Effect of Co-application of Vetiver Grass Biochar and NPK Fertilizer on the Growth of Oil Palm (*Elaeis guineensis* Jacq.) Seedlings and Soil Chemical Properties

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ABSTRACT

Sufficient supply of nutrients is essential for optimum oil palm seedlings growth especially at poor fertile soils Improving nutrient use efficiency is very important to reduce the reliance on excessive use of chemical fertilizers and overcome the harmful impacts to the environment. The objective of this study was to determine the soil chemical properties and oil palm seedlings growth following the application of vetiver grass biochar (VGB) in combination with NPK fertilizer. The experiment was conducted in a greenhouse located at the Farm Unit, UiTM Sarawak Branch, from June 2022 until July 2023. Oil palm seedlings were planted in polybags filled with top soil and arranged in a randomized complete block design (RCBD) with 5 treatments and 5 replicates, each replicate consists of 8 plants, making a total of 200 experimental units. Treatments evaluated were: T0) absolute control; T1) 100% NPK; T2) 100% VGB; T3) 50% VGB + 50% NPK; and T4) 75% VGB + 25% NPK. Soil samples were collected before and after the treatments applied. Plant growth and soil analyses were carried out using standard plant and soil laboratory procedure. Plant growth and soil statistical data were analyzed using ANOVA at $p < 0.05$ followed by DMRT using the Statistical Analysis System (SAS, version 9.3). Soil pH, cation exchange capacity (CEC), and soil organic carbon increased significantly ($p < 0.05$) in treatments with T2, T3, and T4, while the highest value was observed in T2. Soil available N, available P, and available K were higher in the treatments with T1, T3, and T4, while the highest value was recorded in T4. The results of analysis of variance (ANOVA) for plant growth indicate significant difference at $p < 0.05$. Among all treatments, the highest value of plant height, bole diameter, leaf number, chlorophyll content, and plant dry biomass was recorded in T4 (75% VGB + 25% NPK), suggested that the treatment is able to improve the growth performance of oil palm seedlings and enhanced soil chemical properties, hence, allowing reduction of fertilizer application rate in oil palm cultivation.

Keywords: Biochar, NPK, oil palm, growth, soil chemical properties

INTRODUCTION

Biochar is a carbon-rich product produced from the slow thermochemical pyrolysis process of biodegradable materials from organic wastes (Bohari *et al*. 2020). Biochar has many desirable properties such as high porosity, high variable charge, and high surface area charge. Thus, it is an efficient product to be used in the agricultural and environmental applications (Rafael *et al*. 2019). The benefits of biochar mainly depend on its properties which are usually affected by the type of feedstock used as raw material and the temperature of the pyrolysis process (Atkinson *et al*. 2010). Biochar is known as the most valuable soil conditioner (Torabian *et al*. 2021). The most striking effect of biochar application is usually seen on the tropical soils, which are characterized as less fertile and highly weathered acidic (Mete *et al*. 2015; Arif *et al*. 2017). Due to the high cation exchange capacity (CEC) in biochar, it can increase the nutrients availability and pH level in soil to improve plant productivity (Uchimiya *et al*. 2011; Hamzah & Shuhaimi, 2018; Hossain *et al*. 2020; Jindo *et al*. 2020; Singh & Puri, 2023). Biochar increases soil nutrients availability (Duarte *et al*. 2019) by improving soil nutrient retention (Cheng *et al*. 2018) and reducing nutrient leaching from soil (Blanco, 2021). Biochar increases CEC (Gul *et al*. 2015), soil porosity (De Melo *et al*. 2014; Qian *et al*. 2020), and water holding capacity (WHC) (Ouyang *et al*. 2013). Wu *et al*. (2023) reported that the combined application of biochar with chemical fertilizer could improve soil fertility and increase the yield of maize. Pandit *et al*. (2018) stated that there was increase in soil pH and biomass production of maize when biochar is used with NPK fertilizer in a moderately acidic soil. Agegnehu *et al*. (2016) reported that there was increase in the agronomic and physiological activity of barley plant when the biochar is applied with NPK fertilizer in a Nitisol. Ajeng *et al*. (2020) reported that the application of biochar with NPK fertilizer reduced the application rate of the fertilizer, improved the nutritional status of soil, and enhanced the growth and nutrient uptake of oil palm. Numerous studies have evaluated the individual effects of various types of biochar and chemical fertilizers on many plants, however, the effect of combined application of vetiver grass biochar and NPK fertilizer on oil palm growth and soil properties needs investigation. Vetiver grass (*Chrysopogon zizanioides* L.) is a native south and southeast Asian plant which belongs to the Poaceae family (Lakmali *et al*. 2021). Vetiver grass plant is very abundant in southeast Asia regions especially in Malaysia. Vetiver grass has many applications such as toxic soils remediation and contaminated soils rehabilitation (Truong & Truong, 2000). Vetiver grass plant has the potential to absorb nutrients such as N, P, and K from intensive livestock and store it in the root and shoot parts (Maharjan & Pradhanang, 2017). The nutrients, heavy metals, toxic materials are usually removed and absorbed by the root and shoot parts of this plant. However, very low amount of the toxic materials and heavy metals absorbed are translocated to the shoot part, which makes it safely food that can be grazed by animals (Truong & Truong, 2000). The shoot part of this plant contains amount of nutrients which are beneficial for soil and plant. Hence, using the harvested shoots of the vetiver grass as raw material to produce biochar could be beneficial to amend the problematic soils, enhance their quality, boost plant growth, and improve nutrient uptake by plant (Truong & Truong, 2000). Therefore, the objective of this study was to investigate whether that the application of biochar produced from vetiver grass with or without NPK fertilizer could improve the growth of oil palm seedlings and soil chemical properties. It is anticipated that vetiver grass biochar would significantly increase the fertilizer use efficiency, improve growth of oil palm seedlings and soil chemical properties, while reducing the environmental problems caused by nutrients leaching.

