

Oil Palm Seedling Performance and Soil Chemical Characteristics as Influenced by Organic Fertilization Rate

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Abstract

Fertilizer application is a key component in the production of high-quality oil palm (*Elaeis guineensis*) seedlings. Inorganic fertilizers are used to supplement the native nutrient concentrations in the soil; however, their continuous application leads to soil acidification and depletion of soil organic matter. Organic fertilizers promote the growth of crops and improve soil fertility, but their effects on oil palm seedling production still remain elusive. Therefore, a two-year nursery experiment was conducted at Oil Palm Research Institute, Kusi, in the Eastern region of Ghana to determine the effects of organic fertilization rates on oil palm seedling performance and soil chemical characteristics. The experiment was arranged in a randomized complete block design with four replications. The treatments included: 25 g (T1), 50 g (T2), 75 g (T3), 100 g (T4) of organic fertilizer/seedling/month, and compared with farmers' practice: 30 g NPK combined with Mg/seedling/month (Control, T5). Results from the study revealed that organic fertilization significantly stimulated oil palm seedling growth and improved the soil chemical properties. Compared to the control, treatment T2 increased crop growth rate by 38.18% (2022) and 27.84% (2023), total plant biomass by 18.07% (2022) and 11.90% (2023), soil total nitrogen by 44.19% (2023) and soil organic matter by 87.33% (2023). Treatment T2 can be used to replace the inorganic fertilization rate (control) to stimulate oil palm seedling growth and improve soil chemical characteristics. The application of 50 g/seedling/month of the organic fertilizer is the best application rate for producing high-quality seedlings and ensuring sustainable oil palm nursery production.

Keywords: biomass accumulation, crop growth rate, leaf chlorophyll content, nutrient uptake, soil organic matter

Introduction

Oil palm (*Elaeis guineensis* Jacq.) is a heavy feeder crop, and it requires soils with highly inherent fertility status (Danso et al., 2021). It is a major cash crop in Ghana with an annual production of 2.56 million tons in 2023 (FAO, 2024). The demand for vegetable oil has increased globally, and oil palm contributes significantly to the global supply of edible oils. The oil yield from palm fruits is seven to eleven times higher per hectare than that from rapeseed and soybean (Febriani et al., 2020). The oil is used in various products, including shorteners, vanaspati frying fats, margarine, and confectionery fats (Mba et al., 2015). Traditionally, topsoil has served as the primary growing medium for oil palm seedlings during the nursery stage (Rosenani et al., 2016). When nursed on soils with low inherent fertility, oil palm requires more agronomic inputs to

ensure adequate growth and yields (Sabrina et al., 2009). High-quality seedlings are used to establish oil palm plantations, as they mature early and produce high yields of fresh fruit bunches (Danso et al., 2021). The production of high-quality seedlings largely depends on the suitability of the growing medium and proper fertilizer management. Fertilizers are therefore applied to oil palm seedlings at the nurseries primarily to produce seedlings with the needed vigour to perform well in the field. It is impossible to compensate for incorrect practices applied from seed quality through to early field management, which results in considerable loss of oil per hectare (Griffie et al., 2004). Therefore, it is important to use high-quality seedlings for plantation establishment. According to Ekhaton et al. (2024), nutrient management is a key component in producing high-quality oil palm seedlings.

Soils used to nurse oil palm seedlings in Ghana

are generally low in nutrients; hence, inorganic fertilizers (NPKMg at a ratio of 1:1:1:2) are applied to supplement the native nutrient concentrations in the soil. The application of inorganic fertilizers stimulates the growth and development of oil palm seedlings (Uwumarongie-Ilori et al., 2012; Akpo et al., 2014; Ashraf et al., 2017). However, long-term use of inorganic fertilizers can lead to soil acidification and depletion of soil organic matter due to residual effects and degradation of certain soil physical properties (Goh and Hardter, 2003), limiting nutrient availability and plant uptake (Jackson and Meetei, 2018). Excessive application of inorganic fertilizers contributes to nitrous oxide (N₂O) emissions, a potent greenhouse gas (Xu et al., 2022; Kumar and Bordoloi, 2024). Moreover, the high cost of inorganic fertilizers and their scarcity during the period of peak demand make it even more difficult for the resource-poor farmers to afford. Given these challenges, there is a growing need to identify alternative nutrient sources that are affordable, sustainable, and environmentally friendly.

