, and Padang Silojongan Village was 10 years old (productive plants/TM).

The conceptual framework used in this research is presented in Figure 1.

2.2. Determination of the Sample Tree

Sample trees are selected based on the physiographic conditions of the research area. In the garden area in Batuloting Village, with hilly topography, the Stratified Random Sampling method was used, dividing the slope area into three strata: the upper slope, the middle slope, and the lower slope. In each stratum, 10 sample trees were randomly selected because plant diversity was relatively homogeneous. Sampling was carried out starting at the top of the slope by marking the first tree, then selecting every 10 trees towards the north, west, and south until reaching the transition boundary to the middle slope. The same procedure was applied to sampling from the middle slope to the lower slope, from the boundary between the slopes to the roadside area. Meanwhile, in Banjar Selamat Village and Padang Silojongan Village, which have flat land conditions and smaller areas with uniform plants, the Systematic Random Sampling method was used. A total of 10 trees were randomly selected, with the starting point set at the right corner of the land, which was then marked. Next, tree selection was carried out systematically every 10 trees towards the north, then continued towards the west and south until the entire area was represented.

2.3. Leaf Sampling and Disc Soil Samples from Sample Trees

Leaf sampling was conducted on 10 sample trees, each tree being considered a leaf sampling unit (KCD). The leaves were collected from the 17th leaf sheath on the productive plant (TM). Leaf sheath number was determined by counting the fully opened leaf sheaths starting from the top of the plant. The 17th leaf sheath was then cut using a sledgehammer. From each leaf sheath, six leaflets were sampled from each side of the center of the sheath. The leaf veins were separated and excluded from the sample. The collected leaflets were placed in a plastic sample bag and labeled by location. Soil samples were also collected from the same tree in the disc area using a soil drill at a depth of 20–30 cm. Soil samples from several trees in one area were then mixed into a composite, placed in a plastic bag, and labeled with the collection site.