MATERIALS AND METHODS

Experimental site, experimental design and treatment

A glasshouse experiment was conducted in the Farm Unit at the Universiti Teknologi MARA Cawangan Sarawak, Kota Samarahan, Malaysia between June 2022 and July 2023. Plant materials used consist of oil palm seedlings, *Dura* × *Pisifera* (F0046 × 1 HP60). The oil palm seedling was prepared in a plastic polybag (30 cm diameter × 26 cm depth). Five different treatments were used in this experiment (Table 1).

Table 1: Composition of treatments and rate of fertilizer

Treatments	Rate of fertilizer	Quantity (g/plant)
T0	Absolute control	0 g
T1	100% NPK	20 g
T2	100% vetiver grass biochar	140 g
T3	50% vetiver grass biochar + 50% NPK	70 g + 10 g
T4	75% vetiver grass biochar + 25% NPK	105 g + 5 g

Note: NPK = NPK 15-15-15 fertilizer as per the recommendation by Adileksana et al., (2020) with some modifications; VGB = vetiver grass biochar.

The source of N, P and K was the granular compound fertilizer (CF), commonly used commercial fertilizer, where N stands for % N (12%), P for % P_2O_5 (12%), K for % K_2O (17%) and Mg for % MgO (2%). The quantities of nutrient applied to the oil palm seedling were from the quantity of nutrients provided to oil palm seedlings based on Rankine and Fairhurst (1999) and other nutrient elements application and rates followed normal nursery practices. Nursery maintenance practices, such as polythene bag weeding, pests and diseases control were regularly conducted and closely monitored. The oil palm seedlings were watered daily.

Soil analysis

The topsoil layer (0-15 cm depth) collected from the research field of UiTM was used for the experiment. Soil chemical characteristics were analyzed prior and post to the treatments application. Soil samples were collected and analyzed for their pH values to check the acidity using a digital pH meter (HI198103, Hanna Instruments). The pH meter probes were rinsed with distilled water and dried before insertion into the sample suspension to measure pH (Bohari *et al*. 2020). Soil organic carbon was determined using the modified Walkley-Black wet oxidation Method (Nelson & Sommers, 1996). A 10 ml of potassium dichromate ($K_2Cr_2O_7$) was added-dried soil in 500 ml flask. The flask was gently swirled to disperse the soil in the solution. A 20 ml of concentrated sulfuric acid (H_2SO_4) was added and mixed gently and more vigorously for one minute. The mixture was allowed to stand for 30 minutes in afume hood to minimize heat loss. Two hundred ml of distilled water was added. The titration process was carried out manually where three to four drops of the o-phenanthroline indicator were added, and the excess dichromate was titrated with a solution of ferrous ammonium sulphate [$FeSO_4$ $(NH_4)_2$ SO_4 $6HO_2$] until the color changes, indicating the endpoint of the reaction (Wakley and Black, 1934). Soil cation exchange capacity (CEC) was assessed using the ammonium acetate leaching method. In this procedure, the soil underwent leaching with ammonium acetate, and the resultant filtrate was collected to determine the concentrations of exchangeable potassium (K^+), magnesium (Mg^{2+}), and calcium (Ca^{2+}). Subsequently, the soil was washed with denatured alcohol (95%) to eliminate any excess ammonium ions. After drying, the soil was subjected to leaching with 0.1 N potassium chloride (KCl). The filtrate formed from this process was distilled, followed by titration against 0.02 N sulfuric acid (H_2SO_4), with methyl red and methylene blue indicators (MS 678: Part V: 1980). Soil available nitrogen was determined using alkaline permanganate method. In this method, ammonia was removed from soil by oxidization process. For the oxidation reaction to take place, potassium permanganate

