

POTENTIAL OF OIL PALM FIBER FROM MILLS WITH A CAPACITY OF 30 AND 60 TONS/H AS A NUTRIENT IN OIL PALM PLANTATIONS

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Abstract

The palm oil industry produces solid waste in the form of fiber which has been used as boiler fuel, but its potential nutrient content has not been optimally utilized in plantations. This study aims to assess the potential of palm oil fiber from Palm Oil Mills with capacities of 30 and 60 tons/h as a nutrient source for oil palm plants. The study used a quantitative descriptive method to determine differences in nutrient content between mill capacities. The results showed that palm oil fiber from both mill contained the macro nutrients of N, P, K, Mg, and Ca, as well as the micro elements of B, Cu, Zn, Fe, and Mn. Statistical tests showed that most parameters were significantly different ($p < 0.05$) between the two fiber sources. Fiber from the 60 tons/h-mill had a higher N content, making it more potential to support vegetative plant growth. Meanwhile, fiber from a 30 tons/h-mill has higher K, Mg, Ca, and B content, which play important roles in the generative phase. This study concluded that oil palm fiber has the potential to serve as a nutrient source, with an application strategy tailored to the plant's growth phase.

Keywords: *Fiber potential, oil palm fiber, 30 tons/h-mill, 60 tons/h-mill.*

INTRODUCTION

The palm oil industry plays a crucial role in Indonesia's economic structure, contributing significantly to foreign exchange earnings, job creation, and rural development. The surge in global demand for palm oil has triggered the expansion and intensification of operational efficiency in palm oil mills (Purba & Sipayung, 2017). This development can be seen from the area of oil palm plantations, which continues to increase every year with an additional area rate of 150,000 – 200,000 ha (Brahmana et al., 2021). To meet market demands and achieve economic returns based on production scale, mills are designed with various fresh fruit bunch (FFB) processing capabilities, ranging from 30 tons/h to 60 tons/h. This capacity variation accounts for factors such as local raw material supply, supporting plantation size, and estimates of future FFB production growth. Mills with a processing capacity of 30 tons/h are typically used to support medium-scale plantation operations or as an initial step in expanding production capacity. Conversely, mills with a capacity of 60 tons/h are designed to accommodate the processing of substantial volumes of FFB from large-scale plantations, thereby enabling higher operational efficiency and lower production costs per unit of product (Purba & Sipayung, 2017).

The FFB processing in palm oil mills inherently produces various solid residues, including empty fruit bunches (EFBs), shells, and fiber, which originate from the milling activities in the mill (Syukri et al., 2024). A study indicates that every ton of palm oil processed produces 23% EFBs, 6.5% shells, 4% wet decanter (palm sludge), 13% fiber, and 50% liquid waste (Rafly et al., 2022). Oil palm fiber waste, derived from pressing the fruit, is commonly used as boiler fuel in mills. However, this strategy has not fully utilized the fiber's potential as a source of organic matter and nutrient supply for plants. In the context of modern agricultural history, the Green Revolution, which began in the mid-20th century, brought significant advances in agricultural productivity through the use of high-yielding varieties, chemical fertilizers, and synthetic pesticides. While successful in increasing crop yields, the Green Revolution also left behind environmental challenges, including soil degradation, water pollution, and reduced biodiversity due to reliance on external inputs. Therefore, there is a need to develop more sustainable agricultural systems, including in the palm oil sector, which has been under global scrutiny due to environmental issues (Silitonga et al., 2011). Therefore, the use of fiber as an ameliorant or organic mulch in oil palm plantations has the potential to be a sustainable solution for plant nutrient management, while reducing dependence on inorganic fertilizers, a hallmark of the Green Revolution (Hayati et al., 2025).

