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Black Soldier Fly Larvae Composited Organic Materials Improve Growth of Oil Palm Seedlings

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ABSTRACT
Background and Objective: A huge amount of organic waste is generated in agricultural operations, and the black soldier fly provides an opportunity for such waste to be converted into biofertilizers for raising oil palm seedlings. A nursery experiment was therefore conducted at the main station of the Nigerian Institute for Oil Palm Research (NIFOR) to evaluate the performance of a single application of black soldier fly larvae generated bio fertilizer or its combination with an inorganic fertilizer on oil palm seedlings height, stem girth, number of leaves and leaf area. **Materials and Methods:** To achieve the above objective, a factorial experiment was set up and laid out in a Randomized Complete Block Design (RCBD) and consisted of 6 levels (0, 50, 100, 150, 200 and 250 g) of black fly composited bio fertilizer synthesized from different organic sources which included poultry droppings. Cassava tubers, corn cobs, and palm oil mill effluent (POME), and 2 levels (0 and 42 g) of an inorganic fertilizer, namely NPKMgZnB 5:15:26:5:0.3:0.1, were used to grow oil palm seedlings for 9 months. The collected data were analyzed using One-way Analysis of Variance (ANOVA), while significant means were separated using Duncan's Multiple Range Test at a 5% level of probability. **Results:** Pre-treatment analysis showed that the soil was a sandy loam with high acidic content, low nutrient contents, particularly nitrogen, potassium, and organic carbon. Single application of the bio fertilizer at 250 g/palm produced more leaves (14.33) and the tallest palms with a height of 77.17 cm. **Conclusion:** The study concludes that the black soldier fly larvae-generated bio fertilizer can be used to raise oil palm seedlings to transplantable heights without the addition of an inorganic fertilizer.

KEYWORDS
Bio fertilizer, black soldier fly (BSF), oil palm seedlings, growth, organic materials

INTRODUCTION
The use of organic materials for improving crop yields is an age-old practice. Organic materials from plants or animal sources can supply macro and micro nutrients to soils[1,2]. The disadvantage of organic materials as fertilizers is that a large quantity of them is required in one application. This means that several tons of an organic fertilizer material are required to supply a fraction of the nitrogen, phosphorus, and potassium. This challenge has resulted in several studies geared toward the efficient utilization of

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organic materials to improve crop growth and yields. Consequently, studies have shown that combining organic materials used as fertilizers with inorganic fertilizers gives better crop yields. Most organic materials, when applied to soils, act as soil colloids, thereby acting as nutrient reservoirs and binders, and in the process prevent the highly leachable nutrients supplied through inorganic fertilization to the soil from leaching out of the soil exchange complex. This makes the nutrients available to the plants, especially during the period of critical demand. Many organic sources have been used as nutrient sources for fertilizing crops following curing processes that usually discourage farmers, especially where large amounts of the materials need to be cured. With the application of black soldier flies, the challenge in the curing of poultry droppings and cow dung becomes limited. Black soldier flies have the capacity to convert organic materials of all kinds into readily mineralizable organic forms. This process has made it possible to combine materials from different organic sources as one nutrient source, ready for use as a bio-fertilizer. Black soldier fly (*Hermetia illuceus)* belongs to the order Diptera and the family Stratiomyidae. They naturally live in temperate tropical areas[3]. The flies have recently gained significant attention because of the ability of the larvae to convert various organic wastes into compost while generating protein-rich larva biomass for animal feed Banks *et al.*[4]. They are saprophagous at the larval stage, at which stage they biodegrade various organic waste by feeding on it, making them efficient decomposers of organic matter.

In this present study, black soldier flies were used to biodegrade poultry droppings, corn cobs, POME, and cassava tubers as a bio fertilizer and used to grow oil palm seedlings in combination with an NPKMgZnB fertilizer.

MATERIALS AND METHODS

Study area: The study was carried out at the Entomology Division of the Nigerian Institute for Oil Palm Research (NIFOR). It is located on Latitude 6°33'N and Longitude 5°37'E and 149.4 m ASL. The study which was a factorial experiment consisting of 6 levels of a black fly composited organic fertilizer synthesized from different organic sources which included cassava tuber peals, poultry droppings, corn cobs and palm oil mill effluent (POME) and 2 levels of an inorganic fertilizer namely NPKMgZnB 5:15:26:5:0.3:0.1 were laid out as 6×2×3 in a Randomized Complete Block Design (RCBD) at the Nigerian Institute for Oil Palm Research (NIFOR). It commenced in April of 2023 with the sourcing of the organic materials from the Main station of the Nigerian Institute for Oil Palm Research (NIFOR) and terminated in May of 2024 after the last set of biometric readings for the Oil palm seedlings were taken.

