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STUDY ON THE EFFECT OF VARIOUS TYPES OF FERTILISER ON THE PRODUCTION OF OIL PALM ROOT CUTTING

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ABSTRACT

In the context of Indonesia, the cultivation of oil palm (Elaeis guineensis) *is extremely significant and the application of diverse fertiliser variants can affect crop yield through the implementation of root-cutting methods. The modification of root morphology is also a strategy to address the issue of suboptimal nutrient uptake and soil physical properties exert a significant influence on the development. Therefore, this study used a nested plot design as the main plot, comprising plants aged 7, 12 and 16 years. The subplots were demarcated by fertiliser types, including control (no fertilisation), single fertiliser potassium (K) (2.25 kg KCl/tree), palm frond litter (65 kg/tree) and empty fruit bunches (65 kg/tree). Furthermore, the treatment was replicated four times, resulting in a total of 48 experimental units. The results showed that plants aged 7 years exhibited the most robust growth compared to 12 and 16 years, across all fertiliser types, as indicated by stem circumference, stem diameter, and NDVI values. Regarding the primary, secondary, and tertiary optimal root distribution, 7 year old plants responded to K fertiliser. However, tertiary distribution did not significantly differ from 12 year-old plants when K fertiliser was applied. The nutrient levels in 7 and 12 years old plants varied in terms of pH, organic carbon (C-organic), and K.*

Keywords: fertility soil, oil palm, root cutting.

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INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is a significant plantation crop in the agricultural sector. Among different oil-producing plants, it holds economic value as a foreign exchange source and Indonesia, Malaysia, and Thailand are the world's largest producers. Several activities are conducted to enhance palm oil production, including expansion, rehabilitation of existing plantations, and intensification (Nurcahyo & Arian, 2017). Fertilisation can be applied to oil palm plants subjected to root pruning to improve their production and quality.

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Root pruning can result in drought stress for plants due to disrupted nutrient and water absorption. It can also inhibit stem and shoot diameter growth (Fini *et al.*, 2015; Watson, 1998). However, root pruning enhances plant nutrient uptake through morphological and physiological mechanisms. Morphological mechanisms include root hair distribution and formation, where cutting roots stimulate the growth of new ones at the cut ends (Miller & Neely, 1993). Root pruning increases the percentage of dry-weight growth and root dry weight in oil palms (Raharjo *et al.*, 2017). Physiological mechanisms for improving nutrient uptake through root include root kinetics and nutrient mobilisation through root exudation (Rao *et al.*, 1999). Root pruning is performed on different plants with varying distances from the stem, pruning depth, and intensity. In the case of oil palm, it possesses a fibrous root system, with tertiary and quaternary roots playing a crucial role in nutrient and water absorption (Yahya *et al.*, 2010). This condition leads to changes in organic acids expressed by roots as plants adapt to enhance nutrient uptake and optimise the absorption of essential nutrients when provided with the right types of fertiliser.

The application of fertiliser can enhance the production and quality of root-pruned plants. Proper application provides the necessary nutrients for optimal growth and development of plants. Previous studies have shown that providing fertiliser with the appropriate concentration, composition, and dosage can increase plant productivity. One nutrient that aids in plant recovery after drought stress is potassium, enhancing plant resilience to drought stress. This is influenced by physiological and biochemical processes related to the synthesis of compounds such as proline, antioxidant activity and phenols. Under drought stress conditions, the osmotic pressure in the environment is higher than inside plant cells, making it difficult for plants to absorb water. Plants increase the concentration of intracellular solutes such as proline and reduce the intracellular osmotic potential to maintain potential water balance (Cha-um *et al.,* 2010). These compounds actively contribute to the physiological mechanisms that enable plants to withstand drought stress (Egilla *et al.,* 2001). Additionally, using organic and potassium (K) fertiliser offers more environmentally friendly options providing additional benefits to root-pruned plants. Organic fertiliser derived from well-packaged oil palm plant waste can serve as a nutrient source.