($KMnO_4$) was mixed with sodium hydroxide (NaOH). Removed ammonia was collected in boric acid to form ammonium borate. For quantitative identification of nitrogen, ammonium borate was titrated with sulfuric acid (H_2SO_4). The volume of acid required for titration was substituted in the same formula used by used by Hussain & Malik, (1985). Soil available potassium was determined using ammonium acetate extractable method (Pansu & Gautheyrou, 1985). In this method, available potassium in soil was extracted using ammonium acetate solution. Ammonium acetate when mixed in soil reacts with potassium compounds in the soil to form potash. The potassium from potash is then detected using flame photometry. Soil available phosphorus was determined using Mehlich-3 method (Latrou *et al*. 2014). In this method, the soil samples were air dried and ground to pass through a 2-mm sieve. Then, 2 g of soil were weighed and 20 ml of Mehlich 3 extractant were applied [0.2 M CH_3COOH, 0.25 M ammonium nitrate (NH_4NO_3), 0.015 M ammonium fluoride (NH_4F), 0.013 M HNO_3, and 0.001 M ethylene-diamenetetra acetic acid (EDTA)]. The extraction time was 5 min and soil extracts were filtered with Whatman No. 2 filter paper. The filtrates were analyzed by ICP (Perkin-Elmer Optima 2100 DV; Perkin-Elmer, Waltham, Mass., USA) for Mehlich 3 P at 213.6 nm.

Biochar analysis

The pH analysis of the biochar was done following the same method mentioned in the soil analysis section. Electrical conductivity of the biochar was determined using EC meter (Mettler-Toledo AG 8603 Schwerzenbach, Switzerland) after the biochar sample was immersed in distilled water with a ratio of 1:10 (solid: water) and shaken for 24 hours (Bohari *et al*. 2020). Total nitrogen content (N%) of the biochar was determined using the Modified Comprehensive Nitrogen Method, as specified by the Malaysian Standard 677: Part III:1980 - Kjeldahl Digestion and Distillation Method. A biochar sample of 0.5 grams was weighed and digested in a mixture containing catalyst, sodium thiosulphate pentahydrate and sulfuric-salicylic acid. The mixture was then heated until it became clear in order to break down the organic nitrogen compounds into ammonia. The digested solution was added to sodium hydroxide (NaOH) to neutralize the acid. Next, the neutralized solution undergoes distillation to separate the ammonia from the solution. Phosphorus content (P%) and potassium content (K%) were analyzed according to the standard procedures of the United States Salinity Laboratory Staff (United States Salinity Laboratory Staff, 1954).

Plant growth measurements

Growth parameters of oil palm seedlings were measured between the first and eleventh month. Plant height was measured using metered tape. Bole diameter was measured using a digital calliper at 5 cm height from the planting medium. Number of leaf per plant was counted. Leaf chlorophyll content was measured using chlorophyll meter (SPAD-502, Minolta Camera Co., Osaka, Japan) following the same method used by Ajeng et al. (2020).

Statistical analysis

The collected data were analyzed using analysis of variance (ANOVA) and the treatments means were compared with Duncan's Multiple Range Test (DMRT; $p<0.05$) to detect the significant grouping among the treatments. All data were analyzed using Statistical Analysis System (SAS, version 9.3).

RESULTS AND DISCUSSION

Soil properties prior the treatments application

Table 2 shows the properties of soil at the pre-planting stage. The analysis of the soil shows that soil has low pH 4.3 (strongly acidic). However, oil palm plant can grow well in soil with pH range between 4.3 and 6.5 (Tiemann *et al*. 2018). The soil has amount of organic carbon and nutrients.

