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Potential of Palm Oil Mill Effluent From 30 and 60 Tons Hour^{-1} Mills as Nutrient Sources For Oil Palm (*Elaeis guineesis Jacq.)* Planations

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Abstract

Palm Oil Mill Effluent (POME) is one of the main liquid wastes generated from palm oil processing industries and has high potential to cause environmental pollution if not properly managed. However, POME contains various macro- and micronutrients that can potentially be utilized as an organic liquid fertilizer for oil palm plantations. This study aimed to evaluate the potential of POME generated from palm oil mills with capacities of 30 tons hour^{-1} and 60 tons hour^{-1} as nutrient sources for oil palm cultivation. The research was conducted using a quantitative descriptive method through laboratory analysis of macro- and micronutrient contents and statistical analysis using the Independent Samples T-Test. The observed macronutrients included nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca), while the micronutrients included boron (B), copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn). The results showed that POME from both mill capacities contained essential nutrients with different nutrient characteristics. POME from the 60 tons hour^{-1} mill contained higher nitrogen and copper concentrations, indicating greater potential to support vegetative growth. In contrast, POME from the 30 tons hour^{-1} mill contained higher potassium, phosphorus, magnesium, boron, and iron concentrations, which are more favorable for generative growth and fruit formation. Statistical analysis indicated significant differences in most nutrient parameters between the two mill capacities. Overall, POME has considerable potential to be utilized as an organic liquid fertilizer to support sustainable oil palm plantation systems while reducing environmental pollution and dependence on inorganic fertilizers. A key advantage of this study is the identification of distinct nutrient profiles of POME produced by different mill capacities, allowing more targeted utilization according to oil palm growth stages. Therefore, POME from 60 tons h^{-1} mills is recommended for vegetative growth enhancement, while POME from 30 tons h^{-1} mills is more suitable for supporting reproductive growth and fruit development.

Keywords: Agronomic Potential, Nutrient Content, Organic Fertilizer, Sustainable Agriculture, Waste Valorization

1. Introduction

The palm oil industry is one of the most strategic sectors in the Indonesian economy due to its important role in generating foreign exchange, providing employment opportunities, and supporting the development of the agribusiness sector. Indonesia is recognized as one of the world's largest producers of palm oil, with continuously increasing plantation areas and processing capacities (Ewaldo, 2017). In addition to its economic importance, oil palm (*Elaeis guineensis* Jacq.) plantations also support various agricultural activities and influence the growth environment of associated crops within plantation ecosystems, highlighting the broad role of the oil palm sector in agricultural development (Author et al., Year). The increase in crude palm oil (CPO) production consequently results in larger quantities of waste generated from fresh fruit bunch (FFB) processing, including both solid and liquid waste.

Palm Oil Mill Effluent (POME) is the primary liquid waste generated during sterilization, clarification, and purification processes in palm oil mills. POME contains very high organic matter concentrations with elevated

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Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values, making it a potential source of environmental pollution if not properly managed (Saputera et al., 2021). According to Mulia Raja et al. (2021), POME is characterized by a thick brownish liquid, acidic pH, and high concentrations of suspended solids, residual oil, and organic compounds. Conventional treatment systems for POME generally rely on anaerobic and aerobic pond systems, which require extensive land areas and relatively long processing times (Syamsuddin S & Rivai, 2023). In addition, the volume of POME produced is considerably high, ranging from 0.6–0.7 m^3 per ton of processed FFB (Harianja et al., 2018). Therefore, efforts are needed not only to reduce environmental pollution caused by POME but also to increase its added value through sustainable utilization.

Despite the increasing interest in utilizing POME as an organic fertilizer, information regarding the variation of nutrient contents in POME produced by palm oil mills with different processing capacities remains limited. Without such information, POME utilization in oil palm plantations may be conducted without considering nutrient quality differences, potentially resulting in inefficient nutrient management, suboptimal plant growth, and inconsistent fertilization outcomes. Furthermore, the absence of comparative nutrient data among mill capacities limits the development of site-specific recommendations for POME application and reduces opportunities to optimize nutrient recycling while minimizing dependence on inorganic fertilizers. Therefore, studies evaluating the nutrient characteristics of POME from different mill capacities are essential to support sustainable oil palm plantation management.

