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Co-application of Neem-based biochar with poultry manure and its implications for sustainable production of cucumber (*Cucumis sativus* Linn.) in humid tropical soil

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ABSTRACT

In a bid to seek a sustainable solution to hunger and enhance food production in line with sustainable development goals, this research was designed to assess the impact of biochar with poultry manure on cucumber production. Hence, the study evaluated the effect of four levels of poultry manure (PM) (0, 5, 10, and 15 t/ha) and two (2) levels of Neem seed biochar (NSB) (0 and 2 t/ha) on the performance of cucumber (*Cucumis* sativus Linn.) in the humid tropical soil. The study was a factorial experiment laid out in a randomized complete block design (RCBD) and consisted of 8 treatment combinations replicated three times each. The result obtained indicated that the application of biochar and poultry manure alone, or in combination with each other, significantly improved vine length, number of leaves, number of branches, leaf area index, number of fruits plant-1 and yield of cucumber compared with plants from the control plots in two years trial. The yield of cucumber was observed to increase from 10.67 t/ha and 17.87 t/ha in control plots to 21.47 t/ha and 20.13 t/ha in plots amended with 15 t/ha PM + 2 t/ha NSB in 2020 and 2021 cropping year. From the result obtained herein, it can be inferred that the co-application of poultry manure and biochar to cucumber can serve as a sustainable means of producing crops in the tropics.

1. INTRODUCTION

Cucumber (*Cucumis sativus L.*) is an important, and one of the most popular fruits from the Cucurbitaceae family useful in body rehydration. It is a valuable source of conventional antioxidant and has the ability to lower glycemic and antimicrobial activity [1,2], its intake regularly helps to provide the body with vitamin C, beta-carotene, and manganese and also assist in boosting metabolism and improving immunity [1]. The estimated world cucumber production in 2020 was 91,258,272 metric tonnes with China accounting for 80 % of the output (72,779,781 metric tonnes) [3]. In Africa, Egypt, Cameroon and Sudan are the key cucumber-producing countries with 631,031, 314,752 and 307,103 tonnes under production [3]. However, as at the time of this study, cucumber production in Nigeria was not ranked due to a lack of documentation on quantitative data. The output in Nigeria is low due to some limiting factors which hinder production, especially soil fertility.

Soils of the humid tropics across the globe have received overwhelming acceptance for crop production for several decades now. Although these soils in southeastern Nigeria have potential that could be exploited for crop production, they are formed on parent materials which are dominated by massive sand mixed with low silt and clayey fractions. As reported by John *et al*. [4], the nutrient status and mineralogical properties of these soils are low in essential crop nutrients and might give low crop yields without the application of appropriate nutrient amendments.

As a consequence of the inherent low fertility status of most tropical soils, farmers tend to adopt and apply different soil nutrient management strategies to enhance crop production, some of which are not environmentally friendly, and have the potential to further degrade the soil, and might pollute groundwater. In view of achieving sustainable development goals, different options that can effectively increase the fertility of the soil, stimulate crop growth, and enhance plant tolerance to adverse conditions have been made available to farmers including but not limited to precision agriculture, smart agriculture, and conservation agricultural practices [4-6]. These practices have been found to enhance above-ground plant growth in different ecosystems [6-8].

Among the wide range of conservation agricultural practices, biochar application is proven to be an essential and easily sourced input for

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sustainable agriculture [8,9], as it possesses the capacity to sequester huge amounts of soil carbon for a long duration, thus enhancing soil fertility, crop growth, as well as mitigating global warming. Biochars are biological residues from organic materials (of either plant or animal origin) produced by combustion processes (pyrolysis) at very high temperatures (250°C) under complete or partial exclusion of oxygen [10]. Recently, the use of biochars has captured the attention of researchers and land managers as a potentially valuable input in agriculture; which has assisted in improving soil fertility, aided in sustainable agricultural production, and alleviated the adverse effects of biotic and abiotic stresses [9,11,12]. Although biochar is useful, it could increase soil dust emission, reduce available soil water content, and might be a source of contaminants like heavy metals.

According to United Nations [13], “the fast-growing world population forecasted to reach 9.6 billion by 2050 will inevitably result in an increasing demand for food production from a decreasing supply of arable land.” However, to ensure such a population is adequately fed, twofold food production from the present level will be required [14]. Already, in developing countries the few available fertile soils that would have helped in boosting crop productivity and yields have been erroneously appropriated for non-agricultural purposes (i.e., urban, infrastructural or industrial uses), thus making agricultural soils scarce resource [15]. Therefore, it has become expedient to rely on farming practices that can mitigate the emission of greenhouse gases (GHGs) with increased crop production.

