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The Effectiveness of Biochar, Compost, and Natural Phosphate in Improving Soil Quality in Oil Palm Plantations

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ABSTRACT

Oil palm cultivation is increasingly carried out on suboptimal land, such as Ultisols. Application of ameliorant such as biochar and compost may be chosen as an alternative to solve the problem occurred on this sub optimal soil. This study aims to determine the optimal dosage of a mixture of oil palm empty fruit bunch (EFB) biochar, poultry manure compost, and Rock Phosphate (RP) to enhance soil quality and support the growth of one-year-old oil palm plants. The study was conducted over six months in a one-year-old oil palm plantation located in Panca Mulya Village. A randomized complete block design (RCBD) was employed with the application of biochar, compost, and rock phosphate (RP = Togo Rock Phosphate, 33.5% P_2O_5) in the following treatments: control (no treatment), biochar 20 tons.ha^{-1} + RP 200 kg.ha^{-1}, biochar 10 tons.ha^{-1} + compost 10 tons.ha^{-1}+RP 200 kg.ha^{-1}, compost 20 tons.ha^{-1} + RP 200 kg.ha^{-1}, biochar 20 tons.ha^{-1}+compost 10 tons.ha^{-1} + RP 200 kg.ha^{-1}, biochar 10 tons.ha^{-1} + compost 20 tons.ha^{-1} + RP 200 kg.ha^{-1}. Results indicated that the application of biochar, compost, and RP, whether individually or in combination, enhanced oil palm growth compared to the control. The application of biochar and compost improved soil physical properties, increased soil organic matter content, total pore space, available water content, reduced bulk density, soil penetration resistance, and promoted oil palm growth. The best treatment was found to be 10 tons.ha^{-1} biochar + 20 tons.ha^{-1} compost + RP 200 kg.ha^{-1}

INTRODUCTION

Oil palm is a strategic plantation commodity for producing crude palm oil (CPO). Oil palm plantations dominate agricultural land use in Indonesia, about 41.85% of total agricultural land by oil palm plantation (Ministry of Agriculture, 2021). In 2023, the oil palm plantation in Indonesia reached 15,435,700 hectares, with production totalling 46,986,100 tons (BPS, 2024); approximately 6,300,426 hectares are smallholder plantations with a production of 16,273,170 tons (Directorate General of Plantations, 2022). Around 440,977 hectares of smallholder plantations are degraded and categorized as non-productive. Expansion of oil palm cultivation is largely carried out on marginal lands, such as ultisol soils. The utilization of marginal lands for cultivation requires proper and environmentally -friendly management. One effort to improve the quality of marginal lands is through the use

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of organic ameliorants and natural fertilizers, such as biochar, compost, and rock phosphate.

Several researchers have applied organic fertilizers as soil amendments. Zurhalena et al. (2023) used compost derived from cattle manure and Gliricidae leaves to improve soil physical properties, enhancing soil porosity, penetration resistance, and aggregate stability, which resulted in increased soybean yields. Suryanti et al. (2023) applied Leucaena compost, which increased the height and number of fronds in oil palm seedlings. Adileksana et al. (2020) found that cattle manure reduced the need for chemical fertilizers and promoted oil palm growth. Oguike et al. (2020) reported that organic fertilizer from poultry manure could improve soil acidity, increase soil organic matter and available water, and enhance oil palm growth. Sari et al. (2015) mentioned that organic fertilizers can also reduce the use of inorganic fertilizers in oil palm seedlings, effectively stimulating vegetative growth, increasing plant height, leaf number, and stem diameter. Dady et al. (2021) highlighted that solid poultry manure has a pH of 8.20; EC ($dS.m^{-1}$) of 14.7; C (%) of 21.7; total N (%) of 2.8; total P (%) of 2.95; K (%) of 3.3; Ca (%) of 14.5; Mg (%) of 3.7; dry matter (%) of 87.2; and moisture content (%) of 12.8, indicating its potential as an organic soil amendment.

