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# Nodulation, Growth and Yield of Soyabean (*Glycine max* L.) as Influenced by Treated Palm Oil Mill Effluent

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## ABSTRACT

*A pot experiment was set up to evaluate the influence of treated palm oil mill effluent (POME) on the yield of soyabean (Glycine max). The study consisted of four (4) treatments (0m$^3$/ha, 30m$^3$/ha, 90m$^3$/h and 110m$^3$/ha). Ten kilograms of air-dried soil was measured into plastic buckets. Soyabean variety TGX-1448E was used in the trial. Each treatment was replicated 6 times and arranged in a completely randomized designed (CRD). Data collected were subjected to analysis of variance and least significant difference (LSD) was used for separating the means. Results obtained from this research showed that the growth of soyabean (number of leaves, number of branches, plant height and stem girth), increased significantly with increasing rate of POME applied. At 45 days after planting, nodule parameters (number of nodules, nodule weight and nodule effectiveness) increased significantly with increasing rate of POME. Treatment 110 m$^3$/ha had the highest nodule number (8.0), heavier nodule weight (0.007g) while control had the highest nodule effectiveness (138.72). Application of POME at 110 m$^3$/ha also produced more pod numbers (22.16), pod weight (5.11g), 100 seed weight (14.73g) and total biomass production (9.77g). There was also significant difference in the uptake of nitrogen, phosphorus and potassium. The uptake of nutrients increased with increasing rate of POME. Treatment 110 m$^3$/ha had the highest value (N = 4.05%; P = 0.39% and K = 0.39%). From the results obtained in the research, it can be concluded that POMA, at 110m$^3$/ha) gave the highest value in terms of soybean yield in the study area.*

**Keywords**: Palm oil mill effluent (POME), soyabean, growth, yield and soil.

## INTRODUCTION

Soyabean (*Glycine max*), belonging to the family Leguminosae, is a species of legume native to East Asia, with an erect growth habit. It is widely grown for its edible bean which has numerous uses. Soybean nodulates and it leaves are trifoliate (Li et al., 2023). It is the richest plant protein containing 43 % protein and its protein is of the highest quality (Langyan et al., 2022). Soybean also produces high quality oil which is highly digestible, high in unsaturated fatty acid and contains no cholesterol (Ali et al., 2020). It produces pods, within which are enclosed edible seeds. The seed contains high quality protein with substantial levels of most essential amino acid. The carbohydrate content of the seed averages 38 % with total soluble sugar amounting to about 10 % (Moretti et al., 2020). The oligosaccharide fraction, which causes flatulence, is low, thereby making soybean an idea food for infants (Zhao, 2021).

In the tropics, soils are less fertile this is due to the presence of highly weathered soils and high rate of erosion (Basak et al, 2022). Fertilizer is relied upon to boost soil fertility. The hazardous impact of inorganic fertilizer on both man and his environment necessitated various research and studies concerned with the reduction in the use of inorganic fertilizer. High rates as well as long term application of inorganic fertilizers on soils can reduce soil pH, change osmotic potential and ammonia concentrations to levels inhibitory to microbial communities, and leads to accumulation of additional nutrients in the soil such as phosphorous (P) accumulation (Geisseler & Scow 2014; Sabir et al., 2021). On the other hand, soil organic amendments are a good source of organic fertilizers that can be used to improve soil fertility, increase crop productivity as well as promoting environmental sustainability (Garbowski et al., 2023; Pandey et al., 2023; Singh et al., 2024).

Palm oil mill effluent (POME) occurs in forms of high solid, oil, and grease - It is composed of approximately more than 95–96% of water, together with 0.6–0.7% of oils and 2–4% of suspended solids for the source of fruit debris, and is known as a non-toxic substance (Mohammed & Chong, 2014). POME is rich in biochemical oxygen demand (BOD) and chemical oxygen demand (COD) which can constitute environmental problems when directly discharged to the environment (Kamyab et al., 2018). The direct discharge of POME on the land can cause clogging, water logging of the soil, and destruction of the vegetation; its discharge into waterways can cause water contamination resulting in aquatic pollution and mortality of fish and other aquatic organisms (Mohammad et al., 2021). The environmental impact of POME cannot be over emphasized, hence the need for effective techniques for its reuse are of uttermost significance. The application of POME on agricultural soils to improve soil properties and crop productivity has been reported in several studies (Ihem et al., 2015; Obasi et al., 2019; Maliki et al., 2020; Okolie et al., 2020; Alam et al., 2022; Enujeke et al., 2023).