2.4. Research Flowchart

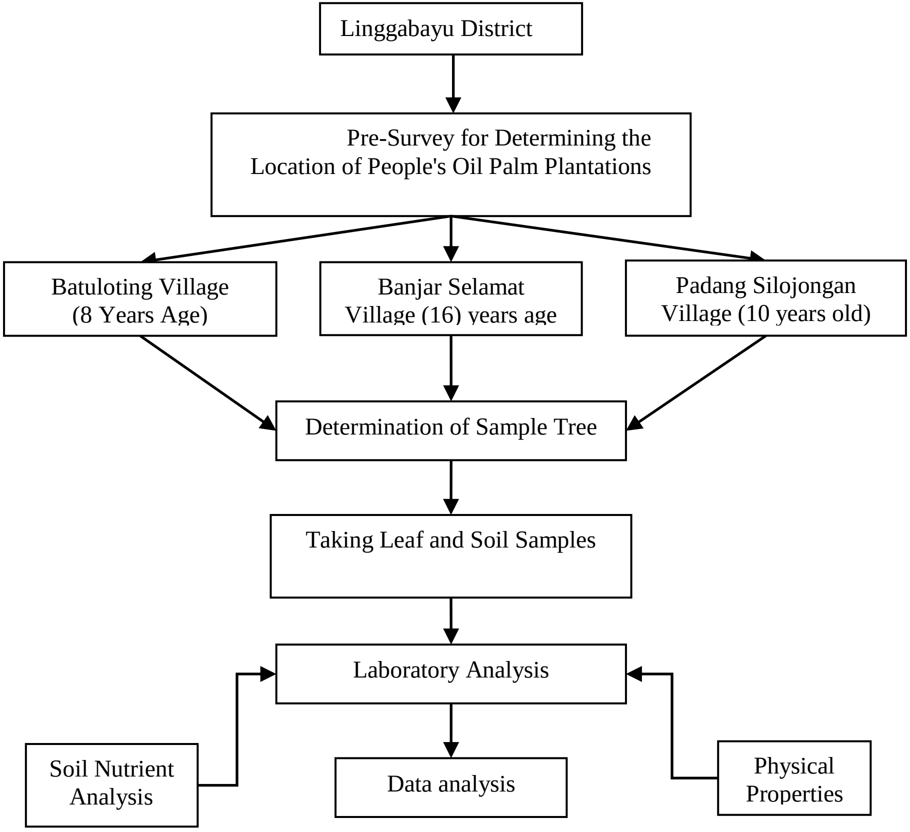

Figure 1. Research Flowchart

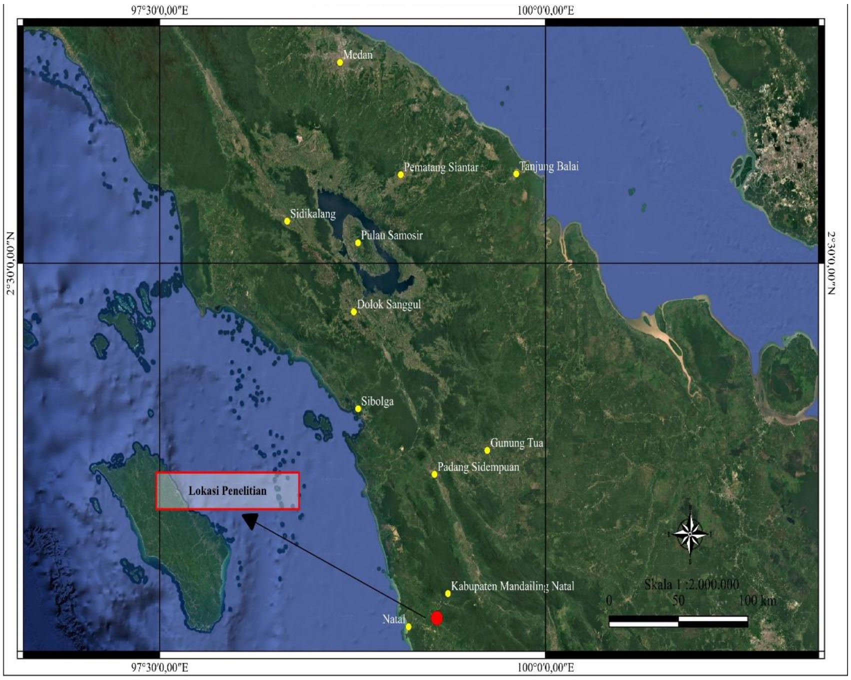

Figure 2. Research Location Map

3. Results and Discussion

3.1. Soil Characteristics

Observation land disc reviewed to observe land in the area. Oil palms that have been fertilized and planted properly. The results of the soil characteristics analysis are presented in Table 1. Based on Table 1, the chemical analysis of soil in the disc area indicates that the pH at the study site ranges from 4.91 to 6.28, indicating acidic to slightly acidic soil conditions. The soil with the most acidic pH is found in Batuloting Village on the upper slopes (pH 4.91) and in Padang Silojongan Village (pH 4.90), while the highest pH is found in Banjar Selamat Village (pH 6.28), which is slightly acidic. Acidic soil conditions can reduce nutrient availability, especially P, Ca, Mg, and K, and increase Al solubility, which can inhibit root growth. At low pH, P is easily fixed by Al and Fe, making it less available to plants. Improving acidic soil can be achieved by adding lime, which neutralizes H^+ and reduces Al solubility (Saswita et al., 2018). Lime application increases the pH from the acidic range (4.5–5.5) to slightly acidic (5.5–6.5), thereby improving the availability of nutrients, especially P, Ca, and Mg (Febriani et al., 2024).

Table 1. Characteristics of the Soil of Smallholder Oil Palm Plantations

Location		**pH $_{H2O}$**	**N total**	**P Bray II**	**K exchange**	**Mg exchange**
			----- % ----	---- ppm ----	--------- me/100 g----------	
Loting Stone	Upper Slope	4.98 M	0.05 SR	12.82 R	0.31 S	1.06 S
	Middle Slope	5:69 AM	0.15 R	5.42 SR	1.53 R	3.01 T
	Lower Slope	4.95M	0.06 SR	11.35 R	0.23 R	0.90 R
Silojungan		4.91 M	0.05 SR	14.76 R	0.28 R	0.88 R
Banjar Selamat		6:28 AM	0.16 R	4.88 SR	0.21 R	3.60 T

Note: M = Sour, SR = Very low R = Low Am = Rather sour S=Medium T = Height; Number of soil samples = 10 samples/location, total soil samples = 30 soil samples without replication

Total nitrogen (N-Total) levels across all study sites were classified as very low to low, ranging from 0.05 to 0.16%. The highest value was found in Banjar Selamat Village (0.16%), while the lowest was in Padang Silojongan and Batuloting Villages on the upper slopes (0.05 each). The low N content is thought to be due to losses through leaching and nitrification–denitrification processes, given the highly dynamic nature of soil nitrogen (Nurulhuda et al., 2017).