Organic fertilizers such as manure have been recommended as a viable substitute for inorganic fertilizers for oil palm seedling production (Uwumarongie-Ilori et al., 2012). Organic fertilizers are a readily available source of organic matter and an alternative source of plant nutrients. According to Gao et al. (2020), the organic fertilization stimulates seedling growth by improving nutrient availability, nutrient uptake, microbial activity, and the physiological functioning and antioxidant activities of plants. Moreover, the application of organic fertilizer improves the physical, chemical and biological properties of the soil over time, which in turn promotes soil health (Brempong and Addo-Danso, 2022; Zhou et al., 2022; Ma et al., 2023; Xing et al., 2024). Therefore, we hypothesized that (1) organic fertilization can replace inorganic fertilization in oil palm seedling production and (2) moderate organic fertilization rate may produce growth performance of oil palm comparable to inorganic fertilization under nursery conditions. The effects of organic

fertilization on the growth performance of oil palm seedling production have been extensively studied (Uwumarongie-Ilori et al., 2012; Danso et al., 2013; Ewulo, et al., 2015). However, the effects of different organic fertilization rates on oil palm seedling performance remain elusive. Therefore, this study was carried out to evaluate the influence of different organic fertilizer application rates on oil palm seedling growth and soil chemical properties.

Materials and Methods

Study area

The experiment was conducted at the CSIR - Oil Palm Research Institute nursery at Kusi, in the Denkyembour District in the Eastern of Ghana, with an altitude of 164 m above sea level. The area lies within the semi-deciduous forest zone of Ghana and has a bimodal rainfall pattern with average annual rainfall of about 1600 mm. Major rainy season starts from March to July and a minor season starts from September to November. The daytime temperatures of the area range from 20 °C to 31 °C, while relative humidity varies from about 95% during the rainy season to about 40% in the dry season.

The soils of the experimental site are well-drained and classified as Ferric Acrisol (Nzema series) under the Ghanaian soil classification system (Owusu-Benoah et al., 2000).

Experimental design and treatments

The study was arranged in a randomized complete block design due to a slope gradient at the experimental site. 20 seedlings were arranged per treatment, and the treatments were replicated four times. The treatments include four organic fertilizer rates namely; 25 g fertiplus 433/seedling/month (T1), 50 g fertiplus 433/seedling /month (T2), 75 g fertiplus 433/seedling /month (T3), 100 g fertiplus 433/seedling/month (T4), which were compared to farmers' practice: 30g of NPK and Mg in the ratio of: 1:1:1: 2 /seedling /month (Control, T5). The organic fertilizer

was obtained from Agrokhem Ghana Limited, leaves per palm were used to determine and the nutrient concentrations in the fertilizer leaf chlorophyll content using the SPAD

TABLE 1
Nutrient composition of the organic fertilizer (Fertiplus 433)

Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)
3.45	1.40	2.02	2.73	1.26

are presented in Table 1.

Nursery establishment

Black polybags (15 cm x 23 cm) were filled with topsoil, leaving a space of about 50 mm at the top to allow room for fertiliser and water addition. The topsoil was a sandy loam and had the following properties: total nitrogen (0.20%), organic matter (3.52%), available phosphorus (34.17 mg/kg), available potassium (0.28 cmol_c/kg), calcium (5.01 cmol_c/kg), sodium (0.09 cmol_c/kg), magnesium (2.53 cmol_c/kg) and pH in water (5.68, 1:2.5 w/v). Pre-germinated oil palm seeds (D x P ex OPRI, cross 131) from the Oil Palm Research Institute, Kade, Ghana, were used for the study. Healthy and uniform oil palm seedlings at the three-leaf stage were transplanted into the polybags using a soil auger. The seedlings were arranged in an east-west direction at a triangular spacing of 70 cm × 70 cm × 70 cm. Organic and inorganic fertilizers were applied one month after transplanting and repeated at monthly intervals. Weeds in the bags were hand-picked, while weeds in the inter-rows were controlled using rice husks as mulch. Irrigation was carried out daily using a sprinkler system. All necessary good nursery practices and plant protection measures were followed consistently for all treatments throughout the trial period.

Data Collection

The vegetative measurements started four months after transplanting to evaluate the growth performance of the seedlings. Six seedlings per plot were tagged for measurement, and their average was computed for data analysis. Growth indicators determined included: plant height, butt diameter, leaf chlorophyll content and total number of fronds. Six fully expanded

502 plus chlorophyll metre, model 2900PL. Butt girth was determined by measuring the butt circumference using a Vernier caliper. Number of fronds was recorded by manually counting all the fronds on the palm. Plant height was measured from the soil surface of the polybag to the highest point of the spear leaf. The seedlings were harvested five months after transplanting. Roots and shoots were carefully removed from the soil to prevent the roots from being broken. The plants were cut into the shoot and root parts and washed thoroughly with distilled water. The plants were then dried in an oven at 65 °C for 48-72 hours to determine the total dry weight. The ratio of root to shoot was determined using the following equation:

$$\text{Root to Shoot Ratio} = \frac{\text{Total root dry weight (g)}}{\text{Total shoot dry weight (g)}} \quad (1)$$