Prior to the layout, the physical and chemical properties of the soil used for the experiment were determined in the laboratory using standard methods. Some chemical properties of the bio fertilizer were also determined.

Synthesis of bio fertilizer from the various organic materials: Cassava tubers, corn cobs and palm oil effluent (POME), and poultry droppings were gathered in a container in a ratio of 50:40:5:5. The organic materials were obtained from the Main station of the Nigerian Institute for Oil Palm Research (NIFOR). The weights were used to determine the ratios. The components were chopped and moistened, and the black soldier fly (BSF) larvae, obtained from the “Love House” of the insect cages used for raising black soldier flies by Entomologists at the Nigerian Institute for Oil Palm Research (NIFOR) were introduced. The container was covered and moistened daily for three weeks, by which time the bio fertilizer was generated while the black soldier fly had grown from the pupa to the adult fly stage, by which stage eggs were laid. The incubation was allowed for another week for the collection of the larvae for the commencement of another bio fertilizer generation. After the collection of the larvae, the generated bio fertilizer was dried in the sun for curing.

Nursery study: Ten kilograms of soil were weighed into polythene bags measuring 40×35 cm. A total of 36 bags were prepared and placed 60 cm apart for the inter rows and 45 cm within intra rows at the Entomology Division of the Nigerian Institute for Oil Palm Research (NIFOR). The polybags were then carefully labeled following treatment randomization. The bio fertilizer was applied by mixing it thoroughly with the soil in the poly bags in July, 2023 and was allowed to consolidate with the soil for one month, after which three-month-old seedlings were transplanted into the poly bags in August, 2023. The inorganic fertilizers were then applied in split applications beginning in September, 2023 by opening up the soil at the corner of a poly bag. The application for October was done opposite the spot for the first application.

Data collection: Growth data were collected at 3, 6, and 9 months after transplanting, but corresponded to 6, 9, and 12 months after planting. The parameters determined were the number of leaves palm^{-1}, palm height, stem girth, and leaf area, which was measured non-destructively[5,6]. Measurements for the number of leaves palm^{-1} were done by counting, seedlings' height was measured with the aid of a ruler from the base of the palm to the tip of the drawn-up leaves. Stem girth was measured with the aid of twine and spread on a ruler. These measurements commenced in November, 2023 and terminated in May, 2024. The palm leaf area was also determined.

Soil and bio fertilizer analysis: The soil particle size distribution (sand, silt, and clay) was carried out using the hydrometer method of Corley *et al*.[7]. The chemical properties of the soil and bio fertilizer used for the experiment were determined using standard laboratory methods. The parameters determined include soil pH in H_2O, organic carbon, total nitrogen, available P, exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+), and exchangeable acidity (Al^{3+} and H^+).

Statistical analysis: Data collected were subjected to One-way Analysis of Variance (ANOVA) using Genstat Statistical package, version 12. The significant means were separated using Duncan's Multiple Range Test at 5% level of probability.

RESULTS

Physical and chemical properties of the soil and bio fertilizer used for the experiment: Table 1 shows that the organic carbon was 1.14% for the soil and 73.56% for the bio fertilizer used for this experiment. Total nitrogen was 0.12 and 35.00% for the soil and bio fertilizer, respectively, pH was 5.50 for soil and 4.34 for the bio fertilizer, and exchangeable calcium was 3.09 cmol+/kg and 45.00% for soil and bio fertilizer respectively while exchangeable magnesium was 0.63 cmol+/kg and 35.00% for soil and bio fertilizer. Exchangeable potassium was 0.02 cmol+/kg and 8.50% for soil and bio fertilizer, respectively, while exchangeable sodium was 0.03 cmol+/kg and 75.00% for soil and bio fertilizer, respectively, while available phosphorus was 6.50 mg/kg and 12.00% for soil and bio fertilizer, respectively (Table 1). Exchangeable aluminium and hydrogen were only determined in soil and were 1.55 cmol+/kg and 0.10 cmol+/kg, respectively. Particle size distribution (sand, silt, and clay) was 779.3, 525.0, and 168.7 g/kg, respectively (Table 1).

