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Analysis of Soil Chemical Property Variations in Oil Palm Plantations of Different Ages in Part of Saliki Village, Muara Badak District

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***Abstract**. Oil palm development in Indonesia faces various agronomic constraints, especially related to soil chemical properties that are less supportive of productivity. This study aims to identify the status of soil chemical properties on oil palm land in Saliki Village, Muara Badak District, East Kalimantan, to support more appropriate land management. The research was conducted from September to November 2024 using a purposive random sampling method on 13 hectares of land, with six sampling center points and four subsamples per point. Laboratory analysis was conducted on soil pH, C-organic content, total N, available P, potential K, cation exchange capacity (CEC), and base saturation. The results showed that the soil in the 6-year-old oil palm land had a pH of 3.63-3.93 and base saturation of 13.69-13.81%, while at the age of 15 years, the pH decreased to 3.12-3.38 and base saturation was only 4.62-6.95%. Meanwhile, available P and potential K levels tended to increase with increasing plant age. Based on these findings, fertilization is recommended according to the IOPRI standard for mineral soils as follows: for 6 years old, urea 2.75 kg/year, TSP 1.75 kg/year, and KCl 2.75 kg/year, while for 11 and 15 years old, urea 3.25 kg/year, TSP 2 kg/year, and KCl 3 kg/year. This study emphasizes the importance of periodic monitoring of soil chemical properties as a basis for sustainable management of oil palm plantations.*
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***Keywords:** Oil palm plantation, Purposive random sampling, Recommendations fertilization, Soil chemical properties*

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INTRODUCTION

Oil palm (Elaeis guineensis Jacq.) is a strategic commodity that plays an important role in the national economy and community welfare, especially in rural areas. Economically, the palm oil industry will contribute up to IDR 600 trillion in foreign exchange by 2023 (GAPKI, 2023) and is the main source of livelihood for millions of farmers. However, from an environmental perspective, oil palm development is often associated with issues of land degradation and soil degradation.

Soil as a growing medium has a direct influence on plant productivity. Soil chemical characteristics, such as pH, organic matter content, and availability of macro and micronutrients, determine the level of soil fertility and the efficiency of nutrient absorption by plants. Based on research by (Alam et al., 2020), variation in soil chemical properties between regions is a key factor that causes productivity differences between oil palm plantations.

Some common challenges in soil management in oil palm plantations in Indonesia include low soil pH, low levels of organic matter, deficiencies in essential nutrients such as potassium (K), calcium (Ca), and magnesium (Mg), low base saturation, and high levels of bound aluminum. These complexities are exacerbated by climatic factors, rainfall, and land management practices that differ from location to location. According to (Fadhillah & Harahap, 2020) in Saliki Village, Muara Badak Subdistrict, East Kalimantan, a number of farmers admitted to not having an adequate understanding of the chemical status of their soil, which has implications for the low effectiveness of fertilization and land productivity.

Soil chemical components, especially colloidal clay, and organic matter, play a central role in ion exchange processes and nutrient provision for plants. The availability of nutrients such as nitrogen (N), phosphorus (P), and potassium (K) is strongly influenced by these soil chemical properties and directly affects the growth and yield of oil palm plants (Hardjowigeno, 2003).

Based on this background, this study aims to identify and analyze soil chemical properties in oil palm plantations owned by residents in some areas of Saliki Village, Muara Badak. It also aims to formulate more appropriate soil management recommendations to optimize land fertility and support oil palm productivity at various plant ages.

LITERATURE REVIEW

Saliki Village, a 17,000 hectare coastal region in Muara Badak District, is composed of two hamlets whose residents primarily work as farmers and fishermen. Oil palm cultivation has become the main economic driver, yet it faces challenges such as high capital demands, price volatility, and reduced yields due to declining soil fertility (BPS, 2023). Understanding oil palm productivity requires chemical soil analysis, particularly at planting ages of 6, 11, and 15 years, where ages 6 and 11 represent peak productivity, and age 15 marks a decline (Darma, 2022)**.** Optimal soil conditions include a pH of 4–6, CEC of 15–20 cmol(+)/kg, and organic carbon content of 1–3% (Nora & Mual, 2018)**,** with nutrient absorption occurring predominantly within the top 0–30 cm of soil (Setyamidjaja, 2006)**.**