Table 2: Soil properties used in the net house experiment

Parameter	**Value**
pH	4.3
CEC (cmol (+)/kg)	31.96
Total organic carbon (%)	1.16
Exchangeable potassium (cmol (+)/kg)	0.09
Exchangeable calcium (cmol (+)/kg)	1.78

Biochar properties

Table 3 shows the vetiver grass biochar properties. Vetiver grass biochar has high pH, which means being able to act as soil liming material. EC value of biochar is high. Furthermore, biochar has amount of nutrients required for plant growth. The alkaline nature of the biochar indicates the suitability of using it as an amendment especially for acidic soil.

Table 3: Vetiver grass biochar properties

Parameter	**Composition**
pH	8.43 ± 0.02
EC (mS cm^{-1})	5.53 ± 0.03
Nitrogen (%)	2.89 ± 0.08
Phosphorus (%)	0.39 ± 0.04
Potassium (%)	7.17 ± 1.30

Oil palm growth measurements

Plant height and bole diameter

Table 4 shows the effect of different treatments on plant height and bole diameter over 11 months after planting. The results of plant height and bole diameter indicated significant difference at ($p <0.05$). Significant variations were noticed among the treatments in terms of height. T4 shows the best effect on plant height followed by T3. According to Adileksana *et al*. (2020), high porosity and CEC of the biochar increase the retention of nutrients and make it more available for plant uptake especially when the biochar is applied with fertilizer, hence increasing the plant height. The development in terms of height was very slow under T2 (100% biochar) and this was in accordance with the findings of Hamzah & Shuhaimi, (2018), they stated that the plant height development was slow when the biochar was applied alone especially at high rate. T1, T3, and T4 show highly significant impact on the bole diameter of oil palm seedlings but the highest mean value of bole diameter was observed under T4. Bole diameter mainly depends on the amount of macronutrients available for plant uptake, especially nitrogen (Adileksana *et al*. 2020) and potassium (Astuti *et al*. 2015).

TABLE 4
Effect of different treatments on plant height and bole diameter over 11 months after planting

Parameter	Treatment	1	3	5	7	9	11
	T0	38.93 ±1.26	42.98 ± 1.26^{c}	44.80 ± 1.19^{c}	46.99 ± 1.21^{d}	49.17 ± 1.21^{e}	52.34 ± 1.22^{e}
	T1	40.41 ± 1.48	51.38 ± 1.47^{a}	59.41 ± 1.56^{a}	64.36 ± 1.52^{b}	67.66 ± 1.62^{c}	71.27 ± 1.85^{c}
Plant Height (cm)	T2	40.47 ± 1.52	42.12 ± 1.52^{c}	45.42 ± 0.67^{c}	50.49 ± 0.78^{c}	53.31 ± 0.67^{d}	57.17 ±1.54^{d}
	T3	42.29 ± 1.18	46.23 ± 1.16^{b}	57.78 ± 0.76^{b}	66.70 ± 0.64^{b}	74.56 ± 0.82^{b}	79.93 ± 0.88^{b}
	T4	39.87 ± 1.25	49.33 ± 1.19^{ab}	61.55 ± 0.97^{a}	73.27 ± 0.95^{a}	83.89 ± 1.03^{a}	96.89 ± 1.11^{a}
	T0	25.85 ± 0.41	27.03 ± 0.43^{c}	29.08 ± 0.57^{b}	30.89 ± 0.59^{b}	33.32 ± 0.60^{d}	34.58 ± 0.61^{d}
	T1	27.78 ± 0.49	31.66 ± 0.68^{a}	37.57 ± 0.76^{a}	42.01 ± 0.84^{ab}	48.18 ± 0.92^{b}	51.60 ± 0.95^{b}
	T2	27.02 ± 0.44	27.33 ± 0.44^{c}	28.96 ± 0.52^{b}	31.88 ± 0.63^{b}	35.16 ± 0.49^{c}	36.76 ± 0.51^{c}
Bole Diameter (mm)	T3	26.43 ± 0.45	29.80 ± 0.47^{b}	35.50 ± 0.36^{ab}	45.40 ± 0.37^{a}	53.93 ± 0.43^{a}	56.88 ± 0.48^{ab}
	T4	27.00 ± 0.48	29.37 ± 0.45^{b}	35.55 ± 0.35^{ab}	43.40 ± 0.39^{ab}	55.11 ± 0.35^{a}	58.93 ± 0.52^{a}