Phosphorus levels (P-Bray II) indicated low to very low nutrient status, ranging from 4.88 to 14.76 ppm. The highest levels were recorded in Padang Silojongan Village (14.76 ppm), and the lowest in Banjar Selamat Village (4.88 ppm). In Batuloting, P levels across all slopes were also low (5.42 to 12.82 ppm). This low available P content is closely related to the acidic soil conditions at most study sites. In soils with low pH (<5.5), inorganic phosphorus in the soil tends to react with aluminum (Al^{3+}) and iron (Fe^{3+}) ions to form poorly soluble Al-P and Fe-P compounds, making them unavailable to plants (Ch'ng et al., 2014). This mechanism, known as phosphorus fixation, is a major factor in the low efficiency of P fertilization in tropical acidic soils (Shen et al., 2023).

Exchangeable potassium (exchangeable K) at all locations was low to moderate, ranging from 0.21 to 1.53 me/100 g. The highest value was found in Batuloting, a mid-slope area (1.53 me/100 g), while the lowest was in Banjar Selamat Village (0.21 me/100 g). In Padang Silojongan, exchangeable K was also low (0.28 me/100 g). Exchangeable K is the fraction of potassium directly available to plants. However, most of the K in the soil is in a non-exchangeable form or fixed in 2:1 clay minerals such as mica, vermiculite, and smectite. These layered minerals can trap K^+ ions between their layers, preventing their easy release into the soil solution, even after K fertilizer has been applied. This process, known as potassium fixation, limits K availability to plants in the short term (Portela et al., 2019).

Meanwhile, exchangeable magnesium (exchangeable Mg) varies widely, ranging from 0.88–3.60 me/100 g. The highest value was observed in Banjar Selamat Village (3.60 me/100 g), while the lowest was observed in Padang Silojongan Village (0.88 me/100 g). The Mg-dd content varies across several locations. The application of dolomite as an ameliorant is an effective strategy to increase the Mg-dd of acidic soils, because, in addition to increasing soil pH, dolomite also directly supplies exchangeable Mg^2 ions into the soil cation exchange system. This result increases Mg availability for plants and contributes to overall soil fertility (Nopriani et al., 2025).

The final fertilization was carried out in November 2024 across all locations, using 1 kg of urea, TSP, KCl, and dolomite fertilizers per tree, applied by spreading. Soil and leaf sampling was conducted in March 2025, approximately 3 months after fertilization. In general, the soil's N, P, and K nutrient content remained low to very low. This finding is thought to be because most of the nutrients have been absorbed by the plants, are lost through leaching to deeper soil layers, and are fixed, especially for potassium. Mg content in the soil varies widely depending on location.

3.2. Leaf Nutrient Content of N, P, K, and Mg

Leaf samples from oil palm plants were analyzed to determine nutrient levels. leaf Which has absorbed by plants due to fertilization achieve good production. The results of leaf nutrient content analysis are presented in

Table 2 as follows.

Table 2. Nutrient Content Leaves on the Area People's oil palm plantations

Location	N	P	K	Mg
	----------------	%	----------------	
Slope On	2.35 O	0.14 O	1.01 O	0.30 O
Central Slope Loting Stone	2.54 O	0.15 O	1.00 O	0.28 O
Lower Slope	2.64 O	0.16 O	0.98 O	0.29 O
Banjar Happy	2.24 D	0.15 O	0.69 D	0.39 O
Silojongan Island	2.23 D	0.15 O	0.84 D	0.35 O

Note: O = Optimum, D = Deficiency; Number of leaf samples = 10 samples/Location, total leaf samples = 30 leaf samples without replication