According to El-Naggar et al. (2019), biochar improves the physical, chemical, and biological properties of soil, thereby enhancing crop yields. Another researcher, Oktavia et al. (2023) reported that the application of palm shell biochar mixed with municipal waste compost on post-mining coal soil increased organic matter content, reduced bulk density, improved field capacity and available water content, and enhanced soybean yields. Additionally, Endriani and Listyarini (2023) concluded that applying coconut shell biochar combined with Leucaena compost at a rate of 20 $tons.ha^{-1}$ increased soil organic matter content, improved soil water retention, reduced soil density, and increased soybean yields. Anwar et al. (2024) found that coffee husk biochar combined with corn straw compost improved the physical properties of coarse-textured Inceptisol, especially water retention, permeability, aggregate stability, and sweet corn production. Negis et al. (2019) noted that the application of 2–4% biochar and compost reduced soil penetration resistance, significantly improving soil penetration resistance scores compared to the control. Arvamusa et al. (2023) stated that biochar derived from oil palm empty fruit bunches (EFB) can effectively remediate heavy metal pollutants in contaminated soil, as evidenced by the improved growth of Pakchoy. Likewise, Hwong et al. (2022) reported that EFB biochar has a pH of 7.10±0.15; moisture content (%) of 9.21±0.71; ash content (wt.%) of 6.64±1.10; total organic matter (wt.%) of 93.36±1.10; N (wt.%) of 0.61±0.04; P (wt.%) of 0.089±0.005; K (wt.%) of 0.27±0.005; Mg (wt.%) of 0.24±0.01; and Ca (wt.%) of 0.26±0.02, indicating its potential as an amendment with positive impacts on agricultural land.

The application of rock phosphate at a rate of 1 kg per oil palm tree within the planting circle increased soil pH and the concentrations of P, K, and Mg in the root zone, while also promoting root density, particularly within a depth of 20–40 cm, with the highest root density observed within a radius of 0–1 m from the base of the trunk (Ginting et al., 2020). Moreover, Rock phosphate application can enhance the efficiency of chemical fertilizer use; an application rate of 100 kg/ha rock phosphate effectively substitutes for synthetic phosphate fertilizers, thereby increasing maize yields. The optimal fertilizer dose is 450 kg $Urea.ha^{-1}$ + 100 kg $RP.ha^{-1}$ + 100 kg $KCl.ha^{-1}$, providing yields equivalent to recommended fertilizer applications (Sugiono and Purwanty, 2019). Likewise, Annisa et al. (2019) noted that the application of rock phosphate, combined with compost and other organic fertilizers in a zig-zag pattern, produced higher maize yields than applying SP36 alone. According to Husnain et al. (2014), the application of reactive rock phosphate improves soil fertility and maize yields, with Moroccan rock phosphate providing the highest citric acid-soluble P_2O_5 content compared to other types of rock phosphate.

Sari et al. (2014) reported that oil palm EFB biochar has a pH of 9.47; total carbon content of 54.08%; cation exchange capacity (CEC) of 63.93 cmol kg^{-1}; total nitrogen of 1.63%; P of 0.21%; K of 5.3%; Ca of 0.11%; Mg of 0.13%; arsenic (As) at 1.15 mg kg^{-1}; and cadmium (Cd) at 0.80 mg.kg^{-1}. EFB biochar has a high specific surface area of 46.32 $m^2.g^{-1}$, which allows it to function effectively as an adsorbent. Its micropore volume is 0.008 $cm^3.g^{-1}$, with an internal specific surface area of 0.61 $m^2.g^{-1}$. However, biochar characteristics are influenced by the feedstock and pyrolysis temperature. Ichriani et al. (2016) noted that EFB biochar, whether inoculated with microbes or not, maintains soil pH and tends to increase it while retaining P and K nutrients that are otherwise lost through leaching. EFB biochar is optimally produced at 400 °C for 10 hours and ground to a fineness of 40 mesh. However, the combined use of EFB biochar, poultry manure compost, and rock phosphate as a soil amendment for enhancing soil quality in oil palm plantations has yet to be studied.

