

INFLUENCE OF BIOCHAR AND NPK 15:15:15 FERTILIZER ON SOIL CHEMICAL PROPERTIES, GROWTH AND YIELD OF CUCUMBER (*Cucumis sativus*) IN SOUTHERN GUINEA SAVANNAH OF NIGERIA

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ABSTRACT

*This research studies the influence of biochar, NPK 15:15:15 fertilizer and their combination on soil chemical properties, growth and yield of cucumber (*Cucumis sativus*) in Anyigba, Kogi State., Nigeria. Treatment includes control at 0 application, biochar application at 8, 10 and 12 tons/ha., NPK fertilizer application at 100, 150 and 200 kg/ha and integrated application of NPK fertilizer and biochar at NPK 50kg/ha + Biochar 4 tons/ha, NPK 75 kg/ha + Biochar 5 tons/ha, NPK 100 kg/ha + Biochar 6 tons/ha the treatments were replicated three times (3x) making a total of thirty (30) plots. Pre-planting soil analysis revealed that the soil was strongly acidic at (pH 5.4) with low carbon (1.07%), total nitrogen (0.07%), and available phosphorus (3.41 mg/kg). Results indicated that biochar significantly improved soil pH, raising it from acidic to slightly acidic (pH 6.5), while sole NPK applications maintained soil acidity (pH 4.9–5.04). Soil carbon, total nitrogen, phosphorus, potassium, exchangeable bases, and effective cation exchange capacity (ECEC) were all enhanced under biochar treatments, with the highest improvements observed at 10 tons/ha (T6). Combined applications (T10: 100 kg/ha NPK + 6 t/ha biochar) resulted in the most stable soil pH and further improved nutrient availability compared to single treatments. Also, the Vegetative growth parameters (number of leaves, leaf area, stem girth, and vine length) were consistently higher in biochar-treated plots, with T6 (10 ton/ha Biochar) outperforming all treatments across seasons. Yield components followed a similar trend, with biochar-inclusive treatments showing the highest fruit weight (2.87 kg/ha), length (16.37 cm), and diameter (11.60 cm²), although significant differences were observed only for fruit diameter (21.17 cm²) in Season 2. The sustained performance of biochar treatments highlights their slow decomposition rate, improved nutrient retention, and long-term soil fertility enhancement, while NPK-only treatments showed reduced residual effects due to nutrient leaching. The study concludes that biochar at 10 t/ha, either applied alone or in combination with moderate NPK rates, is optimal for improving soil health, sustaining cucumber growth, and enhancing yield, thus its use is recommended.*

Keywords; Biochar , Cucumber , Growth and Yield, NPK 15:15:15 fertilizer , Soil chemical properties, Southern guinea savannah

INTRODUCTION

Arable soils in Sub-Saharan Africa (SSA) are typically low in fertility, acidic, and highly prone to leaching, with poor organic matter content (Agegnehu, *et al.*, 2021). These soil limitations are further intensified by human activities such as bush burning, mining, sand excavation, and continuous conventional tillage. Such practices, combined with naturally low organic content, lead to the depletion of essential nutrients like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), all of which are necessary for optimal crop growth and productivity (Selim, 2020). In these soils, phosphorus is often unavailable due to aluminum toxicity, while nitrogen is frequently lost through processes like leaching, volatilization, and runoff, making its supply a consistent challenge (Bhattacharya and Bhattacharya, 2021). As a result, crop yields are inhibited which ultimately, leads to low productivity. The excessive use of chemical fertilizers in agricultural ecosystems now causes serious problems at an alarming rate such as environmental pollution leading to eutrophication among others. It is worthy to also note that, the use of inorganic fertilizer has not really been promising under intensive agriculture because of the high cost, associated reduction in the crop yields over time as a result of soil degradation, nutrient imbalance and increased soil acidity (Muindi, 2019; Daba *et al.*, 2021). In spite of the growing need of cucumber in Nigeria, the production by farmers is consistently declining in fields because of declining soil fertility due to continuous cropping with no proper arrangements set aside for soil amendment.

A promising alternative is the combined use of organic and mineral fertilizers, which enhances fertilizer efficiency and could be more easily adopted by resource-limited farmers. Biochar is a carbon-rich material produced by pyrolyzing biomass at temperatures typically below 500°C in a low-oxygen or oxygen-free environment (Phares, *et al.*, 2022). Field work by Phares, *et al.* (2022), revealed that pairing biochar with mineral fertilizer raised the yields of okra, cassava, and maize and increased cowpea nodulation.

They attributed these gains to biochar's negatively charged surfaces and overall soil-conditioning effect, which allow it to adsorb and gradually release nutrients such as N, P, and K, thereby improving their use efficiency. Studies also show that biochar reduces nitrogen loss due to leaching and volatilization (Zhou *et al.*, 2021) and, in acidic soils, raises pH and frees soluble phosphorus (Glaser and Lehr, 2019). The combined biochar fertilizer approach is being tested across diverse climates; in Nigeria, Frederick *et al.* (2024) reported significant improvements in soil properties, plant growth, and cucumber yield when biochar was blended with NPK fertilizer.

Cucumber (*Cucumis sativus* L.), an annual in the Cucurbitaceae (\approx 90 genera, 750 species), is monoecious and has been cultivated for well over three millennia, probably originating in Africa and Asia (Akinmutimi and Anyanwu, 2024). It ranks fourth in economic importance among Asian vegetables after tomato, cabbage, and onion and is valued for its high levels of vitamins A, C, K, B and minerals such as K, Mg, P, Cu, and Mn. The fruit's ascorbic and caffeic acids also help relieve skin irritation and swelling (Akinmutimi and Anyanwu, 2024). According to a report by Okebalama *et al.*, (2022), continuous applications of NPK fertilizer thus, increase growth and yield of different crops but for a short period of time. However, the combined application of biochar and NPK has shown to have a long-term residual effect on the soil properties, growth and yield of crop (Agegnehu, *et al.*, 2016; Zhou *et al.*, 2021; Khan *et al.*, 2024).