Mills with capacities of 30 and 60 tons/h can produce large quantities of oil palm fiber, much of which remains underutilized on plantations. However, with a circular economy approach, solid waste such as oil palm fiber can be returned to the plantation, thereby increasing the overall efficiency of the palm oil production system. This reflects a shift from the Green Revolution approach to more ecologically sound regenerative agriculture (Syahza, 2002). Utilizing oil palm fiber in plantation areas not only increases land productivity but also supports the principles of sustainable agriculture. Therefore, further studies are essential on the potential of fiber from mills with different capacities as a nutrient source in oil palm plantations, including estimating the amount of fiber produced, its nutrient content, and its potential impact on soil fertility (Harahap et al., 2019).

Extensive research has been conducted on the use of palm fiber as a nutrient source. For example, Andriani et al. (2022) added oil palm fiber ash and oil palm empty bunches as nutrient sources to liquid organic fertilizer made from palm oil mill liquid waste. However, this study did not specifically evaluate the effect of palm oil mill capacity on the nutrient content of oil palm fiber. Asih (2018) reported that the addition of palm oil solid waste to clay loam and sandy loam soil significantly affected organic carbon, total nitrogen, extra potassium, and soil CEC, thereby increasing nutrient availability in Ultisols. Based on data from the Central Statistics Agency (BPS) and reports from palm oil plantation companies, by 2024, there will be approximately 4,000–5,000 palm oil mills in Indonesia, with the potential to supply fiber as a nutrient. This study aims to evaluate the potential of oil palm fiber from two mills with different capacities (30 and 60 ton/h), as a nutrient supplier for oil palm plants. Using a quantitative descriptive approach, this study is expected to provide scientific data to support the use of palm oil fiber as an alternative fertilizer and sustainable palm oil industry waste management.

METHOD

Research Design

This study uses a quantitative descriptive method to characterize the nutrient content of oil palm fiber from two PKS with different production capacities: 30 tons/h and 60 tons/h. Data analysis used the Independent T-Test with IBM SPSS software to provide a clear picture of the potential of oil palm fiber as a nutrient provider in oil palm plantations. The Independent T-Test was conducted at the $\alpha = 0.05$ significance level. The testing hypotheses in this study include:

1. H_0 : There is no significant difference in nutrient content between oil palm fiber from 30 tons/h-PKS and 60 tons/h-PKS.
2. H_1 : There is a significant difference in nutrient content between oil palm fiber from 30 tons/h-PKS and 60 tons/h-PKS.

The nutrients analyzed include macro and microelements. Macro elements include nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca). Micro elements include boron (B), copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn).

Materials and Method

Oil palm fiber was obtained from Adolina mill (30 tons/h) and Bah Jambi mill (60 tons/h), located in North Sumatera Province, Indonesia. The chemicals used include $\text{Sr}(\text{NO}_3)_2$ as a reagent in nutrient analysis, 4 N HCl for sample digestion, standard solutions of magnesium, potassium, calcium, iron, and copper, each at 1000 ppm for calibration, distilled water, and Kjeldahl reagent for nitrogen analysis. The equipment used includes a digestion tool, a Kjeldahl set, an Atomic Absorption Spectrophotometer (AAS), a desiccator, an analytical balance, an oven, laboratory glassware (measuring cylinder, volumetric flask, dropper pipette, test tube), a UV-Vis spectrophotometer, and flame photometry.

Procedure

Oil palm fiber from the mill were dried in an oven at 105°C for 3 hours, or until constant weight was reached. The dried samples were ground using a mortar and pestle, then sieved using a 0.5 mm (100 mesh) sieve. The fiber was analyzed for its macro- and micronutrient content. N levels were tested using the Kjeldahl method. P levels were tested using a UV-vis spectrophotometer. K, Mg, Ca, Fe, Cu, and Zn levels were analyzed using an Atomic Absorption Spectrophotometer (AAS).