However, for about a decade now, a notable increase in scientific studies concerning the integration of organic materials in sustainable agriculture has been observed. Some of these environmentally friendly bio-stimulants have assisted in increasing crop yields. Recent understanding of the beneficial effect of biochar necessitates an adequate scientific evaluation of its impact on plant growth and yield, especially now that different economies of the world are making efforts to alleviate poverty and ensure food security in an environmentally friendly manner. Already, there are increasing numbers of literature on the possible impacts of biochar on the improvement of soil properties [7,8] across the globe. However, only few of such studies have been implemented for crops [[9], and those conducted were mostly pot trials [16,17].

Whereas several research studies including Uko *et al*. [5] have reported poultry manure (PM) to possess high nutrient contents, most especially total nitrogen, and have been used as organic fertilizer for soil amendment for several decades now [18]; nevertheless, its excessive direct application to the soil has many environmental consequences including but not limited to ammonia volatilization, groundwater contamination, greenhouse gas emission, and emission of offensive odors [5,19,20]. Similarly, the application of biochar alone may be limited in supplying all the essential plant nutrients required for crop growth due to its low nutrient contents and recalcitrance to biodegradation [21].

The co-application of biochar and PM to soil has been reported to enhance plant growth and yield; it has the capacity in retaining NH^{4+} and NO^{3-} in PM [9]. Field trials where biochar was co-applied with PM showed reduced N losses and increased humification as well as enhanced crop yield [8]. Therefore, co-application of PM with biochar could have a high potential for soil improvement and subsequently crop yield, but such investigation has not been implemented in degraded soils with a long history of low fertility. Hence, an investigation was conducted to elucidate the combined effects of biochar with PM in a field sown with cucumber.

2. MATERIALS AND METHODS

Two-year field trials were conducted in the 2020 and 2021 cropping years at University of Calabar Teaching and Research farm, located between Latitude 04° 57’ N and Longitude 08° 19’ E. The area within study falls under the humid tropical rainforest zone and receives the mean annual rainfall of above 2500 mm with a temperature range between 22°C and 30°C, and relative humidity of 83%. The soils of the study area as reported by Afu *et al.* [22] are developed from a coastal plain sand parent material. They are characterized by udic moisture and isohyperthemic temperature regimes following Soil Survey Staff [23] classification. The soil order of the experimental site is Ultisols classified as Typic kandiudults according to USDA soil taxonomic classification. The experimental site had previously been used for horticultural and arable crop cultivation where crops such as maize, pepper, watermelon, cucumber, fluted pumpkin, cassava, and yam are grown.

In both years, the experiment consisted of 4 × 2 factorial laid out in a randomized complete block design. Treatments comprised four levels of PM (0, 5, 10, and 15 t/ha) and two levels of neem seed biochar (NSB) (0 and 2 t/ha) resulting in 8 treatment combinations, each replicated thrice to give a total of 24 experimental units. Each experimental unit measured 3m × 2m. Blocks were 1m apart and plots were 0.5 m apart.

The experimental plot was cleared and plowed, and the experimental units mapped. Before seedbed preparation, composite soil samples were augured from 0 to 20 cm soil depth, thoroughly mixed, air-dried, and passed through a 2 mm sieve for determination of soil physicochemical properties using methods outlined by Udo *et al*. [24]. Biochar from neem seed (NSB) was obtained by pyrolysis, sieved, and stored in air-tight containers, while PM was sourced from the poultry section of the Teaching and Commercial Farms, University of Calabar. The NSB and PM used were analyzed for nutrient composition after air-drying and crushed to pass through a 2-mm sieve. Analysis was done for organic carbon (OC), total N, P, Ca, and Mg [25]. Total OC was determined by wet digestion method, total nitrogen content by wet-digestion, distillation, and titration procedures of the Kjeldahl method, phosphorous by Bray-1 method, while the exchangeable bases (Ca and Mg) were determined through the extraction method with 1M ammonium acetate at pH 7.

Before seeding, biochar and PM were weighed according to the determined rates (NSB: 0 and 2 t/ha; PM: 0, 5, 10, and 15 t/ha) evenly spread, and manually worked into the soil to a depth of approximately 10 cm, 3 weeks before sowing the cucumber seeds. The same amendments were applied consecutively to the same plots in both the 2020 and 2021 cropping years. One seed of cucumber was planted per hole. Cucumber seeds were planted at a distance of 50 cm between rows and 50 cm within rows, giving a plant population of 66,600 plants/ha. The plots were manually weeded between rows at 2 and 4 weeks after planting (WAP) while staking was done at 3 WAP. Damet Plus, a contact, and systemic organophosphate pesticide were applied once at 3 WAP by spraying with a knapsack sprayer.