The objectives of this research were to: assess the effect of biochar and NPK 15:15:15 on the chemical properties of soil, examine the influences of biochar, NPK fertilizer and their combination on the growth and yield of cucumber., evaluate the impact of NPK 15:15:15 on the growth and yield of cucumber, evaluate the combined effect of biochar and NPK 15:15:15 on the growth and yield of cucumber and assess the residual effect of biochar and NPK 15:15:15 growth and yield of cucumber in the study area.

MATERIALS AND METHODS

Description of the Study Area

The experiment was carried out at demonstration and research farm of Prince Abubakar Audu University, Anyigba. Anyigba lies on Latitude $7^{\circ}29'N$ and Longitude $7^{\circ}11'E$ in the Southern Guinea Savanna agro ecological zone of Nigeria (Amhikian *et al.*, 2012). Anyigba is humid tropical and has two distinct seasons (dry and wet). The dry season extends from November to March, while the rainfall begins in April and extend to September with an annual range between 1,560mm to 1,808mm and average temperature range of $25^{\circ}C$ and $35^{\circ}C$ (Amhikian *et al.*, 2012).

Biochar Preparation

Corn husk sourced farms was used to produce biochar for this research. The husks were properly dried, the husk was then transferred into a metal drum, which was air tight and placed on a fire. At interval, the husk in the drum was slightly opened and peeped to see the combustion process. The temperature used was maintained between 300 to $450^{\circ}C$.

Experimental Design

The experiment was laid in Randomized Complete Block Design (RCBD). The treatments were varied as follows; control (0) zero application, biochar application at 8, 10 and 12 tons/ha respectively, NPK fertilizer 100, 150 and 200 kg/ha respectively, combination of NPK fertilizer and biochar; 50kg/ha + 4 tons/ha, 75 kg/ha + 5 tons/ha, 100 kg/ha + 6 tons/ha respectively making a total of ten (10) treatments replicated three (3) times making a total of thirty (30) plots. A plot was measured 3m x 3m with alleyway of 1m between replications and 1m between plots, the total experimental area was $385m^2$ (0.0385 hectare). The biochar was incorporated into the soil using a placement method, but, NPK fertilizer was applied at planting using a placement method few centimeters away from the plant root.

Seed Sowing

Seeds were sown at 2 cm deep at the rate of 2 seeds per hole with a spacing of 50 cm apart, making a total of thirty-six (36) plants. After germination, the plant was thinned to one per hole. Staking was done for all plots 10days after emergence for season one (2023) and season two (2024).

Cultural Practices

Regular weeding was carried out on the experimental site round the base of the plants in each plot, along and ahead of the vines using hand picking and hoe, while insecticides was applied at 3 days interval. Staking was done to enable proper spread of vein and to protect the fruit from rutting.

Data Collection

Data collection commenced at 2 weeks after planting and continued at 2 weeks interval till harvest of number of leaves and vine length. While the fruit girth, length and weight were taken at harvest. Number of leaves per plant was obtained by counting all the fully opened leaves. Vine length was measured using a measuring tape. Fruit girth and length were measured at harvest with the use of a thread and measured with a ruler. Fruit weight per plant and total fruit weight per treatment were measured by using a weighing balance.

Soil Sampling and Preparation

Pre-planting and post planting soil samples were collected with an auger from the experimental field. The pre-planting soil analysis was carried out to know the inherent soil properties before treatment application. Soil samples were collected per plot at the end of the

experiment at depth of 0 – 15cm. The samples were air dried, gently crushed with mortar and pestle and sieved with 0.5mm for total nitrogen and organic carbon while 2 mm size sieve was used for other chemical properties evaluations.

Laboratory Analyses

Soil samples were analyzed for selected physical and chemical properties. These include Particle size analysis, which was determined using the Bouyoucos hydrometer method (Bouyoucos, 1951). A 5% dispersing agent (sodium hexametaphosphate, also known as Calgon) was used to separate sand, silt, and clay particles. Soil pH was determined electrometrically using pH meter in a soil: liquid ratio of 1:2.5 (Nnabuiheet *et al.*, 2022). Soil exchangeable acidity (Al^{3+} , and H^+) was determined by the titration method (Mclean, 1965). Exchangeable bases (K, Na, Ca and

Mg) were extracted with 1N ammonium acetate (NH_4OAc) buffered at pH 7, afterwards, sodium (Na^+), and potassium (K^+) were read using flame photometer, while magnesium and calcium were determined using the ethylene-diamine-tetracetic acid (EDTA) titration method as described by Heald (1965). Total nitrogen was determined by the micro Kjeldahl digestion method (Bremner and Mulvaney, 1996). Organic carbon was determined by Walkley and Black (1934) wet oxidation method. Available phosphorus was extracted using Bray II extractant as described by Wuenscher, *et al.*

Statistical analysis

All data collected were subject to analysis of variance (ANOVA) using GenStat software. The means separation was done using Duncan Multiple Range Test (DMRT) (2022 - 2024) at 5% level of probability.

respectively. While the physical properties of the soil were seen to have a bulk density of $1.51/cm^3$ which was low, with a sand, silt and clay of 69.82%, 11.28% and 18.90% respectively. The textural class was to be a sandy loam soil. From the tabulated results above, it can be inferred that the nutrient status of the soil was poor.