The waste generated by oil palm plantations can manifest as solid waste, including empty fruit bunches (EFB), palm fronds and palm leaves. Sarwono (2008) states the advantages of EFB compost, such as the high K content, absence of starter and chemicals, enrichment of existing soil nutrients, and improvement of physical, chemical, and biological properties. This can be used as organic mulch or incorporated into soil to enhance soil fertility. The physical properties of soil are one of the factors that influence root growth, and inadequate physical properties can impede root development (Andiyarto & Purnomo, 2012). La Habi (2015) explains that the increase in soil pore space occurs due to the stimulation of soil aggregates by organic matter, resulting in a decrease in soil bulk density. Additionally, Widodo and Kusuma (2018) state that the increase in organic matter content acts as a binder in soil aggregate formation, leading to the creation of more inter-aggregate (macropores) and intra-aggregate spaces (micropores), enhancing air and water availability in soil.

Applying organic matter increases the total pore space, reduces soil volume (Wolf & Synder, 2003), and improves soil porosity by 13.00% (Endriani *et al.,* 2003). Oil palm plantations possess abundant organic matter in the form of leaf litter and EFB. Oil palm EFB is an abundant waste product derived from palm oil mills. This is known to improve the physical, chemical, and biological properties of soil, in addition to having a high nutrient content. Sarwono (2008) reports that EFB compost contains essential plant nutrients, including 1.50% nitrogen (N), 0.50% phosphorus (P), 7.30% K and 0.90% magnesium (Mg). Furthermore, Hayat and Andayani (2014) indicate that EFB compost's nutrient content includes total N (1.91%), K (1.51%), calcium (Ca) (0.83%), P (0.54%), Mg (0.09%), organic carbon (C-organic) (51.23%), C/N ratio (26.82%) and a pH of 7.

EFB compost serves a dual function by adding nutrients to soil and increasing its organic matter content crucial for improving the physical properties of soil. The increased organic matter enhances the stability of soil structure and improves its water retention capacity. These improvements in soil's physical properties positively impact root growth and nutrient uptake by plants (Rozy *et al.,* 2013). Apart from EFB, there is a significant accumulation of palm frond litter around oil palm trees. Therefore, palm frond litter has the potential to serve as a source of organic matter to improve the physical and chemical properties of soil in oil palm plantations. Using palm frond litter as fertiliser for oil palm trees is viable since it contains an average nutrient content of 1.67% N, 0.17% P, 0.23% K, 0.83% Ca and 0.26% Mg (Yuniati & Widyastuti, 2014).

The application of palm frond litter and EFB aims to increase the organic matter content, improving the physical properties of soil. The use of EFB is a common practice in oil palm plantations. However, the comprehensive exploration of palm frond litter, particularly in the context of its impact on root pruning, remains an area that has not received extensive attention. EFB compost, derived from palm oil mills, is a readily available waste product known to enhance soil's physical, chemical and biological properties. The compost is abundant throughout the year, accounting for approximately 20%-27% of processed fresh fruit bunches (FFB) (Bariyanto *et al.,* 2015). Increasing the dosage has been found to correlate with an increase in root volume (Amri *et al.,* 2018). The advantages of compost derived from palm frond litter include its high K content, the use of bio decomposers obtained from microbial isolates found beneath palm frond stacks in the field, the enrichment of soil nutrients, and the ability to improve the physical, chemical and biological properties of soil (Yuniati & Widyastuti, 2014).

Using palm waste as fertiliser holds great potential for enhancing the productivity of root-pruned crops. Therefore, this study aims to enhance the understanding of how root-pruned crops respond to various fertilisers. It provides valuable information for farmers and agricultural practitioners to improve production efficiency and promote agricultural sustainability in the context of root-pruned crops. By understanding the nutrient requirements of these crops and applying suitable fertiliser, farmers can enhance the quality and quantity of their root-pruned crop yields.

MATERIALS AND METHODS

The study was conducted from October 2022 to May 2023 in Teluk Merbau Village, Dayun District, Siak Sriindrapura Regency, Riau, Indonesia. Soil nutrient analysis was performed at the Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University. The study used K fertiliser, palm frond litter and EFB as materials. Furthermore, the tools employed included a measuring tape, hoe, soil auger, digital scale, SPAD-502, Haga Altimeter and GPS. The study followed a nested design, with plant age as the main plot and fertiliser types as the subplot. The plant age factor consisted of three levels, namely 7, 12 and 16 years, while the fertiliser types factor had four levels, including Control (without fertilisation), single K fertiliser (2.25 kg KCl/tree), palm frond litter (65 kg/tree) and EFB (65 kg/tree). Each treatment was replicated four times, resulting in 48 experimental units of four plants, totalling 192 (Darmosarkoro *et al.*, 2008).