Data were obtained from 8 tagged cucumber plants in the middle rows of cucumber stands from each plot on vine length, number of leaves (NL), number of branches (NOB), leaf area index (LAI), number of fruits per plant, and yield. Growth attributes were monitored at 2 week intervals for 7 weeks, starting from 3 WAP. Statistical analyses included analysis of variance and comparison of treatment means using Fisher’s least significant difference at $P = 0.05$ level of probability.

3. RESULTS

3.1. Initial Properties of Soil and Amendments before Cropping

The initial properties of soil, PM, and NSB are shown in Table 1. The result indicated that the texture of the soil was sandy loam. The soil showed strong acidity with a pH of 5.4 and was low in exchangeable cations (Ca^{2+}, Mg^{2+}, and K^{+}), OC, and total nitrogen. The available phosphorus content was high. NSB had 28.2% total nitrogen, 856.1 mg/kg available phosphorus, 481% OC, 445.5 and 42.8 mg/kg exchangeable Ca and Mg, while PM had 2.72% total nitrogen, 1.4 mg/kg available phosphorus, 20.5% OC, 0.61 and 0.45 mg/kg exchangeable Ca and Mg. The application of these amendments could assist in producing the expected crop growth/yield in addition to improving soil fertility.

3.2. Effects of PM and Biochar Application on the Vegetative Growth of Cucumber

NSB and PM showed marked impacts on the vine length of cucumber [Table 2]. From the result, successive increments in the quantity of NSB applied from 0 to 2 tons per hectare led to corresponding significant ($P \leq 0.05$) improvement in vine length at all sampling periods except 3 WAP in 2020 and 7 WAP in 2021 where vine length of cucumber obtained from soil applied with 2 tons ha^{-1}of NSB was at par with control soils. Furthermore, PM applied at 15 tons ha^{-1} gave plants with the lengthiest vines at all sampling periods, and they were significantly ($P \leq 0.05$) longer than plant vines in plots that received other rates of PM in both years except at 5 and 7 WAP in 2021. In addition, plots that received 10 and 15 tons per hectare of PM at 3 WAP in 2021 and 7 WAP in 2020 produced plants that had similar vine lengths. Plots that did not receive PM had the shortest vines compared with those that received any level of PM. Further results showed no significant ($P > 0.05$) interactive effect of NSB and PM on vine length at 3 and 5 WAP in 2021. However, from 3 to 5 WAP, soils amended with 15 tons ha^{-1} PM + 2 tons ha^{-1} NSB consistently had plants with the longest vines which were significantly higher when compared to all other treatment combinations except 5 tons ha^{-1} PM + 2 tons ha^{-1} NSB, 10 tons ha^{-1} PM + 2 tons ha^{-1} NSB, and 15 tons ha^{-1} PM + 0 tons ha^{-1} NSB at 3 WAP in 2020 cropping season. At 7 WAP in 2020, soils amended with 5 tons ha^{-1} PM + 2 tons ha^{-1} NSB had vine lengths that were at par with those amended with 5 tons ha^{-1} PM + 0 ton ha^{-1} NSB and 10 tons ha^{-1} PM + 2 tons ha^{-1} NSB but significantly longer when compared to all other treatment combinations. Similarly, at 7 WAP in 2021, soils amended with 10 tons ha^{-1} PM + 2 tons ha^{-1} NSB had vine lengths that were at par with all other treatment combinations except control soil and those amended with 5 tons per hectare PM + 2 tons per hectare NSB and 10 tons per hectare PM + 0 ton per hectare NSB.

Table 1: Results of physicochemical analysis of the pre-cropping soil and biochar used for the experiment.