On the other hand, POME contains essential macro- and micronutrients required for plant growth, including nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), copper (Cu), zinc (Zn), and boron (B) (Iriyawati & Widowati, 2022). These nutrient contents indicate that POME has considerable potential to be utilized as an organic liquid fertilizer in oil palm plantations. The utilization of POME as a nutrient source supports sustainable agriculture practices through nutrient recycling and reduced dependency on inorganic fertilizers. Several studies have evaluated the utilization of POME as a nutrient source and organic fertilizer. Ucha et al. (2023) reported that POME application increased plant height, frond number, and biomass production of oil palm seedlings. Ismanto & Rahayu (2024) also demonstrated that liquid waste from palm oil mills positively affected vegetative growth during the nursery stage. In addition, Mulia Raja et al. (2021) characterized the nutrient contents of POME, particularly nitrogen, phosphorus, and potassium concentrations in anaerobic ponds. However, these studies generally focused on the agronomic effects of POME application or nutrient characterization from a single source. Information regarding differences in macro- and micronutrient contents of POME produced by mills with different processing capacities is still limited. Therefore, the novelty of this study lies in the comparative evaluation of both macro- and micronutrient contents of POME generated from palm oil mills with different processing capacities (30 and 60 tons $hour^{-1}$), as well as the assessment of their suitability as nutrient sources for different growth stages of oil palm plantations.

The utilization of POME also supports the implementation of bioeconomy and environmentally sustainable agricultural systems. Ucha et al. (2023) stated that integrating POME utilization with composting technology could maintain soil nutrient balance and support sustainable oil palm plantation management. In addition, Rangkuti et al. (2018) reported that organic fertilizers derived from palm oil waste could reduce dependence on chemical fertilizers, whose prices continue to increase and potentially deteriorate soil quality after prolonged application.

Mill processing capacity may influence the quantity of waste generated, production intensity, and nutrient composition of the resulting effluent. Differences in palm oil mill capacities, such as 30 tons $hour^{-1}$ and 60 tons $hour^{-1}$, result in variations in FFB processing volumes and the amount of liquid waste generated (Agustiar, 2022). Larger processing capacities potentially produce greater quantities of biomass and liquid waste that can be utilized as nutrient sources for oil palm plantations.

Therefore, this study aimed to evaluate the potential of Palm Oil Mill Effluent produced by palm oil mills with capacities of 30 tons hour and 60 tons hour as a nutrient source for oil palm plantations. This study also aimed to analyze the macro- and micronutrient contents of POME, compare nutrient characteristics between the two mill capacities, and evaluate their potential contribution to sustainable nutrient management in oil palm plantations.

2. Material and Methods

2.1. Research Location

This study was conducted at two palm oil mills with different processing capacities. Adolina Palm Oil Mill, located at 3.5833° N and 98.9500° E, with an elevation of approximately 25 m above sea level (asl), has a processing capacity of 30 tons $hour^{-1}$ Fresh Fruit Bunches (FFB). Bah Jambi Palm Oil Mill, located at 2.9883° N and 99.2203° E (02° 59' 18" N; 99° 13' 13" E), with an elevation of approximately 32 m asl, has a processing capacity of 60 tons $hour^{-1}$ FFB. Laboratory analyses of macro- and micronutrient contents were carried out at the Research and Development Centre Laboratory of PT Nusa Pusaka Kencana, Indonesia. The study was conducted from April 2025 to January 2026.

2.2. Research Procedures

This study employed a quantitative descriptive approach to evaluate the potential of Palm Oil Mill Effluent (POME) as a nutrient source for oil palm plantations. The independent variable was palm oil mill processing capacity, consisting of 30 tons/hour and 60 tons/hour mills, while the dependent variables were the macro- and micronutrient contents of POME.