The data were analysed using analysis of variance (ANOVA) with SAS software at a 95% confidence level (α = 5%). Duncan's Multiple Range Test (DMRT) was conducted at a 95% confidence level (α = 5%) when ANOVA indicated a significant treatment effect. The observed variables included plant height, measured from the ground surface to the rudimentary spine on the front using a Haga Altimeter. Stem circumference and diameter were measured with a tape by calculating the average circumference at the base of the stem. Root distribution was assessed after pruning, and samples were taken from one plant in each experimental unit, resulting in 28 sampling points. The number and weight of fruit bunches were observed at 1, 2, 3, 4, 5, and 6 months after the treatment. Furthermore, soil nutrient observations and natrium (Na) with Kjedhal method, P with Bray I, and K with washing method using ammonium acetate (NH_4OAc) at pH 7 in root were conducted.

RESULTS AND DISCUSSION

Agronomic and Production Characteristics

The ANOVA showed a significant variation in the height of oil palm plants due to the application of different fertilisers at the beginning and end of the observation period for each plant age, as shown in *Table 1*.

Table 1 shows that the tallest plant height was observed in 16 year old plants compared to those aged 12 and 7. Among the different types of fertiliser used, including the control, K fertiliser, midrib litter and EFB, there were no significant differences at each plant age. Generally, the height of oil palm plants increased from the initial to the final for each combination of plant age and fertiliser types. A higher plant height indicates better growth; as plants age, their height tends to increase compared to younger plants.

The application of different fertilisers did not significantly impact plant height, resulting in no differences observed among the treatments. Several factors influence the availability of nutrients in the soil for plant absorption and use. Fangeria *et al.* (2009) state that climate, soil conditions, plant-related factors and interactions influence nutrient

TABLE 1. OIL PALM PLANT HEIGHT FOR DIFFERENT PLANTING AGES AND THE APPLICATION OF VARIOUS FERTILISER

Plant age (yr)	Types of fertiliser	Initial plant height	Final plant height
7	Control	343.06 c	373.06 c
	K fertiliser	352.56 c	382.56 c
	Leaf litter	350.69 c	380.69 c
	EFB	338.06 c	368.06 c
12	Control	610.31 b	642.31 b
	K fertiliser	645.50 b	677.50 b
	Leaf litter	629.50 b	661.50 b
	EFB	643.25 b	675.25 b
16	Control	712.31 a	752.31 a
	K fertiliser	747.50 a	787.50 a
	Leaf litter	731.50 a	771.50 a
	EFB	745.25 a	785.25 a

Note: EFB - empty fruit bunches; K - potassium.

availability. Additionally, Syakir and Gusmaini (2012) emphasise the importance of considering factors that ensure plant nutrient availability for growth and development. Nutrients play a vital role in the formation of plant tissue, and any imbalances in soil nutrient levels can disrupt this process.

Even though fertiliser treatments did not yield significant differences, applying K fertiliser resulted in taller plants compared to other types across different ages of oil palm plants. K fertiliser contains the essential macronutrient, which is crucial for various physiological processes in plants, including protein synthesis, photosynthesis, cell osmotic pressure regulation and water and sugar balance control. Applying K fertiliser to oil palm can increase growth, such as plant height, productivity and fruit quality.

Based on the ANOVA, there were significant differences in oil palm trunk circumference among different plant ages. The largest trunk circumference, both at the beginning and end of the measurement, was observed in plants aged seven years, as shown in *Table 2*.

The trunk circumference of oil palm aged seven years showed a greater circumference than aged 12 and 16 years at the beginning and end of the observations. The use of different types of fertiliser at each age did not show significant differences for control, K fertiliser, midrib leaf litter and EFB.