RESULTS AND DISCUSSION

Influence of Biochar and NPK 15:15:15 Fertilizer on Soil pH, Carbon, Nitrogen (N), Phosphorus (P) and Potassium (K)

The influence of biochar and NPK was seen to have a pronounced effect on the soil pH. From the results in Table 2, it was seen that biochar and NPK fertilizer raised the pH of soil from acidic (5.4) as seen in the pre-planting soil analysis to slightly acidic (6.5), according to USDA, (1993), which indicates that biochar was effective in raising the soil pH and this result aligns with the result of Agboola and Moses, (2015) that, changes in soil pH does not depend on the alkalinity of biochar alone, but also on mineralization of organic N and nitrification of NH_4^+ , which was evident in season 2, the residual effect of the treatment was observed to be more stable in the soil, in the following season which was in line with result of Frank *et al.* (2020). Correspondingly, the NPK 15:15:15 was also seen to have influenced the soil pH, which was significantly ranging from T3 (4.9) extremely acidic to T4 (5.04) strongly acidic at the first growing season. However, at season 2, it was observed that there was a decrease in soil pH treated with lone NPK fertilizer, shifting towards very strongly acidic (4.9) which could be as a result of leaching. This indicates that increasing NPK rates slightly raised pH but still left the soil in an acidic state compared to biochar treatments (T5–T7), which shifted the soil closer to neutrality. This result is consistent with findings by Gautam *et al.* (2022) and Ren *et al.* (2025), who reported that continuous application of inorganic fertilizers, particularly nitrogen-based fertilizers, lowers

Table: 1. Pre-planting Soil Analysis

Chemical Properties	Soil	Biochar
pH	5.4	
Organic Carbon	10.7 kg	
Total Nitrogen	0.71 kg	0.92 kg
Phosphorus	5.05 Cmol/kg	0.28 kg
Potassium	1.68 Cmol/kg	0.42 kg
Sodium	0.42 Cmol/kg	
Magnesium	1.91 Cmol/kg	
Calcium	3.47 Cmol/kg	
Total Exchangeable bases	7.48 Cmol/kg	
Exchangeable Acidity	1.22 Cmol/kg	
Effective Cation Exchangeable Capacity	8.70 Cmol/kg	
Physical Properties		
Bulk density	$1.51g/cm^3$	
Sand percentage	69.82 %	
Silt percentage	11.28 %	
Clay percentage	18.90 %	
Textural class	Sandy loam	

Pre-planting Soil Analysis

The result in Table 1 shows that the pH of the soil was 5.4 (strongly acidic), the organic carbon content and total nitrogen was 10.7 and 0.71kg respectively and was seen as low, phosphorus, potassium sodium, magnesium and calcium were observed to be 5.05, 1.68, 0.42, 1.91 and 3.47 Cmol/kg were low respectively. Total exchangeable bases and effective cation exchangeable capacity were seen to be low (1.22Cmol/kg) and medium (8.70 Cmol/kg) respectively. Furthermore, the total nitrogen, phosphorus and potassium of the biochar was seen high with a value of 0.93, 0.28 and 0.42 kg

soil pH over time and may lead to soil degradation if not complemented with organic amendments or liming materials. Similarly, the result also shows a trend that combined nutrients could enhance the soil pH as demonstrated in the result, the highest pH 5.9 was observed at T10 which was the highest following the single application of biochar-treated soils. This result was in agreement with the result of Moe *et al.* (2022), which reported the beneficial effect of integrated organic and inorganic fertilizer which led to a stable pH in season 2.

Soil carbon (C) was also seen to have been significantly raised from 1.07 % to 3.18 % which was still low according to USDA, (1993) and this result was not in concord with report of Mensah and Frimpong, (2018) who reported the highest increase of soil carbon in treatment combined with biochar and NPK fertilizer at both growing seasons and was in line with the findings of Agboola and Moses, (2015) and Frank *et al.* (2020). The result also demonstrated rates that could preserve soil health while maintaining productivity (T7: 12 Ton/ha Biochar and T3: 150 kg/ha NPK). At higher doses of NPK, the organic carbon was seen to be more depleted compared to lower rates of application while on the other hand, at higher rates of biochar, the organic carbon was seen to be higher than at lower application. This result was in line with the result of Idbella *et al.* (2024) increased application rates of NPK fertilizers tend to accelerate the decomposition of soil carbon, while higher rates of biochar application generally increase SOC by adding a stable carbon source and improving soil conditions.

Furthermore, TN was seen to have increased from 0.07 % to 0.21 %. The result gotten was in line with the findings of Agboola and Moses, (2015); Frank *et al.* (2020) and Zhang *et al.* (2021b) where similar view was reported that biochar and NPK often lead to increase of TN (Zhang *et al.*, 2021a). However, both C and TN demonstrated a positive interaction response considering the sole application of NPK fertilizer, which further suggest that TN and C was chiefly enhanced by the addition of biochar. Phosphorus (P) was seen to have been influenced by the various treatment combinations. The result shows that the sole application of biochar (T7: 12 Ton/ha Biochar) led to an increase in soil available P, followed by the combined application (T10:100 Kg/ha NPK + 6 Ton/ha biochar) at higher rate of applications compare to single application of NPK fertilizers at higher dosage (T4: 200 kg/ha NPK). This finding supports the report of Mandle (2021), which evaluated the variety of organic and inorganic fertilizers, which was also in line with the hypothesis of Frank *et al.* (2020) whereby similar results were reported.