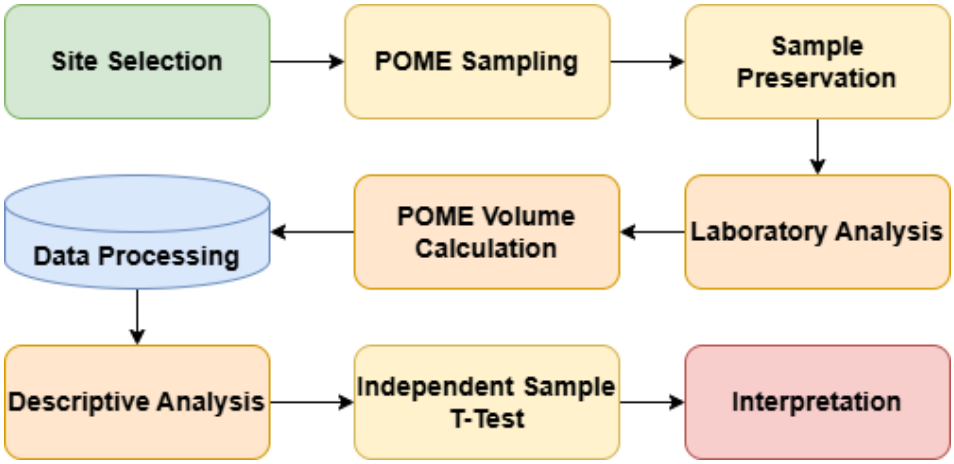


Figure 1. Research Flow Diagram

The analyzed macronutrients included nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca), whereas the analyzed micronutrients included boron (B), copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn). The research procedures consisted of site selection, POME sampling, sample preparation, laboratory analysis, and statistical analysis. POME samples were collected from the primary anaerobic ponds of each mill at a depth of 0–30 cm below the surface using a sampling container. Approximately 5 L of sample was collected from each sampling point following the method described by Jumadi et al. (2020). Sampling was conducted in three replications on different days to obtain representative data. The collected samples were placed into labeled sample bottles and stored in a cooler box to maintain sample quality during transportation to the laboratory. Laboratory analyses were conducted to determine macro- and micronutrient concentrations in the POME samples.

Total nitrogen analysis was performed using the Kjeldahl method. Phosphorus concentration was determined using UV–Visible spectrophotometry, while potassium, magnesium, calcium, iron, zinc, and copper concentrations were analyzed using Atomic Absorption Spectrophotometry (AAS) following the procedure described by Tibebe et al. (2025). All laboratory analyses followed standard analytical procedures and calibration methods to ensure analytical accuracy. The potential volume of POME generated by each mill was calculated using the following equation:

$$\boldsymbol{POME\ Volume = Mill\ Capacity \times Operating\ Hours \times Waste\ Production\ Factor}$$

The waste production factor used in this study was 0.6 m^3 of POME per ton of FFB processed, assuming mill operating hours of 20 hours day.

2.3. Data Analysis

Th Laboratory analysis results were presented as mean values and standard deviations from three replications for each treatment. Data analyses were performed using descriptive and inferential statistical approaches.

Descriptive analysis was conducted to describe the macro- and micronutrient contents of POME from each palm oil mill capacity. The results were presented in tables and discussed based on the physiological functions of nutrients in oil palm growth. Inferential statistical analysis was conducted using the Independent Samples T-Test at a significance level of 5% ($\alpha = 0.05$) to determine differences in nutrient contents between POME from the 30 tons/hour and 60 tons/hour palm oil mills.

The hypotheses tested were as follows:

H_0 : There is no significant difference in nutrient contents between POME from the 30 tons/hour and 60 tons/hour palm oil mills.

H_1 : There is a significant difference in nutrient contents between POME from the 30 tons/hour and 60 tons/hour palm oil mills.

Statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA) to support the interpretation of the potential utilization of POME as a nutrient source for sustainable oil palm plantation management. The software was operated on a computer with an Intel® Core™ i5 processor, 8 GB RAM, and Windows 11 operating system.

3. Results and Discussion

3.1. Pome Production and Characteristics

The production capacities of palm oil mills

significantly influenced the quantity of POME generated during processing activities. During the observation period from September to November 2025, the 30 tons hour^{-1} palm oil mill processed 40,239.44 tons of Fresh Fruit Bunches (FFB) and generated an estimated 26,155.64 tons of POME. Meanwhile, the 60 tons hour^{-1} mill processed 83,563.76 tons of FFB and produced approximately 50,138.26 tons of POME at Table 1.

Table 1. FFB production, estimated POME generation, pH, and C/N ratio of POME.

Parameter	30 ton/hours	60 ton/hours	p-value
Total FFB processed (ton)	40,239.44	83,563.76	-
Estimated POME (ton)	26,155.64	50,138.26	-
pH	4.067	4.041	0.041*
C/N ratio	18.120	28.000	0.000*

Description: Values are presented as mean ± standard deviation (n = 3).

The larger quantity of POME produced by the 60 tons hour^{-1} mill was directly associated with its higher FFB processing capacity. Increased processing throughput generally results in greater water consumption during sterilization, clarification, and hydrocyclone processes, thereby increasing wastewater production (Harianja et al., 2018). Similar findings were reported by Agustiar (2022), who stated that the amount of liquid waste generated in palm oil mills is strongly influenced by mill operational capacity and processing intensity.