	Units	Soil	Neem seed biochar	Poultry manure
Physical properties				
Sand	gkg^{-1}	740		
Silt	gkg^{-1}	78		
Clay	gkg^{-1}	182		
Texture		Sandy loam		
Chemical properties				
pH		5.4		
TN	%	0.11	28.2	2.72
Av.P	mg/kg	22.01	856.1	1.4
OC	%	1.14	481	20.5
Ca		4.30	445.5	0.61
Mg	Cmolkg^{-1}	1.22	42.8	0.45
K		0.08		
Na		0.20		
Al^{+++}		0.40		
H+		0.60		
ECEC		6.80		
BS	%	85.29		

Av.P: Available phosphorus, TN: Total nitrogen, BS: Base saturation

The results also showed that NSB and PM gave significant enhancement in the NL of cucumber in both years under study [Table 2]. From 3 to 7 WAP, each successive increment in the rate of NSB from 0 to 2 tons per hectare resulted in corresponding significant ($P \leq 0.05$) increments in NL except at 5 and 7 WAP in 2021, where the NL of cucumber obtained from soil amended with 2 tons per hectare of NSB was at par with control soils. The results further indicated no significant ($P > 0.05$) effect of PM on the NL at 5 and 7 WAP in 2021. However, PM application at 15 tons per hectare gave plants with more leaves at all sampling periods, and they were significantly ($P \leq 0.05$) more than in the plants in plots that received other rates of PM in both years but were at par with soils amended with 10 tons ha^{-1} PM at all sampling periods. There was no significant ($P > 0.05$) interactive effect of NSB and PM on the NL from 3 to 7 WAP in the 2021 cropping year. However, at 3 WAP in 2020, soils amendment with 15 tons ha^{-1} PM + 2 tons ha^{-1} NSB resulted in plants with more leaves, which were significantly greater than all other treatment combinations, but at par with the NL on soils amended with 10 tons ha^{-1} PM + 2 tons ha^{-1} NSB. Similarly, at 5 WAP in 2020, soils amended with 15 t ha^{-1} PM + 2 t ha^{-1} NSB had plants with the NL which were at par with soil amended with 10 tons ha^{-1} PM + 0 ton ha^{-1} NSB, 10 tons ha^{-1} PM + 2 tons ha^{-1} NSB, and 15 tons ha^{-1} PM + 0 tons ha^{-1} NSB, but were significantly more than all other treatment combinations. Soil with zero rates of both PM and NSB had the least NL. At 7 WAP in 2020, soils amended with 15 tons ha^{-1} PM + 2 tons ha^{-1} NSB had NL that was at par with all other treatment combinations except control soil and those amended with 0 ton ha^{-1} PM + 2 tons ha^{-1} NSB and 0 ton ha^{-1} PM + 2 tons ha^{-1} NSB.

The result showed that NSB and PM had no impact on the NOB of cucumber at 3 WAP in both the 2020 and 2021 cropping seasons as well as at 5 and 7 WAP in 2021 [Table 3]. However, at 5 and 7 WAP in 2020, soil treated with 2 tons ha^{-1} of NSB gave more significant ($P \leq 0.05$) NOB than soil with zero application rate. Similarly, at 5 and 7 WAP in 2020, soil amended with 15 tons per hectare of PM consistently gave a more significant ($P \leq 0.05$) NOB which were at par with soil amended with 5 and 10 tons ha^{-1} of PM at 5 WAP and 10 tons ha^{-1} of PM at 7 WAP, but were significantly ($P \leq 0.05$) more than zero application rate. There was no significant ($P > 0.05$) interactive impact of NSB and PM on the NOB at 3 WAP in the 2021 cropping year as well as at 5 and 7 WAP in the 2020 cropping year. However, at 3 WAP in 2021, soils amended with 15 tons ha^{-1} PM + 0 ton ha^{-1} NSB had plants with a significantly higher NOB ($P \leq 0.05$), than all other treatment combinations, but at par with those from soil amended with 10 tons per hectare PM + 2 tons ha^{-1} NSB, 10 tons per hectare PM + 0 ton per hectare NSB including the control soil. During 5 WAP in 2020, soils amended with 15 tons ha^{-1} PM + 2 tons ha^{-1} NSB had plants with the NOB that were at par with all other treatment combinations except

Table 2: Effect of poultry manure and biochar on cucumber vine length and number of leaves.

