Use of biochar for enhance carbon sequestration to mitigate climate change and growth of maize in Sudan savanna zone of Nigeria

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Abstract

Application of biochar to the soil improves its physical, chemical and biological characteristics, promoting plant growth and productivity. The potential of biochar for carbon sequestration and its ability to reduce greenhouse gas emissions make it a very interesting alternative to counteract the adverse effect of climate change. The study examined the use of Biochar to enhance carbon sequestration and growth of maize in theSudan savanna zone of Nigeria. The experiment was conducted during the dry season of 2021/2022 at the Teaching and Research Farm of the Federal College of Horticulture, Dadin Kowa, Nigeria. Treatments involved seven levels of biochar (0, 2.5, 5.0, 10, 20, 30 and 40 t ha^{-1}) which laid out in a randomized complete block design replicated three times. Data were collected on growth parameters, yield and yield components and post-harvest soil parameters were also determined for each treatment. Results indicated that biochar improves soil properties such as soil organic carbon, total nitrogen, available phosphorus and water-holding capacity of the soil. Carbon was sequestrated with biochar application and significantly higher under 40 t ha^{-1} treatment. It is recommended that biochar could be used for improved soil properties and carbon storage to mitigate the greenhouse effect.

Keywords: soil properties, carbon sequestration, greenhouse effect, climate change.

Resumo

A aplicação de biocarvão ao solo melhora suas características físicas, químicas e biológicas, promovendo o crescimento e a produtividade das plantas. O potencial do biochar para o sequestro de carbono e sua capacidade de reduzir as emissões de gases de efeito estufa o tornam uma alternativa muito interessante para neutralizar o efeito adverso das mudanças climáticas. O estudo examinou o uso de Biochar para aumentar o sequestro de carbono e o crescimento do milho na zona de savana do Sudão na Nigéria. O experimento foi conduzido durante a estação seca de 2021/2022 na Fazenda de Ensino e Pesquisa do Colégio Federal de Horticultura, Dadin Kowa, Nigéria. Os tratamentos envolveram sete níveis de biochar (0, 2,5, 5,0, 10, 20, 30 e 40 t ha^{-1}) dispostos em delineamento de blocos completos ao acaso, repetidos três vezes. Os dados foram coletados sobre os parâmetros de crescimento, produção e componentes da produção e os parâmetros do solo pós-colheita também foram determinados para cada tratamento. Os resultados indicaram que o biocarvão melhora as propriedades do solo, como carbono orgânico do solo, nitrogênio total, fósforo disponível e capacidade de retenção de água do solo. O carbono foi sequestrado com a aplicação de biochar e significativamente maior sob tratamento de 40 t ha^{-1}. Recomenda-se que o biocarvão possa ser usado para melhorar as propriedades do solo e armazenar carbono para mitigar o efeito estufa.

Palavras-chave: propriedades do solo, sequestro de carbono, efeito estufa, mudanças climáticas.

Resumen

La aplicación de biocarbón al suelo mejora sus características físicas, químicas y biológicas, favoreciendo el crecimiento y la productividad de las plantas. El potencial del biocarbón para el secuestro de carbono y su capacidad para reducir las emisiones de gases de efecto invernadero lo convierten en una alternativa muy interesante para contrarrestar el efecto adverso del cambio climático. El estudio examinó el uso de Biochar para mejorar la captura de carbono y el crecimiento del maíz en la zona de sabana de Sudán en Nigeria. El experimento se realizó durante la estación seca de 2021/2022 en la Granja de Enseñanza e Investigación del Colegio Federal de Horticultura, Dadin Kowa, Nigeria. Los tratamientos involucraron siete niveles de biocarbón (0, 2.5, 5.0, 10, 20, 30 y 40 t ha-1) que se dispusieron en un diseño de bloques completos al azar replicados tres veces. Se recopilaron datos sobre los parámetros de crecimiento, el rendimiento y los componentes del rendimiento y también se determinaron los parámetros del suelo poscosecha para cada tratamiento. Los resultados indicaron que el biocarbón mejora las propiedades del suelo, como el carbono orgánico del suelo, el nitrógeno total, el fósforo disponible y la capacidad de retención de agua del suelo. El carbono fue secuestrado con la aplicación de biocarbón y significativamente mayor bajo el tratamiento de 40 t ha-1. Se recomienda que el biocarbón se pueda usar para mejorar las propiedades del suelo y el almacenamiento de carbono para mitigar el efecto invernadero.