The pH values of POME from both mills were within the acidic range (4.04–4.07), indicating the presence of high concentrations of organic acids produced during organic matter decomposition throughout palm oil processing. Acidic characteristics of raw POME have also been reported by Mulia Raja et al. (2021). Such acidic conditions indicate that untreated POME should not be directly applied to agricultural land without prior treatment because excessive application may disrupt soil chemical balance and negatively affect root development.

The C/N ratio of POME from the 60 tons hour^{-1} mill (28.00) was higher than that from the 30 tons hour^{-1} mill (18.12). Higher C/N ratios indicate greater organic carbon accumulation and slower decomposition rates of organic materials. The C/N ratio observed in the 60 tons hour^{-1} mill was also higher than the range of 20–25 reported by Mujdalipah et al. (2014), suggesting a greater potential for long-term organic matter accumulation in soil. In contrast, the lower C/N ratio observed in the 30 tons hour^{-1} mill suggests faster mineralization and nutrient release, potentially supporting more rapid nutrient availability for oil palm plants.

These results demonstrate that palm oil mill capacity influences not only the quantity of POME produced but also the chemical characteristics of the generated effluent. Variations in retention time, organic matter accumulation, and operational efficiency during oil extraction likely contributed to differences in pH and C/N ratio between the two mills.

3.2. Macronutrient Contents of Palm Oil Mill Effluent

Laboratory analysis revealed that POME from both palm oil mills contained essential macronutrients required for oil palm growth, including nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca). The concentrations of macronutrients and statistical analysis results are presented in Table 2.

Table 2. Macronutrient contents of POME and Independent Samples T-Test results.

Parameter	Unit	30 tons/hour	60 tons/hour	p-value
N	%	0.044	0.060	0.000*
P	%	0.014	0.012	0.000*
K	%	0.230	0.150	0.000*
Mg	%	0.038	0.032	0.000*
Ca	%	0.030	0.033	0.060ns

Description: Values are presented as mean ± standard deviation (n = 3)

Nitrogen concentration in POME from the 60 tons hour^{-1} mill was significantly higher than that from the 30 tons hour^{-1} mill. Nitrogen is an essential nutrient involved in chlorophyll formation, protein synthesis, and vegetative tissue development (Malsriwijaya et al., 2017). Higher nitrogen availability indicates that POME from the larger-capacity mill has greater potential to support vegetative growth of oil palm plants, particularly during early growth stages.

In contrast, potassium, phosphorus, and magnesium concentrations were significantly higher in POME from the 30 tons hour^{-1} mill. Potassium is strongly associated with oil synthesis, fruit filling, and regulation of water balance in oil palm plants (Odigie, 2024). The higher potassium concentration observed in the 30 tons hour^{-1} mill suggests greater potential to support reproductive growth and bunch development. The potassium content observed in this study (0.150–0.230%) indicates that POME could contribute to nutrient recycling in oil palm plantations. This finding is supported by Nasution et al. (2023), who reported that the application of Empty Fruit Bunches (EFB) improved soil potassium (K), magnesium (Mg), and calcium (Ca)

availability in oil palm plantations. These findings highlight the potential of palm oil mill by-products as organic nutrient sources for maintaining soil fertility and supporting sustainable plantation management.

Phosphorus also plays a critical role in energy transfer and flower initiation, while magnesium functions as a central component of chlorophyll molecules involved in photosynthesis processes. Therefore, the higher phosphorus and magnesium concentrations in POME from the 30 tons hour^{-1} mill may contribute positively to generative development and biomass production.

Calcium concentrations did not differ significantly between both mill capacities, indicating relatively similar contributions to cell wall formation and plant tissue development. The differences in macronutrient concentrations between mills may be associated with variations in processing intensity, raw material characteristics, retention time, and efficiency of organic matter separation during extraction processes. Similar findings were reported by Ucha et al. (2023), who observed significant variations in nitrogen, phosphorus, potassium, organic carbon, and C/N ratio among composts produced from different combinations of Empty Fruit Bunches (EFB) and Palm Oil Mill Effluent (POME). These results suggest that differences in processing and waste management systems can influence nutrient composition in oil palm waste products.

Overall, these findings indicate that POME from different mill capacities possesses distinct nutrient characteristics and may provide different agronomic benefits depending on the growth stage of oil palm plants.

3.3. Micronutrient Contents of Palm Oil Mill Effluent

In addition to macronutrients, POME from both mills also contained several essential micronutrients, including boron (B), copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn). Although required in smaller quantities than macronutrients, micronutrients are essential for enzyme activation, photosynthesis, flower development, and metabolic activities in plants. The micronutrient concentrations are presented in Table 3.

