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Performance of Eggplant (*Solanum melongena L.*) as Affected by Biochar and Pig Manure Applications

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Abstract

Eggplant (Solanum melongena) is an important vegetable valued for its nutritional and health benefits. The intensification of available land for cultivation has led to fertility depletion and low crop yield. Biochar is increasingly recognized as a soil amendment, while pig manure enhances crop quality and soil health. This study aimed to determine the effects of biochar and pig manure on eggplant performance. A 3×4 factorial combination of biochar levels (0, 2.5, and 5 t/ha) and fertilizer levels (0, 30, 60 kg N/ha of pig manure and 60 kg N/ha urea as a check) was evaluated in a randomized complete block design with three replicates. Eggplant (MERDAN 465 F1) seedlings were transplanted at 60 cm × 50 cm spacing. The results revealed that applying 5 t/ha of biochar and 60 kg N/ha of urea resulted in a significant increase in eggplant growth compared to the other treatments. Fruit yield was significantly higher with the application of 5 t/ha of biochar (2872.2 kg/ha) than with 0 t/ha (939.5 kg/ha) but similar to 2.5 t/ha (1931.1 kg/ha). Fruit yield for the biochar and fertilizer interaction ranged from 1462 kg/ha (5 t/ha biochar with 0 kg N/ha fertilizer) to 4450 kg/ha (5 t/ha biochar with 60 kg N/ha urea). However, the fruit yield for plants treated with 5 t/ha of biochar with 60 kg N/ha of urea was similar to that of 5 t/ha of biochar with 30 kg N/ha of pig manure application. Considering the environmental cost, applying 5 t/ha of biochar with 30 kg N/ha of pig manure was adequate for good eggplant performance.

Keywords: Biochar, Eggplant yield, Pig manure, Sustainable production, Waste management.

1. Introduction

Eggplant is a commercially valuable vegetable from tropical and subtropical zones with different varieties that yield a wide range of fruits that vary in shape, size, and color. Early varieties of *Solanum melongena* looked like eggs, which gave rise to the name eggplant [1]. Additionally, it contains a lot of vitamins and minerals. With advantages that range from reducing the risk of heart disease to helping with blood sugar regulation and weight loss, eggplants are an easy and delicious addition to a healthy human diet.

According to the FAO [2], the average yield of eggplant in Nigeria is significantly lower than observed globally. The average world yield of eggplant in 2021 and 2022 increased from 29,957.4 to 31,353.9 kg/ha, while in Africa, the yield ranged from 20,431.7 to 20,037.9 kg/ha. Given that the population is expected to grow to around 262.6 million in 2030, the demand for food will rise substantially, placing immense pressure on agricultural systems already strained by declining soil health [3].

Low fertility, soil erosion, the use of susceptible and low-yielding cultivars, poor pest and disease control, restricted access to markets and inputs, and inadequate post-harvest handling and processing facilities are some of the causes. Thus, the primary challenges affecting crop performance and output in sub-Saharan Africa are inadequate fertility and ineffective soil management. To address fertility problems, farmers apply inorganic fertilizers such as potassium chloride, urea, superphosphate, and ammonium nitrate. These fertilizers enhance the soil by providing essential nutrients for crop growth and development [3, 4].

Unfortunately, the continuous use of inorganic fertilizers as the primary approach for soil nutrient management is unsustainable and economically burdensome, leading to soil degradation, environmental contamination, and nutrient leaching [5, 6]. Therefore, to safeguard soil health and maximize soil nutrient potential, a more sustainable, cost-effective, and efficient integrated nutrient management system is required. The use of agricultural waste by converting it into a useful source of soil amendment is a beneficial and sustainable method to improve soil fertility [7,8].

Commercial pig farming techniques have come under heavy examination because of their environmental implications or concerns [9], resulting in the need to identify and mitigate their environmental burdens. This is especially due to the industry's growing waste output, which, if improperly managed, poses a threat to environmental pollution [10]. Okoli *et al.* [11] and Ume *et al.* [12] reported that a significant part of agricultural waste currently ends up in rivers and lagoons, condemning numerous freshwater sources. Any kind of poor management might result in environmental issues. Thus, pig dung management is a crucial aspect of the sector [13, 14]. Diverting pig waste from the waste stream and using it as a resource for livestock feeding, biofertilizer production, and bioenergy generation, among other added-value products, is becoming more and more necessary to lessen the negative effects of careless disposal of pig waste into the environment [15].