The diameter of the oil palm stem from the ANOVA reported a significant difference in the diameter of the stem at each age. The largest diameter was shown in aged seven compared to 12 and 16 years old. The application of different types of fertiliser at each age showed no significant difference, as reported in *Table 3*.

The diameter of the stem is an indicator that can be used to determine plant growth and development. Oil palms aged seven years have a larger trunk diameter than others. Plants aged seven years experience faster growth in the vegetative phase using various types of fertiliser, which can spur growth in stem diameter. The application of various types of fertiliser is more optimally used in oil palms aged seven compared to plants aged 12 and 16 years, hence the diameter is more significant.

TABLE 2. OIL PALM TRUNK CIRCUMFERENCE FOR VARIOUS PLANTING AGES AND APPLICATION OF DIFFERENT FERTILISER

Plant age (yr)	Types of fertiliser	Initial trunk circle	Final trunk circle
7	Control	350.43 a	353.43 a
	K fertiliser	362.50 a	365.50 a
	Leaf litter	360.18 a	363.18 a
	EFB	354.43 a	357.43 a
12	Control	294.43 b	298.43 b
	K fertiliser	306.50 b	310.50 b
	Leaf litter	304.18 b	306.31 b
	EFB	298.43 b	302.43 b
16	Control	259.43 c	263.43 c
	K fertiliser	271.50 c	275.50 c
	Leaf litter	267.31 c	271.31 c
	EFB	263.43 c	267.43 c

Note: EFB - empty fruit bunches; K - potassium.

TABLE 3. OIL PALM TRUNK DIAMETER FOR VARIOUS TYPES OF PLANTING AGES AND THE APPLICATION OF VARIOUS TYPES OF FERTILISER

Plant age (yr)	Types of fertiliser	Initial bar diameter	Final bar diameter
7	Control	111.62 a	112.56 a
	K fertiliser	115.50 a	116.50 a
	Leaf litter	113.62 a	114.81 a
	EFB	112.87 a	113.56 a
12	Control	93.81 b	95.00 b
	K fertiliser	97.62 b	98.81 b
	Leaf litter	96.81 b	97.65 b
	EFB	95.06 b	96.37 b
16	Control	82.65 c	83.87 c
	K fertiliser	86.50 c	87.62 c
	Leaf litter	85.06 c	86.56 c
	EFB	83.87 c	85.18 c

Note: EFB - empty fruit bunches; K - potassium.

Oil palm fruit weight from the ANOVA showed a significant difference to the observations at the 1st, 2nd , 3rd , 4th , 6th , 7th and 8th months. During the 5th month of observation, there was no significant difference in using different fertilisers at various plant ages, as shown in *Table 4*.

The highest total fruit weight of oil palms was found in oil palm aged seven years with the application of K fertiliser and midrib leaf litter and in plants aged 12 years with the application of EFB. These three types of fertiliser contributed essential nutrients, resulting in an augmentation of the weight of oil palm fruit. Kasem *et al.* (2010) stated that using nitrogen fertiliser combined with P and K and organic fertiliser increased oil palm yields and fruit colour, weight, weight and length.

Based on the ANOVA, the number of oil palm bunches showed no significant difference in the age of the plants and the application of various types of fertiliser, as shown in *Table 5*.

The bunches are the number of fruits produced by oil palms. The number shows no significant difference with applying various types of fertiliser at different ages of oil palms. Appropriate fertiliser application can affect the growth and productivity of oil palms and the number of bunches produced. Fertilisers rich in N, P and K can be absorbed by plants, influencing the growth and formation of bunches (Syahfitri, 2008).

The formation of oil palm bunches is not solely contingent on fertiliser application, a multitude of factors exert influence, including genetic factors and environmental conditions. Genetic factors, including plant varieties, play an important role in determining the number of bunches produced, with certain varieties exhibiting superior bunch production owing to inherent genetic traits related to bunch formation. Furthermore, environmental conditions, such as the availability of water, sunlight exposure and nutrient levels, exert a profound influence on the proliferation of oil palm bunches. Plants thriving under optimal conditions, characterised by water resources, sufficient sunlight exposure and a well-balanced nutrient supply, tend to manifest an enhanced propensity for bunch production.