Continuous cultivation and erosion contribute to nutrient depletion, emphasizing the importance of soil chemical assessments. Soil fertility is shaped by interactions between climatic conditions, topography, and anthropogenic activities (Zainudin & Kesumaningwati, 2021)**.** Key chemical indicators for oil palm growth include soil pH, which affects nutrient (Taisa et al., 2021); CEC, which determines the soil's capacity to retain and exchange nutrients (Taisa et al., 2021) (Tan, 1998); and organic carbon, which supports oxygen diffusion and moisture retention. Base saturation reflects nutrient availability influenced by groundwater and mineral content. Nitrogen, though essential for growth, is highly mobile and often lost but can be retained through increased organic matter (Ramadhana et al., 2019). Phosphorus availability is limited in acidic soils due to its binding with Al and Fe, despite its importance for root and flower development (Erisa et al., 2018). Potassium is needed in large quantities during flowering, but excess or deficiency can disrupt Mg^{2+} and Ca^{2+} uptake (Wirayuda et al., 2022)**.**

RESEARCH METHODS

This research was conducted from September to November 2024 in an oil palm plantation owned by residents with an area of approximately 13 ha in Saliki Village, Muara Badak District, and soil chemical analysis was carried out at the Soil Science Laboratory, Faculty of Agriculture, Mulawarman University. Materials used in this study include soil from oil palm plantations with planting ages of 6 years, 11 years, and 15 years, respectively, distilled water (distilled water), chemical solutions, HCl, and other materials needed to analyze soil chemical properties in the laboratory. This research is descriptive and uses the observation method. Soil samples were taken using a purposive random sampling method, and each planting age was taken at a depth of 0-40 cm. In an area of 13 ha, there are 6 sample center points, and at each center, there are 4 subsamples based on cardinal directions and then composite.

This study used 7 chemical parameters for soil sample analysis, namely pH using H_2O, Total N using Kjedahl, P available using Bray I, K using HCl 25% extract, Base Saturation through dd cation calculation, Organic C using Walkley & Black and CEC using percolate distillation. Soil chemical status refers to the source of Bogor Soil Research Center 2009.

RESULTS AND DISCUSSION

1. Overview of the Research Location

This research was conducted in Saliki Village, Muara Badak District, Kutai Kartanegara Regency, on three age groups of oil palm: 6 years (±3.4 ha), 11 years (±4.4 ha), and 15 years (±5.2 ha). The 6-year-old fields showed moist soil conditions, with moss and weed growth dominating, and produced relatively high yields of 6-8 tons per harvest. In contrast, 11- and 15-year-old fields had dry, compacted, and dusty soil surfaces, with fern growth on the fronds and production declining to ±4 tons per harvest. This decline is thought to be due to low soil moisture and the dominance of male flowers during the harvest season. The entire field is managed with intensive fertilization and frond cutting, where fronds are left to decompose as organic matter. The lack of an irrigation system leads to dependence on rainfall, which also affects productivity. Total production from the entire field was more than 12 tons per harvest. This finding confirms that plant age, soil physical conditions, and physiological phase significantly affect yield.

2. Identification of Soil Chemical Properties pH

Laboratory analysis showed that soil pH in 6-year-old oil palm fields ranged from 3.63 to 3.93, at 11 years old between 3.38 and 3.40, and at 15 years old between 3.12 and 3.38. All three age groups are categorized as having a very acidic soil reaction.