Biochar is a by-product from charring organic materials rich in carbon and enhances soil properties, including moisture and nutrient retention and pH balance, and fosters the development of soil microbiota [16, 4]. Biochar and poultry manure have been recognized for their significant roles in enhancing soil fertility, promoting sustainable agricultural practices, and improving crop productivity. It could replace inorganic manure fertilizer in crop production to yield similar results while protecting soil health and the environment. However, research has examined the use of sole biochar and pig manure, there is limited investigation into the combined application of biochar and pig manure in Nigerian soils, especially for eggplant cultivation. Therefore, this study aimed to determine the effects of biochar and pig manure combinations on the growth and yield of eggplant.

2. Materials and Methods

2.1. Description of Experimental Site

The field experiment was carried out at the Department of Crop and Horticultural Sciences Research field located along Parry Road, University of Ibadan, Ibadan, Oyo State, Nigeria, with coordinates 7°27´7´´N 3°53´29´´E at an elevation of 162 meters above sea level.

2.2. Soil Collection and Analysis

Soil samples were collected randomly in a "W' shape at 15 cm depth from five sampling points in the site and mixed to give a composite sample [17]. The composite soil sample was air-dried and processed for the evaluation of physical and chemical properties using standard laboratory techniques [18]. Organic matter content was determined with the Walkley Black method using the dichromate wet digestion technique following Nelson and Sommers [19]. Total N was estimated by the micro-Kjeldahl digestion method of Bremner [20], while available P was analyzed by Bray P-1 extraction, after which it was stained with molybdenum blue reagent as described by Koralage *et al.* [21]. Exchangeable potassium, calcium, and magnesium were extracted by water-soluble ammonium acetate. Thereafter, potassium was assayed by a flame photometer while calcium and magnesium were with an atomic absorption spectrophotometer as agreed with Bisergaeva and Sirieva [22]. All the analyses were done in the Service Laboratory of the Department of Soil Resources Management, Faculty of Agriculture, University of Ibadan, Ibadan Nigeria. The soil properties are shown in Table 1.

Table 1. Pre-cropping soil physical and chemical properties of experimental soil.

Properties	Values	Critical range [23]	Remark
Sand (g/kg)	782	0-850	
Clay (g/kg)	82	0-600	
Silt (g/kg)	136	0-850	
Textural Class	Loamy Sand		
pH (1:1, H_2O)	6.17	6.0-7.5	Neutral
Organic carbon (g/kg)	0.68	1.0-5.0	Low
Total nitrogen (g/kg)	0.10	0.1-0.5	Low
Available Phosphorus (mg/kg)	28.43	10.0-30.0	Moderate
K (cmol/kg)	0.08	0.07-0.15	Moderate
Ca (cmol/kg)	2.27	2.0-5.0	Low
Mg (cmol/kg)	0.67	0.5-1.5	Low
Na (cmol/kg)	0.22	0.1-0.5	Moderate
Cu (mg/kg)	0.40	0.2-2.0	Moderate
Zn(mg/kg)	1.16	0.5-5.0	Moderate
Fe (mg/kg)	4.63	4.0-20.0	Low
Mn (mg/kg)	7.63	4.0-40.0	Moderate

2.3. Preparation of Biochar and its Properties

Dried maize cobs from a farm were chipped to smaller sizes to facilitate thermal decomposition. Maize cob biochar was produced using the widely used closed drum kiln method, as described by Adekanye *et al.* [24] at the Department of Crop and Horticultural Sciences, University of Ibadan. The biochar was then air-dried and ground using a mechanical grinder to particle sizes of 2 mm. The analysis of the biochar contained 0.98% nitrogen, 0.33% phosphorus, 0.41 % potassium, 14.79% Organic carbon, and a C: N ratio of 15.09 (Table 2).