Table 3. Macronutrient contents of POME and Independent Samples T-Test results.

Parameter	Unit	30 tons/hour	60 tons/hour	p-value
B	ppm	1.340	0.980	0.000*
Cu	ppm	0.387	1.200	0.000*
Zn	ppm	1.460	1.500	0.015*
Fe	ppm	63.277	61.050	0.041*
Mn	ppm	7.223	7.200	0.256ns

Description: Values are presented as mean ± standard deviation (n = 3).

POME from the 30 tons hour^{-1} mill contained significantly higher concentrations of boron and iron compared with the 60 tons hour^{-1} mill. Boron is closely related to reproductive growth, particularly flower formation and fruit development in oil palm plants. Adequate boron availability may improve bunch formation and reduce abnormalities in fruit development (Prasetiyanto et al., 2024). Therefore, the higher boron concentration observed in the 30 tons hour^{-1} mill indicates greater potential to support generative growth.

Iron concentration was also higher in POME from the 30 tons hour^{-1} mill. Iron plays an important role in chlorophyll synthesis and photosynthesis processes, contributing to biomass accumulation and plant productivity. Similar findings regarding the importance of micronutrients in improving physiological performance of oil palm plants were also reported by Iriyawati & Widowati (2022).

Conversely, copper concentration in POME from the 60 tons hour^{-1} mill was significantly higher than that from the 30 tons hour^{-1} mill. Copper functions as an enzyme activator and contributes to lignin synthesis and vegetative tissue development. Higher copper availability may therefore support vegetative growth processes in oil palm plants. Zinc concentrations differed significantly between the two mill capacities, although the difference was relatively small. Zinc is involved in enzyme activity and auxin synthesis, both of which are important for plant growth regulation. Meanwhile, manganese concentrations were not significantly different, indicating relatively similar physiological contributions from both POME sources.

The variations in micronutrient concentrations between the two mills suggest that operational characteristics, retention time, sterilization processes, and organic matter separation efficiency affect nutrient distribution in POME. These findings confirm that mill processing capacity influences not only POME quantity but also nutrient quality and composition.

3.4. Potential of Palm Oil Mill Effluent as an Organic Fertilizer

The nutrient composition identified in this study indicates that POME has considerable potential to be utilized as an organic liquid fertilizer in oil palm plantations. The larger volume of POME generated by the 60 tons hour^{-1} mill provides greater quantitative potential as a source of organic matter and nutrients for agricultural applications.

POME from the 60 tons hour^{-1} mill demonstrated greater potential to support vegetative growth due to its higher nitrogen and copper concentrations. These nutrients are strongly associated with chlorophyll formation,

vegetative tissue development, and metabolic activity. In contrast, POME from the 30 tons hour^{-1} mill showed greater potential to support reproductive growth because of its higher potassium, phosphorus, boron, and iron concentrations, which are important for flower initiation, bunch formation, fruit filling, and photosynthesis processes.

The utilization of POME as an organic fertilizer may also contribute to environmental sustainability by reducing direct wastewater disposal into surrounding ecosystems. Furthermore, nutrient recycling through POME application can reduce dependence on inorganic fertilizers, whose long-term use may negatively affect soil quality and increase production costs. An example of POME application in oil palm plantations is presented in Figure 2.



Figure 2. Application of Palm Oil Mill Effluent (POME) in oil palm plantation as an organic nutrient source and nutrient recycling practice.

These findings support the concept of sustainable palm oil production through integrated waste management and nutrient recycling systems. Therefore, proper treatment and application strategies are necessary to optimize the agronomic benefits of POME while minimizing potential environmental risks associated with excessive wastewater application.

4. Conclusion

POME from both palm oil mills contained essential macro- and micronutrients and showed strong potential as an organic nutrient source for oil palm (*Elaeis guineensis* Jacq.) plantations. A key finding of this study is that POME from the 60 tons hour^{-1} mill contained higher nitrogen and copper concentrations, making it more suitable for supporting vegetative growth, whereas POME from the 30 tons hour^{-1} mill contained higher potassium, phosphorus, magnesium, boron, and iron concentrations, which are beneficial for reproductive growth and fruit development. Therefore, the utilization of POME should be adjusted according to plantation nutrient requirements to optimize nutrient recycling, reduce environmental pollution, and decrease dependence on inorganic fertilizers.

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