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Comparative Impact of Bio-slurry (Biofertilizer) Produced from Anaerobic Digestion of Domestic Waste and Inorganic Fertilizer on the Growth and Yield of Okra [*Abelmoschus esculentus* (L.) Moench]

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Authors' contributions

This work was carried out in collaboration among all authors. Author AFC designed the study, wrote the protocol and developed the first draft of the manuscript. Author OSE coordinated the cultivation and managed the literature searches while Author UIA managed the measurements of the okra plants and performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

The comparative effect of biofertilizer produced from anaerobic digestion of domestic wastes and inorganic fertilizer on the growth and yield of Okra was analyzed pot experiment and standard analytical procedures. The pot experiment was carried out to evaluate the response of Okra CV. LD88-1 to different rates of bio-slurry as an organic fertilizer, inorganic fertilizer (NPK 15:15:15) and their combinations. The bio-slurry was applied at the rate of 10,000, 20,000, 30,000 and 40,000L/ha, NPK fertilizer at 300kg/ha and combined application all the rates of bio-slurry with half the rate of NKP (150kg/ha). Soils unamended with fertilizer served as the control. There were 10 treatments replicated 3 times and laid out in a completely randomized design (CRD). Data were collected on plant height (cm), number of leaves, stem girth (cm), number of fruits and fresh fruit weight (g)/plant as well as leaf tissue mineral nutrient contents. Results obtained showed that amendment of soil with either the organic fertilizer (bio-slurry) or inorganic fertilizer (NPK) significantly ($P \leq 0.05$) enhanced the growth, fruit yield and leaf mineral content (N, P, K, Ca and Mg) of Okra plants compared to the unamend soil (Control). However, there was a significant ($P \leq 0.05$) decrease in plant height, number of leaves and fruit yield when the bio-slurry was applied at 40,000L/ha relative to 30,000L/ha. Generally, the combination of 20,000L/ha bio-slurry with 150kg/ha NPK 15:15:15 significantly produced the tallest plants (62.00cm) with the highest number of leaves (10.67/plant), fruits (6.67/plant) and fruit yield (89.57g/plant). Also, the highest macronutrient content of N (2.74%), P (0.62%), K (2.80%), Ca (1.92%) and Mg (1.52%) were obtained with this treatment. The combined use of 20,000L/ha of the bio-slurry and 150kg/ha NPK 15:15:15 may be used to enhance Okra production by resource poor farmers.

Keywords: Okra; Bio-slurry; organic fertilizer; inorganic fertilizer; anaerobic digestion; growth; yield.

1. INTRODUCTION

Low soil fertility is the major impediment limiting crop yield in developing countries especially among resource-poor farmers (Mohammadi & Sohrabi, 2012). In other to attain sufficient food production, improving poor soil is the key solution. Soil fertility is inextricably linked to the balance of microorganisms and plants (Vishwakarma et al., 2020). Soil health and plant productivity are severely influenced by numerous interactions among plant, soil and microorganisms (Harman et al., 2020). Soil microbes cooperate with one another and also with plant roots in numerous means providing a wide variety of essential acts which are valuable for sustaining the ecological balance in soil (Kumar et al., 2021).

Bio-slurry produced by anaerobic digestion is considered to be an effective biological fertilizer (biofertilizer) and soil conditioner (Nasir et al., 2010). The slurry retains all the nutrients originally present in the substrate material after anaerobic digestion, which makes it an effective organic fertilizer and a biofertilizer due to the presence of living microorganisms. Bio-slurry possess biofertilizing organisms (*Rhizobium, Azotobacter, Pseudomonas* and *Bacillus* species), which aids nutrient uptake, nitrogen fixation and solubilizes phosphate (Akubuenyi, 2019; Mohammed et al., 2009). The application of bio-slurry (biofertilizer) can be a probable approach to improve soil microbial status that stimulates the natural soil microbiota therefore influencing nutrient accessibility, decomposition of organic matter and improve crop production (Mohammadi & Sohrabi, 2012; Akubuenyi, 2019; Chaudhary et al., 2021). The plants can efficiently absorb these nutrients and the slurry could be applied as ready-to-use manure to seed, root or soil, to enhance the microbial activity through their multiplication which then mobilizes the nutrients to target plants that remarkably improved the soil fertility and sooner increases the crop health and production (Pandey & Singh, 2012; Ismail et al., 2013). Dressing of barely seeds with bio-slurry is an extremely effective way to control the barely yellow mosaic virus, which is one of the most destructive diseases in barley growing areas (Ofoefule et al., 2010).