Palabras clave: propiedades del suelo, secuestro de carbono, efecto invernadero, cambio climático.

1. Introduction

Climate change, environmental degradation and exposure to natural disasters are the greatest agricultural and rural development challenges facing African countries. Global climate change is largely due to anthropogenic carbon dioxide emissions originating from fossil fuel use and land use change (IPCC, 2007). As the climate changes, agriculture needs to transform to become more profitable, sustainable and resilient (Spore, 2015).

Soils hold three times the amount of carbon (IV) oxide (CO_2) currently in the atmosphere or almost four times the amount held in living matter. However, over the last 10,000 years, agriculture and land conversion have decreased soil carbon globally by 840 GtCO2, and many cultivated soils have lost 50–70% of their original organic carbon. Because soils have such a large capacity, enhancing soil storage by even a few percentage points makes a big difference (ICRLP, 2018). Soil organic carbon (SOC) storage has been widely considered as a measure for mitigating global climate change through Carbon (C) sequestration in soils (Huang et al., 2010). Agricultural soils can sequester 12% of human-induced emissions if progressive soil management methods such as improving soil organic matter, conservation tillage and water management are used (Spore, 2012).

Biochar is a carbon-rich product obtained from heated biomass in a closed container with little or no available air. It has been shown that biochar has multiple uses. When added to soil, it can significantly improve soil fertility Rodriguez et al. (2009), reduce greenhouse gas emissions and increase carbon sequestration (Lehmann et al., 2007).

Biochar is produced from residual biomasses such as crop residues, manure, wood residues, and forests and green wastes using modern pyrolysis technology. Agricultural wastes (bark, straw, husks, seeds, peels, bagasse, sawdust, nutshells, wood shavings, animal beds, corn cobs and corn stalks, etc.), industrial wastes (bagasse, distillers' grain, etc.), and urban/municipal wastes Novotny et al. (2015) and Kameyama et al. (2016) have been extensively used, thus also achieving waste management through its production and use (Woolf et al., 2010).

Biochar, when applied to soils, is reported to enhance soil carbon sequestration and provide other soil productivity benefits such as reduction of bulk density, enhancement of water-holding capacity and nutrient retention, stabilization of soil organic matter, improvement of microbial activities, and heavy-metal sequestration (Allohverdi et al., 2021). Furthermore, biochar application could enhance phosphorus availability in highly weathered tropical soils. Converting the locally available feedstocks and farm wastes to biochar could be necessary under smallholder farming systems as well, and biochar use may have applications in tree nursery production and speciality-crop management. Thus, biochar can contribute substantially to sustainable agriculture (Nair et al., 2017).

Changes in land use, particularly by clearing forests, reduce organic C by 20% to 50% in the upper soil layers. The current conversion of forest to agricultural land makes disturbance of this C stock important to the global C balance and net greenhouse gas emissions. Furthermore, IPCC (2015) predicted that food production in Africa could halve by 2020 and that maize production, a staple food for over 300 million Africans, could drop by 30% due to climate change. Because of the above, this research was designed with the following objectives: To determine the effect of the biochar amendment on the soil carbon sequestered, to determine the effect of biochar on some soil properties and to determine the effect of biochar on growth and yield of maize.

2. Materials and Methods

The field experiment was conducted during the dry season (December to March) of 2021/2022 at the Teaching and Research farm of the Federal College of Horticulture, Dadin Kowa, Gombe State in Northern Nigeria (Latitude 11° 30' N, Longitude 10° 20' E and 240 m above sea level) located in Sudan Savanna Agro-ecological zone of Nigeria.

