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Analysis of phosphorus and potassium leaves uptake of immature palm oil smallholder plantation in Lamandau regency, central Kalimantan on fertilization through axil

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Abstract. Nutrient management in immature smallholder oil palm plantations remains a major challenge due to low soil fertility and high nutrient losses, particularly for phosphorus (P) and potassium (K). Conventional soil application often results in low uptake efficiency, limiting plant growth and productivity. This study aimed to evaluate the effectiveness of fertilizer application through the axils on P and K uptake in immature smallholder oil palm. The research was conducted in Lamandau , Central Kalimantan, Indonesia, at an altitude between 90.08 to 153.2 meters above sea level, a type of red and yellow podzolic soil, an average rainfall of 191.4 mm/year and daily air temperature between 23°C to 32°C throughout the year. Randomized complete block design used with different MKP fertilizer dosages namely 226 g and 75 g/tree applied directly into the axils and 226 g/tree applied to the soil. Leaf samples were analysed for P and K concentrations, while soil nutrient status were also assessed. The results showed that the uptake of phosphorus and potassium in MKP fertilization at a dose of 75 g/tree and 226 g/tree through the axil was relatively the same as through the soil at a dose of 226 g/tree. It can be concluded that MKP fertilization through the axil is more effective than through soil even at the lowest dose. These findings suggest that frond axil fertilization is a promising strategy to optimize nutrient management in smallholder oil palm plantations, particularly on marginal soils in Central Kalimantan. The adoption of this method has the potential to improve sustainability and productivity in smallholder oil palm systems.

Keywords: *Oil palm; axil fertilization; phosphorus uptake; potassium uptake*

1. Introduction

Oil palm (*Elaeis guineensis* Jacq.) is one of the most important plantation crops in Indonesia, contributing significantly to both the national economy and smallholder farmers' livelihoods [1]. However, the productivity of smallholder plantations remains relatively low compared with that of private and state-owned estates. One of the key factors underlying this yield gap is suboptimal nutrient management, particularly during the immature stage, when nutrient uptake strongly influences vegetative growth and future yield potential [2]

Phosphorus (P) and potassium (K) are essential macronutrients for oil palm growth and development [3]. Phosphorus is involved in root development, energy metabolism, and genetic information transfer, while potassium plays a critical role in photosynthesis, stomatal regulation, carbohydrate translocation, and stress tolerance [4]. Despite their importance, P and K availability in smallholder plantations is often limited. In highly weathered soils of Central Kalimantan, P is strongly fixed by aluminium and iron oxides, while K is highly susceptible to leaching, particularly in sandy soils [5]. As a result, conventional soil application of fertilizers often leads to low nutrient use efficiency [6].

To overcome these challenges, alternative fertilization methods have been explored. One promising approach is axil fertilization, in which fertilizers are applied directly into the axils of oil palm fronds [7][8]. This method is expected to reduce nutrient losses, enhance nutrient availability, and improve uptake efficiency by placing nutrients closer to absorption sites [9]. Although previous studies have highlighted the potential of innovative fertilization techniques in oil palm [10][8], research focusing on frond axil application, particularly in smallholder contexts and on marginal soils, remains limited [6][2].

Therefore, the present study was conducted to evaluate the effects of frond axil fertilization on P and K uptake in immature smallholder oil palm plantations in Central Kalimantan, Indonesia. Specifically, this study aimed to (i) compare nutrient uptake between frond axil and conventional soil application, and (ii) assess changes in leaf nutrient concentrations, soil nutrient status, and phosphorus and potassium uptake. The findings are expected to provide scientific evidence supporting more efficient nutrient management strategies for smallholder oil palm cultivation on marginal lands.

2. Research Methods

2.1 Research location

The research was conducted on immature smallholder oil palm plantations in Lamandau Regency, Central Kalimantan. The Area have altitude between 90.08 to 153.2 meters above sea level, a type of red and yellow podzolic soil, an average rainfall of 191.4 mm/year and daily air temperature between 23°C to 32°C throughout the year.

2.2 Research design

A completely randomized block design was used with three doses and fertilizer application methods, namely: (1) MKP 226 g/tree applied through the axil (P1), (2) MKP 75 g/tree applied through the axil (P2), and (3) MKP 226 g/tree applied through the soil around the tree disc (P3). Each treatment was repeated three times so that there were 9 experimental units [11]. Each unit used three oil palm plants.

2.3 Tools and materials

The tools used included a camera, envelopes containing leaf samples, a hoe and machete, a knife, a cutter, and laboratory equipment for analyzing soil and plant tissue chemistry.
The materials used in this study consisted of mono-potassium phosphate (MKP) fertilizer, immature oil palm plants (1 year old), and materials used for soil and tissue chemistry analysis in the laboratory.

2.4 Soil and leaf sampling

Soil samples were taken by drilling a 30 cm hole in each plant block [12] and then placed in sample bags. Each soil sample was taken to the laboratory for analysis of pH and P and K content. This soil sampling was carried out before and after the fertilizer treatment.