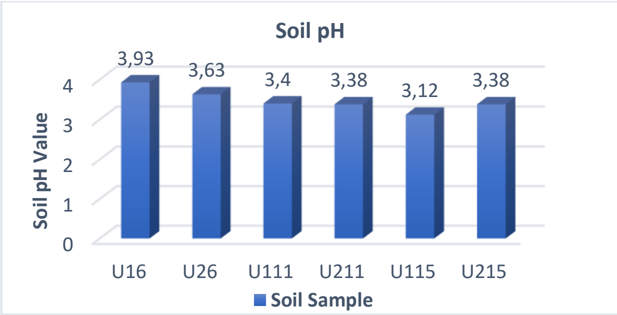

Figure 1. Graph of soil pH in parts of Saliki Village in 2024

Soil pH is an important variable that affects soil chemical properties and plant growth, including biomass formation. Macronutrient availability generally decreases in highly acidic soils because an increase in the concentration of H^+ ions in the soil solution lowers the pH (Lisa et al., 2022). Soil acidity at the research site is influenced by human activities, such as the use of chemical pesticides and herbicides that can increase the accumulation of H^+ ions through disturbances to the balance of soil microorganisms (Sinambela, 2024). This can be seen from the difference in soil pH between 11- and 15-year-old fields that were sprayed with chemicals, compared to 6-year-old fields that were not sprayed and had a higher pH. In addition, intensive NPK fertilization since the beginning of planting without organic fertilizer also contributed to the increase in soil acidity. To overcome this condition, lime application (liming) is recommended to improve pH and increase soil fertility, accompanied by planting cover crops that can improve soil structure and biological activity (Taisa et al., 2021).

Soil Organic Carbon

Soil organic carbon (SOC) is formed through the decomposition of organic matter. It is influenced by factors such as soil type, climate, biomass input, anthropogenic activity, and management practices (Tisdale et al., 1993). SOC content reflects overall soil organic matter and is dynamic, responding to land use and soil management changes. Laboratory analysis revealed that SOC in the 6-year-old oil palm plantation ranged from 0.66% to 0.84%, classified as very low. In the 11-year-old plantation, SOC ranged from 0.95% to 1.10%, categorized as very low to low. Meanwhile, the 15-year-old plantation showed SOC values between 0.64% and 1.25%, also within the very low to low category.

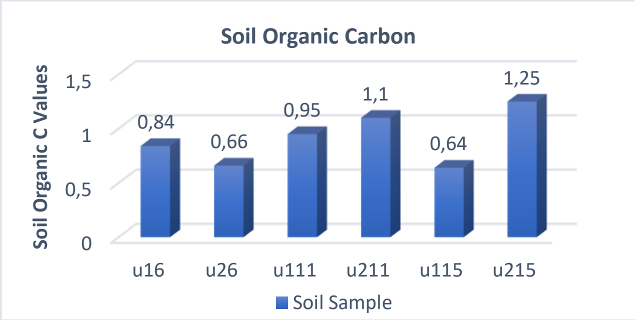

Figure 2. Graph of Soil Organic Carbon in Part of Saliki Village in 2024

Soil organic carbon (SOC) is produced by soil microorganisms through the decomposition and synthesis of organic matter. Its content is influenced by factors such as organic input type, microbial activity, and environmental conditions. Organic materials high in lignin, such as oil palm fronds, decompose slowly and are less effective in increasing SOC (Ramadhana et al., 2019)**.**

At the study site, landowners primarily rely on palm fronds as the sole organic input. However, limited microbial activity and dryland conditions slow down decomposition, making this input insufficient to maintain adequate SOC levels. In 11- and 15-year-old plantations, SOC remains low due to incomplete decomposition of accumulated fronds. In 6-year-old plantations, SOC is also low, attributed to minimal frond accumulation and early-stage decomposition. Dry climate, lack of vegetation cover, and intensive land use further exacerbate SOC depletion. Improving ground cover and applying organic fertilizers are essential to enhance moisture retention and support decomposition. Without proper management, declining SOC can reduce soil fertility and long-term crop productivity (Farrasati et al., 2019)**.**

Nitrogen

Total soil nitrogen originates from the decomposition of organic matter, producing organic acids essential for plant vegetative growth. Laboratory analysis showed that nitrogen content in the 6-year-old oil palm plantation ranged from 0.11% to 0.15%, classified as low. The 11-year-old plantation had a nitrogen level of 0.13%, while the 15-year-old plantation ranged from 0.13% to 0.165%—both also classified as low. These results indicate that nitrogen availability across all plantation ages remains insufficient for optimal plant development.