Calculation of the Production Potential of Oil Palm Fiber

According to Naibaho (1998) in the Palm Oil Technology Manual, every 1 ton of FFB processed in a palm oil mill produces approximately 13% fiber based on the mass balance concept. The potential fiber production from each mill can be calculated using Equation 1.

$$\text{Fiber potential} = \text{Mill capacity} \times \text{fiber material balance} \tag{1}$$

RESULTS AND DISCUSSION

Production of Oil Palm Fiber

Tables 1 and 2 summarize the recapitulation of fiber production at 30 tons/h-mill and 60 tons/h-mill during September to November 2025. Total fiber production for the three months for the two mills was 5,605.859 tons and 10,863.289 tons. The amount of fiber production is influenced by the amount of FFB processed each day. Both mills produced the highest fiber production in September 2025, which was due to the large amount of FFB processed during that period. Sequentially, the average fiber production from September to November 2025 at 30 tons/h-mill was 70,989 tons/day, 59,494 tons/day, and 54,395 tons/day. On the other hand, the average fiber production at 60 tons/h-mill was 128,044 tons/day, 114,560 tons/day, and 115,687 tons/day. The large amount of fiber produced indicates that fiber waste has the potential to be used as a source of organic material and as a nutrient supplement in oil palm plantations. Furthermore, increasing mill capacity will linearly increase the amount of fiber produced. The more FFB processed, the greater the amount of solid oil palm waste produced (Rangkuti et al., 2023). This aligns with the mass balance principle, where solid waste output is directly proportional to raw material input. According to Iswahyudi & Iskandar (2023), oil palm fiber contains macro- and micro-nutrients that can be used as organic fertilizer.

Table 1. Recapitulation of the fiber production in 30 tons/h-mill

Month	Processing Day	Processed FFB (ton)	CPO (Ton)	CPO Yield (%)	Fiber 13% (ton)
September	29	16,382.100	3,743.527	22.85	2,129.673
October	29	14,187.140	3,134.570	22.09	1,844.328
November	24	12,552.750	2,916.073	23.23	1,631.858
TOTAL	82	43,121.990	9,794.170	22.71	5,605.859

Table 2. Recapitulation of the fiber production in 60 tons/h-mill

Month	Processing Day	Processed FFB (ton)	CPO (Ton)	CPO Yield (%)	Fiber 13% (ton)
September	28	29,548.610	7,535.388	25.50	3,841.319
October	24	27,318.110	6,997.700	25.62	3,551.354
November	25	26,697.040	6,885.559	25.79	3,470.615
TOTAL	77	83,563.760	21,418.647	25.63	10,863.289

Nutrient Content in Oil Palm Fiber

Based on the laboratory test results, the summary of macro- and micronutrients in 30 and 60 tons/h-mills is presented in Table 3.

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Table 3. Average nutrient content in oil palm fiber

Nutrient	Unit	30 Tons/H-Mill	60 Tons/H-Mill
N	%	1.05	1.32
P	%	0.13	0.10
K	%	0.81	0.52
Mg	%	0.22	0.14
B	ppm	8.25	6.40
Ca	%	0.54	0.35
Cu	ppm	12.16	15.04
Zn	ppm	20.03	18.49
Fe	ppm	1097.25	629.60
Mn	ppm	79.31	68.97
pH	-	5.15	6.53
C/N	-	51.843	41.623

There are differences in nutrient composition between the fiber from the two palm oil mills. Oil palm fiber from the 30 tons/h-mill contains a relatively complete range of macro- and micronutrients. K is the dominant macronutrient, followed by Ca, Mg, N, and P. Fe dominates the micronutrients, followed by Mn, Zn, Cu, and B. The high Fe and Mn content indicates the fiber's potential to support photosynthesis and plant metabolism. In general, the nutrient composition of the 30 tons/h-mill's fiber demonstrates organic material characteristics that better support the generative growth phase of oil palm plants. Conversely, fiber from the 60 tons/h-mill has a higher N content, which is a key element in the formation of vegetative plant tissue. However, other macronutrients, such as K, Mg, and Ca, are lower than those from the 30 tons/h-mill's fiber. Cu content in the 60 tons/h-mill's fiber is relatively higher, while Fe and Mn are lower than those from the 30 ton/h-mill's fiber. This nutrient composition indicates that fiber from a 60 tons/h-mill has nutritional characteristics that better support vegetative growth than generative growth of oil palms. Therefore, the use of fiber as a nutrient source should be tailored to the growth phase of oil palm plants to optimize the effectiveness of organic fertilization.