Soil pH and exchangeable acidity (EA) were consistently higher in POME amended soils as compared to rubber processing effluent (RPE) while 600 ml POME application performed better for plant height and stem girth of tomato (Lycopersicon esculentum) seedlings (Maliki et al., 2020). Similarly, Obasi et al. (2019) reported that increased rates of POME increased the concentrations of soil exchangeable bases such as calcium and potassium. Soils treated POME (3.5 $m^3$/ha) significantly produced higher grain yield and dry matter of maize plants as well as improved soil properties such as N,P,K, and residual organic C, and soil pH (Ihem et al., 2015). The results from the study of Alam et al. (2022) showed that the application of 70 % POME + 15 % cocopeat + 15 % sand significantly ($P \leq 0.05$) enhanced the growth and yield performance of Brazilian spinach (Alternanthera sissoo) such as plant height, number of branches, number of leaves, canopy coverage area, growth rate, fresh weight, and dry weight. Enujeke et al. (2023) evaluated the toxic effect of POME on maize at varying concentrations (25, 50, 75 and 100 %) alongside the control, the results indicated that POME have negative effects on the germination and growth of maize. Okolie et al. (2020) investigated the impact of POME on the populations of Rhizobium and Meloidogyne species on different cowpea cultivars and reported that increased levels of POME application increased number of functional root nodules in all the cultivars, but decreased length of roots and number of non- functional nodules. Furthermore, nematode populations drastically decreased with increase in POME quantities. The aim of the study was to investigate the influence of different application rates of fermented and treated POME on the performance of soybean.

# MATERIALS AND METHOD

## Study Location

The study was a pot experiment carried out between June and September at the Faculty of Agriculture, Kogi State University, Anyigba Kogi State. The site is located on latitude $7^0 15' N - 7^0 29' N$ and longitude $7^0 11' E - 7^0 32' E$, it is situated within the Southern Guinea Savanna agro-ecological zone of Nigeria. The dry season generally extend from November to March. Temperature shows variation throughout the year with average monthly temperature varying between 170C and rainfall of 1600mm (Amhakhian et al., 2010 and Agboola et al., 2016). The soils used for this experiment was obtained from farms along Faculty of Agriculture, Kogi State University, Anyigba, Kogi State Nigeria.

## Treatments and Experimental Design

The soil samples obtained were air dried and sieved through 2mm sieve to remove stone, gravel and debris. Exactly 10kg of sieved soil was weighted into each experimental pot (24 pots). Palm oil mill effluent was obtained from a palm oil milling site in Anyingba aseptically into a 100 liter drum of diameter 0.83 m. Treatment of the POME was by fermentation as outlined in the procedure of Onyia et al. (2001). Fermentation of the raw POME in the drum was conducted by addition of urea and calcium hydroxide [Ca $(OH)^2$] maintaining a temperature of 30°C to facilitate microbial activity and nitrogen mineralization. The POME was stirred daily to provide aeration and allowed to ferment. The fermentation process lasted for 20 days in an enclosed room to allow for decreased production of phytotoxic compound. The Soyabean variety planted was TGX-1448E procured from an Agro-allied store in Anyigba – this variety is easily available for farmers to use in the study location. The experiment was laid out in a completely randomized design (CRD). The treated POME was applied to the soil in ring form at the middle of each experimental pot at different rates - Treatment one (0$m^3$/ha ) serve as control, treatment two (30$m^3$/ha ), treatment three (90$m^3$/ha), treatment four (110$m^3$/ha ) was replicated 6 (six) times.