Exchangeable potassium (K^+) was seen to have been increased by the different treatment applied. K^+ was increased from 1.68 Cmol/kg to 2.76 Cmol/kg which

was noticed in treatment with sole application of biochar (T6: 10 Ton/ha Biochar). The result, aligns with that of Agboola and Moses, (2015) and Sun *et al.* (2021), which reported a significant increase in exchangeable K^+ with biochar application which may be due to an increase in soil pH and was in line with Okebalama, *et al.* (2022), which reported similar increase in K^+ . Furthermore, the combined application of biochar and NPK was also seen to a pronounced effect on the K^+ (T9: 75 Kg/ha NPK + 5 Ton/ha biochar) compare to the sole application of NPK fertilizer (T2: 100 kg/ha NPK) which was also reported by Alauddin (2021) suggesting the biochar amendment led to the release of soil available K^+ from the soil colloid. This implies that, the use of biochar is a better choice as soil amendment. The bulk density was seen to be low (USDA, 1993), across all treatment and was not in line with reports of (Agboola and Moses, 2015) and Frank *et al.* (2020).

Influence of Biochar and NPK 15:15:15 Fertilizer on Basic Cations: (Ca), Magnesium (Mg), Sodium (Na), Exchangeable Acidity (Ex. Acidity), Effective Cation Exchangeable Capacity (ECEC) and Total Exchangeable Bases (TEB).

The result in Table 3, shows the influence of biochar and NPK 15:15:15 fertilizer on soil exchangeable bases. It was evident that biochar and NPK fertilizer can really influence the Ca, Mg, Na, ECEC and Ex. Acidity. From the various treatment combination, it was observed that plots with 10 Ton/ha biochar (T6), showed a consistent increased compared to other treatment for both cropping seasons which was in line with results of Frank *et al.* (2020), which reported an increase with the application of biochar and mineral fertilizer. According to the result, it was observed that Ca was seen to be moderate, Mg and Na was seen to be high according to the USDA, (1993) and this result aligns with the reports of Sun *et al.* (2021) and this could be attributed to the biochar having a buffering capacity (Frank *et al.*, 2020). Similarly, ECEC, Ex. Acidity and TEB was seen to have also influenced by the treatments applied and ranged from low to medium according to USDA, (1993), respectively. The hypothesis also aligns with the result of Frank *et al.* (2020); Agboola and Moses, (2015). In their results, which also reported the positive effect of the combine application of biochar and NPK fertilizer enhanced soil properties.

Table: 2. Influence of Biochar and NPK 15:15:15 Fertilizer on the Soil Chemical Properties During Season One (2023) and Season Two (2024)

Treatment	pH		Carbon (%)		Nitrogen (%)		Phosphorus (mg/kg)		Potassium (Cmol//kg)	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
T1	5.1 ^c	5.5 ^a	1.99 ^d	1.99 ^{ab}	0.12 ^d	0.13 ^{ab}	4.58 ^c	5.19 ^c	1.87 ^c	1.79 ^{cd}
NPK										
T2	5.4 ^{bc}	4.9 ^b	2.24 ^{cd}	2.02 ^{ab}	0.15 ^{cd}	0.14 ^{ab}	6.48 ^b	7.24 ^{cd}	2.37 ^{ab}	1.87 ^{cd}
T3	4.9 ^c	5.3 ^{ab}	1.86 ^d	2.49 ^{ab}	0.12 ^d	0.17 ^{ab}	6.80 ^b	6.39 ^{de}	1.89 ^c	2.12 ^{abc}
T4	5.0 ^c	5.3 ^{ab}	1.95 ^d	2.28 ^{ab}	0.13 ^d	0.15 ^{ab}	7.25 ^b	7.46 ^{cd}	1.85 ^c	2.07 ^{abcd}
Biochar										
T5	5.0 ^c	5.1 ^{ab}	1.96 ^d	2.46 ^{ab}	0.13 ^d	0.16 ^{ab}	7.11 ^b	7.31 ^{cd}	1.93 ^{bc}	1.93 ^{bcd}
T6	6.5 ^a	5.3 ^{ab}	3.18 ^a	2.52 ^{ab}	0.21 ^a	0.17 ^{ab}	9.06 ^a	9.32 ^{ab}	2.76 ^a	2.40 ^a
T7	6.2 ^a	5.5 ^a	3.10 ^{ab}	2.54 ^{ab}	0.21 ^a	0.16 ^{ab}	9.40 ^a	10.76 ^a	2.60 ^a	2.22 ^{ab}
Biochar + NPK										
T8	5.4 ^{bc}	5.5 ^a	2.33 ^{bcd}	2.18 ^{ab}	0.15 ^{bcd}	0.15 ^{ab}	6.29 ^b	6.40 ^{de}	2.40 ^{ab}	1.90 ^{bcd}
T9	5.8 ^{ab}	5.3 ^{ab}	3.06 ^{ab}	2.88 ^a	0.20 ^{ab}	0.19 ^a	7.06 ^b	8.08 ^{bc}	2.69 ^a	2.22 ^{ab}
T10	5.9 ^{ab}	5.6 ^a	2.79 ^{abc}	1.77 ^b	0.19 ^{abc}	0.12 ^b	9.70 ^a	9.38 ^{ab}	2.64 ^a	1.74 ^d
<i>P.value</i> (≤ 0.05)	0.002	0.329	0.004	0.433	0.004	0.430	0.000	0.000	0.001	0.010

Note: Means that do not share a letter are significantly different, NS= Not significant, T1= Control (0 kg/ha), T2= 100 kg/ha NPK, T3= 150 kg/ha NPK, T4= 200 kg/ha NPK, T5= 8 Ton/ha Biochar, T6= 10 Ton/ha Biochar, T7= 12 Ton/ha Biochar, T8= 50 Kg/ha NPK + 4 Ton/ha biochar, T9= 75 Kg/ha NPK + 5 Ton/ha biochar, T10= 100 Kg/ha NPK + 6 Ton/ha biochar, pH=Potential hydrogen, BD= Bulk density, TP= Total porosity

Table 3. Influence of Biochar and NPK 15:15:15 Fertilizer on Calcium (Ca), Magnesium (Mg), Sodium (Na), Exchangeable Acidity (Ex. Acidity), Effective Cation Exchangeable Capacity (ECEC) and Total Exchangeable Bases (TEB).