Independent T-Test Results

Based on the Independent T-Test results in Table 4, the differences in macro- and micronutrient levels of fiber between 30 tons/h-mill and 60 tons/h-mill are significantly different.

Table 4. Independent T-test results

Nutrient	Mill Capacity	Average	Std. Dev	Sig.(p)	Note
N	30 Tons	1.0500	0.04000	0.008	Significantly different
	60 Tons	1.3167	0.08505	0.018	Significantly different
P	30 Tons	0.1267	0.00577	0.008	Significantly different
	60 Tons	0.1033	0.00577	0.008	Significantly different
K	30 Tons	0.8100	0.00000	<0.001	Significantly different
	60 Tons	0.5167	0.00577	<0.001	Significantly different
Mg	30 Tons	0.2233	0.00577	<0.001	Significantly different
	60 Tons	0.1400	0.00000	0.002	Significantly different
B	30 Tons	8.2500	0.31512	<0.001	Significantly different
	60 Tons	6.4033	0.07506	0.07	Significantly different
Ca	30 Tons	0.5400	0.01000	0.002	Significantly different
	60 Tons	0.3467	0.04509	0.014	Significantly different
Cu	30 Tons	12.1567	0.30501	<0.001	Significantly different
	60 Tons	15.0400	0.08000	0.002	Significantly different
Zn	30 Tons	19.9967	0.04163	<0.001	Significantly different
	60 Tons	18.4900	0.23000	0.006	Significantly different
Fe	30 Tons	1097.1800	6.76594	<0.001	Significantly different
	60 Tons	629.6000	17.50014	<0.001	Significantly different
Mn	30 Tons	79.3100	1.47255	<0.001	Significantly different
	60 Tons	68.9667	0.65501	0.002	Significantly different
pH	30 Tons	5.1467	0.02082	<0.001	Significantly different
	60 Tons	6.5267	0.01155	<0.001	Significantly different
C/N	30 Tons	51.5733	2.38240	0.009	Significantly different
	60 Tons	41.6233	2.70193	0.009	Significantly different

Potential of Fiber as Nutrient Provider

Oil palm growth is divided into vegetative and generative phases. The vegetative phase is characterized by the formation of leaves, stems, and a robust root system, while the generative phase is characterized by flowering, fruit bunch formation, and oil accumulation (Ningsih, 2025). The macronutrients analyzed in oil palm fiber include N, P, K, Mg, and Ca. These nutrients serve in fruit formation, increasing average bunch weight, plant health, and increasing oil content (Pradifta & Wahyuni, 2019). N is a key element in the formation of chlorophyll, proteins, and plant enzymes (Warganegara et al., 2017). This element plays a significant role in vegetative growth, particularly in leaf formation and increasing canopy area. P plays a crucial role in energy transfer, cell division, as well as flower and fruit formation (Marpaung, 2021). Adequate P availability accelerates flower differentiation and increases fertilization success. P regulates the translocation of photosynthetic products to the fruit, increases fruit filling, and plays a significant role in oil production (Huesesan et al., 2025). High K availability directly correlates with increased bunch weight and oil yield. Mg is the central atom of the chlorophyll molecule and plays a crucial role in photosynthesis (Huesesan et al., 2025). This element strengthens cell walls and supports cell division in young fruit tissue (Lubis, 2019). Finally, Ca aids vegetative growth by forming a more robust bunch and fruit structure and reducing the risk of fruit miscarriage.

Meanwhile, the microelements analyzed include B, Cu, Zn, Fe, and Mn. B is essential for flower formation and fruit development (Ginting & Pane, 2023). B deficiency can cause abnormal fruit and incomplete bunch development. Cu functions as an activator of oxidation enzymes and plays a role in lignin formation (Sellyna et al., 2020). During the generative phase, Cu supports healthy flower development and strengthens plant tissues. Zn plays a role in auxin synthesis, which regulates the growth of flowers and young fruit (Ernita et al., 2023). Fe plays a role in chlorophyll formation and respiration (Djs et al., 2020). Good Fe availability supports photosynthesis, optimizing the supply of assimilates for oil formation and supporting vegetative growth. The last, Mn functions as an activator of photosynthetic enzymes and nitrogen metabolism (Seran, 2017).