Plant height: Plant height of the seedlings across the 3 months of sampling was indicated in Table 2. At 3 MAT, plant height of the seedlings measured at 3 months after treatment and 6 months after planting showed that a single application of the bio fertilizer at 50 g/palm gave the tallest seedlings at 43.4 cm, followed by the application of 200 g/palm of the bio fertilizer at 43.00 cm. The least seedlings height (35.20 cm) was produced by a combination of the application of 150 g of the bio fertilizer and 42 g of NPKMg 12:12:17:2. This trend was reversed at 6 MAT when the tallest seedlings were produced with the single application of the bio fertilizer at 250 g/palm followed by 200 g/palm of the bio fertilizer. This trend continued at 9 MAT with 250 g/palm producing the tallest seedlings at 77.17cm, followed by 200 g/palm of the bio fertilizer with a seedling height of 75.00 cm.

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

Parameter	Soil	Bio fertilizer (%)
Organic carbon (%)	1.14	73.56
Nitrogen (%)	0.12	35.00
C:N	10:1	2:1
pH (H_2O)	5.50	4.34
Ca^{2+} (cmol+/kg)	3.09	45.00
Mg^{2+} (cmol+/kg)	0.63	15.00
K^+ (cmol+/kg)	0.02	8.50
Na^+ (cmol+/kg)	0.03	75.00
Al^{3+} (cmol+/kg)	1.55	-
H^+ (cmol+/kg)	0.10	-
Available phosphorus (mg/kg)	6.50	12.0
Sand (g/kg)	779.3	-
Silt (g/kg)	525.0	-
Clay (g/kg)	168.7	-
Textural class	Sandy loam	

Stem girth: At 3 MAT, the biggest of the seedlings girth (7.77 cm) was produced with the application of 250 g/palm of the bio fertilizer, followed by a combination of 50 g of the bio fertilizer with 42 g of NPKMg 5:15:26:5:0.3:0.1 palm^{-1} with a seedlings girth of 7.57 cm. This trend did not continue at 6 MAT. A combination of 100 g of the bio fertilizer and 42 g of NPKMg 5:15:26:5:0.3:0.1 palm^{-1} gave the largest girth of 10.33, followed by a single application of the bio fertilizer at 200 g bio fertilizer palm^{-1}. At 9 MAT, the largest seedlings girths of 13.50 and 12.53 cm were produced with a single application of the bio fertilizer at 250 g/palm and a combination of the bio fertilizer at 250 g/palm with 42 g of NPKMg 5:15:26:5:0.3:0.1.

Number of leaves: At 3 MAT single application of the bio fertilizer at 200 g/palm produced the highest number of leaves, while the least number of leaves was produced by the control palm. At 6 MAT, a single application of the bio fertilizer at 250 and 200 g/palm combined with 42 g of NPKMg produced the highest number of leaves. At 9 MAT, a single application of 250 g/palm produced the highest number of leaves (14), followed by an application of 250 g in combination with 42 g of NPKMg 5:15:26:5:0.3:0.1 palm^{-1} (Table 2).

Leaf area: The leaf area is shown in Table 2. At 3 MAT, a single application of 200 g/palm of the bio fertilizer produced broader and larger leaves than the rest of the treatments. At 6 MAT, this trend was overtaken by the single application of 250 g/palm. The trend continued till 9 MAT, where a single application of 250 g/palm produced the broadest and largest leaves of oil palm seedlings with a leaf area of 977 cm^2 (Table 2).

DISCUSSION

The generated bio fertilizer from black soldier fly larvae performed better than single applications of the inorganic fertilizer or when the inorganic fertilizer was used in combination with the bio fertilizer. Increasing the single application of the bio fertilizer up to 250 g/palm produced taller palms with a higher number of leaves, which were larger and broader than the leaves from other treatment combinations, with higher photosynthetic abilities than when the bio fertilizer was applied at lower rates or when applied in combination with the inorganic fertilizer. The efficacy of the bio fertilizer in performing better than the single application of the inorganic fertilizer could be attributed to the low C:N ratio of the bio fertilizer. The low C:N ratio made nitrogen available for the palms' uptake, which resulted in huge vegetative growth of the oil palm seedlings. According to Brust[1], organic fertilizers and bio fertilizers with C:N ratio between 1 and 15 imply high mineralization and release of nitrogen to plants. This released nitrogen is usually available for plant uptake, and oil palms at all the stages of growth are efficient utilizers of nitrogen[8,9].