Treatment	Ca		Mg		Na Cmol/Kg		ECEC		EX. ACIDITY		TEB	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
T1	4.16 ^b	4.27 ^{bc}	2.06 ^b	1.96 ^{cd}	0.53 ^a	0.39 ^{ab}	9.78 ^{bc}	9.57 ^{bc}	1.17 ^b	1.16 ^{ab}	8.61 ^{bc}	8.41 ^{bc}
NPK												
T2	4.93 ^{ab}	4.28 ^{bc}	2.52 ^a	2.03 ^{cd}	0.43 ^{abc}	0.33 ^{bc}	11.33 ^a	9.69 ^{bc}	1.08 ^{ab}	1.18 ^{ab}	10.26 ^{ab}	8.51 ^{bc}
T3	4.15 ^b	4.67 ^{abc}	2.08 ^b	2.26 ^{abc}	0.54 ^a	0.37 ^{abc}	9.83 ^{bc}	10.54 ^{abc}	1.16 ^{ab}	1.12 ^{abc}	8.67 ^{bc}	9.42 ^{abc}
T4	4.12 ^b	4.41 ^{abc}	2.00 ^b	2.17 ^{bcd}	0.51 ^a	0.38 ^{abc}	9.66 ^c	10.15 ^{abc}	1.18 ^{ab}	1.13 ^{abc}	8.48 ^c	9.02 ^{abc}
Biochar												
T5	4.18 ^b	4.38 ^{abc}	2.80 ^b	2.12 ^{bcd}	0.53 ^a	0.38 ^{abc}	9.89 ^{bc}	9.92 ^{bc}	1.18 ^{ab}	1.11 ^{abc}	8.72 ^{bc}	8.81 ^{bc}
T6	5.71 ^a	5.36 ^a	2.95 ^a	2.53 ^a	0.31 ^c	0.42 ^a	12.69 ^a	11.70 ^a	1.29 ^a	1.00 ^c	11.74 ^a	10.70 ^a
T7	5.50 ^a	5.02 ^{ab}	2.70 ^a	2.38 ^{ab}	0.33 ^{bc}	0.39 ^{ab}	12.14 ^a	11.06 ^{ab}	1.01 ^{ab}	1.05 ^{bc}	11.30 ^a	10.01 ^{ab}
Biochar + NPK												
T8	5.05 ^{ab}	4.19 ^{bc}	2.57 ^a	2.03 ^{cd}	0.45 ^{ab}	0.40 ^{ab}	11.53 ^a	9.68 ^{bc}	1.05 ^a	1.16 ^{ab}	10.47 ^a	8.52 ^{bc}
T9	5.63 ^a	4.99 ^{abc}	2.89 ^a	2.39 ^{ab}	0.31 ^c	0.37 ^{abc}	12.48 ^a	11.06 ^{ab}	0.96 ^b	1.07 ^{bc}	11.52 ^a	9.97 ^{ab}
T10	5.50 ^a	3.99 ^c	2.77 ^a	1.85 ^d	0.36 ^{bc}	0.31 ^c	12.29 ^a	9.12 ^c	1.01 ^{ab}	1.23 ^a	11.28 ^a	7.89 ^c
<i>P.value</i>	(\leq 0.002	0.172	0.000	0.008	0.003	0.256	0.0001	0.055	0.485	0.093	0.001	0.053

Note: Means that do not share a letter are significantly different, NS= Not significant, T1= Control (0 kg/ha), T2= 100 kg/ha NPK, T3= 150 kg/ha NPK, T4= 200 kg/ha NPK, T5= 8 Ton/ha Biochar; T6= 10 Ton/ha Biochar; T7= 12 Ton/ha Biochar; T8= 50 Kg/ha + 4 Ton/ha biochar; T9= 75 Kg/ha + 5 Ton/ha biochar; T10= 100 Kg/ha + 6 Ton/ha biochar. Calcium (Ca), Magnesium (Mg), Sodium (Na), Effective Cation Exchangeable Capacity (ECEC), Exchangeable Acidity (Ex. Acidity) and Total Exchangeable Bases (TEB).

Table: 4. Influence of Biochar and NPK 15:15:15 Fertilizer on Number of Cucumber Leaves and Leaf Area.