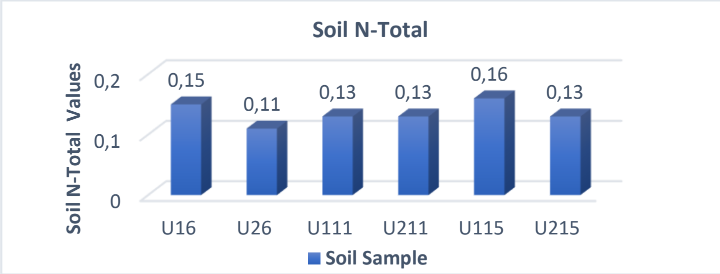

Figure 3. Soil N-Total Graph in Part of Saliki Village in 2024

Total nitrogen (N) in soil originates from the decomposition of organic matter, which releases organic acids. Laboratory results indicate that N-total levels in 6-, 11-, and 15-year-old oil palm plantations range from 0.11% to 0.16%, all classified as low. At 6 years, high nitrogen demand for vegetative growth contributes to N depletion, while at 11 and 15 years, nitrogen dynamics become more stable as plant growth slows.

Low nitrogen levels are attributed to its mobility and losses through leaching, volatilization, and plant uptake. The absence of cover vegetation further limits organic matter input and nitrogen retention. Leguminous cover crops can enhance nitrogen levels through biological fixation by *Rhizobium* spp. However, in the study area, low microbial activity and organic matter content reduce nitrogen storage capacity. Additionally, NPK fertilization is less effective without organic inputs, increasing the risk of volatilization if not properly applied.

Phosphorus

Laboratory analysis of available phosphorus (P_2O_5) showed that in 6-year-old oil palm plantations, P content ranged from 8.44 to 16.16 ppm, classified as medium to high. In 11- and 15-year-old plantations, P levels ranged from 16.66 to 19.03 ppm and 16.65 to 35.36 ppm, respectively, both classified as very high.

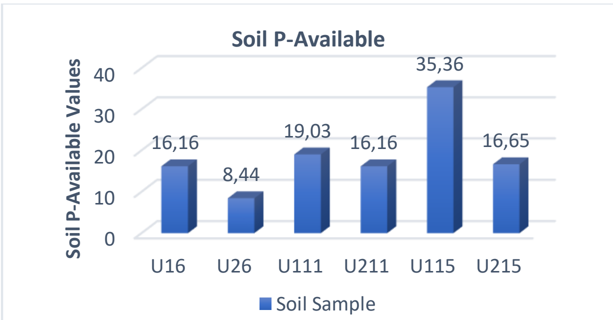

Figure 4. Soil P-Available Graph in Part of Saliki Village in 2024

Analysis at the research site indicates that soil phosphorus content is classified as very high, largely due to prolonged and intensive NPK fertilization. Farmers apply fertilizers twice annually at a uniform dose of 8 kg/tree/year, regardless of plant age. This practice, based on estimation rather than soil or plant needs, contributes to phosphorus accumulation in the topsoil.

Over-application of NPK without proper dosing leads to phosphorus buildup, reducing nutrient uptake efficiency and causing imbalance-excess P alongside nitrogen deficiency. Due to its low mobility and lack of leaching, phosphorus tends to accumulate, especially in unirrigated soils. This was evident in the 11- and 15-year-old plantations, where available P reached very high levels, with signs of phosphorus saturation, particularly in older soils.

Potassium

The potential K^+ content in 6-year-old oil palm plantation soils ranged from 5.67 to 17.23 mm/100 g, classified as very low to low. In 11- and 15-year-old plantations, values ranged from 20.14 to 25.87 mm/100 g and 20.12 to 43.89 mm/100 g, respectively, falling within the low to high category.