For optimum plant growth, nutrients must be available in sufficient and balanced quantities (Chen, 2006). Farmyard manure is not as rich in micro-nutrient as biogas slurry (Gupta, 2007). Biofertilizers contain live microbes that helps in enhancing soil fertility by fixing atmospheric nitrogen, solubilizing phosphorus, decomposing organic wastes or by elevating plant growth through the production of growth hormones with their biological activities (Okur, 2018). They also protect host plants from pathogen by the synthesis of certain plant hormones (Aasfar, et al. 2021; Ghimirey et al., 2024).

The common Okra (*Abelmoschus esculentus*) is an important vegetable crop, highly valued for its succulent leaves and fresh immature pods. The important component of okra fruit is its high content of mucilage. Mucilage substances are acidic polysaccharides associated with proteins and minerals (Kumar et al., 2010). Most tropical rainforest soils are fragile and very prone to leaching, low in nutrients, acidic as well as low in organic matter as a result of poor soil management practices. The frequent use of inorganic fertilizer aggravates the problem. Okra is a tropical crop and its uptake of mineral nutrients is reportedly high (Siemonsma & Kouame, 2004). To guarantee high yield of okra on such marginal soils, there is need for an alternative source of fertilizer that is ecofriendly and cost-effective. The efficacy of bio-slurry as an organic fertilizer for enhanced crop yield has been tested and reported (Chen 2006; Hazarika & Ansari, 2007; Nasir et al., 2010).

A balanced fertilization strategy that combines the use of inorganic and organic fertilizers could proper solution to the challenge of food insecurity by enhancing soil fertility for improved crop production. This research work is therefore aimed at evaluating the impact of bio-slurry, NPK fertilizer and their combined effect on the growth and yield of Okra.

2. MATERIALS AND METHODS

2.1 Study Site and Sample Collection

The experiment was carried out in the screen house of the Faculty of Biological Sciences, University of Cross River State, Calabar Campus from August to December 2024. The bio-slurry was obtained from an anaerobic digester located close to the Department of Microbiology laboratory. The domestic wastes; plantain peels, vegetable stalks, yam peels and cow dung were collected from households and Akim slaughter in Calabar respectively. Okra seeds cv. LD88-1 were obtained from National Horticultural Research Institute (NIHORT), Ibadan, Oyo State, Nigeria. The NPK 15-15-15 fertilizer was bought from a fertilizer shop in Calabar, Cross River State. Top soil (0-15cm) was randomly collected from a fallow land behind the Microbiology laboratory and bulked to form a composite sample.

2.2 Soil and Bio-Slurry Samples Preparation and Analysis

The composite sample was air dried, ground and sifted through 2mm mesh sieve. The sample was then subjected to physicochemical analysis to determine for its physical and chemical properties following standard procedures (Jou, 1979; APHA, 1998).

2.3 Experimental Set-up

On the same fallow land, surface soil (0-15 cm) was collected and used in filling 30 perforated plastic pots with diameter of 20 cm and depth of 40 cm. Each pot was filled with 13.5kg of the surface soil (Table 1). Four seeds of Okra were planted per pot and thinned to one per pot a week after emergence. Bio-slurry collected from the digester was applied at different rates singly and in combination with NPK 15-15-15 fertilizer thus, 10,000L/ha, 20,000L/ha, 30,000L/ha, 40,000L/ha, 10,000L + 150kg NPK/ha, 20,000 + 150kg NPK/ha, 30,000L + 150kg NPK/ha, 40,000L + 150kg/ha and a full dose of the inorganic fertilizer 300kg NPK/ha. Equivalent rate of application per pot was 67.5ml, 135ml, 202ml, 270ml, 67.5ml + 1.0g NPK, 135ml + 1.0g NPK, 202ml + 1.0g NPK, 270ml + 1.0g NPK and 2.0g NPK respectively. Soil not amended with NPK or bio-slurry served as the control. Thus, there were 10 treatments laid out in a completely randomized design (CRD) with 3 replicates giving a total of 30 experimental units (pots). Application of bio-slurry and NPK fertilizer was done two weeks after planting. Plants were watered daily and grown to full maturity.