Note: Means ± standard error of the mean was analyzed by ANOVA.
Different letters within each row indicate significant differences at p <0.05 based on DMRT. T0 = absolute control; T1 = 100% NPK fertilizer; T2 = 100% vetiver grass biochar; T3 = 50% vetiver grass biochar + 50% NPK fertilizer; T4 = 75% vetiver grass biochar + 25% NPK fertilizer

Leaf number and SPAD chlorophyll content

Table 5 shows the effect of different treatments on leaf number and SPAD chlorophyll content over 11 months after planting. The results of leaf number and SPAD chlorophyll content indicated significant difference at ($p <0.05$). Significant variations were noticed among the treatments in terms of leaf number and SPAD chlorophyll content. The highest mean value of leaf number was recorded in treatment T4. The development of leaf number in plants treated with T2 was very slow due to insufficient supply of nutrients. Insufficient supply of nutrients acts as a barrier in front of growing new leaves and that was reported by Corley & Tinker, (2016). SPAD chlorophyll content of oil palm was significantly influenced by the biochar. The highest mean value of SPAD chlorophyll content was recorded in T4. According to Ajeng *et al*. (2020) there is a corelation between N and enhanced chlorophyll reading. Plants' chlorophyll content depends on the absorption and availability of nutrients in the soil, which is enhanced by biochar application (Albalasmeh *et al*. 2023). The high chlorophyll content can be related to increased soil N content because of biochar application.

TABLE 5
Effect of different treatments on leaf number and chlorophyll content over 11 months after planting

Parameter	Treatment	1	3	5	7	9	11
Leaf Number	T0	7.44 ± 0.28	8.46 ± 0.42^{d}	8.76 ±0.39^{c}	9.33 ± 0.42^{c}	10.13 ± 0.50^{d}	12.56 ± 0.58^{e}
	T1	7.25 ± 0.27	10.28 ± 0.49^{a}	14.69 ± 0.65^{a}	19.47 ± 0.71^{a}	23.31 ± 0.49^{b}	25.80 ± 0.53^{c}
	T2	7.33 ± 0.31	9.63 ± 0.26^{c}	10.18 ± 0.80^{b}	13.64 ± 0.68^{b}	15.18 ± 0.60^{c}	19.20 ± 0.52^{d}
	T3	7.47 ± 0.24	9.96 ± 0.30^{b}	12.49 ± 0.68^{ab}	18.64 ± 0.76^{a}	25.87 ± 0.80^{ab}	29.73 ± 0.91^{b}
	T4	7.46 ± 0.31	9.64 ± 0.39^{c}	12.33 ± 0.70^{ab}	17.96 ± 0.77^{ab}	27.89 ± 0.68^{a}	33.17 ± 0.71^{a}
Chlorophyll content	T0	33.20 ± 0.26	33.80 ± 0.46^{c}	36.27 ± 0.56^{b}	36.56 ± 0.54^{d}	36.89 ± 0.55^{d}	37.52 ± 0.62^{e}
	T1	33.49 ± 0.26	38.91 ± 0.55^{a}	43.67 ± 0.33^{a}	46.80 ± 0.46^{bc}	52.84 ± 0.39^{b}	52.91 ± 0.33^{c}
	T2	33.29 ± 0.27	33.91 ± 0.29^{c}	35.29 ± 0.72^{b}	38.31 ± 0.71^{c}	39.97 ± 0.67^{c}	41.88 ± 0.63^{d}
	T3	33.53 ± 0.24	37.53 ± 0.69^{b}	43.09 ± 0.76^{a}	48.29 ± 0.29^{b}	55.87 ± 0.30^{a}	55.09 ± 0.31^{b}
	T4	33.62 ± 0.26	38.64 ± 0.63^{a}	43.48 ± 0.29^{a}	50.33 ± 0.65^{a}	55.97 ± 0.59^{a}	57.65 ± 0.60^{a}

Note: Means ± standard error of the mean was analyzed by ANOVA.
Different letters within each row indicate significant differences at p <0.05 based on DMRT. T0 = absolute control; T1 = 100% NPK fertilizer; T2 = 100% vetiver grass biochar; T3 = 50% vetiver grass biochar + 50% NPK fertilizer; T4 = 75% vetiver grass biochar + 25% NPK fertilizer.