The ANOVA showed significant differences in the distribution of oil palm root based on the age and various types of fertiliser applications on the distribution of primary, secondary, and tertiary roots. There were no significant differences in the plant's age and the application of various types of fertiliser, as shown in *Table 6*.

The distribution of roots reported significant differences among primary, secondary, and tertiary roots. *Table 6* shows that the overall distribution of roots is influenced by the age of the plant and the types of fertiliser used. The use of K fertiliser significantly affected the distribution of roots at various ages of the plants. Fertiliser had the highest primary, secondary and tertiary root distribution values for oil palms aged seven years, even for plants aged 12 and 16 years. It also affected the distribution of roots of oil palms aged 12 and 16 years but towards secondary and tertiary roots (Syafitri, 2008).

The use of K fertiliser increased the distribution of primary, secondary and tertiary roots in oil palms. K fertiliser application also affected root distribution by increasing root growth. K fertiliser stimulated primary root growth, cell division and extension of primary root, which supported plant growth and development. Another function was to influence plant growth hormones such as auxin, which affected root formation and increased the distribution of roots.

The ANOVA showed a significant difference in the Normalised Difference Vegetation Index (NDVI) for plants of different ages, with the highest value found in plants aged seven years. However, there was no significant difference for plants aged 12 and 16 years, as shown in *Table 7*.

The NDVI index is a form of vegetation index used to evaluate, and monitor plant conditions and calculate the ratio of the spectral values of the red and near-infrared bands reflected from plants (Cahyono *et al.,* 2019; Yuniasih, 2022). A 7-year-old oil palm with a high NDVI value compared to the age of other plants at 0.736-0.756 indicates that the plant is in healthy condition and actively carrying out photosynthesis. Furthermore, the plant has a sufficient amount of chlorophyll and can absorb red light optimally for the process. Healthy plants also have dense, healthy cells, affecting near-infrared light's reflection. Oil palm aged seven years shows that the plants have sufficient chlorophyll content and dense cells, reflecting good photosynthetic activity and optimal growth conditions. According to (Lilles *et al.,* 2015; Sum & Shukor, 2019;), healthy plants provide low and high reflectance values in red and near-infrared waves, and the NDVI is expressed in the range -1 to 1. Negative and positive values indicate non-vegetative and vegetative objects, where an NDVI value close to 1 indicates dense and healthy vegetation.

Nutrient Analysis Results

Soil analysis showed significant difference in the parameters of pH H_2O, C-Organic, P and K. There was no difference in soil nitrogen content on land planted with oil palm aged 7, 12 and 16 years. The application of various fertilisers did not affect soil N content as shown in *Table 8*.

TABLE 4. OIL PALM FRUIT WEIGHT FOR VARIOUS TYPES OF PLANTING AGES AND APPLICATION OF VARIOUS TYPES OF FERTILISER

Plant age (yr)	Types of fertiliser	Fruit weight								
		1st month	2nd month	3rd month	4th month	5th month	6th month	7th month	8th month	Total
7	Control	19.35 b	17.88 bc	26.37 abc	20.56 ab	18.81 a	21.25 abc	21.33 bcd	27.01 ab	145.58 ab
	K fertiliser	23.18 ab	16.28 bc	29.45 ab	24.26 ab	20.81 a	25.40 ab	25.50 abc	25.07 ab	164.95 a
	Leaf litter	22.30 ab	24.50 ab	31.25 a	24.87 ab	20.31 a	30.68 a	15.38 cd	16.27 b	169.51 a
	EFB	27.93 ab	15.48 c	18.31 c	27.37 a	14.06 a	23.12 abc	31.52 ab	24.02 ab	157.83 ab
12	Control	21.22 b	27.01 a	18.68 c	27.27 a	23.30 a	19.18 bcd	22.26 bcd	18.38 b	158.96 ab
	K fertiliser	25.55 ab	25.07 ab	22.75 abc	21.95 ab	22.77 a	11.18 d	25.32 abc	19.41 b	153.91 ab
	Leaf litter	15.38 bc	16.25 bc	27.03 abc	18.30 ab	16.08 a	18.00 bcd	33.45 a	19.37 b	144.54 ab
	EFB	31.52 a	24.05 ab	18.00 c	20.93 ab	24.23 a	15.12 bcd	23.07 bcd	16.45 b	164.54 a
16	Control	15.38 c	23.87 ab	19.96 bc	20.56 ab	15.76 a	20.05 abc	18.81 cd	21.25 ab	131.54 b
	K fertiliser	19.52 b	25.25 ab	24.77 abc	25.81 ab	22.52 a	21.12 abc	20.81 cd	25.41 ab	159.82 ab
	Leaf litter	23.75 ab	25.18 ab	25.63 abc	17.65 b	22.37 a	14.30 cd	20.31 cd	30.68 a	141.56 ab
	EFB	17.97 bc	26.31 ab	22.90 abc	22.81 ab	20.97 a	18.42 bcd	14.06 d	23.12 ab	143.47 ab