Table 2: Effects of black soldier fly composited bio-fertilizer and their interactions with NPKMg on plant height, stem girth, number of leaves and leaf area of oil palm seedlings

Treatments	3 MAT				6 MAT				9 MAT			
	Plant height (cm)	Stem girth (cm)	Number of leaves	Leaf area (cm^2)	Plant height (cm)	Stem girth (cm)	Number of leaves	Leaf area (cm^2)	Plant height (cm)	Stem girth (cm)	Number of leaves	Leaf area (cm^2)
0 g CPM+0 g NPKMg	38.67^{a}	6.87^{abc}	8.00^{a}	352.1^{ab}	47.90^{a}	8.37^{a}	9.67^{a}	518.0^{a}	71.33^{a}	10.50^{a}	10.33^{a}	546.10^{a}
0 g CPM+42 g NPKMg	40.33^{a}	6.90^{abc}	8.67^{a}	409.5^{ab}	49.07^{a}	8.77^{a}	9.33^{a}	600.9^{a}	59.67^{a}	10.73^{a}	10.33^{a}	504.90^{a}
50 g CPM+0 g NPKMg	43.37^{a}	6.63^{ab}	8.67^{a}	395.6^{ab}	55.60^{a}	8.03^{a}	9.33^{a}	644.8^{a}	73.67^{a}	10.50^{a}	10.00^{a}	816.60^{a}
50 g CPM+42 g NPKMg	37.37^{a}	7.57^{bc}	8.67^{a}	371.3^{ab}	57.83^{a}	9.60^{a}	9.67^{a}	695.8^{a}	67.00^{a}	11.17^{a}	10.33^{a}	594.80^{a}
100 g CPM+0 g NPKMg	39.47^{a}	7.03^{abc}	8.67^{a}	355.9^{ab}	49.07^{a}	8.40^{a}	9.00^{a}	523.2^{a}	75.67^{a}	10.67^{a}	10.33^{a}	615.90^{a}
100 g CPM+42 g NPKMg	38.03^{a}	6.00^{a}	9.00^{a}	304.3^{ab}	54.23^{a}	10.33^{a}	9.33^{a}	529.2^{a}	64.33^{a}	10.83^{a}	10.33^{a}	681.40^{a}
150 g CPM+0 g NPKMg	35.63^{a}	7.13^{abc}	9.33^{a}	317.8^{ab}	51.00^{a}	9.00^{a}	9.67^{a}	502.1^{a}	61.67^{a}	11.37^{a}	10.67^{a}	597.70^{a}
150 g CPM+42 g NPKMg	35.17^{a}	6.47^{ab}	8.33^{a}	260.9^{a}	49.83^{a}	8.57^{a}	9.33^{a}	466.2^{a}	74.67^{a}	10.90^{a}	10.67^{a}	603.10^{a}
200 g CPM+0 g NPKMg	43.03^{a}	8.17^{c}	9.67^{a}	497.3^{b}	59.53^{a}	10.30^{a}	9.67^{a}	625.6^{a}	75.00^{a}	11.00^{a}	11.00^{a}	670.60^{a}
200 g CPM+42 g NPKMg	37.30^{a}	6.83^{abc}	9.00^{a}	336.0^{ab}	47.73^{a}	10.03^{a}	10.67^{a}	675.8^{a}	66.67^{a}	11.03^{a}	10.67^{a}	488.20^{a}
250 g CPM+0 g NPKMg	40.40^{a}	7.77^{bc}	9.00^{a}	402.5^{ab}	60.00^{a}	9.97^{a}	10.67^{a}	782.6^{a}	77.17^{a}	13.50^{a}	14.33^{a}	977.90^{a}
250 g CPM+42 g NPKMg	35.83^{a}	8.20^{c}	9.33^{a}	373.9^{ab}	49.83^{a}	8.77^{a}	7.67^{a}	604.0^{a}	68.67^{a}	12.53^{a}	13.33^{a}	614.80^{a}
SE	NS	0.59	NS	85.2	NS	NS	NS	NS	NS	NS	NS	NS