Leaf samples were taken from leaf stalk number 17 according to oil palm nutrient analysis standards [13][14] (Figure 1.)

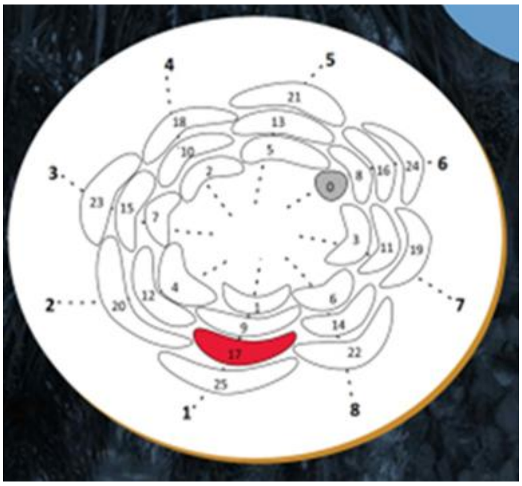

Figure 1. Position of the 17th leaf sheath in the phyllotaxis of an oil palm plant.

2.5 Fertilizer application

Fertilization through the leaf axils is done by sprinkling it into the leaf axils according to the specified dose [10][6]. Meanwhile, fertilization through the soil with a dose of 226 grams is done using a direct spreading technique (broadcast) in the disc area around the oil palm tree, in the outermost circle parallel to the projection of the plant canopy [7].

2.6 Observation variables

The observed variables were the concentration of P and K in leaf tissue three months after fertilization. Furthermore, the P and K content values were used to determine the absorption value with the formula: P or K absorption = (% P or K plant tissue) x (leaf dry weight) [15]. Nutrient absorption is expressed in g nutrient/1kg leaf. Nutrient content analysis was carried out in the laboratory using the spectrophotometric method for P and a flame photometer for K. The sampling method was the same as when taking samples before fertilization. Data were analysed using analysis of variance (ANOVA), and if there was a significant effect, it was continued with DMRT at the 5% level [11].

3. Results and Discussion

3.1 P and K content of soil and leaves before fertilization

Before applying MKP fertilizer through the soil and leaf axils, an analysis of the P and K content was carried out in both the soil and oil palm leaves (table 1).

Table 1. P and K content of soil and leaves before fertilization with MKP fertilizer

	Soil		Leaf	
MKP dose treatment plot	P total (ppm)	K total (ppm)	P (%)	K (%)
226 g - through the soil			0.147 a	0.790 a
226 g - through the axil			0.133 a	0.944 a
75 g - through the axil	90.2	4.887	0.150 a	1.046 a

As seen in Table 1, the treatment plots were homogeneous before fertilization. The P and K content of plant leaves was relatively similar in all potential treatment plots.

3.2 P and K content of soil

Three months after fertilization with MKP, either through the soil or the leaf axils, the P and K content of the soil was measured as shown in Table 2.

Table 1. P and K content of soil three months after fertilization with MKP

	Soil	
MKP dose treatment plot	P total (ppm)	K total (ppm)
226 g - through the soil	212.1	840.8
226 g - through the axil	287.4	852.6
75 g - through the axil	330.8	609.8

Judging from tables 1 and 2, the application of MKP through the soil and leaf axils successfully increased the availability of soil P by about 2.3–3.6 times compared to the initial conditions, namely from 90.2 to 212.1–330.8 ppm. Meanwhile, K after application decreased to 609.8–852.6 ppm. This decrease indicates that the MKP fertilizer given was more absorbed/bound or leached [3], [6], [16], so that even though there was additional fertilizer, the soil K status decreased drastically compared to the initial condition.

3.2.2 P and K content of leaves

Three months after fertilization, analysis was carried out on the phosphorus (P) and potassium (K) content in oil palm leaves (table 3).

Table 3. Average percentage of P and K content in leaves three months after MKP fertilization on oil palms one year after planting,

MKP dose (g/tree) and fertilization location	Leaf P content (%)	Leaf K content (%)
226 g - through the soil	0,117 a	0,836 a
226 g - through the axil	0,129 a	0,854 a
75 g - through the axil	0,124 a	0,772 a

Note: The average number followed by the same letter in the same column indicates that there is no real difference between the fertilization treatments according to the F test at the 5% level.

The results showed that the application of MKP fertilizer through the leaf axils had no significant effect on increasing the phosphorus and potassium content of leaves. However, there was a tendency for fertilization at 226 g/tree through the leaf axils to produce higher leaf P and K content compared to 226 g/tree through the soil. This indicates that the application method in the leaf axils is more efficient because the fertilizer dissolves and is absorbed more quickly, and avoids loss through fixation and washing [10]. When compared with the initial conditions before fertilization (table 1), there was a change in P nutrients, namely a slight decrease in leaf P content, even though soil P increased. This indicates an imbalance between the availability of P in the soil and plant uptake [2], [16] (possibly due to the acidic soil pH factor of 4.29, causing P to be fixed). Analysis of leaf K content showed a decrease despite the application of MKP. This coincided with a decrease in soil K, leaving the remaining K in the soil relatively insufficient to maintain leaf tissue K levels.