Treatment	NL Week 2		NL Week 4		NL Week 6		LA Week 2		LA Week 4		LA Week 6	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
	T1	4.07 ^a	3.67 ^b	7.33 ^{ab}	5.67 ^c	17.17	9.67 ^c	16.90 ^{ab}	12.05 ^b	121.7	52.47	219.2
	NPK											
T2	4.00 ^a	4.00 ^{ab}	7.00 ^{ab}	7.00 ^{bc}	16.70	11.67 ^{bc}	16.67 ^{ab}	14.60 ^b	116.43	71.60	186.3	114.8 ^{ab}
T3	3.67 ^a	4.00 ^{ab}	5.93 ^b	7.00 ^{bc}	12.63	11.00 ^c	16.73 ^{ab}	11.35 ^b	83.64	47.50	162.8	83.20 ^b
T4	1.33 ^b	4.00 ^{ab}	5.93 ^b	7.00 ^{bc}	14.43	10.67 ^c	9.31 ^b	11.22 ^b	90.6	52.10	164.8	99.00 ^b
	Biochar											
T5	3.77 ^a	4.56 ^a	8.27 ^{ab}	10.67 ^a	18.87	23.67 ^{ab}	20.05 ^{ab}	39.1 ^a	161.8	94.70	203.2	143.8 ^b
T6	4.27 ^a	4.33 ^{ab}	9.60 ^a	9.33 ^{ab}	18.10	26.33 ^a	28.6 ^a	22.11 ^{ab}	134.8	107.9	194.3	215.2 ^a
T7	3.40 ^a	4.00 ^{ab}	6.87 ^{ab}	9.00 ^{abc}	17.10	15.00 ^{abc}	15.81 ^{ab}	28.01	141.00	76.23	238.7	99.30 ^b
	Biochar + NPK											
T8	3.87 ^a	4.00 ^{ab}	6.53 ^{ab}	8.00 ^{abc}	16.27	12.67 ^{bc}	12.51 ^{ab}	10.56 ^b	116.0	65.30	202.3	99.30 ^b
T9	3.83 ^a	4.00 ^{ab}	6.60 ^{ab}	7.00 ^{bc}	20.03	13.76 ^{bc}	13.80 ^{ab}	16.67 ^b	137.2	62.90	218.66	148.5 ^{ab}
T10	3.73 ^a	4.17 ^{ab}	7.03 ^{ab}	10.00 ^{ab}	16.77	20.67 ^{abc}	19.18 ^{ab}	15.43 ^b	130.4	91.10	187.7	155.1 ^{ab}
<i>P. value</i> (\leq 0.05)	0.022	0.471	0.451	0.148	NS	0.087	0.684	0.082	NS	NS	NS	0.126

Note: Means that do not share a letter are significantly different, NS= Not significant, NL= Number of leaf, LA= Leaf area, T1= Control (0 kg/ha), T2= 100 kg/ha NPK, T3= 150 kg/ha NPK, T4= 200 kg/ha NPK, T5= 8 Ton/ha Biochar, T6= 10 Ton/ha Biochar, T7= 12 Ton/ha Biochar, T8= 50 Kg/ha NPK + 4 Ton/ha biochar, T9= 75 Kg/ha NPK + 5 Ton/ha biochar, T10= 100 Kg/ha NPK + 6 Ton/ha, P. valaue = probability value biochar. Number leaf (NL), Leaf area (LA).

Influence of Biochar and NPK 15:15:15 Fertilizer on Number of Leaves and Leaf Area.

The results in Table 3.4 demonstrate the influence of biochar and NPK 15:15:15 fertilizer on cucumber leaf production and leaf area provide an interesting insight. In Season 1, T6 (10 Ton/ha biochar) produced the highest number of leaves at Week 4 (9.60) and Week 6 (18.10), along with the largest leaf area at Week 2 (28.6 cm²). Although differences in leaf area at Weeks 4 and 6 were not statistically significant ($P \leq 0.05$), the overall trend suggests that biochar treatments supported more vegetative growth compared to NPK only treatments. Similar result was also reported by Agboola and Moses, (2015) where the number of leaves has no significant difference from week 2 to 6. On contrary, T4 (200 kg/ha NPK) had the lowest performance, likely due to possible nutrient leaching or imbalances associated with high synthetic fertilizer application rates (Drishya *et al.*, 2021). The sustained advantage of biochar treatments can be attributed to its ability to improve soil properties, enhance nutrient availability and efficiency Frank *et al.* (2020), which are critical factors for healthy leaf development (Yu *et al.*, 2019). The best treatments performance was observed in plots with biochar-

inclusive such as T6 and T5 (10 Ton/ha biochar and 8 Ton/ha biochar) aligns with previous findings that biochar enhances soil fertility and plant development over time Agboola and Moses, (2015); Pandit, (2018) and Frank *et al.* (2020).

In Season 2, the residual effects of biochar treatments became evident. T6 maintained the highest leaf production (26.33 leaves at Week 6) and the largest leaf area (215.2 cm² at Week 6). The long-lasting effect of biochar observed on the field prove to be consistent which indicates a slow decomposition rate and capacity to retain nutrients in the soil for plant uptake (Agboola and Moses, (2015); Frank *et al.* (2020) and Kalu *et al.*, (2021). The continued superior performance of biochar treatments compared to NPK only treatments, further highlights the potential for nutrient depletion in NPK fertilizer plots over time, leading to reduced plant growth (Agegnehu *et al.*, 2016 and Frank *et al.*, 2020). Correspondingly, the control plot (T1) showed relatively stable but low performance in both seasons. The persistence of residual biochar benefits in biochar inclusive treatments demonstrates the importance of adopting organic soil amendments alongside synthetic fertilizers for long-term productivity and sustainability.

Table: 5. Influence of Biochar and NPK 15:15:15 Fertilizer on Stem Girth (cm) and Vine Length (cm)