The area is situated in Yamatu-Deba Local Government Area in the state. The local government has a land area of 222,756 km^2 with a population of about 350,000 people (National Population Census-NPC, 2006). The mean temperature ranges from 30 to 33^0C. The rainfall pattern is unimodal, ranging from 700 to 1250 mm and is characterized by distinct dry (October – May) and rainy (June – September) seasons (Mustapha et al., 2010). The landscape of the area has isolated hills. The drainage pattern is tree-like, the tributaries draining from west to east and discharging their load into the Gongola River. The crest and the upper slopes are characterized by a concave slope, while the middle slope and valley are typically concave. The soils range from shallow to deep loamy, sandy clay, loam and vertisols with cracking clays.

The vegetation is predominantly grasses, shrubs and trees, with the grasses often drying during the dry season due to the nature of the climate (Nigeria Physical Setting Gombe State, 2013). The principal occupation of the people in the area is farming, livestock rearing and fishing. At the same time, the common crops include rice, millet, maize, groundnut, watermelon, sweet melon, tomatoes, okra and onions.

2.1. Biochar preparation and source of planting materials

Oil drums were used to make a kiln for pyrolysis because they are relatively cheap and readily available to smallholder farmers in Nigeria. Dry maize stalks were chopped into small pieces, put into a 200 litres drum container and sealed with a lid to limit the amount of oxygen entering and heated at high temperature of about 400^0C for two hours as described in Woolf et al. (2010). The fire source was afirewood purchased from firewood seller. After cooling, the biochar was crushed and passed through a 2 mm sieve before applying it to the soil. Martaba maize variety used for the experiment was purchased from certified agro-seeds dealer Minangi in Gombe.

2.2. Experimental design and treatments

The design for the experiment is a randomized complete block design with biochar amendment at the rates of 0, 2.5, 5, 10, 20, 30 and 40 t ha^{-1}. Each treatment replicated three times. The size of each experimental plot was two by three meters (2m x 3m = $6m^2$), giving a total experimental area of 126 m^2. The experimental area was divided into check basins, laid out into set of three blocks consisting of seven basins each as described in Figure 1. The treatments were assigned at random to the blocks in randomized complete block design.

The quantity of Biochar amendment was calculated according to the rate of application for the treatments and applied by incorporation into the soil two weeks before sowing. Biochar was uniformly spread on the surface of the soil and mixed into the soil thoroughly to a depth of approximately 15 cm. Subsequently, the soil was turned two to three times to achieve a thorough mixture of the biochar and soil left for two weeks before sowing. The mixing and turning were also performed for the controls without biochar addition to maintain consistency.

REPLICATION 1	REPLICATION 2	REPLICATION 3
B3	B2	B4
B4	B7	B7
B6	B3	B1
B5	B6	B2
B2	B5	B6
B7	B1	B3
B1	B4	B5

Figure 1. Field layout and Randomization

Key:

B1 = 0 t/ha biochar | B5 = 20 t/ha biochar

B2 = 2.5 t/ha biochar | B6 = 30 t/ha biochar

B3 = 5.0 t/ha biochar | B7 = 40 t/ha biochar

B4 = 10.0 t/ha biochar

2.3. Soil sampling and measurement

Composite soil samples were collected from the experimental area at random at depth of 0-20cm before the application of Biochar and after harvest at the same depth from each treatment plots. In each plot, soil samples were collected from five randomly selected locations using soil auger. Then, the samples were mixed to form one representative sample for treatment. Thereafter the following properties were determined. Soil pH was determined in water 1:1 soil: water using pH meter (Udo et al., 2009). Total carbon was measured using Walkey-Black wet oxidation method and total nitrogen by the modified Microkjeldahl method as described by Udo et al. (2009). Available phosphorus was measured by the method of Bray-IP method as outlined by Page et al. (1982). Exchangeable cations (Ca, Mg, K, Na) were extracted using a 1.0 M Ammonium Acetate Sodium and determined by atomic absorption spectrometry AAS (Thomas, 1982). Particle size analysis was done using the hydrometer method of Bouyoucus. Bulk density (BD) was determined by the clod method (Black et al., 1986), Moisture Content, pH, Electric Conductivity (EC), Exchangeable Acidity and Cation Exchangeable Capacity (CEC) were determined by the KCl extraction and titration method of Mclean (1982). The effect of biochar on carbon storage in the soil (sequestration) was taken to be the SOC concentration in biochar treated plots after harvest minus the SOC content in untreated plots (control). Soil Carbon Stock as a measure of Carbon Sequestration was determined from the SOC, BD and soil depths using the expression SOC storage (t C ha) = 10000 (m^2 g) * soil depth (m) * Bulk density (g cm^3) * SOC (%) (Saiz and Albrecht, 2016).

2.4. Agronomic practices

The field was manually prepared by clearing the existing vegetation and ridges prepared. Thereafter biochar treatments were applied and left for two weeks.

Martaba Maize seeds were sown on the 19th of December, 2021 at the rate of 15 kg ha^{-1} of seeds and spaced at 25cm x 75cm intra and inter row spacing respectively. Two seeds were sown to a depth of 4 cm and no thinning was done. Fertilizer was applied to each plot at the recommended rate of 120 N, 60 P_2O_5, 60 K_2O kg ha^{-1} (Nair et al., 2017) in split doses, first dose at planting and second dose six weeks after sowing applied by side dressing. Weed control was achieved using chemical and manual. Atrazine was applied as pre-emergence at 3 kg a.i/ha and supplemented with manual weeding at 6 weeks after sowing. Harvesting was done when most of the cobs were dried on the 19th March, 2022.

2.5. Pest and diseases control

Optimal 20 SP was applied at 200g a.i. per ha to control aphids, whiteflies etc and also Caiman R (Emamectine Benzoate 50 g kg^{-1} WG) at 240g ha^{-1} to control stemborers and other worms.

2.6. Crop growth data parameters measured

Morphological data (plant height, number of leaves per plant, leaf area, leaf area index, stem girth, days to tassel and silk appearance) were collected at 2 weeks interval from the 4th week after germination to 12th week while yield and yield components (grain yield/net plot, number of seeds per cob, weight of 100 seeds and shelling percentage and total dry matter weight) were determined at harvest.

2.7. Data analysis

Data collected from the experiments were subjected to test of normality and relevant analysis of variance for the experimental design (RCBD). The differences among the means of significant effects were separated using Least Significant Difference (LSD) at 5% probability level using the R statistical environment (R, 2017).

3. Results

3.1. Physical and chemical properties of the soil in the experimental site

The results of physical and chemical properties of soil of the experimental site are shown on Table 1. The results presented were interpreted according to Esu (1991) ratings. The pH in water value is 6.78. These values indicated that the pH of the soil used for the experiment is almost neutral. The Organic carbon content and total nitrogen of the soil was 5.9 g kg^{-1} and 0.2 g kg^{-1} respectively indicating low (< 10 g kg^{-1}). However, after the experiment the values increased to 11.10 g kg^{-1} and 0.67 g kg for soil organic carbon and total nitrogen respectively (Table 2). The available phosphorus was also low (<10 g kg^{-1}) as the values obtained was 8.91 mg kg^{-1} but increased to 12.31 mg kg^{-1} for plot treated with 40 t ha^{-1} biochar indicating the influence of biochar on some soil characteristics as shown on Table 2. Exchangeable acidity is also low 0.56 cmol kg^{-1}. This indicated low fertility status of the experimental soil. The moisture content of the soil was 5.21% prior to the experiment but increased to 7.64% after the experiment indicating that biochar application improves water holding capacity of the soil (Table 2). All the exchangeable bases; calcium (2.73 $cmol_c$ kg^{-1}), magnesium (0.74 $cmol_c$ kg^{-1}), potassium (0.30 $cmol_c$ kg^{-1}), sodium (0.12 $cmol_c$ kg^{-1}) and cation exchange capacity (9.25 $cmol_c$ kg^{-1}) were rated medium. The textural class of the experimental soil is sandy clay.