Low dose treatment (75g MKP/tree) also showed an increase in P and K content compared to the conventional method through the soil although the values were lower than the highest dose. This proves that absorption efficiency can be achieved with lower doses if the application method is correct. Figure 2 shows a tendency for P and K contents to be higher in fertilization through the axil than through the soil.

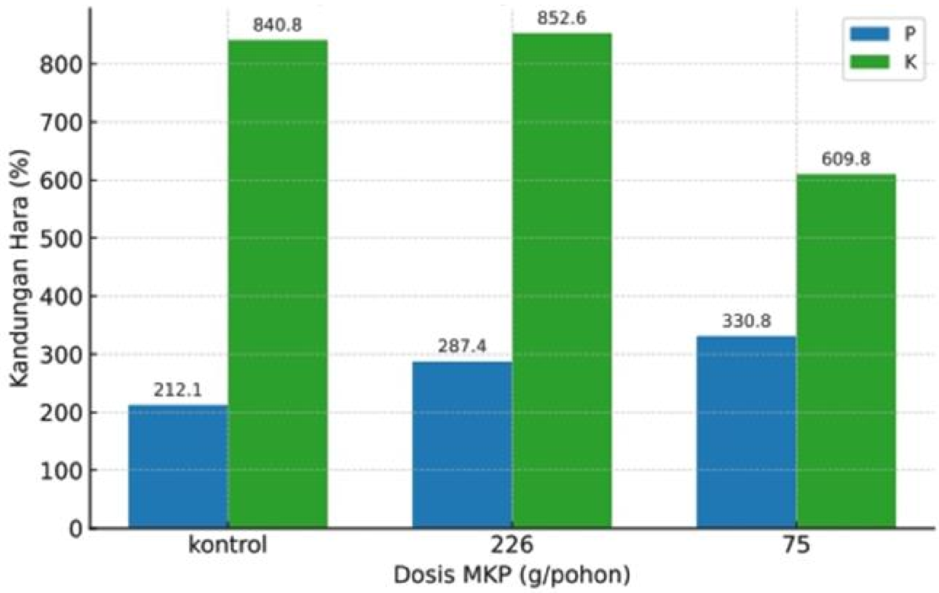

Figure 2. P and K nutrient content of oil palm leaves at various doses. MKP fertilization through the leaf axils and soil.

3.3 P and K uptake of leaves after fertilization

Based on the P and K content in the leaves, the absorption value of each nutrient can be calculated as shown in Table 4.

Table 4. Average P and K uptake three months after MKP fertilization on oil palm leaves 1 year after planting

	Soil	
MKP dose treatment plot	P total (ppm)	K total (ppm)
226 g - through the soil	212.1	840.8
226 g - through the axil	287.4	852.6
75 g - through the axil	330.8	609.8

The uptake of P and K by oil palm leaves fertilized with MKP at a dose of 226 g/tree through the axil and soil and 75 g/tree through the axil showed no significant difference, although when viewed from the trend it appears that through the soil the uptake of P and K was lower. Both high and low doses produced similar uptake values; higher doses should have higher uptake. Axillary application of fertilizer should be more readily available due to direct contact with the moist leaf sheath, but leaf data show no significant increase in P and K uptake compared to soil application, this indicates relatively low absorption efficiency. This is probably caused by [3], [4], [5], [16], [17]: 1. The dose is too high, causing excess nutrients in the soil but not mobilized to the leaf tissue. 2. Low soil pH, thus increasing P fixation by Al/Fe. 3. Interaction of P-K nutrients which mutually inhibit absorption if the dose is high.

The low-dose treatment (75 g/tree) also showed increased uptake compared to the conventional method (226 g/tree via soil), although the value was lower than the 226 g/tree via axil. This demonstrates that uptake efficiency can be achieved with lower doses if the application method is appropriate. This finding is in line with previous research reports that fertilization through the leaf axils can reduce nutrient loss and increase fertilizer availability for plants [8], [10]. This condition shows the potential of this method as an environmentally friendly and cost-effective nutrient management strategy for smallholder oil palm farmers on marginal land.

In soil application (226 g/tree), soil P increased more steadily, but leaf uptake remained low. This indicates that increasing nutrient availability in the soil does not automatically increase leaf nutrient content, perhaps due to plant physiological problems [18], for example rooting, plant age, or environmental conditions.

4. Conclusions

The phosphorus and potassium content of immature smallholder oil palm leaves fertilized through the axil using MKP fertilizer with a dose of 75 grams, 226 grams and through the soil with a dose of 226 grams is relatively the same, namely ranging between 0.124%, 0.129% and 0.117% for phosphorus and potassium content ranging from 0.772%, 0.854% and 0.836%. The absorption of phosphorus and potassium in the same fertilization is also relatively the same. Application of MKP fertilizer through both soil and axils successfully increased the availability of P in the soil, but was not followed by an increase in P content in the leaves, while the availability of K in the soil decreased drastically after fertilizer application, as indicated by a decrease in K levels in the leaves.

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