Plant dry biomass

Figure 1 shows the effect of different treatments on plant dry biomass is an important indicator that determines the quality of plant seedlings (Fried and Hademenos, 2000). The results of plant dry biomass indicated significant difference at (P <0.05). The highest mean value of plant dry biomass was observed under T4. According to Adileksana *et al*. (2020) plant height and bole diameter mainly affect the accumulation of plant dry matter. The highest mean value of plant height and bole diameter was observed in plants treated with T4, hence, the plant biomass in this treatment was the highest.

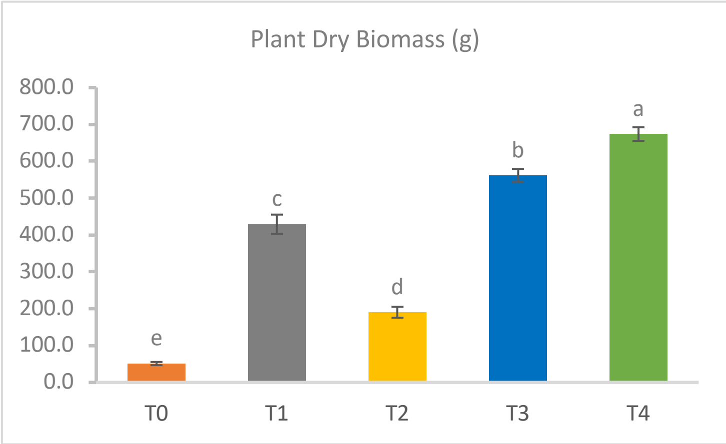

Figure 1. Effect of different treatments on plant dry biomass. Different letters represent significant differences at $p < 0.05$ using Duncan's Multiple Range Test. T0 = Absolute control; T1 = 100% NPK fertilizer; T2 = 100% vetiver grass biochar; T3 = 50% vetiver grass biochar + 50% NPK fertilizer; and T4 = 75% vetiver grass biochar + 25% NPK fertilizer

Soil chemical properties

Soil pH, CEC, and organic carbon

Figure 2 shows the effect of different treatments on soil pH, CEC, and organic carbon. Soil pH, CEC, and OC were highly affected by the addition of biochar. The highest soil pH value was recorded with T2 (100% biochar). According to Zhang *et al.* (2017), biochar increased soil pH due to its ability to consume soil protons, increase base saturation, and decrease the amount of exchangeable aluminium. The positive change in soil pH as a result of biochar addition was previously observed by Hidayati, (2014); Hanpattanakit *et al*. (2021); Wangmo *et al*., (2022). Zwieten *et al*. (2010) reported that soil acidity was reduced by 31.9% as a result of biochar addition. The highest value of CEC was recorded in T2. The addition of biochar increased soil cation exchange capacity (CEC) and that may be attributed to some characteristics of the biochar. The existence of strong functional groups and exchangeable sites on the biochar surface could increase soil CEC (Tian *et al*. 2017; Alkharabsheh *et al*. 2021). Joseph *et al*. (2010) also reported that increasing soil CEC with the biochar addition could be related to the adsorption, desorption, and redox reaction processes. The highest value of soil organic carbon was recorded in T2 (*Figure 2*). Soil organic carbon is an aggregate component which is mainly affected by the addition of biochar and that was in accordance with Wu *et al*. (2023), they stated that soil organic carbon was increased with the biochar addition.