Table 1. Physical and Chemical Properties of the Soil at the Experimental Site Prior to the Treatments

Parameters	Values
pH (1:1)	6.78
Organic Carbon (g/kg)	5.90
Total Nitrogen (g/kg)	0.60
Available Phosphorus (mg/kg)	8.91
Soil Moisture (%)	5.21
Bulk Density (mg/m³)	1.70
Electric Conductivity (dS/cm	62.00
Exchangeable Acidity (cmol/kg)	0.56
Exchangeable bases (cmol/kg)	
Calcium (Ca)	2.73
Magnesium (Mg)	0.74
Potassium (K)	0.30
Sodium (Na)	0.12
Cation Exchange Capacity (CEC)	9.25
Soil Texture (g/kg)	
Sand	311.10
Silt	298.80
Clay	390.10
Textural Class	Sandy Clay

Table 2. Physical and chemical properties of the experimental soil on plot basis after the experiment

Biochar (t/ha)	pH (1:1)	SOC (g/kg)	TN (g/kg)	Av-P (mg/kg)	MC (%)	BD (mg/m³)	EC (dS/cm)	EA (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)	CEC (cmol/kg)
0	5.74	4.27d	0.273b	5.52d	5.36b	1.58a	70.00	0.480	3.80	0.860	0.317	0.117	11.200
2.5	5.76	4.57d	0.187b	6.31cd	4.95b	1.52b	65.33	0.493	4.05	0.713	0.257	0.117	11.430
5	5.81	4.63d	0.273b	8.38bcd	5.18b	1.53b	85.33	0.723	3.61	0.930	0.273	0.117	12.560
10	5.92	4.67d	0.190b	6.63cd	5.84ab	1.54b	52.67	0.430	4.02	0.827	0.263	0.100	13.000
20	6.02	5.24c	0.293b	10.19ab	5.94ab	1.53b	73.00	0.497	3.51	0.770	0.297	0.107	10.840
30	5.81	6.20b	0.290b	9.48abc	5.26b	1.52b	77.00	0.553	3.11	0.763	0.217	0.143	10.890
40	6.36	11.03a	0.667a	12.31a	7.64a	1.39c	70.67	0.580	2.95	0.667	0.497	0.110	11.860
S.E.	0.383	0.133	0.099	0.936	0.566	0.009	15.250	0.097	0.726	0.163	0.166	0.020	2.120
CV (%)	7.93	3.98	38.88	13.64	12.07	1.00	26.46	22.08	24.84	25.24	67.01	21.53	22.18

Keys: REP = replicates; OC = Organic carbon; TN = Total nitrogen; Av-P = available phosphorus; Moist = Soil moisture content; BD = Bulk density; EC = Electric conductivity; EA = Exchangeable acidity; Ca = calcium; Mg = magnesium; K = potassium; Na = sodium; CEC = cation exchange capacity

3.2. Effect of biochar application on the growth parameters of maize

3.2.1. Effect of biochar application on maize plant height (cm)

Results of the effects of biochar on plant height are presented on Table 3. Results on plant height for maize showed no significant difference (p≤0.05) throughout the measurement periods. This indicated that biochar application did not have any significant effect on maize plant height.