2.4 Data collection and analysis

Data were collected on stem girth (cm) measured 5cm above the soil level, plant height (cm), number of leaves/plants at 8 weeks after planting and at harvest. Data on number of pods, total fresh weight of pod/plant and mean weight of pod were collected at harvest. Pods were harvested on a 4- day interval and the total yield obtained through summation of such yields. At flowering, leaf sample were collected and ash content obtained by heating at 500^{o}C in a muffle furnace for 4 hours. Extraction and nutrient element determinations were done as described by Tel and Rao (1982). Data collected were subjected to analysis of variance (ANOVA) for a CRD using GenStat Discovery edition 4 and means were compared with Turkey's Honest Significant Difference (THSD) at 5% level of probability.

Table 1. The treatments pots, their combinations and connotations

Treatment pots	Treatment combinations	
A	Control (No slurry, no NPK fertilizer)	
B	10,000L of slurry/ha	- 67.5ml slurry/13.5kg soil
C	20,000L of slurry/ha	- 135ml slurry/13.5kg soil
D	30,000L of slurry/ha	- 202ml slurry/13.5kg soil
E	40,000L of slurry/ha	- 270ml slurry/13.5kg soil
F	NPK fertilizer (300kg/ha	- 300kg NPK/13.5kg soil
G	B + ½ F	- 67.5ml slurry/13kg soil + 150kg NPK
H	C + ½ F	- 135ml slurry/13kg soil + 150kg NPK
I	D + ½ F	- 202ml slurry/13kg soil + 150kg NPK
J	E + ½ F	- 270ml slurry/13kg soil + 150kg NPK

3. RESULTS

The soil was loamy sand in texture, moderately acidic in reaction (pH = 5.20), low in organic matter contents (1.59%), low in exchangeable cations but moderate in available P (15.03mg kg^{-1} soil). Results of the analysis of the bio-slurry showed that the pH was 6.80 with a temperature of 31°C, contained 5.00, 1.56, 0.79, 0.60 and 0.20g l^{-1} of N, P, K, Ca and Mg, respectively.

Application of bio-slurry or inorganic fertilizer or their combination significantly (P≤0.05) led to an increase in Okra leaf nutrient elements evaluated when compared to the control (no fertilizer) excepting Ca and Mg where full dose of NPK had no significant (P>0.05) different with the control (Table 2). With the exception of P and Mg, the combination of half dose of NPK fertilizer with 20,000L/ha bio-slurry significantly (P≤0.05) produced plants with highest tissue contents of all the nutrient elements. Generally, increase in the concentration of the bio-slurry up to 30,000L/ha as sole application led to a significant increase in Okra leaf N and P, but with significant decrease with further increase to 40,000L/ha. However, for K, Ca and Mg, successive increase in the concentration of the bio-slurry significantly (P≤0.05) increased their concentration in Okra leaf.

Application of bio-slurry, inorganic fertilizer and their combination significantly (P≤0.05) enhanced Okra growth at 8WAP and at harvest compared to the control (no fertilizer) (Table 3). Pots amended 20,000L/ha of bio-slurry plus 150kg/ha NPK had significantly the tallest plants (46.00cm). There was a significant increase in the height of okra plants as the bio-slurry rate was increased from 10,000L/ha to 30,000L/ha but further increase to 40,000L/ha caused a significant (P≤0.05) decrease in growth. However, there was a no significant (P>0.05) difference in height between plants treated with full rate of NPK fertilizer (300kg/ha) and those treated with either 10,000 or 30,000L/ha bio-slurry in combination with the half dose NPK fertilizer. For leaf production, with the exception of 10,000L/ha and 40,000L/ha bio-slurry, other treatment significantly (P<0.005) increase the number of leaves produced by Okra plants compared to the control. The highest number of leaves per plant was obtained in pots where 10,000 or 20,000 or 30,000L/ha bio-slurry was combined with half dose of the NPK fertilizer. Increase in the rate of bio-slurry up to 30,000L/ha led to an increase in leaf production, but further increase to 40,000L/ha significantly impaired leaf production.

The stem girth of Okra plants was significantly increased with bio-slurry or inorganic fertilizer application only in pots treated with 40,000L/ha bio-slurry or full dose of NPK fertilizer, 10,000 and 20,000L/ha bio-slurry in combination with half dose of NPK fertilizer. The widest stem girth (2.93cm) was obtained in pots amended with 10,000L/ha bio-slurry plus half dose of NPK fertilizer. However, this treatment did not differ significantly (P<0.05) from either full dose of NPK or 20,000L/ha bio-slurry plus half dose of NPK fertilizer. At final harvest, pots amended with 20,000L/ha bio-slurry in combination with half dose of NPK fertilizer had significantly the tallest (62cm) plants closely followed by those treated with either 10,000 or 30,000L/ha bio-slurry in combination with half dose of NPK fertilizer.