Treatments	Vine length (cm)						Number of leaves					
	3WAP		5WAP		7WAP		3WAP		5WAP		7WAP	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Poultry manure (PM)												
P_0	17.14^{b}	16.73^{c}	70.99^{c}	77.47^{a}	99.60^{c}	153.39^{a}	6.04^{b}	5.94^{c}	21.00^{c}	24.06^{a}	40.33^{c}	49.63^{a}
P_1	20.16 ^{b}	21.22^{b}	80.30^{b}	83.56^{a}	148.50^{b}	150.43^{a}	6.21^{b}	6.52^{b}	26.17^{b}	26.34^{a}	48.67^{b}	48.54^{a}
P_2	19.77 ^{b}	22.41^{ab}	86.25^{b}	94.01^{a}	158.50^{ab}	158.62^{a}	7.08^{a}	6.94^{ab}	31.42^{a}	29.48^{a}	53.50 ^{ab}	53.19^{a}
P_3	24.04^{a}	23.87^{a}	102.53^{a}	88.54^{a}	171.90^{a}	157.69^{a}	7.29^{a}	7.11^{a}	33.50^{a}	29.56^{a}	55.96^{a}	54.71^{a}
Biochar (B)												
B_0	19.56^{a}	19.81^{b}	81.53^{b}	83.62^{a}	136.50^{b}	152.87^{a}	6.25^{b}	6.37^{b}	26.27^{b}	26.89^{a}	47.20^{b}	50.68^{a}
B_1	21.00^{a}	22.31^{a}	88.52^{a}	88.17^{a}	152.80^{a}	157.19^{a}	7.06^{a}	6.87^{a}	29.77^{a}	27.84^{a}	52.10^{a}	52.36^{a}
PMxB												
P_0B_0	17.63^{bc}	16.74^{a}	68.78^{e}	74.20^{a}	88.20^{e}	146.68^{b}	6.08^{b}	5.88^{a}	18.25^{d}	22.88^{a}	37.67^{d}	49.67^{a}
P_0B_1	16.65^{c}	16.73^{a}	73.21 ^{de}	80.75^{a}	111.00^{d}	160.10^{ab}	6.00^{b}	6.00^{a}	23.75^{c}	25.25^{a}	43.00^{cd}	49.58^{a}
P_1B_0	19.29^{bc}	22.78^{a}	77.92^{de}	84.77^{a}	143.00^{c}	156.29^{ab}	5.83^{b}	6.96^{a}	25.08^{c}	27.09^{a}	46.00^{bcd}	51.33^{a}
P_1B_1	21.03^{abc}	19.66^{a}	82.69^{cd}	82.35^{a}	154.10^{bc}	144.57^{b}	6.58^{b}	6.09^{a}	27.25^{bc}	25.59^{a}	51.33^{abc}	45.75^{a}
P_2B_0	18.90^{bc}	23.67^{a}	82.29^{cd}	84.30^{a}	150.20^{bc}	150.31^{b}	6.58^{b}	7.13^{a}	30.75^{ab}	28.75^{a}	52.67^{ab}	53.00^{a}
P_2B_1	20.64^{abc}	21.15^{a}	90.22^{bc}	103.71^{a}	166.80^{ab}	166.93^{a}	7.58^{a}	6.75^{a}	32.08^{ab}	30.21^{a}	54.33^{ab}	53.38^{a}
P_3B_0	22.41 ^{ab}	26.04^{a}	97.02^{b}	91.22^{a}	164.50^{abc}	158.20^{ab}	6.50^{b}	7.50^{a}	31.00^{ab}	32.63^{a}	52.33^{abc}	55.42^{a}
P_3B_1	25.68^{a}	21.69^{a}	108.03^{a}	85.86^{a}	179.30^{a}	157.17^{ab}	8.08^{a}	6.71^{a}	36.00^{a}	26.50^{a}	59.58^{a}	54.00^{a}

WAP: Weeks after planting, B: Biochar, P: Poultry manure, PB: Biochar+Poultry manure, B_0: 0 tons ha^{-1}, B_1: 2 tons ha^{-1}, PM_0: 0 tons ha^{-1}, PM_1: 5 tons ha^{-1}, PM_2: 10 tons ha^{-1}, PM_3: 15 tons ha^{-1}, Note: means within a column not sharing a letter in common differ from other means significantly following Duncan's New Multiple Range Test (DNMRT) at 5% probability

Table 3: Effect of poultry manure and biochar on number of leaves and leaf area index.