Table 3. Effect of biochar application on the maize plant height (cm)

Biochar (t/ha)	4PLH	6PLH	8PLH	10PLH	12PLH
0	25.00	59.22	113.00	188.78	227.00
2.5	25.78	61.89	119.77	203.22	220.22
5	26.11	59.22	126.11	209.22	257.78
10	25.22	61.56	115.56	201.44	211.33
20	26.33	66.11	131.33	206.11	232.78
30	23.11	54.67	102.55	190.33	235.56
40	22.22	55.67	119.22	209.44	238.56
S.E.	2.845	6.259	11.541	17.916	18.673
CV (%)	14.036	12.827	11.956	10.905	9.862

PLH = plant height; S.E. = standard error; CV = covariant of variance

3.2.2. Effect of biochar application on number of leaves per plant of maize

Results of the effects of biochar on number of leaves per plant are presented on Table 4. Results on number of leaves per plant showed no significant difference (p≤0.05) throughout the measurement periods. Nevertheless, plants treated with biochar appear to produce relatively more number of leaves than the control.

3.2.3. Effect of biochar application on maize plant girth (cm)

Results of the effects of biochar on maize plant girth are presented on Table 5. Results on maize plant girth showed no significant difference (p≤0.05) throughout the measurement periods. Nevertheless, plants without biochar amendment appear to be thinner than those treated indicating possible effect of biochar on maize plant girth.

Table 4. Effect of biochar application on the number of leaves per plant for maize plant

Biochar (t/ha)	4NLV	6NLV	8NLV	10NLV	12NLV
0	9.00	11.33	13.22	14.00	13.33
2.5	8.89	12.11	14.00	14.78	13.56
5	8.67	11.78	14.89	15.78	13.67
10	9.00	11.67	13.56	14.67	13.56
20	9.33	12.11	13.67	14.67	13.67
30	9.00	11.33	13.67	14.44	13.11
40	8.78	12.22	13.56	14.33	12.56
S.E.	0.541	0.665	0.757	0.762	0.827
CV (%)	7.395	6.909	6.722	6.361	7.590

NLV = number of leaves per plant; S.E. = standard error; CV = covariant of variance

Table 5. Effect of biochar application on stem girth for maize plant (cm)

Biochar (t/ha)	4PLG	6PLG	8PLG	10PLG	12PLG
0	2.97	4.40	4.39	3.82	3.66
2.5	3.03	4.36	4.52	3.97	3.96
5	2.86	4.38	4.48	4.29	4.18
10	2.93	4.28	4.41	4.10	4.00
20	3.13	4.56	4.67	4.24	4.24
30	2.80	4.31	4.53	4.08	4.01
40	2.87	4.58	4.72	4.31	4.32
S.E.	0.259	0.177	0.330	0.262	0.211
CV (%)	10.783	4.907	8.925	7.798	6.377

PLG = plant girth; S.E. = standard error; CV = covariant of variance

3.2.4. Effect of biochar application on maize plant leaf area (cm^2)

Results of the effects of biochar on maize plant leaf area (cm^2) are presented on Table 6. Results on maize plant leaf area (cm^2) showed no significant difference ($p \leq 0.05$) throughout the measurement periods.

Table 6. Effect of biochar application on maize plant leaf area (cm^2)

Biochar (t/ha)	4PLA	6PLA	8PLA	10PLA	12PLA
0	164.20	382.31	574.36	640.14	700.94
2.5	166.42	386.43	656.01	713.65	735.33
5	167.29	455.54	683.42	737.40	769.96
10	181.33	400.01	580.09	680.56	624.31
20	162.07	436.23	626.85	708.85	713.42
30	160.43	402.22	590.40	656.78	663.74
40	140.13	417.40	618.15	750.44	781.51
S.E.	37.065	62.202	86.766	44.788	59.184
CV (%)	27.829	18.515	17.182	7.856	10.170

PLA = plant leaf area; S.E. = standard error; CV = covariant of variance

3.2.5. Effect of biochar application on maize plant leaf area index

Results of the effects of biochar on maize plant leaf area index and days to tasseling and silk appearance (DAYSTS) are presented on Table 7. Results on maize plant leaf area index and days to tasseling showed no significant difference ($p \leq 0.05$) throughout the measurement periods. Nevertheless, leaf area index index increased from control (no biochar) 0.427 and 0.467 to 0.500 and 0.521 at 10 and 12 weeks after germination respectively indicating the influence of biochar on leaf area index of maize.