Table 2. Chemical properties of the biochar and pig manure

Properties	Biochar	Pig Manure
Total N (%)	0.98	2.66
C: N Ratio	15.09	5.8
Total P (%)	0.33	0.78
Organic carbon (%)	14.79	15.43
Organic matter (%)	0.75	0.79
Ca (%)	0.07	1.84
Mg (%)	0.08	0.67
K (%)	0.41	0.25
Na (%)	0.04	0.16
Mn (mg/kg)	38.15	295.2
Fe (mg/kg)	1005.6	4289.8
Cu (mg/kg)	5.85	37.00
Zn (mg/kg)	114.6	221.2

2.4. Pig Manure Properties

The pig manure was collected from the pig unit of the Teaching and Research Farm of the University of Ibadan; and cured and air-dried. The pig manure had 2.66% total nitrogen, 0.78% Phosphorus, 0.25% potassium, 15.43% organic carbon, and a C: N ratio of 5.80.

2.5. Experimental Design and Treatment

The layout of the field experiment was a 3×4 factorial arrangement using a randomized complete block design replicated three times. The treatments were biochar application at 0, 2.5, and 5 t/ha and fertilizer applications at 0 kg N (No Fertiliser), 30 kg N/ha Pig Manure, 60 kg N/ha Pig Manure, and 60 kg N/ha of Urea.

2.6. Planting Procedure

The experimental field was cleared manually and stumped; debris was removed. Marking out of the various plots was done and a tillage operation was carried out. Each block had 12 plots, each measuring 2.4 m in length by 2 m in width with an alley of 1 m between plots and replicates. The cured pig manure used for the study was obtained from the Teaching and Research Farm of the University of Ibadan. The eggplant (*Solanum melongena* L.) MERDAN 465 F1 seed was obtained from a commercial seed store. Seedlings were raised in a nursery tray in the screenhouse of the Department of Crop and Horticultural Sciences for 6 weeks. Seedlings were transplanted to the field 6 weeks after sowing at 50 cm x 60 cm totalling 16 plants per plot and 33,333 plants/ha. Transplanting of the seedlings was carried out in the evening after a shower of rain.

2.7. Management Practices

Weeding was carried with a hoe on the field at 3, 6, and 9 WAT (WAT) and complimented with hand to uproot where needed. The pig manure and biochar were weighed according to the treatments using a weighing balance, applied using the broadcasting method two weeks before planting, and incorporated into the soil [24]. The ring application method was used for urea applications at 2 weeks after transplanting (WAT).

2.8. Data Collection

Data from each plot was collected non-destructively and the averages per plant were used. This entailed choosing four plants per plot from the middle row of each plot. The parameters measured were plant height (determined from ground level to tips of the youngest expanded leaves on the main stem using a measuring tape), stem diameter (using a Vernier caliper to measure the thickness of the stem), the number of leaves per plant and canopy spread (measured using a measuring tape to measure the widest expanse of the canopy of the plant). Leaf area per plant was calculated using the Rivera *et al.* [25] formula:

$$LA = 0.641\ (Lw \times Ll)$$

Where Lw is the width of the widest portion of the leaf and Ll is the length of the leaf from the base to the tip.

Shoot dry biomass and mature fruit yield (kg/ha) were measured using a portable laboratory weight balance (GX-10K Precision Balance).

2.9. Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using Statistical Analytic Software (SAS) version 9.0. Significantly different treatment means were separated using the Duncan Multiple Range Test at a 5% level of probability.

3. Results and Discussion

3.1. Soil Properties Before Cropping

The soil test conducted before planting showed that the soil was sandy loam with very high sand content but low clay content, classifying it as loamy sand (Table 1). The results indicated that the soil pH of 6.17 was within acceptable range. However, the soil organic carbon and total N were low, indicating an insufficient nutrient status to support good garden egg growth and yield [5]. The composition of the soil properties would require amendments like biochar and pig manure to improve the soil's physical, nutrient status, and biological properties [16, 4].