Means with the same letters are not significantly different using Duncan's Multiple Range Test at $p<0.05$

The results obtained from the single application of the bio fertilizer at 250 g/palm were comparable with findings from earlier works on oil palm seedlings, where organic materials or inorganic fertilizers were used. Plant height of oil palm seedlings obtained from a single application of 250 g/palm was higher than that obtained from the works of Abidemi *et al.*[10] but lower than that of Osayande *et al.*[11] The higher seedling height obtained by Osayande *et al.*[11] could be attributed to the high exchangeable cations of the soils used for the experiment, which were a Rhodic Paleudalf from Epe and a Plinthic Tropudalf from Ibadan. The soils used for the experiment were a sandy loam Rhodic Paleudult. Rhodic Paleudult is the major soil occupying the NIFOR main station of the Nigerian Institute for Oil Palm Research (NIFOR). They are low in exchangeable cations with high exchangeable acidity[2,12]. The application of organic fertilizer sources becomes a direct method to increase the cation exchangeable capacities of Rhodic paleudult, which are high in variable clays, iron, and aluminium oxides. As observed by Efosa *et al.*[13], organic materials, when applied to soils, increase the negative charges of the soils, which in turn increase the cation exchange capacity of the soil. High cation exchange capacity of a soil indicates a high adsorption of cations on the soil exchange complex, which are then exchanged in soil solutions for the benefit of plant growth, usually measured by the height of the plant, number of leaves, as well as leaf area[9]. It has been shown that some of the criteria for measuring oil palm seedlings quality are the height of the seedlings, the number of leaves on the seedlings, and their leaf area, as well as the girth of the seedlings[10,11,13]. This study has shown that the use of the black fly-generated bio fertilizer improved these parameters. These parameters, namely oil palm seedlings height, number of leaves, leaf area, and stem girth, could only be improved through regular supply of nutrients, water, and light intensity for the formation of leaves. Nutrients responsible for the listed vegetative growth are nitrogen and phosphorus. These nutrients were high in the black soldier fly-generated bio fertilizer, which resulted in the ample formation of leaves. As reported by Efosa *et al.*[13], seedlings grown on soils with nutrient deficiencies will have fewer leaves due to difficulty in the formation of new ones. This is one of the challenges in raising oil palm nursery seedlings because it is a high-nutrient-demanding crop even at the nursery stage of growth. At the nursery stage, it produces one leaf in a month, which can easily dry off when nutrients such as nitrogen and phosphorus are limiting[8]. Regular production of leaves in the presence of nutrients results in taller and healthier palms. The number of leaves of oil palm has a direct correlation with the leaf area of oil palm seedlings. The bio fertilizer used for this study produced a higher number of leaves when applied at 250 g/palm, which meant that it supplied the required nitrogen and phosphorus for the growth and development of new leaves. Similarly, the application of the bio fertilizer at 250 g/palm also produced palms with larger girth. The values obtained were higher than those of earlier workers, such as Abidemi *et al.*[10].

CONCLUSION

Black soldier fly (BSF) generated bio fertilizer improved all oil palm seedlings' growth parameters and produced the tallest palms with larger and broader leaves. It also produced the highest number of leaves. This was achieved through the application of 250 g/palm of the black soldier fly composited organic materials. It is therefore recommended that black soldier fly larvae-generated bio fertilizer should be used to grow oil palm seedlings in the absence of inorganic fertilizers in a sandy loam soil.

SIGNIFICANCE STATEMENT

Black soldier fly larvae are currently being used in agriculture to convert the numerous wastes generated into bio fertilizer. Consequently, a study was initiated to determine the prospect of black soldier fly larvae-generated bio fertilizer on the growth of oil palm seedlings. The results showed that applying 250 g/palm of the bio fertilizer increased oil palm seedlings' height significantly ($p<0.05$) over the control and indicates that the bio fertilizer could be used to raise oil palm seedlings to transplantable heights. The study showed that using black soldier fly larvae-generated bio fertilizer is highly promising due to its narrow C:N ratio that allows for quick release and mineralization of nitrogen for oil palm seedlings uptake.

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