Nutrient concentrations in plant leaves were determined by taking the middle of fully opened fronds of seedlings 10 months after transplanting for each treatment with a knife, washed with water and then oven dried at 70°C for 48 hours. The dried samples were ground and sieved through 1-mm mesh for nutrient composition analysis at CSIR – Soil Research Institute, Kumasi. Phosphorus content was determined by molecular absorption spectrophotometry; potassium by flame photometry; calcium and magnesium by atomic absorption spectrophotometry according to the standard methods of plant analysis. Nitrogen content was determined by the Kjeldahl method (O'Dell, 1993). Soil samples were taken from five polybags within an experimental unit to form a composite sample. Plant roots, animal debris, and other visually detectable organisms were removed from the samples. The samples were then air-dried for 14 days and then ground through a 1 mm mesh. The sieved samples

were sent to the CSIR-Soil Research Institute laboratory for soil physicochemical analysis. Available potassium, magnesium, and calcium were determined by ammonium displacement of the exchangeable cations as described by Chapman (1965). Soil pH (1:2.5 soil: water suspension) was measured using a portable pH meter. Soil organic carbon content was determined using the potassium dichromate digestion method (Walkley and Black, 1934) and multiplied by a constant of 1.724 to determine the soil organic matter content. Available phosphorus was determined using the Bray 1 method (Kurtz and Bray, 1945) Total nitrogen content was measured using a modified Kjeldahl method as described by Bremner (1996).

Statistical data analysis

The data obtained were tested for normality and homogeneity of variance and then subjected to one-way Analysis of Variance (ANOVA) using GenStat statistical software (12th edition), and where significant differences were observed,

treatment means were separated using the least significant difference test at a 0.05 probability level.

Results

Effect of organic fertilization rate on oil palm seedling growth and development

Fertilizer application rate significantly ($p < 0.05$) influenced the vegetative growth of the oil palm seedlings 10 months after transplanting during both the 2022 and 2023 growing seasons (Fig. 1- 3). Treatments T1, T2, and T3 had statistically ($p > 0.05$) similar crop growth rates (CGR); these, however, were higher than the other treatments (Fig. 1a-b). Compared to the control (T5), treatment T2 increased crop growth rate by 38.18% in 2022 and 27.84% in the 2023 season. Treatment T2 had a statistically similar leaf weight ratio (LWR) with treatment T1; however, it stimulated LWR by 15.58% and 9.33% compared to the control in 2022 and 2023