## Laboratory Analysis

Prior to planting, treated POME was taken to the laboratory for chemical analysis to ascertain nitrogen (N), phosphorus (P) and potassium (K) contents. Also, sieved soil samples were taken to the laboratory for pre planting and post planting analysis. Soil particle size analysis was carried out using hydrometer method which involves the dispersion of soil sample with sodium hexametaphosphate. The percentage clay, silt and sand were determined according to Bouyocous (1962). The textural class of the soil was determined using textural triangle. Soil pH was determined with the used of pH meter using glass and reference electrode (McLean, 1982). Organic carbon content was

determined using Walkley-Black (1934) wet digestion method. It involves oxidation with dichromate and tetra-oxo-sulphate (vi) acid. The residual dichromate was titrated against ferrous sulphate. The available phosphorus in the soil and plant was determined by the (Bray and Kurtz, 1945) extraction procedure. Extracted phosphorus was read calorimetrically at a wavelength of 660um after the development of molybdenum blue colour. Cation exchange capacity (C.E.C) and exchangeable bases (K, Ca, Mg and Na) were determined after extracting the soil samples by ammonium acetate at pH 7.0. Exchangeable Ca and Mg in the extracts were analyzed using atomic absorption spectrophotometer, while Na and K were analyzed by flame photometer (Thomas, 1982). The total nitrogen content of the soil and plant tissue samples was determined using the Kjeldahl method (Bremner and Mulvancy, 1982). Sample was digested with concentrated H2SO4 the percentage of Nitrogen plant was calculated thus:

$$\%N = M \times T \times 0.014 \times \frac{V_1}{V_2} \times \frac{V_2}{w_t}$$

M=Molarity of acid
T=Control of litre value
$V_1$=Final volume of digest
$V_2$=Volume of digest used in distillation
$w_t$=Weight of plant used for digest

### Measurement of Crop Growth and Yield Parameters

Growth parameters such as plant height (cm), number of leaves per plant, number of branches per plant and plant stem girth (cm) were measured once in two weeks. Nodule parameters were taken 45 days after planting, the plants were carefully uprooted, and roots were washed with water thoroughly such that they were free of soil particles. Nodules were collected from the roots, they were counted and weighed. The fresh weight of the plants, shoots fresh weight, roots fresh weight were also taken. Plant shoots, roots and nodules were oven dried at 700C for 24 hours and the dry weight was taken. Nodule effectiveness was determined using the following method:

$$Nodule\ effectiveness = \frac{shoot\ dry\ weight}{nodule\ dry\ weight}$$

### Statistical Analysis

At harvest, the number of pods per plant, weight of pods and number of seeds per pots were computed. The data collected were subjected to analysis of variance (ANOVA) as described by Gomez (Gomez and Gomez, 1984) and significant difference among treatment means were separated using the least significant difference (LSD) at 5% level of significance (Steel and Torrie, 1982).

## RESULTS AND DISCUSSION

### Physical and chemical properties of the soils used for experiment

Some selected physical and chemical properties of soil used are shown in Table 1. The pH of the soil was 6.2. This is closer to the neutral range of pH, which is optimum for most crops and would ensure the optimal performance of nitrogen fixing organism (Rhizobia) in the soil. The total nitrogen content of the soil used was low (0.07 %) making it suitable for assessing the impact of the organic material added to the soil in the experiment. The phosphorus content of the soil was 8.30 mg/kg while the exchangeable bases - calcium, potassium, magnesium, and sodium were 2.04, 0.32, 0.40, and 0.23 cmol/kg respectively. The exchangeable acidity and cation iron exchange capacity were 0.30 and 3.29 cmol/kg respectively. The texture of the soil was loamy sand according to USDA system of classification..

**Table 1:** Physical and chemical properties of the soils used for the experiment

| Soil properties | Values |
|---|---|
| pH in $H_2O$ | 6.2 |
| Organic Carbon (%) | 0.83 |
| Total nitrogen (%) | 0.07 |
| Available phosphorus (mg/kg) | 8.3 |
| Calcium (cmol/kg) | 2.04 |
| Potassium (cmol/kg) | 0.32 |
| Magnesium (cmol/kg) | 0.4 |
| Sodium (cmol/kg) | 0.23 |
| Exchangeable acidity (cmol/kg) | 0.3 |
| C.E.C (cmol/kg) | 3.29 |
| Sand (%) | 85.2 |
| Silt (%) | 10 |
| Clay (%) | 4.8 |
| Textural class (USDA system) | Loamy sand |

### Analysis of Palm Oil Mill Effluent

Prior to planting, the POME used contained Nitrogen (0.0078 %), (50.50 mg/kg) phosphorus and potassium (186 cmol/kg) as seen in Table 2.