The results of the yield of the Okra plants revealed that the number of fruits was significantly (P≤0.05) increased by soil amendment with either bio-slurry or NPK fertilizer or their combinations compared with the control except in pots treated with 40,000L/ha bio-slurry or its combination with half dose of NPK fertilizer (Table 4). Pots amended with 20,000L/ha bio-

Table 2. Effects of different rates of bio-slurry, inorganic fertilizer and their combination on macronutrient elements (%) contents of Okra leaf

Treatment	N	P	K	Ca	Mg
A (Control)	1.96i	0.29g	1.40i	1.48h	0.96f
B (10,000L/ha)	2.24g	0.35f	1.65h	1.60g	1.04e
C (20,000L/ha)	2.26g	0.42e	1.85g	1.65f	1.15d
D (30,000L/ha)	2.52c	0.56c	1.92f	1.72e	1.20c
E (40,000L/ha)	2.20h	0.41e	2.10e	1.86d	1.48b
F (NPK 300kg/ha)	2.38e	0.59b	1.90f	1.50h	0.92g
G (B+1/2 F)	2.66b	0.60ab	2.76b	1.90bc	1.49b
H (C+1/2 F)	2.74a	0.62a	2.80a	1.95a	1.52a
I (D+1/2 F)	2.49d	0.58bc	2.54c	1.88cd	1.50ab
J (E+ 1/2 F)	2.30f	0.47d	2.20d	1.92b	1.48b

**Means followed by the same letter within a column are not significantly different according to Turkey's Significant Difference (TSD) at 5% level of probability.*

Table 3. Effects of different concentrations of bio-slurry and inorganic fertilizer on height (cm), number of leaves and stem's girth (cm) per plant of Okra

Treatment	Height at 8WAP	No. of leaves at 8WAP	Stem's girth at 8WAP	Height at final harvest
A (Control)	24.67h*	4.33e	1.68de	35.33e
B (10,000L/ha)	29.00g	5.67de	2.10cd	42.33b
C (20,000L/ha)	33.33ef	6.33d	2.30cd	47.67c
D (30,000L/ha)	37.00cde	7.33cd	1.36ef	49.00c
E (40,000L/ha)	31.00fg	4.33e	2.41bc	46.33cd
F (NPK300kg/ha)	38.33bcd	8.33bc	2.62ab	50.00c
G (B + 1/2F)	41.33b	9.67ab	2.93a	57.33b
H (C + 1/2F)	46.00a	10.67a	2.51abc	62.00a
I (D + 1/2F)	40.00bc	9.33ab	1.68de	56.00b
J (E + 1/2F)	35.67de	6.67cd	1.05f	48.33c

** Means followed by the same letter within a column are not significantly different according to Turkey's Significant Difference (TSD) at 5% level of probability.*

Table 4. Effects of different concentrations of bio-slurry and inorganic fertilizer on number of fruits/plants, total weight (g) of fruit/plant and mean weight (g) of fruit of *Okra*

Treatment	No. of fruits/pant	Total wt. of fruits/plant	Mean wt. of fruits
A (Control)	3.00d*	24.26f	8.09c
B (10,000L/ha)	4.67bc	47.38d	10.59bc
C (20,000L/ha)	5.67abc	67.39c	11.94b
D (30,000L/ha)	6.33a	73.35bc	11.63b
E (40,000L/ha)	4.33cd	46.42d	10.82bc
F (NPK300kg/ha)	5.67abc	68.57c	12.19ab
G (B + 1/2F)	5.33abc	79.94b	15.08a
H (C + 1/2F)	6.67a	89.57a	13.50ab
I (D + 1/2F)	6.00ab	73.92bc	12.32ab
J (E + 1/2F)	4.33cd	36.11e	8.44c

** Means followed by the same letter within a column are not significantly different according to Turkey's Significant Difference (TSD) at 5% level of probability.*

slurry in combination with half dose of NPK fertilizer had plants with the highest number of fruits (6.67), but this treatment did not differ significantly (P>0.05) from many other treatments. Increase in bio-slurry rate significantly increased Okra –pod yield. However, there was a significant decrease in total fruit weight per plant when the rate of bio-slurry was increased to 40,000L/ha. Pots amended with 20,000L/ha bio-slurry in combination with half the dose of NPK fertilizer had higher pod yield (89.57g/plant) followed closely by 10,000L/ha bio-slurry plus half dose of NPK fertilizer (79.94g/plant). The mean fruit weight was significantly increased with bio-slurry and NPK fertilizer treatment with the exception of 10,000L/ha bio-slurry and 40,000L/ha bio-slurry plus half dose of NPK compared with the control. The highest fruit weight (15.08g) was obtained when pots were amended with 10,000L/ha bio-slurry in combination with half dose of NPK fertilizer. However, this treatment did not differ significantly (P<0.05) from NPK fertilizer (300kg/ha), 20,000 or 30,000L/ha bio-slurry in combination with half dose of NPK fertilizer.