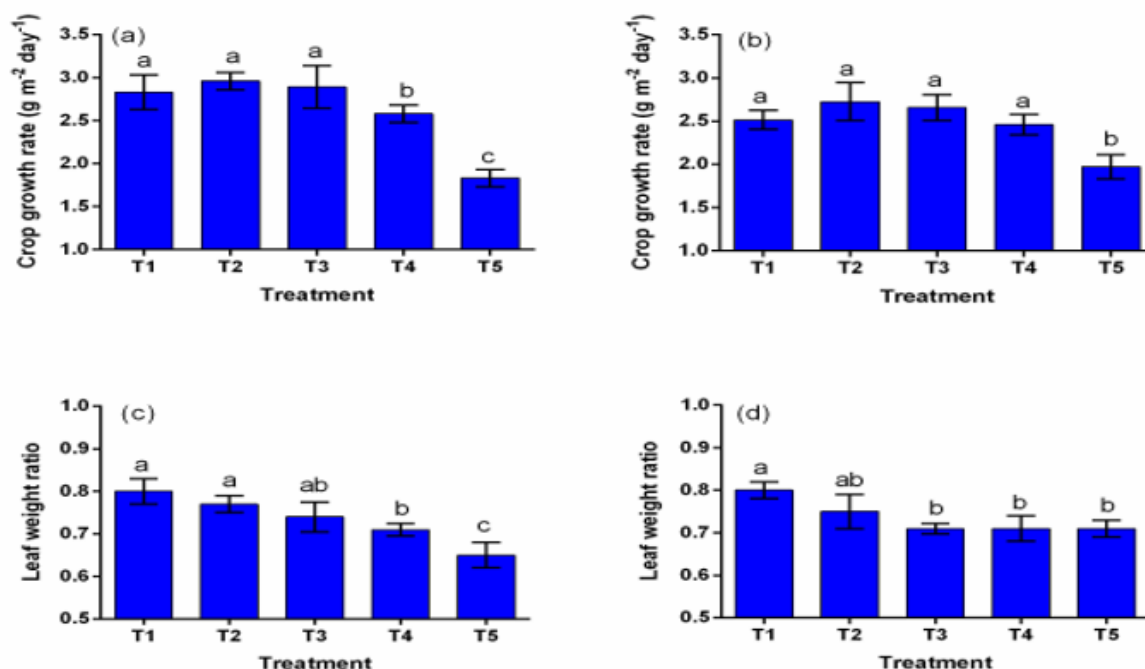


Figure 1 Effects of inorganic and organic fertilization rate on crop growth rate in 2022 (a) and 2023 (b); leaf weight ratio in 2022 (c) and 2023 (d). Bars represent \pm standard error of means at three replications. T1, 25 g of fertiplus plant⁻¹; T2, 50 g of fertiplus plant⁻¹; T3, 75 g of fertiplus plant⁻¹; T4, 100 g of fertiplus plant⁻¹; T5, 30 g NPKMg plant⁻¹

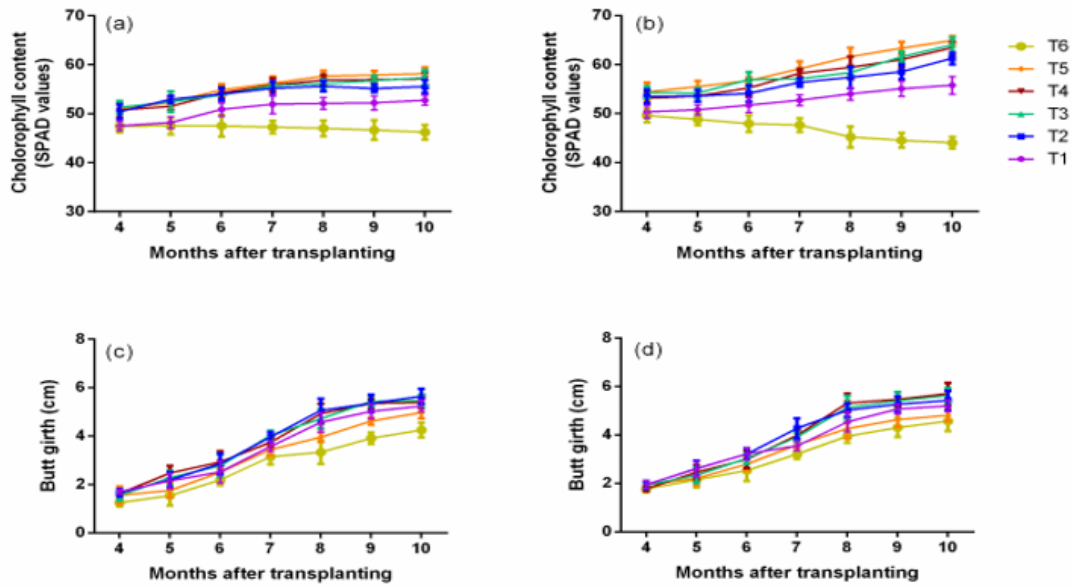


Figure 2 Effects of organic and inorganic fertilization rate on chlorophyll content in 2022 (a) and 2023 (b); butt girth in 2022 (c) and 2023 (d). Bars represent \pm standard error of means at three replications. T1, 25 g of fertiplus plant⁻¹; T2, 50 g of fertiplus plant⁻¹; T3, 75 g of fertiplus plant⁻¹; T4, 100 g of fertiplus plant⁻¹; T5, 30 g NPK & Mg plant⁻¹

growing seasons, respectively (Figure 1c-d). Chlorophyll content of the oil palm leaves was significantly affected by the fertilizer application rates in both 2022 and 2023 seasons (Figure 2a-b). Treatments T2, T3, T4 and T5 produced statistically similar chlorophyll content in both seasons; however, treatment T2 increased chlorophyll content by 15.13% and 9.01% in the 2022 and 2023 seasons, respectively, compared to the treatment T1 at

10 months after transplanting. Butt girth was also influenced by the organic application in both seasons, and it increased from 4 to 10 months after transplanting (Figure 2c-d). Treatments T5, T4, T3 and T2 produced statistically similar butt girth, while the treatment T1 had the lowest girth throughout the season in both seasons. Compared to the treatment T1, treatment T2 increased butt girth by 7.23% in 2022 and 3.64% in 2023 at