The findings from this study aim to offer insights into the potential of biochar derived from oil palm EFB biomass, chicken manure compost, and RP in enhancing soil properties and promoting oil palm growth. These positive effects are expected to improve nutrient use efficiency and reduce fertilizer input in plantations. This research specifically determines the optimal dosage of a mixture of EFB biochar, poultry manure compost, and RP to improve soil quality and the growth of oil palm plants.

MATERIALS AND METHOD

The study was conducted over six months on sub-optimal dry land classified as Ultisols, owned by a farmer in Panca Mulya Village, Sungai Bahar District, Muaro Jambi Regency, Jambi Province, located at 2º00'09.38" S and 103º29'02.35" E, at with an elevation of 50 meters above sea level. Soil analysis was carried out at the Soil Chemistry and Fertility Laboratory, Faculty of Agriculture, Jambi University. The oil palm studied were only given fertilizer at the beginning of the planting of seedlings to the land, namely by giving 10 kg of chicken manure in the planting hole, and 1 kg of NPK compound fertilizer.

The study used a Randomized Complete Block Design (RCBD) with treatments involving the introduction of organic soil amendments and natural phosphate (Togo Rock Phosphate with 33.5% P_2O_5) on one-year -old oil palm plants. The treatments were as follows: P0 = control (no treatment); P1 = biochar 20 tons.ha^{-1} + RP 200 kg.ha^{-1}; P2 = biochar 10 tons/ha + compost 10 tons.ha^{-1} + RP 200 kg.ha^{-1}; P3 = compost 20 tons.ha^{-1} + RP 200 kg.ha^{-1}; P4 = biochar 20 tons.ha^{-1} +compost 10 tons.ha^{-1} + RP 200 kg.ha^{-1}; P5= biochar 10 tons.ha^{-1} + compost 20 tons.ha^{-1} + RP 200 kg.ha^{-1}. Each treatment was replicated four times, totaling 24 experimental units, with five plants per unit. The planting distance used was 9m x 8m x 9m.

The research was conducted on a one-year-old oil palm plantation with a slope of 7%. The studied oil palm plants were of the Tenera Damimas variety. The biochar used was derived from oil palm empty fruit bunches, while the compost was made from a mixture of chicken manure and kirinyuh green waste in a 3:1 ratio. The soil characteristics at the research location prior to treatment were as follows: it had a sandy clay loam texture, organic-C content of 1.64% (low); bulk density of 1.45 g.$(cm^3)^{-1}$ (moderate); Total pore space of 45% (low); permeability of 3.23 cm.$hour^{-1}$ (slow); infiltration rate of 2.54 cm.$hour^{-1}$ (slow); infiltration capacity of 11.7 cm.$hour^{-1}$ (slow); field capacity of 27.8% (moderate); available water content of 11.7% (low); and permanent wilting point of 16.1% (moderate).

The compost was prepared using an anaerobic method, utilizing chicken manure as the primary material along with chopped Chromolaena biomass sized 10–20 cm, and the biodecomposer Trichoderma. The ratio of chicken manure to kirinyuh green waste was 3:1. The chicken manure and green waste were layered and then sprayed with the Trichoderma biodecomposer (150 grams of solid Trichoderma mixed with 10 liters of clean water for every 50 kg of compost materials). The mixture was incubated in a closed environment for four weeks. During the composting process, the mixture was turned every seven days until the compost matured, which was characterized by a black color, a crumbly structure, no odor, and no visible original materials. According to the analysis, the chicken manure compost contained 32.28% organic matter and 2.23% nitrogen, with a carbon-to-nitrogen (C/N) ratio of 15.48.

Empty fruit bunch oil palm biochar (EFB biochar) was produced using a traditional method (soil pit). The empty fruit bunches were collected from an oil palm mill near the research site, cut into small pieces, and sun-dried until they were completely dry. The dried pieces were then placed in the soil pit and burned for 6 to 10 hours or until they turned black. After burning, water was added to extinguish the fire, and the biochar was dried before being ground. The ground biochar was then sieved using a 2 mm mesh. The resulting biochar, in both powdered and granular forms, was ready to be applied to the research area according to the treatments. Based on the analysis, the EFB biochar contained a total carbon content of 58.65% and an ash content of 13.26%.