Note: EFB - empty fruit bunches; K - potassium.

TABLE 5. THE NUMBER OF OIL PALM BUNCHES FOR VARIOUS TYPES OF PLANTING AGES AND THE APPLICATION OF VARIOUS TYPES OF FERTILISER

Plant age (yr)	Types of fertiliser	Number of bunches (month)								
		1st month	2nd month	3rd month	4th month	5th month	6th month	7th month	8th month	Total
7	Control	2 a	1 a	2 a	1 a	2 a	1 a	2 a	2 a	13 a
	K fertiliser	2 a	2 a	2 a	2 a	2 a	2 a	2 a	1 a	15 a
	Leaf litter	2 a	2 a	2 a	2 a	2 a	2 a	2 a	1 a	15 a
	EFB	2 a	1 a	2 a	2 a	2 a	2 a	2 a	2 a	15 a
12	Control	2 a	1 a	2 a	1 a	2 a	2 a	2 a	2 a	14 a
	K fertiliser	2 a	1 a	2 a	1 a	2 a	1 a	2 a	2 a	13 a
	Leaf litter	2 a	1 a	2 a	1 a	2 a	1 a	2 a	2 a	13 a
	EFB	2 a	2 a	2 a	1 a	2 a	2 a	2 a	2 a	15 a
16	Control	1 a	1 a	1 a	2 a	2 a	2 a	2 a	2 a	13 a
	K fertiliser	2 a	1 a	1 a	2 a	1 a	2 a	2 a	2 a	13 a
	Leaf litter	2 a	1 a	1 a	1 a	2 a	2 a	2 a	2 a	13 a
	EFB	1 a	1 a	1 a	2 a	2 a	2 a	2 a	2 a	13 a

Note: EFB - empty fruit bunches; K - potassium.

TABLE 6. DISTRIBUTION OF OIL PALM ROOT TO VARIOUS TYPES OF PLANTING AGES AND APPLICATIONS OF VARIOUS TYPES OF FERTILISER

Plant age (yr)	Types of fertiliser	Distribution of root		
		Primary	Secondary	Tertiary
7	Control	0.41 ab	0.27 ab	0.16 ab
	K fertiliser	0.66 a	0.42 a	0.25 a
	Leaf litter	0.49 ab	0.34 ab	0.20 ab
	EFB	0.51 ab	0.34 ab	0.20 ab
12	Control	0.31 b	0.22 ab	0.13 ab
	K fertiliser	0.49 ab	0.35 a	0.21 a
	Leaf litter	0.36 ab	0.28 ab	0.17 ab
	EFB	0.38 ab	0.28 ab	0.17 ab
16	Control	0.13 c	0.10 c	0.05 c
	K fertiliser	0.19 c	0.14 bc	0.08 bc
	Leaf litter	0.16 c	0.11 c	0.07 c
	EFB	0.16 c	0.11 c	0.06 c

Note: EFB - empty fruit bunches; K - potassium.

TABLE 7. OIL PALM NDVI FOR VARIOUS TYPES OF PLANTING AGES AND APPLICATIONS OF VARIOUS TYPES OF FERTILISER

Plant age (yr)	Types of fertiliser	NDVI
7	Control	0.736 A
	K fertiliser	0.754 A
	Leaf litter	0.737 A
	EFB	0.756 A
12	Control	0.682 B
	K fertiliser	0.681 B
	Leaf litter	0.694 B
	EFB	0.682 b
16	Control	0.682 b
	K fertiliser	0.681 b
	Leaf litter	0.694 b
	EFB	0.682 b

Note: EFB - empty fruit bunches; K - potassium.