4. DISCUSSION

The bio-slurry contained moderate concentration of the essential nutrient elements needed for plant growth. According to Akubuenyi (2019), bio-slurry contains adequate concentrations of essential macronutrients (Nitrogen, Phosphorous, Potassium, Calcium and Magnesium). The application of either bio-slurry or inorganic fertilizer or their combination significantly enhanced both growth and fruit yield of okra plants, as well as its nutrient contents, compared to the control. This could be attributed to the biofertilizing organisms (*Rhizobium, Azotobacter, Pseudomonas* and *Bacillus* species), which aids nutrient uptake, nitrogen fixation and solubilizes phosphate (Akubuenyi, 2019; Pandey et al., 2006) and also the presence of macronutirents in the inorganic fertilizer. According to Akanbi et al. (2004) and Uwah and Ogbonna (2013), growth and yield potential of okra could be fully expressed if nutrients are supplied in the right quantity, proportion and time. Okra being a high nutrient demanding crop could have responded to the nutrients added to the poor soil by amendment with the bio-slurry or inorganic fertilizer.

Generally, a combination of bio-slurry and half dose of the NPK fertilizer resulted in better growth and yield attributes of Okra than individual application of these fertilizer sources. The best combination was 20,000L + 150kg NPK/ha. This result is in line with the findings of earlier researchers (Chand et al., 2006; Abd El-Kader et al., 2010; Kujur et al.,2023;). They all observed in different crops that the combination of organic and inorganic fertilizer was more effective than individual application. The better fertilizing value of the combined use of the two sources of fertilizer could be attributed to a slow release of nutrient elements from the organic source complementing the quick release by the inorganic fertilizer. There is always the leaching of cations especially in loose soil with application of inorganic fertilizers. From the chemical composition of the bio-slurry and NPK fertilizer, it can be deduced that about 50kg N/ha, 100kg N/ha, 150kg N/ha 200kg N/ha and 45kg N/ha could have been released to the soil with application of 10,000 20,000, 30,000, 40,000l/ha bio-slurry and 300kg NPK 15-15-15/ha, respectively.

Application of 40,000l/ha of the bio-slurry either alone or in combination with the half dose of NPK fertilizer significantly reduced growth and yield of Okra. It is possible that there could have been nutrient toxicity arising from such high rate of application or the presence of some plant secondary metabolites such as phenols, alkaloids, tannins, etc., in higher concentration to induce phytotoxicity in Okra. Biofertilizer mitigates the effects of commonly used high quantity of chemical or synthetic fertilizers which included; environmental pollution, persistent changes in the soil ecology, physiochemical composition, decreasing agricultural productivity and cause several health hazards (Chaudhary et al., 2022). This result corroborates the findings of Salisu and Isiya (2024), who studied the effectiveness of a biofertilizer on crops like maize, beans, and millet by measuring the height of the plants with and without the biofertilizer over seven days, and reported that the biofertilizer significantly enhanced the growth of all three crops, with the most notable improvement seen in maize, followed by millet and then beans.

This trial has illustrated the need to complement the use of inorganic fertilizer with bio-slurry as biofertilizer which could enhance crop production, environmental safety and human health.

5. CONCLUSION

Bio-slurry produced by anaerobic digestion can be used as an effective biological fertilizer (biofertilizer). The nutrients originally present in the substrate material are retained after anaerobic digestion. The bio-slurry is a biofertilizer because of the presence of living microorganisms like *Rhizobium, Azotobacter, Pseudomonas* and *Bacillus* species which aids nutrient uptake, nitrogen fixation and solubilizes phosphate. Its application improves soil microbial status which stimulates natural soil microbiota, influences nutrient accessibility, decompose of organic matter and improve crop production. The combined use of the bio-slurry and NPK 15:15:15 can be used to improve soil fertility and enhance

Okra production. This concept can be scaled up for the attainment of food sufficiency.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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