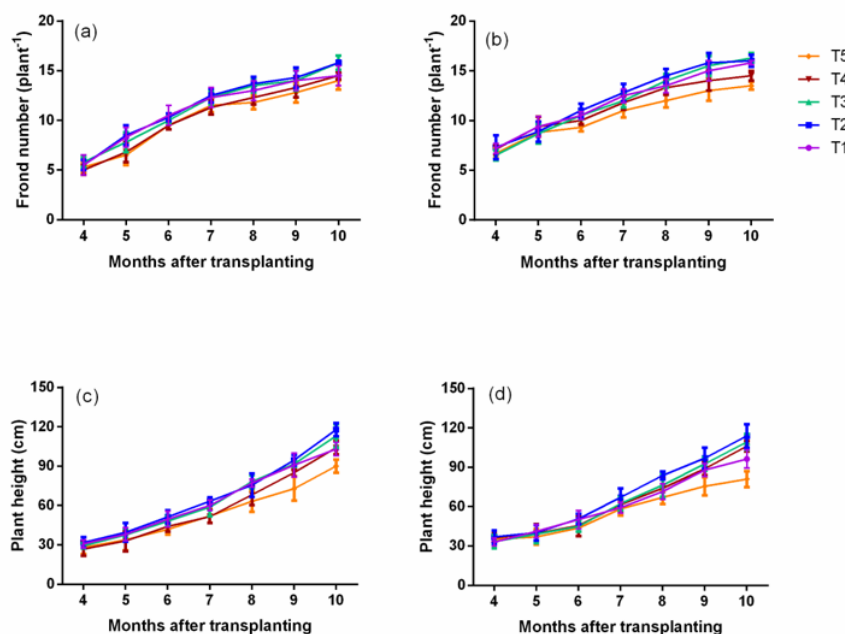


Figure 3 Effects of inorganic and organic fertilization rate on leaf number in 2022 (a) and 2023 (b); plant height in 2022 (c) and 2023 (d). Bars represent \pm standard error of means at three replications. T1, 25 g of fertiplus plant⁻¹; T2, 50 g of fertiplus plant⁻¹; T3, 75 g of fertiplus plant⁻¹; T4, 100 g of fertiplus plant⁻¹; T5, 30 g NPKMg plant⁻¹

10 months after transplanting.

Fertilizer application rate did not significantly influence the number of fronds in both seasons (Figure 3a-b). All the treatments had statistically similar frond number throughout the trials. Plant height was significantly varied by the application rates from 9 to 10 months after transplanting in both seasons (Figure 3c-d). Treatment T2 produced the tallest plants throughout the experiment in both seasons, while the control produced the shortest plants from 9 to 10 months after transplanting. Compared with the control, treatment T2 increased plant height by 23.60% in 2022 and 28.97% in 2023 at 10 months after transplanting.

Fertilizer application rate did not significantly affect oil palm seedling root biomass at 10 months after transplanting in both seasons (Table 2). Treatment T2 and the control had the highest and lowest root biomass, respectively. Butt biomass was only significantly affected in the 2023 season. Treatment T5, T4, T3 and T2 produced statistically similar butt biomass; however, treatment T4 stimulated butt biomass by 12.9% in 2023 compared with the control (Table 2). Organic fertilization significantly influenced leaf biomass in both seasons. Treatment T1 produced the highest leaf biomass in both seasons, while the control recorded the lowest biomass in the 2022 and 2023 seasons (Table 2). Total plant biomass was significantly influenced by the organic fertilization rate in both seasons. In

2022, treatment T2 produced statistically similar total plant biomass with treatment T1; however, the latter stimulated the biomass by 18.07% and 11.90% compared to the control (Table 2). In 2023, treatment T1 produced the highest total plant biomass, significantly compared to the other treatments, whereas the control recorded the lowest biomass. Root and shoot ratios were significantly affected by the fertilizer application rate in only 2022 season (Table 2). The control recorded the highest root and shoot ratio, whereas treatment T1 had the least root-to-shoot ratio in both seasons.

Effects of organic fertilization rate on oil palm leaf nutrient concentrations

Fertilizer application rate significantly affected total nitrogen (TN) and potassium (K) concentrations in the oil palm leaves; nevertheless, it had an insignificant effect on phosphorus (P) concentration (Table 3). TN content increased with increasing fertilization rates, while K content decreased with an increase in the application rate. The control and treatment T1 recorded the highest concentration of TN and K in the oil palm leaves, respectively. The concentrations of phosphorus and magnesium in the leaves were not significantly affected by the fertilizer application rates (Table 3). The concentration of calcium (Ca) in the leaves was also significantly influenced by the fertilizer application rates (Table 3). Ca contents decreased with an increase in fertilizer

TABLE 2

Effects of inorganic and organic fertilization rate on root, butt, leaf, total plant biomass and root shoot ratio of oil palm seedlings in 2022 and 2023 seasons