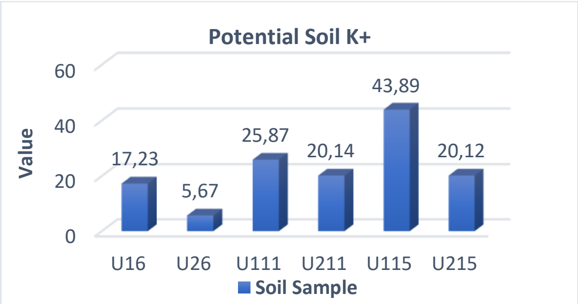

Figure 5. Potential soil K^+ graph in part of Saliki village in 2024

K^+ levels in oil palm soils were very low, ranging from 0.03–0.04 me/100g (ages 6 and 15) and 0.01–0.03 me/100g (age 11). At 6 years, limited root development restricts K^+ uptake, while at 11 and 15 years, higher plant demand is not met due to insufficient K^+ availability. Although potential K^+ increased with plant age, actual K^+ levels remained low, indicating poor potassium availability.

This issue is compounded by intensive NPK fertilization (8 kg/tree/year) since planting, leading to nutrient saturation. Potassium is prone to leaching and may also be bound in minerals like feldspar and mica. High phosphorus levels from fertilization can inhibit K^+ absorption due to nutrient competition. Additionally, potassium availability is governed by sorption–desorption dynamics, where K^+ is retained at high concentrations and released under deficiency conditions (Nursyamsi, 2012).

Cation Exchange Capacity

Soil cation exchange capacity (CEC), expressed in me/100g, reflects the soil's ability to retain and exchange cations. Laboratory analysis revealed that CEC in 6-year-old oil palm soils ranged from 4.49 to 6.50 mm/100g, and in 11-year-old soils from 4.88 to 6.01 mm/100g—both classified as very low to low. In 15-year-old plantations, CEC increased to 7.14–12.08 me/100g, classified as low.

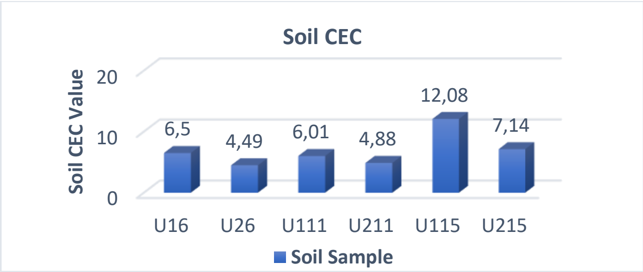

Figure 6. Graph of Soil CEC in Part of Saliki Village in 2024

Cation exchange capacity (CEC), expressed in me/100g, represents the soil's ability to retain and exchange cations. CEC values may be overestimated if free salt ions are not subtracted (Tan, 1998). At the study site, low CEC values (4.49–12.08 me/100g) corresponded with highly acidic soil pH (3.12–3.93), as low pH reduces negative charges on soil colloids, thereby limiting cation retention (Ramadhana et al., 2019).

The dominant clay mineral at the site is kaolinite, which has a low surface charge and contributes to the soil's inherently low CEC (Costa et al., 2020). Soils rich in hydrated oxides of Al and Fe also tend to exhibit low colloidal charge. Additionally, low organic carbon levels due to minimal organic matter inputs further reduce CEC, confirming the strong relationship between organic content, clay type, and cation exchange capacity (Costa et al., 2020).

Base Saturation

Base saturation, expressed as a percentage, is the ratio of exchangeable base cations to the soil’s cation exchange capacity (CEC) and is generally proportional to CEC. Laboratory analysis revealed that base saturation in 6-year-old oil palm soils ranged from 13.69–13.81%, in 11-year-old soils from 9.63–11.65%, and 15-year-old soils from 4.62–

6.95%, all classified as very low, indicating limited base cation availability across all plantation ages.

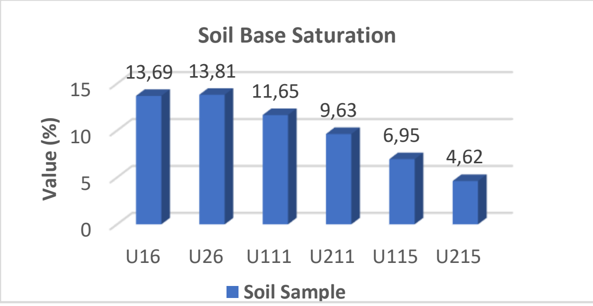

Figure 7. Soil base saturation Graph in Part of Saliki Village in 2024

Low CEC values (4.49–12.08 me/100g) at the study site are closely linked to very acidic soil pH (3.12–3.93), which limits the development of negative charges on organic matter and reduces cation retention. Similarly, base saturation was very low across all plantation ages, influenced by low pH, intensive NPK fertilization without organic inputs, and leaching of basic cations such as Ca^{2+} and Mg^{2+}. A notable decline in base saturation in 11- and 15-year-old plantations reflects increased nutrient uptake and reduced soil buffering capacity. Soil improvement through organic matter addition and pH correction is recommended.