The soil variables observed included soil texture measured using the hydrometer method, bulk density determined by the ring sample method, porosity calculated using the volume-weight and particle density comparison method, and penetration resistance measured with a cone penetrometer. The plant variables consisted of increases in stem girth, leaf length, and the number of leaflets, which were measured at 4 weeks after treatment (WAT) and recorded every 2 weeks until 16 weeks after treatment. Subsequently, the increases were calculated by comparing them to the initial measurements taken before the treatments were applied.

The data were analyzed statistically using Analysis of Variance (ANOVA), followed by the honest significant different (HSD) test at α=5%. The obtained data were presented in the form of graphs, tables, and curves.

RESULTS AND DISCUSSION

Organic Matter Content and Some Physical Properties of Soil

The results of the analysis of variance showed that the application of biochar, compost and rock phsphat was significantly different from some of the physical properties of the soil. The amelioration of soil in oil palm plantations using biochar, compost, and rock phosphate resulted in a significant increase in soil organic matter (Table 1). Highest organic matter content was achieved by application of combination of 10 tons.ha^{-1} of biochar + 20 tons.ha^{-1} of compost + 200 kg.ha^{-1} of RP (P5), and followed by 20 tons.ha^{-1} of biochar + 10 tons.ha^{-1} of compost + 200 kg.ha^{-1} of RP(P4). The application of ameliorants P1, P2, and P3 also led to significant increases in soil organic matter content, demonstrating their effectiveness in improving soil quality.

This increase is attributed to the organic matter contributed by the applied compost, which also plays a role in enhancing the

Table 1. Organic matter, bulk density, porosity and water content due to using ameliorant

Treatment	OM (%)		BD (g/cm³)		Total Pore Space (%)		AWC (%)	
P0	2.48	a	1.37	a	46.45	a	22.06	a
P1	3.05	b	1.29	b	51.16	b	24.18	a
P2	3.13	b	1.27	bc	51.26	bc	25.94	ab
P3	3.37	b	1.25	bc	51.94	bc	24.55	ab
P4	4.03	c	1.23	bc	53.12	bc	28.80	b
P5	4.65	d	1.18	c	55.24	c	32.39	b

Note: The numbers followed by the same letter in the same column are not significantly different according to the the honest significant different (HSD) test with α 5% confidence level.

rhizosphere environment. This improved environment promotes soil microorganism activity and supports root development in oil palm plants. These findings align with previous research by Zurhalena et al. (2023); Endriani and Listyarini (2023); Oguike et al. (2020), which similarly demonstrated that compost application can increase soil organic matter.

According to Liu et al. (2017), biochar plays a significant role in increasing soil organic matter due to its carbon-rich composition, which remains stable in the soil and aids in carbon sequestration. The porous nature of biochar helps retain water and serves as a medium for soil microorganism activity, thereby contributing to soil organic matter. This finding is in line with Tugiman et al, (2024): Endriani and Kurniawan (2018); Barus (2016); Hartati et al, (2015) who applied compost and biochar as soil amendment. Meanwhile, Tugiman et al. (2024) observed that using EFB biochar increased soil organic carbon, while Dang et al. (2022) studied biochar and compost. In the context of oil palm plantations, the application of biochar, compost, and rock phosphate also influenced soil bulk density and porosity (Table 1).

The application of biochar, compost, and rock phosphate effectively reduced soil bulk density and increased soil porosity. Table 1 shows that the bulk density decreased with biochar, compost, and RP applications at rates of 20 tons/ha and 30 tons/ha. This is because compost plays a role in forming soil aggregates so that macro pores in the soil increase, while biochar that has a low bulk density causes the soil to nest more, both of which will cause the soil BD to decrease. This aligns with previous studies by Adekiya et al. (2020), Darmawan et al. (2021), Malyan et al. (2021), and Hwong et al. (2022), which demonstrated that biochar decreased soil bulk density, increases porosity and soil organic carbon. Similarly, this result is consistent with findings by Sax et al. (2017); Somerville et al. (2018)' Ghorbani et al. (2019); and Castellini et al. (2022), who observed that compost application reduces soil bulk density and helps decrease soil compaction.