**Table 2:** Analysis of Palm Oil Mill Effluent

| Nitrogen (%) | Phosphorus (mg/kg) | Potassium (cmol/kg) |
|---|---|---|
| 0.0078 | 50.5 | 186 |

### Effect of Palm Oil Mill Effluent on Number of Branches per Soybean plant

The application of POME had no significant effect on the number of branches of soybean at second, fourth, and sixth weeks after sowing (WAS) but had significant effect ($P<0.05$) at eight, tenth and twelfth WAS (Table 3). The

number of branches per plant increased with increasing rates of POME application. At 8 WAS, 110m$^3$/ha had the highest number of branches (9.66) which is statistically different from other treatments. Treatments 90 and 30m$^3$/ha recorded (8.16) and 0m$^3$/ha gave the lowest (6.83). At 10 WAS, the number of branches per plant (13.33) recorded in treatment 110m$^3$/ha was only significantly different from 30m$^3$/ha (10.83) and the control (9.66). There was no significant difference in the number of branches between 110m$^3$/ha and 90m$^3$/ha which had 11.16. At 12 WAS, there was no significant difference among treatments 110m$^3$/ha, 90m$^3$/ha, and 30m$^3$/ha which had 15.16, 14.16, 13.66 respectively. However, lowest number of branches (12.00) at 12 WAS were recorded from the control.

## Effect of Palm Oil Mill Effluent on the Number of Leaves Per Soybean Plant

The application of POME had no significant effect on number of leaves of soybean at second WAS but had significant effect (P<0.05) at fourth, sixth, eight and twelfth WAS (Table 4). The number of leaves per plant increased with increasing rate of POME applied except for 2 WAS. At fourth WAS, T4 (110m$^3$/ha) gave the highest number of leaves (9.83) which is statistically different from other treatment except T3 (90m$^3$/ha) which is not statistically different from T4 (110m$^3$/ha). T2 (30m$^3$/ha) recorded (8.66) and control gave the lowest (8.33). At 6 WAS, T4 (110m$^3$/ha) was only significantly different (12.00) from the control (8.66) while T¬3 (90m$^3$/ha) and T2 (30m$^3$/ha) recoded (11.00 and 10.50) respectively. However, at 8 to 12 WAS, T4¬ (110m$^3$/ha) consistently had the highest mean number of leaves which were statistically different from other treatments (90m$^3$/ha, 30m$^3$/ha, and control). It is also important to highlight that there was no statistical difference in the number of leaves recorded for 90m$^3$/ha, 30m$^3$/ha, and control within 8 to 12 WAS. At 12 WAS, 110m$^3$/ha produced 30.33a mean number of leaves while 27.00, 24.66, and 22.16 were recorded for 90m$^3$/ha, 30m$^3$/ha, and control respectively.

## Effect of Palm Oil Mill Effluent on Height (cm) per Soybean Plant

The application of palm oil mill effluent had no significant influence (p<0.05) on the height (cm) of soybean at 2 WAS (Table 5). Plant height increased with increasing rates of POME applied consistently at 4, 6, and 12 WAS. The application of 110m$^3$/ha produced tallest soybean plants followed by 90m$^3$/ha, 30m$^3$/ha, and the lowest recorded from control. At 12 WAS, 110m$^3$/ha recorded the highest plant height (32.00) which is statistically different from 90m$^3$/ha, 30m$^3$/ha, and control which had 30.00, 28.66, and 26.33 cm respectively.

**Table 3:** Effect of Palm Oil Mill Effluent on Number of Branches per Soybean plant

| Treatment | Number of branches | | | | | |
|---|---|---|---|---|---|---|
| | 2 WAS | 4 WAS | 6 WAS | 8 WAS | 10 WAS | 12 WAS |
| $T_1$ (control) | 3.5 | 4.5 | 5.33 | 6.83c | 9.66b | 12.00b |
| $T_2$ (30m$^3$/ha) | 3.3 | 4.3 | 5.6 | 8.16b | 10.83b | 13.66a |
| $T_3$ (90m$^3$/ha) | 3.5 | 4.3 | 5.3 | 8.16b | 11.16ab | 14.16a |
| $T_4$ (110m$^3$/ha) | 3.5 | 4.3 | 5.5 | 9.66a | 13.33a | 15.16a |
| LSD (P<0.05) | NS | NS | NS | 1.17 | 2.44 | 1.76 |

**Note:** LSD = Least significant difference, WAS = Week after sowing, NS = Not significant.
Treatment means in a column with different letters are statistically significant ($P < 0.05$).

