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Effects of Regular and Fortified Biochar on the Yield and Phenological Properties of Cucumber (*Cucumis sativus L.*) under Check Basin Irrigation

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Abstract
The effectiveness of normal biochar (NB) on the performance of cereal crops has been well studied. However, in the arid climate, such studies are deathly limited for garden crops. As such, a field experiment was conceived and executed during the 2023 dry season to determine the yield, and phenological responses of cucumber (*Cucumis sativus* L) to the application of NB and inorganically fortified biochar (FB). The experimental treatments consist of NB, FB, inorganic fertilizer (IF), and control (CT) assigned in a randomized complete block design and replicated three times. The NB was applied at 11 tonnes ha^{-1} equivalent rate, while plots under IF treatment received a standard rate of 130$kgha^{-1}$ N, 95 P_2O_5 and 200 K_2O $kgha^{-1}$ equivalence using split application at 3 and 6 weeks after emergence. The test crop was seeded at 2$kgha^{-1}$. The yield outcome under FB (0.1277kgm^{-2}) outmatched those under NB, IF, and CT by 60, 42, and 77% respectively. Similarly, FB recorded a significantly greater number of leaves (12.0 per stand), and leaf area index (236.86cm^2) compared to other treatments. Having produced better yield and biomass, FB treatment can be recommended for Guinea Savana soils of Nigeria under the check basin irrigation system.

Keywords: Cucumber, Biochar, Yield, Irrigation, Phenological Properties

Introduction

Cucumber (*Cucumis sativus* L) is a widely cultivated horticultural crop (FAOSTAT, 2023; Onuwa et al., 2023) that is ranked third in terms of production after tomato and onion (FAOSTAT, 2023). It is a creeping vine plant in the family of *Cucurbitaceae* that bears cylindrical to spherical edible fruits (Ren et al., 2009). The nutritional value of cucumber (Onuwa et al., 2023) particularly vitamins and minerals (Okafor & Yaduma, 2021), and its pleasant flavour increase its demand for salads and cooking recipes. In Nigeria, a yield of 576.7$kgha^{-1}$ can be obtained when good management practices such as pruning, control of mosaic and mildew, and 50cm × 50cm spacing (Akinpelu et al., 2011; Chinatu et al., 2017) are practised. Cucumber production increases spontaneously (Wilcox et al., 2015) since it can be grown in frames, glasshouses, backyards, and or in large agroforests. In the Northern Guinea savannah, supplemental irrigation may be necessary for year-round production (Okafor & Yaduma, 2021).

Biochar is a stable carbon material produced by the pyrolysis of raw materials (O'Laughlin & McElligott, 2009; Bolan et al., 2022) from different bio-feedstock. Yamato et al. (2006), Khan et al. (2023) and Edussuriya et al. (2023) observed that the application of biochar significantly increased the yields of maize, groundnut, wheat, and cowpea under varying soils. For example, Yeboah et al. (2016) observed a 30.7% grain yield increase in maize upon the addition of biochar made from rice straw feedstock at a rate of 5tha^{-1}. Similarly, Coumaravel et al. (2015), Oladele (2019), and Obeng et al. (2021) also pointed out that conditioning soil with biochar enhances long-term soil productivity. This is because biochar has a high proportion of stable carbon and expanded pools of essential nutrients (Arif et al., 2017). According to Faloye (2017) and Kanouo et al. (2019), even highly weathered, infertile tropical soils respond positively to the addition of biochar particularly through enhancement of cation exchange capacity and soil organic carbon, and reduction of soil acidity and toxicity. It also reduces nutrient leaching, which invariably improves fertilizer retention and nutrient use efficiency (Faloye, 2017).

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Despite the established positive effects of biochar, and the fact that Cucumber (*Cucumis sativus L*) farming provides great economic stimulation to many dry season farmers particularly women due to its less labour, land, and capital burdens, however, the biochar affects the yield, phenological components and profitability on cucumber plant has not been adequately researched upon in sub-Saharan Africa. The research question is, can the application of normal biochar improve the yield of cucumber which is currently less than half of the average of 2.0 tons/ha as well as other phenological attributes? Moreso, some studies have raised concern about the bulky nature of feedstock required to process optimum biochar rate. As such, a question was raised "can fortifying biochar with mineral fertilizer increase its effectiveness" so that less feedstock can serve optimally?

This research is therefore aimed at determining the effectiveness of biochar and fortified biochar on the growth, and yield performance of cucumber under check-basin irrigation.

Materials and Methods

The experiment was conducted at the Department of Agricultural and Bio-Environmental Engineering Technology experimental farm, Federal Polytechnic Bauchi, during the 2022/2023 dry season. The location is on latitude 10˚30'N and longitude 10˚00'E. The area is meteorologically characterized by a distinct rainy season which spans from April to October and a distinct dry season from November to March. The mean annual rainfall is 1,300 millimetres with June/July being the wettest months (700 millimetres) and the mean daily maximum temperature is 34˚C (BSADP, 2015).