Available Water Content (AWC) represents the soil moisture percentage at a field condition without additional watering or immediately after rainfall. Soil amelioration in oil palm plantations with biochar, compost, and RP has shown to increase AWC, with higher doses resulting in higher soil water content compared to untreated plots (Table 1). According to Liu et al. (2017), biochar can increase soil water content by enhancing intraparticle porosity (between particles), especially mesopores (0.08 –0.03 mm in diameter) and macropore volume. Biochar amendments influence both inter- and intra-particle pore structures, as irregularly shaped biochar particles form interparticle pores. Alotaibi and Schoenau (2019) also noted that adding biochar improves soil water retention, which in turn increases soil moisture content.

Amelioration of one-year-old oil palm plantation soil with biochar, compost, and RP affected soil penetration resistance four months after application. Soil penetration resistance in oil palm plots showed a significant reduction due to amelioration treatments compared to untreated control plots across depths of 0–10 cm, 10–20 cm, and 20–30 cm (Table 2). It is

Table 2. Penetration resistance due to using ameliorant 120 days after treatment

Treatment	Penetration resistance (Bar)		
	0–10 cm	10–20 cm	20–30 cm
P0	15.5 a	26.3 a	37.0 a
P1	14.5 a	21.0 ab	28.0 b
P2	13.3 ab	18.0 bc	25.0 b
P3	12.5 bc	16.8 c	24.0 bc
P4	10.3 c	14.0 cd	23.0 cd
P5	9.8 c	12.5 d	20.0 d

Note: The numbers followed by the same letter in the same column are not significantly different according to the honest significant different (HSD) test with α 5% confidence level.

due to the soil becoming looser as impact of the application of ameliorant. The PR values after amelioration ranged from 10 to 15 bars at a depth of 0-10 cm, 13 to 21 bars at 10–20 cm, and 20 to 28 bars at 20–30 cm. Penetration resistance increased with soil depth, as the amelioration effect was most pronounced in the top layer (0–10 cm), followed by the 10–20 cm layer, with diminishing effects at greater depths. This depth-dependent reduction is due to the concentrated impact of ameliorants in the surface layers, which are directly exposed to treatment.

The deeper the soil layer, the higher the penetration resistance. This is because the top soil layer (0–10 cm) is more influenced by higher organic matter content and a more porous structure. However, penetration resistance in the deeper soil layer (20–30 cm) is affected by a denser soil matrix and lower organic matter content at this depth, which consequently limits root penetration as the soil layer deepens.

Biochar and compost can effectively decrease soil penetration resistance , as demonstrated across various agricultural soils with different textures (Li et al., 2018). The study highlights that microbial activity, nutrient uptake, and water retention are influenced by soil compaction and the fluctuating interactions between soil-air and soil-water (Martinez and Zinck, 2004). Findings from multiple studies indicate that increased organic matter content leads to decreased soil PR (Alotaibi and Schoenau, 2019; Juriga et al., 2018; Iqbal, 2018; Alameda et al., 2012; Celik et al., 2010).

Oil Palm Plant Growth Due to Ameliorant Biochar, Compost and Rock Phosphate

The growth of one-year-old oil palm plants after the application of biochar, compost, and rock phosphate (RP) is illustrated in Figure 1. The results indicate significant increases in petiole length (PL), stem circumference (SC), and frond count (FC) following the application of biochar, compost, and RP. The combination of biochar and RP, compost and RP, or the mixture of biochar, compost, and RP enhanced the growth of petiole length, stem circumference, and frond count compared to the control without any ameliorants. The treatment of biochar at 10 tons.ha^{-1} + compost at 20 tons.ha^{-1} + RP at 200 kg.ha^{-1} (P5) exhibited the best growth in SC, PL, and FC compared to other treatments. This improvement can be attributed to the ameliorants' role in enhancing the root environment of the oil palm plants through the improvement of soil physical and chemical properties, as well as the addition of nutrients. Optimal growth of oil palm is achievable when the soil is relatively fertile, with adequate water and nutrient availability for plant growth. As noted, the applied ameliorants have been effective in increasing organic matter (OM) and decreasing soil density, thereby allowing oil palm to grow well. Higher doses