Treatment	SG Week 2		SG Week 4		SG Week 6		VL Week 2		VL Week 4		VL Week 6	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
	T1	1.30 ^{ab}	1.13 ^{abc}	3.18	1.90 ^{ab}	2.87 ^{abc}	2.23 ^b	1.30	4.17 ^a	9.28 ^b	6.67	62.67 ^{ab}
	NPK											
T2	1.25 ^{ab}	1.20 ^{abc}	3.50	2.03 ^{ab}	2.77 ^{abc}	3.00 ^{ab}	1.30	3.17 ^{ab}	7.42 ^b	9.67	55.17 ^{ab}	28.33 ^{bcd}
T3	1.27 ^{ab}	1.10 ^{abc}	2.94	1.83 ^{ab}	2.33 ^c	2.36 ^{ab}	1.17	2.83 ^b	6.23 ^b	10.00	42.87 ^b	22.67 ^{cd}
T4	0.80 ^b	0.77 ^c	2.93	1.90 ^{ab}	2.50 ^{bc}	2.37 ^{ab}	0.97	3.17 ^{ab}	8.37 ^b	7.00	56.23 ^{ab}	29.7 ^{bcd}
	Biochar											
T5	1.30 ^{ab}	1.63 ^{ab}	3.82	2.67 ^a	3.10 ^{ab}	3.36 ^a	1.60	5.17 ^a	12.33 ^{ab}	18.33	63.5 ^{ab}	65.3 ^{ab}
T6	1.31 ^{ab}	1.63 ^{ab}	4.13	2.67 ^a	3.37 ^a	3.67 ^a	2.00	3.17 ^{ab}	21.6 ^a	13.00	78.1 ^a	79.7 ^a
T7	1.16 ^{ab}	1.70 ^a	3.68	1.79 ^{ab}	3.17 ^{ab}	2.90 ^{ab}	1.07	3.83 ^{ab}	1071 ^{ab}	15.67	73.63 ^a	52.7 ^{abcd}
	Biochar + NPK											
T8	1.15 ^{ab}	0.73 ^c	3.08	1.70 ^b	2.70 ^{abc}	2.40 ^{ab}	1.13	2.67 ^b	7.75 ^b	8.00	54.4 ^{ab}	27.33 ^{bcd}
T9	1.37 ^{ab}	1.03 ^{abc}	3.83	2.07 ^{ab}	2.60 ^{bc}	2.80 ^{ab}	1.13	3.00 ^{ab}	8.74 ^b	10.67	60.30 ^{ab}	31.00 ^{bcd}
T10	1.44 ^a	0.93 ^{bc}	3.65	2.67 ^a	3.07 ^{ab}	3.27 ^{ab}	1.47	3.17 ^{ab}	7.56 ^b	17.33	55.80 ^{ab}	62.3 ^{ab}
<i>P. value</i> (\leq 0.05)	0.731	0.067	NS	0.151	0.095	0.235	NS	0.535	0.339	NS	0.502	0.056

Note: Means that do not share a letter are significantly different, NS= Not significant, SG= Stem girth, VL= Vine length, T1= Control (0 kg/ha), T2= 100 kg/ha NPK, T3= 150 kg/ha NPK, T4= 200 kg/ha NPK, T5= 8 Ton/ha Biochar, T6= 10 Ton/ha Biochar, T7= 12 Ton/ha Biochar, T8= 50 Kg/ha + 4 Ton/ha biochar, T9= 75 Kg/ha + 5 Ton/ha biochar, T10= 100 Kg/ha + 6 Ton/ha biochar, SG = Stem girth, VL = Vine length.

Influence of Biochar and NPK 15:15:15 Fertilizer on Stem Girth (SG) and Vine Length (VL).

The results in Table 3.5 examine the influence of biochar and NPK 15:15:15 fertilizer on cucumber stem girth and vine length revealed intriguing trends. In Season 1, T6 (10 Ton/ha biochar) produced the highest stem girth (3.37 cm) and vine length (78.1 cm) at Week 6, outperforming NPK only treatments. T3 (150 Kg/ha NPK) recorded the lowest vine length (42.87 cm), similar results were also reported by Frank *et al.* (2020), which demonstrated the lasting effect of biochar in soil. However, the differences across most treatments were not statistically significant, indicating that external factors such as environmental conditions may have influenced plant growth, potentially masking treatment effects.

In Season 2, the residual effects became more pronounced, with T6 continuing to produce the highest stem girth (3.67 cm) and vine length (79.7 cm), while T1 (control) recorded the lowest vine length (21.67 cm). Although statistical significance was limited, the notable residual benefits observed in biochar treatments suggest its long-term soil enhancement properties. Biochar's

ability to improve soil fertility (especially soil physio-chemical properties) likely contributed to these results (Shao *et al.*, 2024). Additionally, its slow nutrient release capability may have supported sustained growth compared to the faster-depleting NPK treatments (Agboola and Moses, (2015); Frank *et al.* (2020) and Okebalama *et al.*, 2022).

The diminished performance of higher NPK-only treatments, such as T3 and T4, could be attributed to nutrient leaching, a common challenge with synthetic fertilizers (Mohammed, 2024). Biochar's porous structure likely mitigated this issue by retaining nutrients and gradually releasing them, creating a balanced nutrient supply for plant uptake (Agboola and Moses, (2015) and Alkharabsheh *et al.*, 2021). However, Agboola and Moses, (2015) also reported biochar's role in fostering beneficial microbial communities may have enhanced nutrient cycling and overall plant health Dai *et al.*, (2021). The sustained superior growth observed in biochar-inclusive treatments underscores the importance of integrating organic amendments into fertilization strategies for long-term agricultural productivity.

Table: 6. Influence of Biochar and NPK 15:15:15 Fertilizer on Yield (Fruit Weight, Fruit Diameter, Fruit Length and Number of Fruit) of Cucumber.

Treatment	Fruit Weight (Kg/ha)		Fruit Diameter (cm2)		Fruit Length (cm)		Number of Fruit	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
T1	2.00	1.43	10.87	12.17 ^{ab}	15.33	12.37	10.67	5.00
NPK								
T2	1.30	0.73	8.33	7.67 ^{ab}	16.60	9.10	6.67	3.00
T3	1.07	0.33	9.30	5.00 ^b	12.87	7.83	7.00	1.33
T4	1.73	1.13	12.50	9.67 ^{ab}	15.57	14.77	8.67	3.33
Biochar								
T5	2.10	3.10	10.10	19.43 ^{ab}	16.13	16.37	9.67	8.67
T6	2.27	2.87	11.60	21.17 ^a	16.37	19.73	10.00	8.00
T7	2.20	1.57	12.20	10.17 ^{ab}	17.30	9.90	10.33	8.50
Biochar + NPK								
T8	1.87	0.83	10.97	8.00 ^{ab}	15.67	10.90	10.33	2.67
T9	1.70	2.30	8.93	17.33 ^{ab}	13.97	16.37	7.67	7.00
T10	1.60	1.17	11.40	13.00 ^{ab}	14.40	16.60	10.00	3.33
<i>P.value (≤ 0.05)</i>	<i>NS</i>	<i>NS</i>	<i>NS</i>	<i>0.483</i>	<i>NS</i>	<i>NS</i>	<i>NS</i>	<i>NS</i>