Treatment	Root biomass (g/plant)		Butt biomass (g/plant)		Leaf biomass (g/plant)		Total plant biomass (g/plant)		Root / Shoot ratio	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
T1	61.4a	61.4a	69.8a	67.3b	539.4a	515.2a	670.6a	643.8a	0.10b	0.11a
T2	63.2a	63.2a	77.4a	75.6ab	372.0ab	379.6b	513.6a	518.4b	0.15ab	0.14a
T3	60.2a	63.9a	81.2a	85.2a	371.3ab	370.9b	512.7ab	520.1b	0.13ab	0.14a
T4	60.7a	60.7a	80.0a	85.3a	341.2ab	360.7b	481.9ab	506.7b	0.15ab	0.14a
T5	57.4a	59.9a	71.3a	74.3ab	292.1b	322.5b	420.8b	456.7b	0.20a	0.15a
LSD (5%)	13.9	11.79	15.36	11.72	153.7	63.28	163.3	69.96	0.08	0.06

Means followed by the same letter are not significantly different from each other. Bars represent \pm standard error of means at three replications. T1, 25 g of fertiplus plant⁻¹; T2, 50 g of fertiplus plant⁻¹; T3, 75 g of fertiplus plant⁻¹; T4, 100 g of fertiplus plant⁻¹; T5, 30 g NPKMg plant⁻¹

TABLE 3

Effects of organic fertilization rate on nutrient concentrations in oil palm leaves in 2023

Treatment	TN (%)	P (%)	K (%)	Ca (%)	Mg (%)
T1	1.62d	0.16a	1.26a	0.22a	0.54a
T2	1.76c	0.19a	0.97b	0.19ab	0.45a
T3	1.82c	0.16a	0.79c	0.19ab	0.43a
T4	1.96b	0.15a	0.71c	0.16bc	0.41a
T5	2.27a	0.16a	0.77c	0.16bc	0.43a
LSD (5%)	0.13	0.08	0.16	0.05	0.20

Means followed by the same letters within a column are not significantly different from each other at 5% probability level. TN: total nitrogen, P: phosphorus, K: potassium, Ca: calcium, Mg: magnesium.

T1, 25 g of fertiplus plant⁻¹; T2, 50 g of fertiplus plant⁻¹; T3, 75 g of fertiplus plant⁻¹; T4, 100 g of fertiplus plant⁻¹; T5, 30 g NPKMg plant⁻¹

application rate. Treatment T1 had the highest Ca content; however, these values were not significantly different from those of treatments T2 and T3 while treatment T4 and the control had the lowest Ca content.

Residual effects of organic fertilization rate on soil chemical characteristics

Total nitrogen, organic matter and phosphorus content in the soil were significantly influenced by the fertilizer application rate after the experiment in 2023 (Table 4). Total nitrogen decreased with increasing the rate of organic fertilizer; however, organic matter and phosphorus content increased with an increase in the rate of organic fertilizer. Compared with the control, treatment T2 stimulated the content of total nitrogen by 44.19% and organic matter by 87.33%. Fertilizer application rate significantly stimulated the content of potassium (K), calcium (Ca),

sodium (Na) and magnesium (Mg) in the soil (Table 4). The content of K, Ca and Na in the soil decreased with increasing the rate of the organic fertilizer; however, Mg content increased with an increase in application rate. All the treatments with the organic fertilizer had significantly higher K, Ca, Na and Mg content than the control. Compared to the control, treatment T2 stimulated K content by 60.22%, Ca by 66.25%, Na by 74.19% and Mg by 85.31%. Soil reaction (pH) was significantly influenced by the fertilizer application rates. Organic amendment treatments (T1, T2, T3 and T4) increased the soil pH close to the neutral range, while the control had significantly the lowest pH value. Total plant biomass showed an insignificant ($p > 0.05$) but positive correlation with TN, K, Mg, Ca, pH, and organic matter; however, it had a negative relationship with P (Table 5). Plant height had an insignificant ($p >$

TABLE 4

Residual effects of organic fertilization rate on soil chemical characteristics after the experiment in 2023

Treatment	TN (%)	OM (%)	P (mg/kg)	K (cmol _c /kg)	Ca (cmol _c /kg)	Na (cmol _c /kg)	Mg (cmol _c /kg)	pH (1:2.5)
T1	2.39a	28.64a	34.95c	1.10a	29.61a	0.32a	21.73b	6.85a
T2	2.15ab	29.83a	35.26c	0.93b	29.03a	0.31a	23.22b	6.62a
T3	2.02b	30.27a	39.97b	0.89b	28.97a	0.31a	25.77a	6.97a
T4	2.10b	30.76a	47.00a	0.55c	22.15b	0.28a	26.40a	6.85a
T5	1.20c	3.78b	37.96bc	0.37d	9.80c	0.08b	3.41c	4.88b
LSD (5%)	0.34	2.35	4.64	0.11	4.52	0.06	2.29	0.46