Fertilizer Recommendations

The analysis indicates a progressive decline in soil pH with plant age, reflecting increased acidity influenced by prolonged chemical input and lack of liming. Soil Organic Carbon content slightly improves at age 11 but decreases by age 15, highlighting limited decomposition and insufficient organic inputs. Total Nitrogen remains consistently low across all ages, with a minor increase at age 15, suggesting restricted nitrogen cycling and retention. Available Phosphorus increases markedly over time due to continuous over-fertilization, potentially leading to nutrient imbalances. While Potential Potassium content rises with age, its actual availability remains limited, affected by leaching and nutrient competition. Cation Exchange Capacity (CEC) shows moderate improvement in older plantations, likely due to gradual increases in organic matter and mineral weathering, yet remains below optimal levels. Base Saturation steadily declines with age, indicating ongoing nutrient loss, reduced soil buffering capacity, and the need for base-cation restoration.

Table 1. Soil Parameters Across Oil Palm Ages (6, 11, and 15 years) in Saliki Village

Parameter	6 Years Mean	6 Years SD	11 Years Mean	11 Years SD	15 Years Mean	15 Years SD
Soil pH	3.78	0.15	3.39	0.01	3.25	0.13
Soil Organic Carbon (%)	0.75	0.09	1.03	0.08	0.95	0.31
Total Nitrogen (%)	0.13	0.02	0.13	0.00	0.15	0.02
Available Phosphorus (ppm)	12.30	3.86	17.85	1.19	26.01	9.41
Potential Potassium (mm/100g)	11.45	5.78	23.01	2.86	32.01	11.94
CEC (me/100g)	5.50	1.00	5.45	0.57	9.61	2.47
Base Saturation (%)	13.75	0.08	10.64	1.01	5.79	1.17

According to the Oil Palm Research Center, fertilization recommendations are standardized based on soil type and plant age, with specific dosage guidelines provided accordingly.

Table 2. Mineral Soil Fertilization Recommendations Based on Indonesian Oil Palm Research Institute (IOPRI)

Umur Tanaman (year)	Urea (kg/tree/year)	TSP (kg/tree/year)	KCl (kg/tree/year)
3-4	2,50	1,50	2,50
5-8	2,75	1,75	2,75
9-15	3,25	2,00	3,00

It is known that the fertilization dose of farmers using compound fertilizer (NPK 16- 16-16) 8 kg/tree/year is equivalent to 1.28 kg for each N, P, and K^+. For 6-year-old oil palms based on converted fertilization produces the recommended N is 1.26 kg, 0.78 kg P_2O_5 and 1.65 kg K_2O so it can be seen for the dose that farmers use is 1.28 kg than for N and P excess doses while at the dose of K^+ deficiency equivalent to 0.61kg of KCl. for 11 years to 15 years old oil palm also converted resulted in 1.49 kg N, 0.9 kg P_2O_5, and 1.8 kg K_2O so that for N and K^+ the dose given by farmers is less than recommended, the shortage is equivalent to 0.45 kg urea and 0.86 kg KCl.

CONCLUSION

Oil palm plantations in Saliki Village face significant soil chemical challenges, particularly very acidic pH, low nitrogen (N), potassium (K^+), and cation exchange capacity (CEC), alongside imbalanced fertilization practices that result in nutrient excesses and deficiencies. Although phosphorus (P) levels are high due to intensive NPK use, the lack of organic matter, poor decomposition of fronds, and absence of irrigation contribute to low soil fertility and poor nutrient retention, especially in older plantations. A shift toward site-specific fertilization, incorporation of organic matter, cover cropping, and soil pH correction through liming is urgently recommended to optimize productivity and sustainability.

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