Table 7. Effect of biochar application on maize plant leaf area index and days to tasseling and silk appearance

Biochar (t/ha)	4PLAI	6PLAI	8PLAI	10PLAI	12PLAI	DAYSTS
0	0.109	0.255	0.383	0.427	0.467	74.333
2.5	0.111	0.258	0.437	0.476	0.490	75.333
5	0.112	0.304	0.456	0.492	0.513	73.667
10	0.121	0.267	0.387	0.454	0.416	72.000
20	0.108	0.291	0.418	0.473	0.476	74.667
30	0.107	0.268	0.394	0.438	0.442	75.000
40	0.093	0.278	0.412	0.500	0.521	74.333
S.E.	0.025	0.042	0.058	0.030	0.040	1.692
CV(%)	27.829	18.515	17.182	7.856	10.170	2.793

LAI = leaf area index, DAYSTS = days to tasseling and silk appearance, S.E. = standard error, CV = coefficient of variation

3.2.6. Effect of biochar application on yield parameters and yield of maize

The results on yield parameters and yield of maize are presented on Table 8. The results on yield per plot, 100 grain weight, number of seeds per cob, shelling percentage and total dry matter showed no significant difference ($p \leq 0.05$). Biochar application did not improve maize yield.

Table 8. Effect of biochar application on yield parameters and yield of maize

Biochar (t/ha)	Y/Plot (kg)	Y (Kg/ha)	100GW	NS/Cob	SHP (%)	TDM(Kg/ha)
0	1.60	2661.12	20.20	406.67	57.02	7450.00
2.5	1.66	2772.23	22.23	414.00	56.91	6794.44
5	2.48	4133.34	32.27	572.67	70.58	8116.67
10	1.66	2772.23	20.50	338.67	53.26	7622.22
20	1.96	3272.23	23.77	496.00	70.75	7811.11
30	1.76	2938.90	24.53	431.00	58.63	7783.33
40	1.33	2216.67	16.51	338.33	54.63	9222.22
S.E.	0.624	1040.659	7.843	112.584	13.527	1297.247
CV(%)	42.962	42.962	42.021	32.202	27.495	20.295

Y/plot = yield per plot; Y(kg/ha) = yield per hectare; 100GW = 100 grain weight; NS/Cob = number of seeds per cob; SHP(%) = shelling percentage; TDM = total dry matter

3.2.7. Effect of biochar on carbon sequestration on maize farm

The results of Biochar application on carbon sequestration on maize farm are shown on Table 9. The effect of biochar on carbon sequestration showed highly significant effect ($p \leq 0.01$) on the experimental plot. This indicated positive impact of biochar on carbon storage for each treatment and sequestered and increased with increase in the rate of applied biochar.

Table 9. Effect of biochar application on carbon sequestration

Biochar (t/ha)	SOC (t/ha)	SOC sequestered (t/ha)
0.00	13.49g	0.00g
2.50	13.89f	0.40f
5.00	14.04e	0.55e
10.00	14.38d	0.89d
20.00	16.11c	2.62c
30.00	19.98b	6.49b
40.00	30.86a	17.36a
SE	0.010	0.007
CV (%)	0.102	0.287

SOC = soil organic carbon storage, S.E. = standard error, CV = coefficient of variation. Means within the same factor and column followed by the letter are not significantly different at 5 % level of significance.