Means followed by the same letters within a column in not significantly different from each other at 5% probability level. TN: total nitrogen, OM: organic matter, P: phosphorus, K: potassium, Ca: calcium, Na: sodium, Mg: magnesium, pH: soil reaction. T1, 25 g of fertiplus plant⁻¹; T2, 50 g of fertiplus plant⁻¹; T3, 75 g of fertiplus plant⁻¹; T4, 100 g of fertiplus plant⁻¹; T5, 30 g NPKMg plant⁻¹

TABLE 5
Pearson correlation matrix between growth indicators and soil chemical properties

Parameters	Plant biomass	Plant height	Root/shoot	Chlorophyll	Butt girth
Total nitrogen	0.770 ^{ns}	0.683 ^{ns}	-0.693 ^{ns}	-0.694 ^{ns}	0.468 ^{ns}
Phosphorus	-0.396 ^{ns}	0.154 ^{ns}	0.375 ^{ns}	0.535 ^{ns}	0.566 ^{ns}
Potassium	0.835 ^{ns}	0.540 ^{ns}	-0.769 ^{ns}	-0.777 ^{ns}	0.307 ^{ns}
Magnesium	0.444 ^{ns}	0.895 [*]	-0.373 ^{ns}	-0.287 ^{ns}	0.930 [*]
Calcium	0.690 ^{ns}	0.803 ^{ns}	-0.608 ^{ns}	-0.583 ^{ns}	0.646 ^{ns}
pH	0.594 ^{ns}	0.831 ^{ns}	-0.526 ^{ns}	-0.430 ^{ns}	0.856 ^{ns}
Organic matter	0.534 ^{ns}	0.889 [*]	-0.463 ^{ns}	-0.401 ^{ns}	0.874 ^{ns}

NS means not significant at 0.05 probability level; * means significant at 0.5 probability level

0.05) relationship with TN, P, K, Ca, and pH; however, it showed a significant ($p < 0.05$) and strong positive correlation with Mg and organic matter (Table 5). Root-to-shoot ratio showed an insignificant and negative correlation with TN, P, K, Mg, Ca, pH, and organic matter, while it had a positive relationship with P content in the soil (Table 5). Leaf chlorophyll content was negatively correlated with TN, K, Mg, Ca, pH, and organic matter in the soil; however, it was positively correlated with P content. Butt girth showed a significant and positive relationship only with Mg content in the soil; however, it had an insignificant and positive correlation with TN, P, K, Ca, pH, and organic matter contents in the soil (Table 5).

Discussion

Effects of organic fertilization rate on oil palm seedling growth and development

Organic fertilization significantly stimulated the growth and development of the oil palm seedlings in both the 2022 and 2023 seasons. Treatments with the organic amendment (T1, T2, T3, and T4) produced better growth and development traits than the inorganic treatment (T5), partly due to micro nutrients released from the organic fertilizer to the soil. Moreover, the organic fertilizer improved the soil properties (Table 4), which in turn enhanced the oil palm seedling growth and development. The vegetative growth parameters (total plant biomass, plant height, and butt girth) were positively correlated with the soil chemical properties (Table 5).

This finding corroborates previous studies which states that treatments with organic amendment produced better oil palm growth than inorganic fertilizer treatments (Ashraf et al., 2017). However, treatment T5 produced higher chlorophyll content than the organic amendment treatments, which could be attributed to its rapid availability kinetics and release method compared with the organic amendment, which promoted nutrient uptake. Inorganic fertilizers have rapid availability kinetics; hence, they provide readily available nutrients for plant uptake (Fairhurst, 2012; Bindraban et al., 2015). Chandler and Dale (1995) noted a positive correlation between N availability and leaf chlorophyll content. This finding agrees with (Che Radziah et al., 2009) who reported that inorganic fertilization produced higher leaf chlorophyll content than treatments with organic fertilization. Root biomass accumulation was not influenced by the treatments, which contrasts with the observations of Mašková and Herben (2018), who found out that root biomass accumulation decreased with increasing nutrient availability in the growth medium. Additionally, Danso et al. (2012) reported that fertilizer application stimulates root biomass of oil palm seedlings. Discrepancies among these studies may be partly due to differences in variety and climatic conditions at the study sites. Increasing the rate of the organic amendment did not correlate with the growth traits of the oil palm seedlings, which might be partly due to luxury consumption and nutrient saturation through nutrient response efficiency (Schmidt et al., 2021). Moreover, the relationship between

plant performance and nutrient availability generally follows a nonlinear rate-response pattern (Sileshi, 2022; Veresoglou and Begum 2024).