3.2. Effect of Biochar on Eggplant Growth

The height, number of leaves, and leaf area of eggplants treated with 5 t/ha of biochar were significantly higher than the other treatments (Table 3). However, the stem diameter and canopy spread of plants treated with biochar at 5 and 2.5 t/ha were similar, but the 5 t/ha biochar differed significantly from the control. The general pattern of growth recorded showed regularities as the plants were recorded to have similar trends for height, canopy spread, stem diameter, number of leaves, and leaf area. However, the plots that had biochar incorporated into the soil two weeks before transplanting were significantly higher in all growth parameters as mineralization of the nutrients began earlier and improvement in the soil's physical parameters. The better plant growth observed at an application rate of 5 t/ha of biochar can be attributed to the relatively high concentrations of biochar near the plant's root zone, which ultimately improves soil physical condition, enhances the availability of nutrients and moisture for the plants to use [26]. This finding agrees with the study of Berihun *et al.* [27], who reported an increase in plant height of garden peas following the application of maize biochar. The improved soil conditions promote the plant's root system for enhanced acquisition of nutrients for enhanced photosynthesis [28]. This assertion was evident in the observations made on the growth parameter with the increase in biochar application.

Applying fertilizers improved the growth of eggplants with a significantly higher response observed at 60 kg N/ha of urea compared to the other treatments for height, number of leaves, leaf area, and canopy cover of eggplants (Table 3). The responses observed for the levels of pig manure applications were similar to the control, except for 60 kg N/ha PM treated plants with significantly higher canopy cover than the control. The higher plant growth observed with urea application could be attributed to a sufficient supply of nitrogen, thus stimulating shoot elongation, and cell multiplication that promotes crop development. This result agrees with the investigations of Amiri *et al.* [29] that nitrogen fertilizer significantly affected the plant height, number of leaves, leaf area, and canopy cover of eggplant. However, the pig manure was able to promote eggplant development than the control indicating better growing conditions for growth. These results conformed with Sanni *et al.* [30] and Luo *et al.* [31] report that pig manure promotes plant growth by amending soil physical conditions and enhancing nutrient uptake. Consequently, the increase in pig manure application further enhances photosynthesis in the plant causing accumulation of more assimilates for increased growth.

The combined application of biochar and fertilizers indicated significant variations among the treatments (Table 3). Across the biochar levels, the highest responses of eggplant to fertilizer applications were when combined with urea. However, the values observed for biochar combined with 60 kg Nha urea were similar to the values for biochar at 2.5 t/ha or 5 t/ha in combination with 60 kg N/ha pig manure. The plant height, stem diameter, and number of leaves range from 11.03 to 20.73 cm, 0.29 to 0.51 cm, 3.33 to 6.66 in plants treated with biochar at 2.5 t/ha with 0 fertilizer and biochar at 5 t/ha with 60 kg N/ha of urea, respectively. Similarly, the respective eggplant leaf area and canopy spread were lowest in plants treated with biochar at 2.5 t/ha with 0 fertilizer (28.83 and 9.76 cm^2) and highest in plants treated with biochar at 5 t/ha with 60 kg N/ha of urea (347.80 and 24.30 cm^2). The highest plant height recorded at the combined application of 5 tonnes/ha biochar and 60 kg N/ha urea application rates in the study could be attributed to the adequate amount of nitrogen and the retention property of biochar which enhances healthy and faster growth of plants. This result agrees with She *et al.* [32] who noted that an increase in the quantity of biochar leads to an increase in the height of the plant (stem) and supported by Peng *et al.* [33] who reported increased nitrogen uptake and nitrogen retention under combined application of biochar and fertilizer.

Table 3. The influences of biochar, fertilizer, and their interactions on the growth of eggplants.