The experimental treatments consisted of normal biochar (NB), fortified biochar (FB), inorganic fertilizer (NPK 20-10-10) (IF), and control (CT) which were randomly assigned into the experimental plots using Randomize Complete Block Design (RCBD) and replicated four times constituting a total of 16 plots (4x4). The experimental site was divided into four blocks and each block contained four basins of size 1.524 x 1.524m = 2.3m^2. Both the blocks and the basins were separated by a 0.5m buffer zone to minimize vertical and lateral interference between treatments. As shown in Figure 1 below.

Field Experimental layout

BLOCK 1		**BLOCK 2**		**BLOCK 3**		**BLOCK 4**
B4		B2		B3		B1
0.5m	0.5m	**0.5m**	0.5m	**0.5m**	0.5m	**0.5m**
B2		B1		B4		B4
0.5m		**0.5m**		**0.5m**		**0.5m**
B3		B4		B1		B2
0.5m		**0.5m**		**0.5m**		**0.5m**
B1		B3		B2		B3

Assumed fertility gradient from low to high

Figure 1: Treatment Assignment in RCBD. B1 = control; B2 = normal biochar; B3 = fortified biochar; B4 = inorganic fertilizer

The biochar was formed from soybean chaff through pyrolysis following Kanou et al (2019). Some fraction of the formed biochar was fortified with NPK 20:10:10 in a ratio of 1:1 (7.5kg of Biochar mixed with 7.5kg of NPK) using water as a reagent. The FB was left for two weeks in a container to maximize suction, absorption, and stability. A land area of 45m^2 was cleared and tilled using hoe to form a good tilth. The experimental plots were pre-irrigated for two days before planting the seeds 2.5kg each of FB and NB were applied appropriately which is equivalent to 11 tonnes ha^{-1}. For the IF treatment standard of 130kgha^{-1} N, 95kgha^{-1} P_2O_5, and 200kgha^{-1} K_2O using split application at 3 and 6 weeks after emergence as recommended by Odeleye and Adedokun (2006). Planting was carried out in the evening at 50cm inter and intra-row spacing. The seeds were sown on each basin at the rate of $2kgha^{-1}$ seed which gave rise to 18 cucumber stands per basin. The crops emerged four days after planting. Weeding was manually carried out twice during the growing seasons. There was an emergence of termites at the plot, but that was managed using Rambo powder and Laraquat insecticide. The crop was harvested by hand-picking three months after emergence. Surface irrigation system by check-basin method was adopted in the experimental field using a 20Ltr Watering Can which calibrated the water application depth throughout the experiment. A thin polythene membrane was used to ensure water even and light distribution of the irrigation water within the basin to minimize water drop impact (Sadiq et al., 2022).

Phenological parameters were determined following the Xu et al. (2022) method. The height of the vines above-ground and leaf area were determined using the meter rule, while the number of leaves, the number of flowers, and the number of fruits were determined by direct counting. A 1000g-capacity RS PRO analytical sensitive balance was used to determine the weight of the fruit for each treatment. The yield response factor was computed for each irrigation depth (Igbadun & Oiganji, 2012, as cited in Sadiq et al., 2022, p. 91).

$$Y = \frac{W}{A} \quad (1)$$

Where;
Y = Crop Yield (kgm^{-2})
W = Weights of the Harvested Fruit (kg)
A = plot Area of the Harvested Fruit

The results recorded were analyzed using a one-way Analysis of Variance (ANOVA). Q-Q and residual plots were run to check the normality and equal variance of the data. The least significant difference (LSD) was used to compare means for significant differences.

Results

The soil of the experimental site was sandy clay with a bulk density of $1.22gcm^{-3}$, soil reaction of 6.5 pH value, and electrical conductivity of 13.49 $Meq100g^{-1}$. The organic matter was 0.306% and total nitrogen (N) of 1.93%. Extractable prosperous (P) was 29.59ppm and extractable potassium (K) of 12.48ppm. The exchangeable magnesium, and calcium (Ca) were 42.92 $Meq100g^{-1}$ and 29.75 $Meq100g^{-1}$ respectively (Table 1).

Table 1: Soil properties of the experimental site

Parameters	Units	Value
Sand	%	63.9
Silt	%	0.10
Clay	%	36.0
Textural class		Sandy clay
Bulk density	$g\ cm^{-3}$	1.22
Particle density	$g\ cm^{-3}$	2.62
Total Pore Space and Porosity	%	5.33
pH		6.5
Electrical conductivity (EC)		2.6
Cation Exchange Capacity (CEC)	$Meq100g^{-1}$	13.491
Organic matter	%	0.31
Organic carbon	%	8.60
Available Nitrogen (N)	%	1.93
Extractable Phosphorous (P)	$mgkg^{-1}$	29.59
Extractable Potassium (K)	$Cmolkg^{-1}$	12.4818
Extractable Sodium (Na)	$Cmolkg^{-1}$	79.42
Magnesium (Mg)	$Cmolkg^{-1}$	11.083
Calcium (Ca)	$Cmolkg^{-1}$	29.75

Effects of Normal Biochar, Fortified Biochar, Inorganic Fertilizer and Control on Length of vines, **Number of Leaves, Leaf area of Cucumber**

The effects of normal biochar, fortified biochar, inorganic fertilizer, and control resulted in 6.14cm, 13.65cm, 9.45cm, and 5.27cm vine length respectively. The FB recorded the highest mean length over the rest by 55.0, 30.8, and 61.4% respectively.