Based on Table 2, the analysis results show that the nitrogen (N) content in leaves in Batuloting Village is high, at 2.35% on the upper slope, 2.54% on the middle slope, and 2.64% on the lower slope, all of which are considered optimal for plant growth. These values indicate that the plants have sufficient N to support key physiological functions, such as protein and chlorophyll synthesis, which are vital for photosynthesis and leaf expansion. The optimum nitrogen content in oil palm leaves across all slopes in Batuloting Village indicates that the plants can still effectively absorb N even when soil N availability is low to very low. This ability is related to the deep and widespread root system of oil palms, which allows them to access nitrogen from deeper soil layers. Active fibrous roots also help increase nutrient absorption, even in soils with limited N content. In addition, the decay of litter and leaf sheaths around the base of the plant gradually provides organic nitrogen. Topography also influences nitrogen movement, with the middle and lower slopes acting as areas of organic matter accumulation carried from the upper slopes by rainwater flow.

In contrast, leaf N levels in Banjar Selamat Village (2.24%) and Padang Silojongan (2.23%) were lower than in Batuloting and were classified as deficient based on diagnostic standards for leaf N concentration. In oil palm, the optimal leaf N range is generally 2.07–4.29%, and values below this limit are associated with reduced growth and unmet plant nutrient requirements (Kamireddy et al., 2023).

This condition indicates that, despite fertilization, the plants in both locations were unable to meet their nitrogen requirements. The impacts can include chlorosis, stunted vegetative growth, and decreased productivity if not addressed promptly.

The causal factors vary across locations. In Banjar Selamat, the deficiency is thought to be influenced by low organic matter, limited N fertilizer supplies, and flat land prone to flooding, which increases nitrogen loss through denitrification. Furthermore, the presence of other vegetation can increase competition for nutrient uptake. Meanwhile, in Padang Silojongan, high soil acidity inhibits the mineralization of organic matter, limiting the release and availability of nitrogen to plants.

Leaf phosphorus (P) content across all locations ranged from 0.14 to 0.16%, categorized as moderate to optimum. The highest value was found on the lower slope of Batuloting (0.16%), while the lowest was on the upper slope of Batuloting (0.14%). This range indicates that plants obtain sufficient P to support essential physiological processes such as energy (ATP) production, nucleic acid synthesis, and new tissue growth. Phosphorus is mobile within plants, allowing it to be translocated from older leaves to younger tissues when soil supply is limited. Therefore, even though chemical soil P availability may be low, plants can still maintain leaf P levels within the optimal range through internal absorption mechanisms and efficiency. On the lower slope, slightly higher P levels are likely influenced by soil conditions that are more conducive to nutrient accumulation and absorption, while on the upper slope, although lower values are still sufficient to support normal plant growth (Veneklaas, 2022).

The potassium (K) content of leaves in Batuloting (upper, middle, and lower slopes) was within the optimum range, 0.98–1.01%. However, in Padang Silojongan (0.84%) and Banjar Selamat (0.69%), K was classified as deficient. Magnesium (Mg) in leaves showed optimum nutrient status across all locations, with a range of 0.28–0.39%. The highest value was found in Banjar Selamat Village (0.39%), and the lowest in Batuloting, the middle slope (0.28%).

Figure 3. Research documentation of harvesting leaves at 8 years of planting

Planting too closely also increases competition among plants for nutrients, water, and light, leading to uneven nitrogen absorption. Therefore, improvements in fertilizer strategies—regarding dosage, timing, and application methods—are necessary to enhance the availability and efficiency of nitrogen uptake in plants across all study sites (Hardjowigeno, 2007).

However, the leaf tissue analysis showed that N, P, K, and Mg were within the optimal range in almost all locations, except in Banjar Selamat and Padang Silojongan Villages, which exhibited deficiency symptoms.

4. Conclusion

In general, the analysis results indicate that soil nutrient levels, particularly nitrogen (N), phosphorus (P), and potassium (K), remain low across nearly all locations, necessitating increased fertilizer application. However, site-specific recommendations are provided based on soil and leaf analyses, including reducing nitrogen in Batuloting (lower slope) and decreasing magnesium in Banjar Selamat and Padang Silojongan. This data-driven approach enables more precise and tailored fertilizer dosing, thereby enhancing cost efficiency, preventing nutrient over- or under-application, and supporting optimal oil palm productivity.

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