Based on the nutrient composition analysis, fiber from a 60 tons/h-mill predominantly supports vegetative growth due to its high N and Fe content. Furthermore, the fiber has a pH closer to neutral, indicating faster decomposition of organic matter and making nutrients more readily available to plants. These conditions are ideal for supporting early vegetative growth. Conversely, fiber from a 30 tons/h-mill is more supportive of generative growth due to its higher K and B content, as well as a higher C/N ratio. This indicates that decomposition is slower and nutrient release is gradual. These characteristics are beneficial for the generative phase, as plants require a stable nutrient supply during bunch formation and fruit filling. The use of fiber as an organic material should be tailored to the growth phase of oil palm plants. A 60 ton/h-mill's fiber is more suitable for immature plants (TBM) to encourage vegetative growth. In contrast, a 30 ton/h-mill's fiber is more ideal for mature plants (TM) to support generative growth through bunch formation and increased production.

Potential of Fiber Based on the Oil Palm Mill Capacity

Differences in macro- and micronutrient content in oil palm fiber from 30 tons/h-mill and 60 tons/h-mill indicate that the chemical characteristics of the organic material produced by FFBs processing are not homogeneous, but rather influenced by the dynamics of the process and the nature of the processed raw materials. Fiber from the 60 tons/h-mill has an N content of 1.32%, higher than that from the 30 tons/h-mill (1.05%). Conversely, other macronutrients, such as K (0.81% and 0.52%), Mg (0.22% and 0.14%), and calcium (0.54% and 0.35%), tend to be higher in fiber from the 30 tons/h-mill. A similar pattern also occurs for micronutrients, with higher Fe, Mn, and B content in the 30 tons/h-mill's fiber. In contrast, Cu content is relatively higher in the 60 tons/h-mill's fiber. Variations in N content in organic matter are closely related to the composition of the plant tissue that forms the residue. N in fiber primarily originates from proteins and non-structural organic compounds in the mesocarp tissue of oil palm fruit. The higher N content in the 60 ton/h-mill's fiber indicates that the resulting residue still contains a relatively more easily degraded organic tissue fraction. This is supported by the lower C/N ratio in the 60 tons/h-mill's fiber (41.623) compared to the 30 tons/h-mill's (51.843), indicating a more advanced initial decomposition rate of organic matter and a greater relative proportion of nitrogen to structural carbon. A lower C/N ratio generally correlates with higher nitrogen content and a greater potential for faster soil mineralization. Conversely, the high K, Ca, and Mg content in the 30 tons/h-mill's fiber can be explained by the mechanism of mineral retention in the lignocellulosic matrix. K is the dominant cation in plant cell fluids. It is readily soluble in water, so its extraction and leaching processes are strongly influenced by the intensity of these processes. In larger-capacity processing systems, the material flow rate and liquid-phase separation efficiency tend to be higher, allowing more soluble minerals, such as K and Mg, to be carried along with the liquid phase and not retained in the fiber residue. Conversely, in smaller-

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capacity processing systems, the relatively less intensive separation process allows more mineral fractions to remain bound to the solid material, resulting in higher concentrations of macronutrients other than N. The differences in micronutrient content between the two fiber sources can also be explained through soil chemistry and organic matter chemistry. The Fe content in the 30 tons/h-mill's fiber reached 1,097.24 ppm, significantly higher than the 629.60 ppm from the 60 ton/h-mill's fiber. Fe and Mn in organic matter tend to associate with phenolic compounds and lignin components, so their presence is influenced by the degree of degradation of plant tissue structure. Fiber with a higher C/N ratio indicates a greater dominance of structural components, which chemically have a higher capacity to bind micrometal cations. Therefore, the high Fe and Mn content in the 30 tons/h-mill's fiber indicates that the material retains a greater fraction of minerals bound to the lignocellulosic tissue.