Effects of organic fertilization rate on leaf nutrient concentration of oil palm seedling

Palm seedlings with inorganic fertilization produced higher nitrogen concentration in the leaves than those from the organic amendments, and it might be due to the fact that nitrogen is very mobile and is readily available to the seedlings since the fertilizer is in readily available inorganic form. This outcome concurs with previous studies that nutrients in inorganic fertilizers are readily available for plant uptake (Fairhurst, 2012; Bindraban *et al.*, 2015). However, treatments with organic amendments had higher potassium, phosphorus, calcium and magnesium contents in their leaves than the treatment with inorganic fertilization. The organic amendment was applied on the surface of the soil, which in turn acted as a mulching material and therefore created a conducive environment (conserving soil moisture) for nutrient uptake. Moreover, the organic amendment contains high nutrient concentrations (Table 1), which were released into the soil for plant uptake after mineralization. According to Mengel and Kirk (2001), plant biomass is one of the characteristics of an increase in nutrient uptake in plants; this may explain why organic amendments recorded the highest nutrient uptake. This outcome aligns with previous studies (Hastuti, 2021), which reported that organic amendments stimulate leaf nutrient concentrations.

Effects of organic fertilization rate on residual soil chemical characteristics

Treatments with organic amendment improved the chemical properties of the soil compared to the inorganic fertilization, partly due to the mineralization mechanisms of the organic fertilizer (Baldi and Toselli, 2014; Navi *et al.*, 2025). According to Navi *et al.* (2025), nutrients in organic fertilizers are released through natural processes, ensuring a slow

and steady nutrient supply, enhancing soil fertility, and supporting microbial activity, thereby promoting long-term soil health. Furthermore, organic fertilization improves soil nutrient retention efficiency by increasing organic matter content, enhancing cation exchange capacity (CEC), and fostering microbial activity (Liu *et al.*, 2024). This finding is in agreement with previous studies, which reported that organic amendments improve the chemical properties of soils better than inorganic fertilization (Ma *et al.*, 2023). Nutrients contained in the inorganic fertilizer absorbed quickly and sometimes are easily lost by leaching, while the nutrients contained in organic fertilizers decompose slowly and are more easily retained in the soil (Richter *et al.*, 2000; Ma *et al.*, 2023). The use of organic amendments improves nutrient balance in the soil and strongly increases organic matter content capacity as well as improving water holding capacity (Brempong and Addo-Danso, 2022). Treatment T4 recorded the highest concentration of soil organic matter, available phosphorus and magnesium, and it may be attributed to its high application rate. The higher the fertilizer application rate, the more nutrients it contains, consequently improving the soil fertility after decomposition and mineralization. This outcome is in consonance with previous studies that reported that increasing the application rate of organic fertilizer stimulates the content of soil organic matter, available potassium and magnesium (Zhou *et al.*, 2022; Xing *et al.*, 2024). Treatments with organic fertilization increased the pH of the soil, partly due to the displacement of hydrogen ions (H^+) by cations and the complexation of Al^{3+} ions by organic molecules contained in the fertilizer (Jaoude *et al.*, 2020). Organic fertilization adds organic matter to the soil (Table 4), which contains functional groups such as carboxylic and phenolic groups that form stable organo-aluminium complexes (chelates) with Al^{3+} ions, thereby increasing soil pH in acidic soils (Dai *et al.*, 2021; Zhang *et al.*, 2024). This finding is consistent with previous studies reporting that organic amendment increases

soil pH in acidic soils (Laurent et al., 2020; Xing et al., 2024).

Conclusion

Organic fertilization significantly promoted the growth and development of the oil palm seedlings in both seasons. Treatments with the organic fertilization improved the soil chemical characteristics, which indicates that the organic fertilizer can maintain or improve the soil fertility under nursery experimental conditions and thereby promote sustainable agriculture. Despite the low rate of treatment T2 (50 g/seedling/month), it has a statistically similar effect on oil palm seedling growth, leaf nutrient concentration and soil chemical properties with treatments T3 (75 g/seedling/month), and treatment T4 (100 g/seedling/month). The study recommends treatment T2 since it provided optimal seedling growth and soil chemical responses under nursery experimental conditions. Organic fertilization affects microbial community structure and enzymatic activities in the soil; however, our study did not consider these factors. Hence, future studies should focus on the effect of the organic fertilizer (Fertiplus 433) on soil biological activity and functional microbial diversity, soil carbon stabilization, and nutrient mineralization kinetics in the soil.

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