Treatments	Number of branches						Leaf area index					
	3WAP		5WAP		7WAP		3WAP		5WAP		7WAP	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Poultry manure (PM)												
P_0	1.00^{a}	0.90^{a}	2.33^{b}	2.55^{a}	4.00^{c}	4.71^{a}	0.10^{d}	0.16^{a}	0.57^{d}	0.97^{a}	1.23^{d}	2.30^{a}
P_1	1.00^{a}	0.88^{a}	3.08^{ab}	3.09^{a}	4.71^{bc}	4.78^{a}	0.17^{c}	0.19^{a}	0.94^{c}	1.07^{a}	1.88^{c}	2.17^{a}
P_2	1.00^{a}	0.98^{a}	3.50^{a}	3.21^{a}	5.12^{ab}	5.38^{a}	0.24^{b}	0.21^{a}	1.28^{b}	1.28^{a}	2.38^{b}	2.37^{a}
P_3	1.08^{a}	0.92^{a}	3.79^{a}	3.27^{a}	5.83^{a}	5.38^{a}	0.30^{a}	0.19^{a}	1.67^{a}	1.27^{a}	2.96^{a}	2.48^{a}
Biochar (B)												
B_0	1.04^{a}	0.95^{a}	3.00^{b}	3.08^{a}	4.50^{b}	5.15^{a}	0.17^{b}	0.17^{a}	0.95^{b}	1.06^{a}	1.86^{b}	2.26^{a}
B_1	1.00^{a}	0.89^{a}	3.35^{a}	2.98^{a}	5.33^{a}	4.97^{a}	0.23^{a}	0.21^{a}	1.28^{a}	1.24^{a}	2.37^{a}	2.40^{a}
PMxB												
P_0B_0	1.00^{a}	0.92^{abc}	2.17^{b}	2.46^{a}	3.67^{d}	4.59^{a}	0.019^{e}	0.16^{a}	0.45f	0.94^{a}	1.09^{e}	2.21^{a}
P_0B_1	1.00^{a}	0.88^{bc}	2.50^{b}	2.63^{a}	4.33^{cd}	4.84^{a}	0.12^{de}	0.17^{a}	0.69^{e}f	1.01^{a}	1.38^{de}	2.39^{a}
P_1B_0	1.00^{a}	0.88^{bc}	2.83^{ab}	2.92^{a}	4.50^{cd}	4.63^{a}	0.14^{d}	0.24^{a}	0.82^{de}	1.28^{a}	1.65^{cd}	2.54^{a}
P_1B_1	1.00^{a}	0.88^{bc}	3.33^{ab}	3.25^{a}	4.92^{bc}	4.92^{a}	0.21^{c}	0.15^{a}	1.05^{cd}	0.87^{a}	2.11^{bc}	1.81^{a}
P_2B_0	1.00^{a}	0.96^{ab}	3.50^{ab}	3.04^{a}	4.50^{cd}	5.55^{a}	0.20^{c}	0.22^{a}	1.16^{bc}	1.28^{a}	2.21^{b}	2.29^{a}
P_2B_1	1.00^{a}	1.00^{ab}	3.50^{ab}	3.38^{a}	5.75^{ab}	5.21^{a}	0.27^{b}	0.21^{a}	1.41^{b}	1.28^{a}	2.55^{b}	2.45^{a}
P_3B_0	1.17^{a}	1.04^{a}	3.50^{ab}	3.88^{a}	5.33^{abc}	5.84^{a}	0.25^{b}	0.21^{a}	1.38^{b}	1.46^{a}	2.48^{b}	2.58^{a}
P_3B_1	1.00^{a}	0.79^{c}	4.08^{a}	2.67^{a}	6.33^{a}	4.92^{a}	0.34^{a}	0.17^{a}	1.96^{a}	1.08^{a}	3.44^{a}	2.39^{a}

WAP: Weeks after planting, B: Biochar, P: Poultry manure, PB: Biochar+Poultry manure; B_0: 0 tons ha^{-1}, B_1: 2 tons ha^{-1}, PM_0: 0 tons ha^{-1}, PM_1: 5 tons ha^{-1}, PM_2: 10 tons ha^{-1}, PM_3: 15 tons ha^{-1}, Note: Means within a column not sharing a letter in common differ from other means significantly following Duncan's New Multiple Range Test (DNMRT) at 5% probability

soil amended with 0 ton ha^{-1} PM + 2 tons ha^{-1} NSB and soil with zero rate of PM and NSB. Moreover, at 7 WAP in 2020, soils amended with 15 tons ha^{-1} PM + 2 tons ha^{-1} NSB had NOB that were at par with 15 t ha^{-1} PM + 0 t ha^{-1} NSB and 10 tons ha^{-1} PM + 2 tons ha^{-1} NSB, but with significantly ($P \leq 0.05$) more branches than other treatment combinations.

Considering the LAI of cucumber, the application of PM and NSB did not show any significant difference between the various rates of treatment applications at 3 to 7 WAP in the 2021 cropping year [Table 3]. However, during the 2020 cropping period, each successive increment in the rate of NSB from 0 to 2 tons per hectare and PM from 0 to 15 tons per hectare resulted in corresponding significant ($P \leq 0.05$) increments in LAI, with the highest rate of an application having the largest LAI while zero application had least LAI. The result did not show any significant ($P > 0.05$) interactive effect of NSB and PM on LAI at 3–7 WAP in the 2021 cropping year, whereas, between 3 and 7 WAP in 2020, soils amended with 15 tons per hectare PM + 2 tons per hectare NSB consistently had plants with largest LAI, that were significantly ($P \leq 0.05$) larger than other treatments.