4. Discussion

The results of this experiment indicated that biochar improves some soil properties such as total nitrogen, available phosphorus, bulk density and moisture content (Table 2). This is in agreement with the findings of Chan et al. (2007) and Nelissen et al. (2014) who also observed in their works on agronomic values of green waste biochar as a soil amendment and short-term effect of feedstock and pyrolysis temperature on biochar characteristics, soil and crop response in temperate soils, that applied biochar increased most of the soil properties tested. When biochar is applied to the soil it improves soil fertility and at such add to soil essential nutrient for plant growth, increased microbiological activity, mycorrhizal associations and create a microhabitat in soil (Steiner et al., 2008 and Warmock et al., 2007). The findings is in consonance with that of Onwuka and Nwangwu, 2016 who found that total nitrogen was significantly increased to 0.15 % by the application of ukpo shell biochar. The increase in soil organic carbon observed is due to the organic carbon content of the biochar (Onwuka and Nwangwu, 2016). Greater nutrient retention by biochar is what increases the nutrient content of biochar amended soils (Blackwell et al., 2015).

Biochar has been reported to increase water-holding capacity in sandy soils (Rasool et al. 2008), improve soil structure (Chan et al., 2008). Even across soil types, water holding capacity (WHC) improves with biochar amendment (Razzaghi et al., 2020). With just 9% addition of biochar (yellow pine wood pyrolyzed at 4000C) there was a 100% increase of WHC (Yu et al., 2013). Meaning that there was a doubling of WHC (Yu et al., 2013). This is also in consonance with another study which discovered that the water holding capacity was increased by 30% when sunflower husk biochar was applied at 9.52% weight (Gluba et al., 2021).

Most of the growth and yield parameters of maize did not improve significantly on biochar application. This may be due poor nutrients status of the soil, biotic N immobilization, reduced soil organic matter, volatilization and leaching of some nutrients (Nelissen et al., 2014). This finding conforms to that of Chan et al. (2007) who applied biochar at 10, 50 and 100 t ha^{-1} to radish on alfisol but did not improve yield. The finding however is in contrary with that of Borchard et al. (2014) who found improved maize yield when applied 15g kg^{-1} of biochar and that of Keske et al. (2020) who applied corn cob biochar on maize and the growth improved significantly.

The data from this study revealed that soil organic carbon storage increased as the biochar application increases indicating sequestration of carbon as shown on Table 8. Biochar application to soils reduces carbon dioxide (CO_2) in the atmosphere as long-term carbon sink due to its resistance to degradation to all the carbon present in its structure. This gives its ability to remain in soils for hundreds of thousands of years (Woolf et al., 2010) and to reduce the rate at which carbon fixed by photosynthesis returns to atmosphere. Carbon retention increased when soil carbon stocks increase (Ding et al., 2018 and Ventura et al. 2019). The addition of biochar reduced the amount of released carbon by 18,479.35–37,457.66 kg of carbon dioxide (Xu et al. 2018), i.e., a reduction of 47% and 57% for both rice and maize, respectively (Lehmann et al., 2009).

Biochar can sequestrate not only CO2 but also other greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4) Moreno-Riasco et al. (2020). When straw derived biochar was amended into sandy-loam soils (low in organic matter) a five-year wheat and maize crop rotation resulted in a decrease of N_2O emissions. Other studies prove that even when accounting for the GHG release during production, there remains a net decrease in GHG release when biochar is added to agricultural soils (Spokas and Reicosky, 2009). Over a 100-year period of this practice, the removal of the emissions from fallen branches reduced from 340 to 70 kg CO_2 eq. MWh^{-1}. This is a significant decrease in emissions from a very indirect and passive form of biomass breakdown Repo et al. (2010).

5. Conclusions

Biochar application can improve agricultural soils by improving the physical and chemical properties of soils. This study has shown that application of biochar increased soil organic carbon, total nitrogen, and available phosphorus and also enhanced water holding capacity and bulk density of the soil. The findings indicated that biochar sequestrate significant amount carbon thereby reducing CO_2 a major greenhouse gas in the atmosphere and prevent the escalation of climate change. Though there was no significant effect of biochar on maize growth and yield, but the soil physico-chemical properties were significantly improved. It is recommended that the experiment be tried during the rainy season and in other agro-ecological zones of the country.

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