Another chemical factor contributing to the differences in nutrient composition is the pH of the organic matter. The 30 tons/h-mill's fiber has a pH of 5.15, while the 60 tons/h-mill's fiber has a pH of 6.53. This difference affects the stability of micronutrients during processing. At lower pH, metal elements such as Fe and Mn tend to be in a more stable, insoluble form, resulting in higher concentrations in the solid residue. Conversely, pH conditions closer to neutral increase the mobility of some microelements, allowing some to be released from the organic matrix during the separation process. Theoretically, in a biomass processing system, production capacity is related to the intensity of mechanical and thermal energy applied to the material. Higher process intensity increases oil extraction efficiency but also increases the likelihood of mineral element loss through the liquid phase. This explains why fiber from a 60 tons/h-mill exhibits a higher N content but lower contents of most other mineral elements. In other words, increasing processing capacity not only affects the quantity of residue produced but also modifies the chemical balance between the organic and inorganic components of the fiber.

Differences in nutrient content in oil palm fiber result from differences in mineral retention rates, plant tissue composition, C/N ratio, and the chemical conditions of the material during processing. The fiber from a 60 tons/h-mill is characterized by a predominance of N fractions and more readily decomposed organic matter. In contrast, the fiber from a 30 tons/h-mill is characterized by a higher macro- and micro-mineral content due to the retention of inorganic elements within the structural matrix of the organic matter. This pattern confirms that mill capacity is a technical factor that indirectly influences the nutritional quality of fiber residues through physical, chemical, and biological mechanisms during fresh fruit bunch processing. In addition to nutrient quality, the quantity of fiber produced by the mill also determines its potential contribution to soil fertility. Based on a mass balance approach, a 30 tons/h-mill can produce approximately 5,605.859 tons of fiber every three months, while a 60 tons/h-mill produces approximately 10,836.28 tons every three months. In a single operational day, this amount is significant and could provide large-scale organic matter. If some of this fiber is returned to the plantation as mulch or compost, it will significantly increase the soil's organic matter input. The addition of organic matter improves soil structure, increases cation exchange capacity (CEC), enhances soil water retention, and increases the activity of soil microorganisms. The long-term impact is increased fertilizer efficiency and sustainable soil health improvement (Ginting, 2020). Thus, fiber utilization not only serves as a nutrient provider but also as a soil conditioner, supporting long-term plantation productivity (Augustien & Suhardjono, 2023).

CONCLUSION

The results of the study indicate that palm oil fiber from both mills contains macro- and micronutrients needed by oil palm plants. The Independent T-Test showed that almost all macro- and micronutrient were significantly different ($p < 0.05$), indicating that mill capacity influences the nutrient quality of the fiber produced. The 60 tons/h-mill produces 10,863.289 tons of fiber for three months and has greater potential to support the vegetative growth of oil palm plants. This is indicated by its higher N content and pH conditions closer to neutral, which allow decomposition of organic matter to proceed more rapidly. Meanwhile, the 30 tons/h-mill produces 5,605.859 tons of fiber for three months and has greater potential to support the generative growth of oil palm plants. The relatively higher K, B, Mg, and Ca content in the 30 tons/h-mill fiber plays an important role in the flowering process, bunch formation, fruit filling, and oil synthesis. In addition, a higher C/N ratio indicates slower, more stable nutrient release, which is suitable for the plant's production phase (TM). Utilizing oil palm fiber as a nutrient source supports the concepts of sustainable agriculture and a circular economy. Returning fiber to plantations not only reduces solid factory waste but also has the potential to reduce the use of inorganic fertilizers, improve soil physical and chemical properties, and increase the efficiency of sustainable palm oil production systems.

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POTENTIAL OF OIL PALM FIBER FROM MILLS WITH A CAPACITY OF 30 AND 60 TONS/H AS A NUTRIENT IN OIL PALM PLANTATIONS

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