Soil pH from *Table 8* showed significant difference for plants of different ages with the application of various types of fertiliser. Plants aged 7 years with the application of leaf litter and EFB had the highest pH values, namely 5.65 and 6.00 (slightly acidic) and the lowest were found in plants aged 12 years with control treatments and application of K fertiliser (4.38 and 4.30 with very acidic criteria). The use of midrib and EFB, both rich sources of organic matter, significantly influenced soil pH levels when subjected to decomposition. The breakdown of these organic materials generated compounds that altered the pH of the soil. Furthermore, the humification process stemming from coarse organic matter decomposting produces humic and fulvic acids, both of which increased soil pH. Butterley *et al.* (2013) affirmed that the use of dry matter in the form of residue, at a rate of 10 g/kg, was capable of augmenting soil pH values, leading to a temporary shift towards alkalinity. The condition was a consequence of the decomposition processes, driven by abiotic association reactions between H+ ions and the introduced organic matter. Additionally, the processes of ammonification and decarboxylation, occurring during decomposition, contributed to the generation of alkaline conditions in soil.

The application of leaf litter fertiliser and EFB on plants aged 12 years increased the C-organic content of the soil to around 9.72-10.3 (very high). The use of midrib litter and EFB as a source of organic matter increased the availability of soil C-organic when decomposed. The application of these two materials was also a form of using oil palm waste which was returned to the soil as a source of nutrients. Some results showed that the use of waste palm fronds and leaf residues restored soil nutrients and increased soil C-organic (Ariyanti *et al.*, 2019; Singh *et al.*, 2013).

Table 8 shows that the soil P content of 16-year-old oil palms was much higher than 7 and 12-year-old plants for various types of fertiliser applications. However, the application of different types of fertiliser did not have a significant effect on the phosphorus content in oil palms aged 16 years for both controls, K fertiliser, midrib leaf litter, and EFB with P values ranging from 144.19-152.45 (very high). This was due to the accumulation of P during fertilisation which was carried out until the age of 16 years. For soil K content there were also significant differences in the use of various types of fertiliser at various plant ages. The highest K value was found in the treatment of plant leaf litter aged 7 years after planting with the application of leaf litter to provide the needs in soil.

N content in soil at various ages of oil palm with the use of various types of fertiliser did not show significantly different results with N values ranging from 0.17-3.05 (low-very high). The nitrogen content that did not differ in soil was influenced by the availability of sufficient amounts in soil. This nutrient was the most important limiting factor for plant productivity, and its availability was very important (Niu *et al.,* 2016). Excessive use of fertiliser in agricultural management causes loss of N through leaching and denitrification processes (Liu *et al.,* 2010).

Root NPK levels based on ANOVA reported significant differences in observed parameters both in N, P and K content. *Table 9* showed that plant age and the application of various types of fertiliser had a significant effect on root NPK.

Table 9 shows the NPK levels in the roots of various ages of oil palms due to the application of fertiliser. Root N content in oil palms aged 12 and 16 years with the use of frond litter fertiliser showed the highest N content compared to others. The use of midrib litter was able to provide nitrogen in the roots of oil palms and was used for plant growth. Yama (2018) stated that midrib litter contained a C/N ratio of 16, C-organic 34.18, N 2.09%, P 826 ppm and K 1790 ppm. This litter was obtained from fallen fruit, fronds, and stems stored in the armpits of fronds and experienced weathering. Meanwhile, weathered organic matter enriched the planting medium and the planting medium became fertile, loose, and grew freely. The results of other studies indicated that litter on oil palm stems was used to replace topsoil as a nursery medium for *Pueraria javanica* plants.