**Table 4:** Effect of Palm Oil Mill Effluent on the Number of Leaves per Soybean Plant

| Treatment | Number of leaves | | | | | |
|---|---|---|---|---|---|---|
| | 2 WAS | 4 WAS | 6 WAS | 8 WAS | 10 WAS | 12 WAS |
| $T_1$ (control) | 5.33 | 8.33c | 8.66b | 19.50c | 23.83b | 22.16b |
| $T_2$ (30m$^3$/ha) | 5.66 | 8.66bc | 10.50ab | 22.00bc | 26.00b | 24.66b |
| $T_3$ (90m$^3$/ha) | 5.16 | 9.50ab | 11.00a | 22.83bc | 27.66b | 27.00ab |
| $T_4$ (110m$^3$/ha) | 5.66 | 9.83a | 12.00a | 27.16a | 33.16a | 30.33a |
| LSD (P<0.05) | NS | 0.89 | 2.16 | 3.85 | 4.24 | 3.93 |

**Note:** LSD = Least significant difference, WAS = Week after sowing, NS = Not significant.
Treatment means in a column with different letters are statistically significant ($P < 0.05$).

**Table 5:** Effect of Palm Oil Mill Effluent on Height (cm) per Soybean Plant

| Treatment | Plant height per plant (cm) | | | | | |
|---|---|---|---|---|---|---|
| | 2 WAS | 4 WAS | 6 WAS | 8 WAS | 10 WAS | 12 WAS |
| $T_1$ (control) | 9.5 | 11.33d | 15.00d | 17.66b | 21.83b | 26.33d |
| $T_2$ (30$m^3$/ha) | 9.51 | 12.50c | 16.33c | 18.50b | 22.50b | 28.66c |
| $T_3$ (90$m^3$/ha) | 9.83 | 13.66b | 17.83b | 19.16b | 23.00a | 30.00b |
| $T_4$ (110$m^3$/ha) | 10 | 15.00a | 18.83a | 21.50a | 24.50a | 32.00a |
| LSD (P<0.05) | NS | 1.01 | 0.97 | 1.55 | 1.51 | 1.39 |

**Note:** LSD = Least significant difference, WAS = Week after sowing, NS = Not significant. Treatment means in a column with different letters are statistically significant ($P < 0.05$).

## Effect of Palm Oil Mill Effluent on Stem Girth (cm) per Soybean Plant

The results in Table 6 shows that the application of POME had no significant effect on stem girth per soybean plant at second, fourth, sixth and eight WAS, but had significant influence ($p < 0.05$) for tenth and twelfth WAS. At 10 to 12 WAS, T4¬ (110$m^3$/ha) had the highest stem girth per plant which was statistically different from other treatments (90m3/ha, 30 $m^3$/ha, and control). Conversely, there was no significant difference in stem girth between 90$m^3$/ha and 30 m3/ha. At 12 WAS, 110$m^3$/ha had the highest stem girth per plant (0.91 cm) which was statistically different from 90$m^3$/ha, 30$m^3$/ha, and control which had 0.86, 0.83, and 0.75 cm respectively.

## Effect of Palm Oil Mill Effluent on the number of nodules, nodule weight and nodules effectiveness of per Soybean Plant

Table 7 shows the effect of POME application on the number of nodules, nodule weight, and nodules effectiveness in soybean. Statistical analysis showed that there was no significant differences in the nodules effectiveness in soybeans from the different rates of POME assayed. The application of POME at 110$m^3$/ha had the highest number of nodules (8.00) which was not statistically different from the response at 90$m^3$/ha (6.33) and 30$m^3$/ha (5.66) but was significantly different from the control (2.66). On the other hand, the results showed that there was significant difference in the value of the dry weight of nodules at different rate of POME application compared to control. The application of POME at 110$m^3$/ha and 90$m^3$/ha gave the highest nodule weight (0.005 and 0.007 g repectively) which were statistically significant from 30$m^3$/ha and control (0.004 g and 0.002 g respectively). It is important to highlight that there was no significant difference between the dry weight of nodules from 30$m^3$/ha and the control.