Treatment	Plant height (cm)	Stem diameter (cm)	Number of leaves	Leaf area (cm^2)	Canopy spread (cm^2)
Biochar					
0 (No biochar)	13.05b	0.34b	4.16b	67.93b	14.21b
2.5 t/ha	14.25b	0.38ab	4.33b	105.62b	17.03ab
5 t/ha	16.71a	0.43a	5.25a	175.15a	20.25a
Fertiliser					
0 (Control)	12.80b	0.32b	4.11b	57.07b	13.00c
30 kg N/ha PM	14.06b	0.39ab	4.22b	96.18b	16.51bc
60 kg N/ha PM	14.47b	0.38ab	4.33b	91.30b	17.21b
60 kg N/ha Urea	17.34a	0.43a	5.66a	220.38a	21.94a
Interactions					
B1F1	12.33bc	0.31bc	4.33b	47.07b	11.93cd
B1F2	12.06bc	0.32bc	3.33b	39.70b	11.53cd
B1F3	13.47bc	0.35bc	4.00b	58.47b	14.76b-d
B1F4	14.33bc	0.39a-c	5.00ab	126.47b	18.63a-c
B2F1	11.03c	0.29c	3.66b	28.83b	9.76d
B2F2	14.90bc	0.41a-c	4.33b	115.07b	18.13a-c
B2F3	14.10bc	0.39abc	4.00b	91.70b	17.33a-c
B2F4	16.97ab	0.44ab	5.33ab	186.87b	22.90a
B3F1	15.03bc	0.37bc	4.33b	95.30b	17.30abc
B3F2	15.23bc	0.44ab	5.00ab	133.77b	19.86ab
B3F3	15.87bc	0.41abc	5.00ab	123.73b	19.53ab
B3F4	20.73a	0.51a	6.66a	347.80a	24.30a

Note: B1- 0 t/ha (No biochar), B2- 2.5 t/ha biochar, B3 -5 t/ha biochar, F1 - 0 kg N/ha, F2 - 30 kg N/ha Pig Manure, F3 - 60 kg N/ha Pig Manure, F4 - 60 kg N/ha Urea, Treatment means having the same letter(s) along the same column are not significantly different at 0.05 probability level according to Duncan Multiple Range Test.

3.3. Effect of Biochar and Fertilizer on Dry Biomass of Eggplant

Biochar application at 2.5 and 5 t/ha significantly increased eggplant dry biomass weight than the control (Table 4). Eggplant in soils amended with 5 t/ha biochar had the highest biomass weight (153.23) but was at par with 2.5 t/ha biochar application. The increase in eggplant dry biomass with the applications of 5 and 2.5 t/ha of biochar compared to no biochar plots confirms the properties of biochar to improve crop growth as reported by Ramadhan *et al.* [34] findings. They indicated that the incorporation of biochar in the growth media had a notable impact on the growth, as evidenced by the increase in plant height, leaf area, and canopy spread. These parameters are indicators of crop performance [16]. The plant's ability to acquire nutrients promotes the accumulation of assimilate through photosynthesis. Consequently, there is the deposition of carbohydrates in the plants' tissue leading to biomass increase. The observed result indicated that further increase in biochar application promotes the conditions that encourage the accumulation of photosynthates, thus the higher dry biomass.

Fertiliser application also increased eggplant biomass weight. Eggplant in soils amended with 60 kg N/ha urea had the highest biomass weight and was significantly better than 60 kg N/ha pig manure, 30 kg N/ha pig manure, and 0 kg N/ha (control) treatments. This result agrees with Raksun *et al.* [35] who reported that urea had a significant effect in promoting crop growth.

Considering the interaction of biochar and fertilizer, eggplant in soils amended with 5 t/ha biochar and 60 kg N/ha urea had the highest biomass weight, which was significantly better than other treatments. The highest biomass weight was recorded at 5 t/ha biochar and 60 kg N/ha urea application rates in this study; this could be attributed to biochar's ability to improve nutrient availability and nitrogen-promoting rapid vegetative growth and it also underscores the importance of a nutrient-rich fertile soil for eggplant cultivation. This result agrees with the findings of Hannachi *et al.* [36] that biochar addition significantly increased eggplant aerial biomass by 39.7% and Chew *et al.* [37] that the application of biochar increased plant biomass by 67%, highlighting the role of biochar in enhancing nutrient uptake and biomass accumulation.

Table 4. Dry biomass and Fruit weight of eggplant as affected by Biochar and Fertiliser

Treatment	**Dry biomass (kg/ha)**	**Fruit weight (kg/ha)**
Biochar		
0 (No biochar)	110.37b	939.50b
2.5 t/ha	137.22a	1931.10ab
5 t/ha	153.23a	2872.20a
Fertiliser		
0 (Control)	71.92c	487.2c
30 kg N/ha PM	118.10b	1674.8bc
60 kg N/ha PM	137.36b	2127.0ab
60 kg N/ha urea	207.07a	3368.0a
Interactions		
B1F1	91.82d	0c
B1F2	58.33de	0c
B1F3	132.88c	1108bc
B1F4	158.48c	2650abc
B2F1	40.83e	0c
B2F2	163.48bc	2886abc
B2F3	145.60c	1833abc
B2F4	198.98b	3005abc
B3F1	83.10d	1462abc
B3F2	132.49c	3495ab
B3F3	133.60c	2083abc
B3F4	263.75a	4450a