Note: Means that do not share a letter are significantly different, NS= Not significant, T1= Control (0 kg/ha), T2= 100 kg/ha NPK, T3= 150 kg/ha NPK, T4= 200 kg/ha NPK, T5= 8 Ton/ha Biochar, T6= 10 Ton/ha Biochar, T7= 12 Ton/ha Biochar, T8= 50 Kg/ha NPK + 4 Ton/ha biochar, T9= 75 Kg/ha NPK + 5 Ton/ha biochar, T10= 100 Kg/ha NPK + 6 Ton/ha biochar.

Influence of Biochar and NPK 15:15:15 Fertilizer on Yield (Fruit Weight, Fruit Diameter, Fruit Length and Number of Fruit) of Cucumber.

The results in Table 3.6 demonstrate the influence of biochar and NPK 15:15:15 fertilizer on cucumber yield. The results showed variation in yield, particularly with the higher treatment combinations which sustained performance of biochar treatments. In Season 1, none of the measured parameters (fruit weight, diameter, length, and number of fruits) were statistically significant ($p \leq 0.05$). However, in Season 2, the residual effect of treatments showed significant differences in fruit diameter (Agboola and Moses, (2015); Frank *et al.*, (2020) while other parameters remained non-significant. A possible reason for the observed trends is the inherent properties of biochar, which has been reported to improve soil structure, nutrient retention, and water-holding capacity (Alkharabsheh, *et al.*, 2021). This justifies why treatments containing biochar (especially T5, T6, and T7) consistently outperformed NPK only treatments. The porous structure of biochar can serve as a reservoir for nutrients, gradually releasing them to plants over time as reported by Frank *et al.*, (2020). Whereas, NPK fertilizers tend to release nutrients quickly, which may lead to nutrient leaching and a reduced residual effect (Das and Ghose, 2023). The absence of significant differences in Season 1 might be due to environmental factors such as rainfall patterns or initial soil fertility levels, which was poor, as seen in the pre-planting soil analysis or land-use type may have masked the immediate impact of the treatments. Additionally, cucumber plants might require time to fully exploit the benefits of biochar-enhanced soil properties. This aligns with findings by Agboola and Moses, (2015); Zhao *et al.* (2017) and Frank *et al.*, (2020), which reported similar view on biochar amendment, too often exhibit stronger effects over time on crop yield rather than immediately after application. In Season 2, the significant difference in fruit diameter can be attributed to the improved residual nutrient availability in biochar-amended plots. The slow-release nature of biochar-adsorbed nutrients likely created a more balanced nutrient supply for the plants. This may have contributed to the superior performance of treatments such as T6 and T5 (Agboola and Moses, 2015).

CONCLUSION AND RECOMMENDATIONS

Conclusion

The study reveals the significant role of biochar in soil amendment and improving the growth, yield, and soil health of cucumber crops compared to NPK 15:15:15 fertilizer alone. Biochar, particularly at higher application rates such as 10 Ton/ha (T6), consistently demonstrated superior performance across multiple parameters, including leaf number, leaf area, stem girth,

vine length, and yield. Its ability to enhance soil properties such as pH, carbon content, nutrient retention, and cation exchange capacity resulted in improved vegetative growth, yield components, and soil fertility over two cropping seasons.

The single application of NPK demonstrated a positive impact the growth of cucumber with a pronounced effect in season 2 where the application of NPK was lowest (T2: 100 kg/ha NPK) at the number of leaves, leaf area, stem girth and vine length in season 2 while season had no significant difference. Conversely, T4 (200 kg/ha NPK) significantly influenced fruit diameter.

Correspondingly, the combined application of both biochar and NPK 15:15:15 also demonstrated a positive response on the soil chemical properties, growth and yield cucumber. From the result, it was observed that a minimal dose of biochar and NPK (T9: 75 Kg/ha NPK + 5 Ton/ha biochar) carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sodium, effective cation exchangeable capacity, exchangeable acidity and total exchangeable bases level of the soil except for pH which strong affected by the highest treatment combination (T10: 100 Kg/ha + 6 Ton/ha biochar) pH of the soil. Furthermore, T10 (100 Kg/ha + 6 Ton/ha biochar) prove to be demonstrated a positive impact on the number of leaves, leaf area, vine length and stem girth in the season 2 which shows a continuous mineralization process of the treatment applied while in season 1, T9 (75 Kg/ha NPK + 5 Ton/ha biochar) showed a positive impact. Also, the fruit diameter was influenced at T9 (75 Kg/ha NPK + 5 Ton/ha biochar).

The residual benefits observed in biochar treatments highlight its slow decomposition rate (mineralization) and nutrient release capacity, which sustained plant growth over time, unlike the diminishing effects of NPK fertilizers which is prone to nutrient leaching. This study supports the integration of biochar as a sustainable soil amendment to enhance the effectiveness of fertilizers, particularly in nutrient-deficient soils.

Recommendation

The integration of biochar as a sustainable soil amendment method to enhance the effectiveness of fertilizers, particularly in nutrient-deficient soils. Should be encouraged

Based on the findings from this study, it is recommended that the research be carried out with higher varied rates of treatment to ascertain a rate that will significantly influence the yield of cucumber.

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