## Effect of Palm Oil Mill Effluent on the number of pods, Pod weight, 100 seed weight and Total biomass (g) of Soybean at harvest

The effect of palm oil mill effluent on the number of pods, pod weight, 100 seed weight and total biomass (g) of soybean at harvest are presented in Table 8. The results of the analysis revealed that the highest rate (110$m^3$/ha) of POME application produced the highest number of pods (22.16), pods weight (5.11 g), 100 seed weight (14.73 g), and total biomass at harvest (9.77 g). There were no significant difference in the number of pods, pods weight, and 100 seed weight recorded from application of POME at 90$m^3$/ha, 30$m^3$/ha, and the control. Similarly, there was no statistical difference in the total biomass at harvest between application of POME at 30$m^3$/ha (7.09 g) and control (6.12 g). However, the application of POME at 90$m^3$/ha produced higher total biomass at harvest (7.68 g) compared to control.

## Effect of Palm Oil Mill Effluent on Nutrient Uptake of Soybean

Table 9 shows the effect of application of POME on the nutrient uptake of soybean. The highest nitrogen uptake (4.05 %) in the soybean plant was recorded from 110$m^3$/ha which was statistically different (P<0.05) from 90$m^3$/ha, 30$m^3$/ha, and control (3.60 %, 3.62 %, and 3.23 % respectively). Also, phosphorus uptake in the soybean plants also increased with increasing rate of POME applied. The application of POME at 110$m^3$/ha and 90$m^3$/ha gave the highest phosphorus uptake (0.39 % and 0.36 % respectively). However, there was no statistical difference in phosphorus uptake between 90$m^3$/ha and 30m3/ha (0.33 %) while control had the lowest mean value of phosphorus uptake (0.27%). The results from the analysis of potassium uptake in the soybean plants showed that there was no statistical difference in potassium uptake in soybean plants following the application of POME at 110$m^3$/ha, 90$m^3$/ha, and 30$m^3$/ha (0.39, 0.37, and 0.35 % respectively) but they were significantly higher than the control which had 0.20 % potassium content.

**Post-harvest Soil Chemical Properties from the Application of Palm Oil Mill Effluent planted to Soybean**

The post-harvest soil chemical properties from the application of palm oil mill effluent planted to soybean is presented in Table 10. The results of the analysis showed that there was no statistical difference (P<0.05) in the magnesium, potassium, and exchangeable aluminum following the application of the different rates of POME. The application of POME showed statistical difference in the concentrations of calcium and cation exchange capacity with the control but not within treatments (110 $m^3$/ha, 90 $m^3$/ha, and 30 $m^3$/ha). Similarly, there was no statistical difference recorded for 90 $m^3$/ha, 30 $m^3$/ha, and control in pH and sodium. Although, 110 $m^3$/ha recorded highest pH (6.6) and sodium (0.47 cmol/kg) levels. A trend in increase rate of POME application with increased rate in organic carbon and total nitrogen was recorded. The application of 110 $m^3$/ha, 90 $m^3$/ha, and 30 $m^3$/ha resulted in 2.47, 2.18, and 1.81 % respectively of organic carbon and the lowest recorded from control (1.32 %). Likewise 110 $m^3$/ha, 90 $m^3$/ha, and 30 $m^3$/ha gave 0.25, 0.20, and 0.16 % respectively of total nitrogen and the lowest (0.12 %) recorded from control. Highest available phosphorus were recorded from 110 $m^3$/ha and 90 $m^3$/ha (21.68 and 20.02 mg/kg respectively) followed by 30 $m^3$/ha (17.33 mg/kg) and the control (11.18 mg/kg).

**Table 6:** Effect of Palm Oil Mill Effluent on Stem Girth (cm) per Soybean Plant

| Treatment | Stem girth per plant (cm) | | | | | |
|---|---|---|---|---|---|---|
| | 2 WAS | 4 WAS | 6 WAS | 8 WAS | 10 WAS | 12 WAS |
| $T_1$ (control) | 0.25 | 0.36 | 0.51 | 0.68 | 0.68c | 0.75c |
| $T_2$ (30$m^3$/ha) | 0.28 | 0.38 | 0.53 | 0.7 | 0.73b | 0.83b |
| $T_3$ (90$m^3$/ha) | 0.3 | 0.4 | 0.55 | 0.75 | 0.75b | 0.86b |
| $T_4$ (110$m^3$/ha) | 0.31 | 0.41 | 0.56 | 0.76 | 0.80a | 0.91a |
| LSD (P<0.05) | NS | NS | NS | NS | 0.06 | 0.06 |

**Note:** LSD = Least significant difference, WAS = Week after sowing, NS = Not significant. Treatment means in a column with different letters are statistically significant ($P < 0.05$).