For the P content in the root, oil palms at the age of 12 years reported the highest content compared to the ages of 7 and 16 years using K fertiliser, leaf litter and EFB. *Table 9* shows that the numerical content of leaf litter has a high value compared to K fertiliser and EFB. This was because the leaf litter

TABLE 8. OIL PALM NORMALISED DIFFERENCE VEGETATION INDEX (NDVI) FOR VARIOUS TYPES OF PLANTING AGES AND APPLICATIONS OF VARIOUS TYPES OF FERTILISER

Plant age (yr)	Types of fertiliser	Soil analysis				
		pH H_2O	C-organic	N	P	K
7	Control	4.86 ab	2.12 b	0.30 a	24.75 b	0.65 b
	K fertiliser	4.68 ab	4.29 ab	0.31 a	46.25 ab	1.09 b
	Leaf litter	6.00 a	5.75 ab	0.31 a	55.81 ab	2.18 a
	EFB	5.65 a	1.93 b	0.17 a	22.77 b	1.51 ab
12	Control	4.38 b	5.96 ab	0.30 a	97.36 ab	0.26 b
	K fertiliser	4.30 b	9.25 ab	0.41 a	103.59 ab	0.40 b
	Leaf litter	5.46 ab	10.3 a	0.34 a	120.71 ab	0.93 b
	EFB	4.88 ab	9.72 a	0.30 a	101.83 ab	0.82 b
16	Control	4.95 ab	6.45 ab	2.76 a	145.49 a	0.37 b
	K fertiliser	4.80 ab	9.31 ab	0.50 a	152.45 a	0.34 b
	Leaf litter	5.15 ab	6.89 ab	3.05 a	147.06 a	0.40 b
	EFB	4.70 ab	5.98 ab	0.63 a	144.19 a	0.45 b

Note: EFB - empty fruit bunches; K - potassium; N - nitrogen; P - phosphorus; H_2O - water.

TABLE 9. NPK CONTENT OF OIL PALM PLANT ROOT FOR VARIOUS TYPES OF PLANTING AGES AND THE APPLICATION OF VARIOUS TYPES OF FERTILISER

Plant age (yr)	Types of fertiliser	Root NPK levels		
		N	P	K
7	Control	0.15 c	0.22 b	0.68 a
	K fertiliser	0.17 c	0.22 b	0.54 ab
	Leaf litter	0.19 bc	0.18 b	0.78 a
	EFB	0.12 c	0.15 b	0.56 ab
12	Control	0.30 ab	0.22 b	0.31 b
	K fertiliser	0.21 ab	0.58 a	0.51 ab
	Leaf litter	0.38 a	0.68 a	0.70 a
	EFB	0.20 ab	0.51 a	0.50 ab
16	Control	0.19 bc	0.27 b	0.58 ab
	K fertiliser	0.16 c	0.36 b	0.63 ab
	Leaf litter	0.35 a	0.31 b	0.66 ab
	EFB	0.19 bc	0.23 b	0.24 b

Note: EFB - empty fruit bunches; K - potassium; N - nitrogen; P - phosphorus.

had a high P content and when applied as fertiliser more nutrient was provided to be absorbed. The application of EFB of fertiliser to 12-year-old palms also provided high P. According to Hayat and Andayani (2014), the nutrient content of EFB compost contained a total of N (1.91%), K (1.51%) and Ca (0.83%), P (0.54%), Mg (0.09%), C-organic (51.23%), C/N ratio 26.82% and pH 7.

The application of K fertiliser indirectly increased the P content in the root of oil palms. The use provides potassium to plants and indirectly affects the absorption of P in the root. Potassium fertiliser given correctly can increase the efficiency of P use by plants, and assist in the process of transporting the element in plants to increase the efficiency of absorption. The element improves the quality of plant roots and explores more areas of soil, including areas rich in P.

CONCLUSION

In conclusion, the growth of plants aged 7 years was the best response compared to plants aged 12 and 16 years in terms of stem circumference, stem diameter, and NDVI values for all types of fertiliser applied. The primary root distribution for plants aged 7 years with the use of K fertiliser showed the best results for the distribution of secondary and tertiary roots and was not significantly different from those aged 12 years. Soil analysis showed that there were differences in the use of various types of fertiliser on soil nutrient content, specifically on pH, C-organic, P, and K values. The use of midrib and EFB affected plants aged 7 years, while those aged 12 years had C content. The high organic matter with the use of leaf litter and EFB for oil palms aged 16 years had the best effect on P values compared to those aged 7 and 12 years.

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