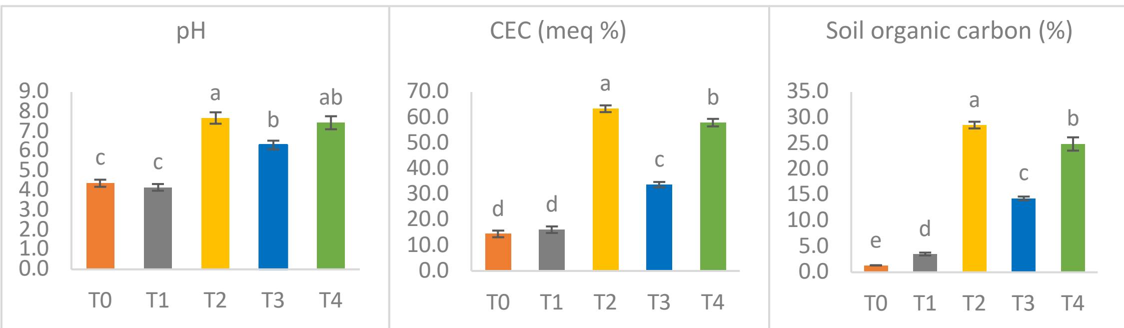

Figure 2. Effect of different treatments on soil pH, CEC, and soil organic carbon. Different letters represent significant differences using Duncan's Multiple Range Test. T0 = Absolute control; T1 = 100% NPK fertilizer; T2 = 100% vetiver grass biochar; T3 = 50% vetiver grass biochar + 50% NPK fertilizer; and T4 = 75% vetiver grass biochar + 25% NPK fertilizer

Soil available nitrogen, phosphorus, and potassium

Figure 3 shows the effect of different treatments on soil available macronutrients (N, P, and K). Changes in soil available macronutrients were also recorded. Soil available N was increased with the biochar addition. The highest value was recorded in T4 and that may be due to the high CEC and other slow-release characteristics of the biochar which increase the amount of nutrients available in soil (Jindo *et al*. 2020). However, in T2 a decrease in available N was noticed with the corresponding increase in pH, because of the increase in soil pH leads to improve the transformation process of nitrogen from ammonium N into nitrate N, hence reducing the available amount of nitrogen in soil (Wangmo *et al*. 2022). Soil available P and K were also increased with the biochar addition. The highest available P and K value was also recorded in in T4. The addition of biochar increased the amount of phosphorus available in soil because it alters the solubility of P through changes in soil pH (Arif *et al*. 2017), Furthermore, biochar may alter the soil available P by acting as P source and that was reported by Wangmo et al., (2022). The addition of biochar to soil increased the soil available K. This increase may relate to the large surface area and negative surface charge of the biochar, as well as, the porous structure of the biochar, which improves the nutrient retention including K (Liang *et al*. 2006). Hanpattanakit *et al*. (2021) reported that the addition of biochar to soil increased the amount of K available in soil.

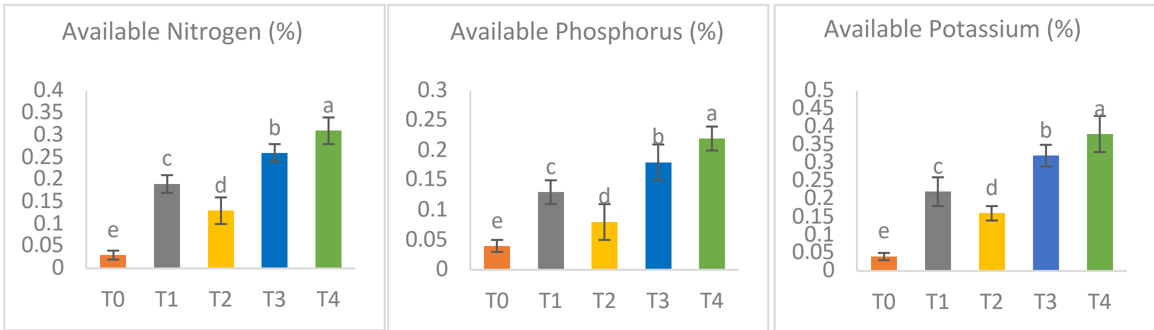

Figure 3. Effect of different treatments on soil Available N, Available P, and Available K. Different letters represent significant differences using Duncan's Multiple Range Test. T0 = Absolute control; T1 = 100% NPK fertilizer; T2 = 100% vetiver grass biochar; T3 = 50% vetiver grass biochar + 50% NPK fertilizer; and T4 = 75% vetiver grass biochar + 25% NPK fertilizer

CONCLUSION

The combined application of vetiver grass biochar and NPK fertilizer significantly increased plant height, bole diameter, number of leaves, and chlorophyll content of oil palm seedlings. It also improved the soil chemical properties. This study revealed that the application of vetiver grass biochar could improve the growth of oil palm seedlings and the soil chemical properties. To improve the growth of oil palm planted in an acidic soil in tropical regions, combined application of vetiver grass biochar with NPK fertilizer (75% VGB + 25% NPK) is recommended based on the findings of the study. However, further research pertaining to combined application of vetiver grass biochar with different inorganic fertilizers and their impact on plant growth is necessary to validate the findings.

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