**Table 7:** Effect of Palm Oil Mill Effluent on the number of nodules, nodule weight and nodules effectiveness of per Soybean Plant

| Treatment | Nodules parameters | | |
|---|---|---|---|
| | Number of nodules | Nodule weight (g) | Nodules effectiveness |
| $T_1$ (control) | 2.66b | 0.002b | 138.72 |
| $T_2$ (30$m^3$/ha) | 5.66a | 0.004b | 70.57 |
| $T_3$ (90$m^3$/ha) | 6.33a | 0.005a | 79.38 |
| $T_4$ (110$m^3$/ha) | 8.00a | 0.007a | 73.83 |
| LSD (P<0.05) | 2.69 | 0.002 | NS |

**Note:** LSD = Least significant difference, WAS = Week after sowing, NS = Not significant. Treatment means in a column with different letters are statistically significant ($P < 0.05$).

**Table 8:** Effect of Palm Oil Mill Effluent on the number of pods, Pod weight, 100 seed weight and Total biomass (g) of Soybean at harvest

| Treatment | Number of pods | Pods weight (g) | 100 seed weight (g) | Total biomass at harvest (g) |
|---|---|---|---|---|
| $T_1$ (control) | 14.66b | 3.37b | 9.39b | 6.12c |
| $T_2$ (30$m^3$/ha) | 16.16b | 3.80b | 10.52b | 7.09bc |
| $T_3$ (90$m^3$/ha) | 17.66b | 4.04b | 11.98b | 7.68b |
| $T_4$ (110$m^3$/ha) | 22.16a | 5.11a | 14.73a | 9.77a |
| LSD (P<0.05) | 3.84 | 0.75 | 2.64 | 1.37 |

**Note:** LSD = Least significant difference, WAS = Week after sowing, NS = Not significant. Treatment means in a column with different letters are statistically significant ($P < 0.05$).

**Table 9:** Effect of Palm Oil Mill Effluent on the Nutrient Uptake of Soybean

| Treatment | Nutrients (%) | | |
|---|---|---|---|
| | Nitrogen | Phosphorus | Potassium |
| $T_1$ (control) | 3.23b | 0.27c | 0.20b |
| $T_2$ (30m$^3$/ha) | 3.62b | 0.33b | 0.35a |
| $T_3$ (90m$^3$/ha) | 3.60b | 0.36ab | 0.37a |
| $T_4$ (110m$^3$/ha) | 4.05a | 0.39a | 0.39a |
| LSD (P<0.05) | 0.39 | 0.05 | 0.07 |

**Note:** LSD = Least significant difference, WAS = Week after sowing, NS = Not significant. Treatment means in a column with different letters are statistically significant ($P < 0.05$)

**Table 10:** Effect of Palm Oil Mill Effluent on the Nutrient Uptake of Soybean

| Treatments | pH | OC (%) | TN (%) | Av. P (mg/kg) | Ca | Mg | Na | K | EA | CEC |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | cmol / Kg | | | | | |
| $T_1$ (control) | 6.20b | 1.32d | 0.12d | 11.18c | 2.30b | 0.41 | 0.31b | 0.52 | 0.31 | 3.85b |
| $T_2$ (30m$^3$/ha) | 6.28b | 1.81c | 0.16c | 17.33b | 3.17a | 0.5 | 0.33b | 0.55 | 0.32 | 5.68a |
| $T_3$ (90m$^3$/ha) | 6.36ab | 2.18b | 0.20b | 20.02a | 3.24a | 0.51 | 0.38ab | 0.62 | 0.34 | 5.02a |
| $T_4$ (110m$^3$/ha) | 6.63a | 2.47a | 0.25a | 21.68a | 2.98a | 0.55 | 0.47a | 0.66 | 0.36 | 5.28a |
| LSD (P<0.05) | 0.29 | 0.2 | 0.01 | 1.87 | 0.33 | NS | 0.11 | NS | NS | 0.49 |