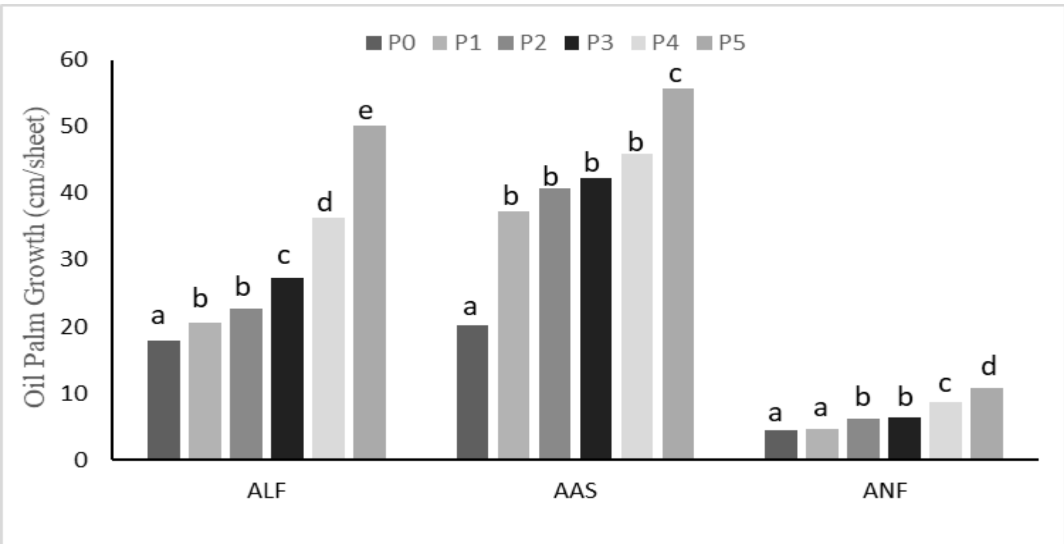

Figure 1. Increase in leaf length (ALF), stem circumference (AAS), and leaf number (ANF) of oil palm 120 days after treatment.