Note: B1- 0 t/ha (No biochar), B2- 2.5 t/ha biochar, B3 -5 t/ha biochar, F1 - 0 kg N/ha, F2 - 30 kg N/ha Pig Manure, F3 - 60 kg N/ha Pig Manure, F4 - 60 kg N/ha Urea, Treatment means having the same letter(s) along the same column are not significantly different at 0.05 probability level according to DMRT.

3.4. Effect of Biochar and Fertilizer on Fruit Fresh Weight of Eggplant

The fresh weight of eggplant fruits varied significantly across biochar amendments (Table 4). Eggplants in soils amended with 5 t/ha biochar had the heaviest fruits (2872.2), which was significantly better than the no-biochar (939.5) treatment but at par with 2.5 t/ha biochar (1931.1). The increase in fruit yield observed for the higher biochar application could be attributed to the increased carbon content of the soil with a loamy sand texture. Thus promoting the soil's porosity, water-holding capacity, and cation exchange capacity which are essential for good root development for nutrient acquisition [16]. This claim is asserted in the observed growth parameters. This finding is corroborated by Abdulsalam and Akinrinola's [4] report that biochar application increased garden egg yield. The increase in plant height, leaf area, and canopy spread enhances light interception for better photosynthesis, leading to increased photosynthates accumulation for partitioning during fruit set.

Fertiliser application also increased the fresh weights of eggplant fruits significantly. Eggplants in soils amended with 60 kg N/ha had the heaviest fruits (3368.0), which were significantly different from 30 kg N/ha pig (1674.8) manure and no fertilizer (487.2) but was at par compared to 60 kg N/ha pig manure. A similar result was reported by Raksun *et al.* [35] that urea had a significant effect on the stem, leaf length, and leaf width. Although the fruit yields observed in plants treated with 60 kg N/ha urea were higher than the pig manure in the study, this could be attributed to the spontaneous release of nitrogen in urea for growth compared to pig manure. The atter manure had to undergo microbial decomposition [38], which releases nitrogen over an extended period, making it less likely to contribute to immediate spikes in soil nitrogen levels. Consequently, the magnitude of the difference observed was not prominent enough to cause significant variation in fruit yield.

The interaction of biochar and fertilizer amendments on eggplants' fruit weight varied across treatments. Eggplant in soils amended with 5 t/ha biochar and 60 kg N/ha urea had the highest fruit weight which was significantly better than the No biochar and no fertilizer, sole application of 30 kg N/ha pig manure, sole application of 2.5 t/ha biochar, and sole application of 60 kg N/ha pig manure treatments. The highest fruit weights were recorded at 5 t/ha biochar and 60 kg N/ha urea application rates in this study; this could be attributed to biochar's ability to improve nutrient availability and urea-promoting rapid vegetative growth compared to pig manure amendment which in turn improved the photosynthetic ability and dry matter partitioning to the fruits. This result agrees with the findings of the study conducted by Honda *et al.* [39] which revealed that larger leaves result in higher photosynthetic rates and increased biomass production which in turn improves the quantity and quality of eggplant fruit produced. The result is corroborated by Aujla *et al.* [40] whose study reported increased eggplant yield through increased nitrogen applications.

4. Conclusion

The findings of this investigation indicated that eggplant responded positively to the various rates of application of biochar and fertilizer across the treatments. The study also suggests that biochar and fertilizers influence the growth and yield of *Solanum melongena.* The 5 t/ha biochar application was more effective for the improved growth and yield of eggplant. A comparison of 60 kg N/ha urea and 30 kg N/ha pig manure indicated that for all the growth and yield attributes, 60 kg N/ha urea treatments gave a higher response than pig manure applications. However, in a bid for healthier fruits while protecting soil health 5 t/ha biochar and 30 kg N/ha pig manure was recommended.

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