The application of PM and NSB significantly affected yield and yield components in the 2 years under investigation except for the number of fruits plant^{-1} in 2021 [Table 4]. In the 2020 cropping year, each successive increment in the rate of NSB from 0 to 2 tons per hectare and PM from 0 to 15 tons per hectare resulted in corresponding significant ($P \leq 0.05$) increments in the number of fruits plant^{-1} and yield, with the highest rate of an application having the most notable number of fruits plant^{-1} and yield. However, in the 2021 cropping year, soil amended with 10 t ha^{-1} of PM gave a yield that was similar to soil amended with 5 and 15 tons ha^{-1} of PM but was significantly ($P \leq 0.05$) higher than soil with zero application rate. The result also showed no significant ($P > 0.05$) interactive effect of NSB and PM on the number of fruit plant^{-1} and yield in the 2021 cropping year. However, in the 2020 cropping year, soils amended with 15 tons per hectare PM + 2 tons per hectare NSB had the number of fruit plant^{-1} and yield which were at par with soil treated with 15 tons per hectare PM + 0 ton per hectare NSB, but significantly higher than NOF plant^{-1} and yield in soil with other treatment combinations.

Table 4: Effects of poultry manure and biochar on yield and yield attributes of cucumber.

Treatments	No. of fruit plant^{-1}		Yield (t/ha)	
	2020	2021	2020	2021
Poultry manure (PM)				
P_0	2.71^{d}	3.03^{a}	10.67^{d}	17.87^{b}
P_1	3.79^{c}	4.31^{a}	12.65^{c}	18.67^{ab}
P_2	5.00^{b}	4.86^{a}	16.05^{b}	19.27^{a}
P_3	6.77^{a}	4.86^{a}	20.30^{a}	18.33^{ab}
Biochar (B)				
B_0	4.00^{b}	3.86^{a}	14.35^{a}	18.07^{b}
B_1	5.10^{a}	4.67^{a}	15.73^{a}	19.0^{a}
PMxB				
P_0B_0	2.42^{f}	2.71^{a}	9.97^{d}	18.0^{a}
P_0B_1	3.00^{ef}	3.34^{a}	11.37^{cd}	18.40^{a}
P_1B_0	3.33^{de}	5.04^{a}	11.60^{cd}	18.80^{a}
P_1B_1	4.25^{c}	3.58^{a}	13.70^{bc}	18.53^{a}
P_2B_0	3.92^{cd}	5.54^{a}	15.70^{b}	18.40^{a}
P_2B_1	6.08^{b}	4.17^{a}	16.40^{b}	17.33^{a}
P_3B_0	6.33^{ab}	5.38^{a}	20.13^{a}	18.67^{a}
P_3B_1	7.08^{a}	4.34^{a}	21.47^{a}	20.13^{a}

WAP: weeks after planting B_0: 0 tons ha^{-1}, B_1: 2 tons ha^{-1}, PM_0: 0 tons ha^{-1}, PM_1: 5 tons ha^{-1}, PM_2: 10 tons ha^{-1}, PM3: 15 tons ha^{-1} Note: means within a column not sharing a letter in common differ from other means significantly following Duncan's New Multiple Range Test (DNMRT) at 5% probability.

4. DISCUSSION

The soil texture of the experimental site was sandy loam. This soil type is known to be susceptible to leaching and erosion by run-off water [26]. The soil was also observed to be strongly acidic in soil reaction with a pH of 5.4, having low exchangeable cations (Ca^{2+}, Mg^{2+}, and K^{+}), OC, and total nitrogen. The previous studies [5,6,27] also reported that "essential nutrients such as total N, organic C, and exchangeable cations in coastal plain soils are mostly low, and the low status of these nutrients in the experimental soil is an indication of low fertility." Thus, an additional supply of nutrients through biochar and PM to improve the growth and yield of cucumber was necessary.