**Note:** LSD = Least significant difference, WAS = Week after sowing, NS = Not significant. Treatment means in a column with different letters are statistically significant ($P < 0.05$)

## DISCUSSION

### The effect of Application of Palm Oil Effluent on the Growth and Yield of Soybean

The highest nitrogen and phosphorus uptake was recorded from the application of POME at 110m$^3$/ha indicating that increased rate of POME increased nitrogen and phosphorus uptake in soybean which was translated into growth (stem girth, plant height, number of leaves, and number of branches) and yield (dry weight of nodules, nodule weight, number of pods, pods weight, 100 seed weight, and total biomass at harvest). Similar results of increased application rates of POME contributing to crop growth and yield were reported in previous studies (Ihem et al., 2015; Agboola et al., 2016; Maliki et al., 2020; Okolie et al., 2020). Soils treated POME (3.5 m$^3$/ha) significantly produced higher grain yield and dry matter of maize plants (Ihem et al., 2015). Agboola et al. (2016) reported an increase in the number of leaves of amaranth from the application of POME to the soil. The application of 600 ml of POME performed better in terms of plant height and stem girth of tomato (Lycopersicon esculentum) seedlings (Maliki et al., 2020). Okolie et al. (2020) reported that increased levels of POME application increased number of functional root nodules in different cultivars of cowpea but decreased length of roots and number of non- functional nodules.

An increase in the number of leaves enhances photosynthesis which will ultimately boost the yield of crop. The increase in the pod weight per plant of soybean may be due to an increase in the overall number of pods produced by each treatment relative to the control. Also, increased application of POME had a significant influence on plant height and total biomass such that greater assimilate production of soybean possibly due to increase in soil nutrient (nitrogen, phosphorus and organic carbon) due to addition of POME. The improvement of the chemical properties of soils by application of organic amendments have been reported to impact on soybean metabolism and production significantly, enabling high photosynthetic performance as well as improved growth and yield (Mutammimah et al, 2020; Bossolani et al., 2022; Wu et al., 2024). The significant increase in nodule weight per plant of soybean with increasing rate of POME can be attributed to increased soil phosphorus levels from the POME added. Phosphorus is a very vital soil nutritional element required for soybean growth and nodule nitrogen fixation (Rabbani et al., 2023). The application of different rates of phosphorus to different genotypes of soybean showed highest phosphorus use efficiency, root exudation, root dry weight, total root length, shoot dry weight, and yield and yield-contributing traits relative to the controls without phosphorus application (Salim et al., 2023). Nodule effectiveness decreased significantly with increasing rate of POME. This may be due to increase in soil phosphorus content as a result of POME application evident in post cropping soil analysis. DeMooy et al. (1973) reported disruption in nodule activity as a result of high phosphorus in soil.

**The effect of Application of Palm Oil Effluent on Soil Chemical Properties planted to Soybean**

The application of POME improved the levels of soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable bases (calcium and sodium), and cation exchange capacity planted to soybean. The application of POME to the soils probably increased the microbial population and mineralization in the soil and thereby increasing the fertility of the soil for beneficial crop performance. Eze et al. (2013) reported minimal increase in microbial population of soil receiving palm oil mill effluent. Soils treated POME (3.5 $m^3$/ha) significantly improved soil properties such as N, P, K, and residual organic C, and soil pH (Ihem et al., 2015). In another study (Maliki et al., 2020) reported that soil pH and exchangeable acidity were consistently higher in POME amended soils as compared to rubber processing effluent. Similarly, Obasi et al. (2019) reported that increased rates of POME increased the concentrations of soil exchangeable bases such as calcium and potassium.

## CONCLUSIONS

This study showed that POME fermentation provided enough period for microbial activity which promoted nutrient mineralization. Treated POME increased nodulation, growth, yield, nutrient uptake and also increase soil fertility. In the control, where POME was not added, there was a decrease in yield, growth, nodulation and nutrient uptake in soybean. Findings from this research also showed that increasing level of application of POME brought about an increase in growth and yield parameters of soybean, and treatment T4 (110$m^3$/ha) was found to be most beneficial of the different loading rates of treated POME evaluated. The potential of the application of POME on agricultural soils to improve soil chemical properties as well as growth and yield performance of soybean was explored in this study using pot experiment. Field studies are suggested to investigate the economic and environmental impact from the application POME particularly soybean intercropping system with cereals.

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