The analysis showed a significant difference among the treatments. Based on Table 3 NB, FB, Inorganic Fertilizer, and control had 8.00, 12.00, 11.00, and 6.00 leaves per stand respectively. That suggested that FB and IF essentially affected cucumber vegetativeness. Table 2 presents the effect of NB, FB, IF, and CT on the cucumber leaves area. Similar to other results, FB got the highest mean area of 236.86cm^2 greater than those of IF, NB, and CT by 64.5, 75.7, and 82.8%, respectively.

Table 2: Effects of Normal Biochar, Fortified Biochar, Inorganic Fertilizer and Control Treatment on Length of vines, number of leaves, leaves area

Treatment	Length of vines (cm)	Number of leaves	Leaf area (cm^2)	Number of flowers
Control	6.14c	8.00b	40.82c	3.00c
Normal Biochar	13.65a	12.00a	57.65c	4.00c
Fortified Biochar	9.45b	11.00a	236.86a	8.00a
Inorganic Fertilizer	5.27c	6.00c	84.29b	6.00b
SE	1.352	1.222	11.781	0.999

Effects of Normal Biochar, Fortified Biochar, Inorganic Fertilizer, and Control on the number of flowers, number of fruits, Fruit thickness, Fruit length, Fruit Weight, and Yield of Cucumber

Based on the outcome of the experiment - 4.00, 8.00, 6.00, and 3.00 mean flowers of cucumber grown under NB, FB, IF, and CT were respectively observed. As expected, FB significantly caused more flower production compared to other treatments by 33.7%. The respective mean values of the number of fruits obtained by the respective treatments imposed were 5.00, 11.00, 7.00, and 4.00. These indicated that FB has the significantly highest number of cucumber fruits which surpassed the average yield by 38.6%. Further, the cucumber fruit thickness showed a significant variation which signified that the treatments led to different cucumber responses. The highest mean value of 5.83cm was recorded under FB, while NB, IF, and CT obtained 3.78cm, 12.89cm, and 2.63cm respectively. By implication, the cucumber fruit under FB was thicker by 3.4 times compared with NB. Additionally, based on the cucumber fruit length depicted a significant superiority by recording 8.25cm, which was greater than the next to it (IF) by 28.5%.

Looking at the cucumber fruit weight index as affected by the treatments confirms that FB gave the best performance relative to others by outperforming them by 74.5, 62.6, and 94.2% respectively. The results of the analysis for the cucumber yields on all the treatments shows that FB has major outcompeted the others by being about 2 times the average yield of all the treatments thus, bearing 'a' superscript.0.1277kgm^{-2}.

Table 3: Effects of Normal Biochar, Fortified Biochar, Inorganic Fertilizer, and Control on the number of fruits, Fruit thickness, Fruit length, Fruit Weight, and Yields

Treatment	Number of fruits	Fruit thickness (cm)	Fruit length	Fruit weight (kg)	Yields (kg m^{-2})
Control	4.00c	2.63c	3.31c	0.046c	0.021d
Normal Biochar	5.00bc	3.78b	3.91c	0.112b	0.030c
Fortified Biochar	11.00a	5.83a	8.25a	0.774a	0.128a
Inorganic Fertilizer	7.00b	2.89b	6.12b	0.197b	0.051b
SE	1.055	0.776	0.979	0.0043	0.0088

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Discussion

The findings of the study show that FB has significant effects on cucumber growth and other phenological properties considered for the 8-week application study. This was in line with the results of Xu et al. (2022) who in their study disclosed that biochar enriched with inorganic NPK fertilizer improves the overall soil quality and further enhances cucumber yields and irrigation productivity. More so, results revealed that FB can significantly reduce the cost of inorganic fertilizer procurement, thereby simplifying low-income farmers' access to fertilizer with convenience. Table 2-3 further explained the details of how the three variables appeared to have different degrees of effects on plants based on their average score. This is in line with the results of Samuel et al. (2021), who reported high yields, net income, and nutrient content in cucumber production when co-applied Biochar with NPK fertilizer.

Conclusion

The study established that the use of biochar in combination with inorganic fertilizer (IF) has the most promising effects on cucumber yield and phenological properties. As such, adopting and putting this into practice under an irrigation system would address the problems of poor cucumber yield and the high cost of inorganic fertilizer procurement. Hence, recommended for farmers as a good soil conditioner.

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