Cucumber growth and yield responded positively to the amendments applied differently depending on the rate of application and nutrients present. The growth parameters of cucumber were significantly increased by the application of PM compared to the ones with no application. This implies that essential nutrients promoting the vegetative growth of cucumber present in the PM were subsequently released and absorbed by the plants. This observation corroborates the findings of Oke *et al.* [18] that nutrients from the mineralization of organic manure promote the growth and yield of cucumber. Njoku *et al.* [7] also attributed an increase in vegetative growth of crops that received organic manure to an increase in the amount of mineral nitrogen. The growth attributes of cucumber significantly increased with the application of biochar compared to the control, indicating that high levels of essential nutrients that promoted the vegetative growth of cucumber were present in the biochar, which could be subsequently released and absorbed by the plants.

The highest application rates of NSB (2 tons per hectare) and PM (15 tons per hectare) consistently gave better vegetative parameters compared to other application rates and the control plots at all sampling periods. Such enhanced growth with applied biochar and PM has been demonstrated repeatedly in several studies [7,8]. Adekiya *et al.* [8] have reported that "increased vegetative growth may be attributed to enhanced nutrient availability and improved soil properties". The significant increase in growth parameters and LAI in response to applied NSB and PM were consistent with the pre-cropping analysis of NSB and PM [Table 1]. The decomposition of organic matter components of these amendments releases nutrients to the soil and hence, cucumber plants. Thus, from the findings of the study, increasing the rates of NSB and/or PM increases the growth attributes of cucumbers. Furthermore, "biochar is very efficient at adsorbing dissolved soluble nutrients such as ammonium, nitrate, phosphate, and other ionic solutes [28], thus making them available for plant uptake."

Further results indicated that using NSB and PM significantly enhanced the number of fruits (NOF) plant^{-1} and yield relative to control plots with no application. From our investigations, increasing the rate of NSB applications from 0 to 2 tons ha^{-1} and PM from 0 to 15 tons per hectare resulted in corresponding increments in NOF and yield, with the highest rate of an application having the greatest NOF plant^{-1} and yield. PM applied at 10 and 15 t ha^{-1} as well as biochar applied at 2 t ha^{-1} consistently gave the highest yield. The observed yield increment compared to the control may be a result of the significant increase in the vegetative attributes (e.g., NL, LAI, NOB, and vine length) of the cucumber. The results obtained herein corroborate similar studies by Agegnehu *et al.* [29] who reported that "improvement in soil properties following application of biochar led to an increase in the number of fruits, fruit length, vine length, and yield of cucumber relative to control". Similar studies [7-9,17,30] attributed "the effect of biochar on crop yield to associated nutrients retention, increased pH, base saturation available phosphorus, and increased plant available water."

Co-application of NSB with PM increased growth parameters, the number of fruit plant^{-1}, and yield compared to the control and using individual treatments. This increment might be a result of the retention of labile nutrients from PM on biochar pores [31]. The limitations encountered when only PM is applied to the soil could be ameliorated by the combined application of PM and NSB. Biochar has shown potency in adsorbing nutrients and protecting them from leaching [9,11]. Several studies [16,17,30] have also attributed the increase in crop yield to the co-application of biochar with PM. Both amendments are known to have a high carbon and nitrogen contents. Thus, the observed results could be explicable by these facts. In addition, co-application of biochar with PM could reduce fertilizer utilization thus proving beneficial for resource-poor farmers who cannot afford the scarcely available inorganic fertilizers.

5. CONCLUSION

The result of this experiment has indicated that co-application of biochar and PM improved the growth attributes, number of fruits plant^{-1}, and yield of cucumber compared with plants on control plots. From our investigations, increasing the rate of NSB applications from 0 to 2 tons per hectare and PM from 0 to 15 tons per hectare resulted in corresponding increments in growth parameters and yield, with the highest rate of an application having the greatest increments in growth parameters and yield. The yield of cucumber was observed to increase from 10.67 tons per hectare and 17.87 tons per hectare in control plots to 21.47 tons per hectare and 20.13 tons per hectare in plots amended with 15 tons per hectare PM + 2 tons per hectare NSB. The co-application of PM and NSB to cucumber as nutrient sources also serves as an essential means of its safe disposal and maintenance of cleaner production through sequestration of carbon and amelioration of release of GHGs and subsequent global warming challenges.

6. AUTHORS' CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agreed to be accountable for all aspects of the work. All the authors are eligible to be an author as per the International Committee of Medical Journal Editors (ICMJE) requirements/guidelines.

7. FUNDING

There is no funding to report.

8. CONFLICTS OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

9. ETHICAL APPROVALS

This study does not involve experiments on animals or human subjects.

10. DATA AVAILABILITY

All the data is available with the authors and shall be provided upon request.

11. PUBLISHER'S NOTE

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