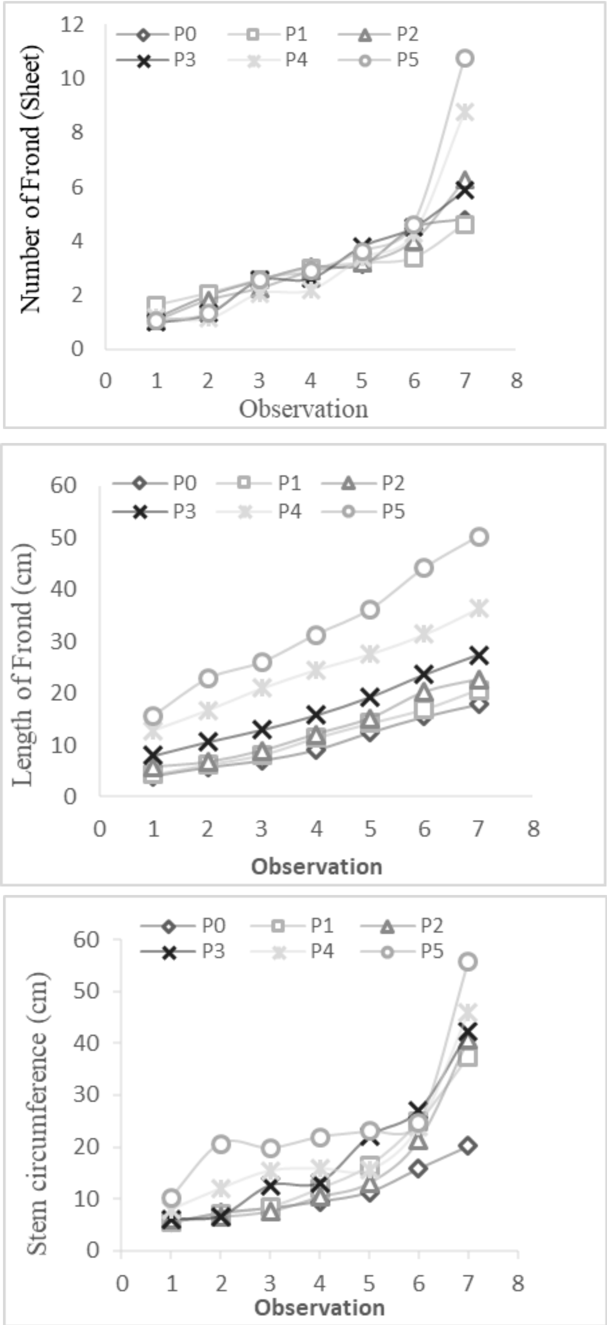

Figure 2. Growth rate of leaf number (top), leaf length (middle), and stem circumference (bottom) of oil palm 120 days after treatment.

of .ameliorants related with improvement of soil properties, and also correlate with better plant growth.

The increases in stem circumference, petiole length, and frond count indicate that the oil palm plants are growing well, attributed to the enhanced nutrient availability from the compost and rock phosphate ameliorants. According to Ullah et al. (2018), the effect of incorporating biochar into the soil is to improve the chemical properties of the soil and enhance the availability of nutrients for the plants, thereby increasing the growth rate of the plants. Ginting et al. (2020) reported that the application of rock phosphate increases soil pH as well as the levels of phosphorus (P), potassium (K), and magnesium (Mg) in the root zone, improving soil chemical properties, stimulating root growth, and enhancing nutrient uptake by the plants.

The growth rates of frond count, petiole length, and stem circumference after four weeks of applying ameliorants were observed biweekly, as shown in Figure 2. The growth rates of frond count (NF), petiole length (LF), and stem circumference (AS) increased with the age of the oil palm plants; however, the best treatments were P5 > P4 > P3 > P2 > P1 > P0.

The improved growth of the plants can be attributed to the application of compost, rock phosphate (RP), and biochar, which resulted in a significant increase in stem circumference, petiole length, and frond count compared to the control without ameliorants. This finding is consistent with the research by Bakar et al. (2015), which indicated that the use of oil palm empty fruit bunch (EFB) biochar combined with compost reduced soil acidity, mitigated aluminum toxicity, and enhanced crop yields. Similarly, Rusaati et al. (2020) demonstrated that the use of organic fertilizers and rock phosphate improved soil quality and increased plant performance and yields.

The results of the study showed that there was a significant improvement in the growth of oil palm due to the application of biochar, compost and Rock phosphate. In line with Nurjaya et al. (2009), oil palm requires phosphorus (P), and this nutrient can be supplied through reactive natural P fertilizers, which can replace conventional fertilizers like SP 36. Phosphorus is essential for the growth of stems and leaves as well as for the reproductive development of the plants. Wang et al. (2018) found that the addition of biochar to the soil affects nutrient availability and enhances potassium uptake by plants, resulting in improved plant growth. Hartati et al. (2015) reported that the application of biochar and organic fertilizers increases productivity in Ultisol dryland areas.

CONCLUSIONS

The use of biochar, compost, and rock phosphate, whether applied individually or in combination, enhances the growth of oil palm compared to the control (no treatment). The application of biochar and compost improves soil physical properties, increases soil organic matter content, total pore space, and available water content, reduces bulk density and soil penetration resistance, and enhances the growth of oil palm. The best treatment was achieved at 10 tons.ha^{-1} of biochar + 20 tons.ha^{-1} of compost + 200 kg.ha^{-1} of rock phosphate. The positive effects will lead to increased nutrient use efficiency and reduced fertilizer input in plantations.

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