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Biochar Application: An effective Measure in Improving the Fertility Status, Carbon Stock and Aggregate Stability of Eroded Soil

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ABSTRACT

In search for an efficient means of building up the carbon stock, improving the fertility levels and aggregate stability of tropical soils for optimum crop yield, a field study was carried using different biochars and comparing the effects with inorganic fertilizer. The biochars were palm bunch biochar (PBB), saw dust biochar (SDM) and rice mill husk biochar (RMHB). Treatments consisted of 10 t/ha palm bunch biochar + 0.25t/ha poultry manure (T1), 10 t/ha rice mill husk biochar + 0.25t/ha poultry manure (T2), 10 t/ha saw dust biochar + 0.25t/ha poultry manure (T3), 500kg/ha N.P.K 15:15:15 fertilizer + 0.25t/ha poultry manure (T4) and plot without biochar + 0.25t/ha poultry manure (T5) (control plot). These were replicated five times on experimental plots of 4m^2 in a randomized complete block design. Maize (*Zea mays*) was used as a test crop and data obtained were statistically analyzed using analysis of variance and correlation. Soils amended with biochars significantly improved soil pH, organic carbon, exchangeable bases and base saturation than non biochar fertilized soils. Saw dust biochar increased soil carbon stock by 95.1% against NPK fertilizer plots and control. There was 19% decrease in soil bulk density and 17% increase in soil pH with application of palm bunch biochar. Amending soils with palm bunch biochar increased soil organic carbon by 51.5%. The biochars increased the values of critical level of soil organic matter, modifies clay ratio and reduced the value of clay flocculation index more than NPK fertilized soils or control. Among the treatments, rice mill husk biochar recorded the highest maize cob weight though not significant with palm bunch biochar. Therefore, applying biochars on eroded soil is an effective measure of improving the stability, soil carbon stock as well as enhancing higher maize yield than inorganic fertilizer.

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Introduction

For some time now, there has been a tremendous pressure on agricultural lands due to high rise in human population, and the need to meet food demand both for humans and industrial purposes. These forces have resulted to land degradation, infertile soils and poor aggregate stability (Onwudike et al., 2019). High temperature and rainfall intensity as a result of climate change that increases the rate of organic matter decomposition and leaching of soil organic matter has deteriorate the situation.

Researchers have advocated the use of organic manure such as animal dropping (Ojeniyi and Adeyemo, 2008), compost materials (Whalen et al., 2008) and mineral fertilizers (Chang et al., 2010) to boost soil quality and these measures have proved to be effective to an extent. However, it has been reported that these amendments when applied on eroded soil do not last long on soils in sustaining the aggregate strength of soils due to edaphic factors. Hence, there is need to use soil amendment that are recalcitrant and that will have the tendency to store plant nutrients in soil for a long periods and retain the soil organic carbon. One of such amendment is biochar.

Biochar is a material formed from the pyrolysis of organic residues under no or little oxygen (Jien and Wang, 2013). The material has the ability to retain its organic carbon in soils due to its aromatic structure (Zhang et al., 2012) and the recalcitrant nature of biochar is 10 to 1000 times higher than other plant or animal residues as stated by Christopher et al. (2010). The roles of biochar in improving the physical, chemical and biological attributes of soils are well documented (Steinbeiss et al 2009, Barrow, 2011). It is better than mineral fertilizers that cause soil acidity, nutrient imbalance and contamination of water.

Research findings have shown that the efficacy of biochar in improving the fertility of soil and storing organic carbon on soil over a period of time depends on the heat intensity applied during the pyrolysis.(Zeeshan et al., 2014). One could ask if applying biochar made from different organic residues will have any significant effect on soil properties especially on soil carbon stock and aggregate stability of soil. Little information is available on this hypothesis. Therefore, this work was aimed at assessing the effect of different biochar materials on soil fertility, soil carbon stock and aggregate stability of eroded soils and comparing these biochar materials with inorganic fertilizer.

Materials and Methods

We conducted this work at Teaching and Research Farm of Federal University of Technology Owerri, Imo State, South-eastern Nigeria which is located at latitude 5° 21'N and Longitude 7°02'E with annual mean temperature range of 25ºC-30ºC, mean rainfall of 2000 - 2500 mm. Due to high rate of precipitation, the soils are acidic and eroded with poor plant nutrients and this makes farmers to apply animal droppings and mineral fertilizers to increase crop yield. September usually have the highest monthly rainfall ranges of between 250 and 300 mm while February has the lowest mean monthly rainfall of between 0.5 and 1.0 mm. The highest mean monthly temperature occurs between November and March and ranges from 30 to 40°C. The highest mean sunshine hours of 5.5 to 6.5 are recorded in December and the lowest hours of about 2 to 2.3 hours are recorded in August. The relative humidity is generally high all the year round with the highest values obtained in the wet season. Soil in the area is derived from coastal sediments and classified as ultisol (USDA) and Acrisol (FAO/UNESCO). The soil has inherent constrains to agricultural productivity such as inherent low exchangeable bases, low organic matter and total nitrogen, low activity clay, poor structural stability and very high susceptibility to erosion and drought as well as poor water holding capacity (Onwudike et al., 2017).

Land Preparation and Experimental Design

A three year fallow land measuring 16 m X 18 m was manually cleared using machetes, hoes and rakes. After stumping and raking the debris, the area was tilled into beds measuring 2 m × 2m. Each bed was 1 m apart. The layout was replicated five times in a randomized complete block design.

Sourcing and Preparation of Biochar Materials

Palm bunch and rice mill husk were obtained from the oil mill farm and rice mill farm at Ohaji Egbema in Imo State and Akaeze in Ebonyi State Nigeria respectively while saw dust was obtained from Naze timber market in Imo State. A drum made of galvanized metal pan with length 200 cm and 100 cm diameter was constructed for biochar production. It has small opening through which little amount of oxygen enters into it. Saw dust, rice mill husk and palm bunch materials were separately pyrolyzed at 400°C for 6 hours. Five kilogramme of N.P.K 15:15:15 fertilizer was bought from Imo State Agricultural Development Authority while Oba super 2 maize variety was purchased from seed council at National Root Crop Institute Umudike, Abia State Nigeria.

Treatments and their Applications

The treatments studied were 10 t/ha palm bunch biochar + 0.25t/ha poultry manure (T1), 10 t/ha rice mill husk biochar + 0.25t/ha poultry manure (T2), 10 t/ha saw dust biochar + 0.25t/ha poultry manure (T3), 500kg/ha N.P.K 15:15:15 fertilizer + 0.25t/ha poultry manure (T4) and plot without biochar + 0.25t/ha poultry manure (T5) (control plot). Here, 0.25t/ha poultry manure was constant in all the treatments. Maize (Oba super 2) was used as test crop which was planted a week after applying the treatments. The crop was planted at 50 cm interval at 1 cm depth and this gave a total of 25 seeds per bed and plant population of 62,500 seeds per hectare of land. The biochars were applied at low wind intensity. The materials were damped with water before spraying on the plots and then pulverized. These were done to avoid loss through wind and water erosion due to light weight of the biochar.

Collection of Data and Analysis

Before seed bed preparation, randomly undisturbed soil samples were collected at 10 sampling points within the experimental area at 30 cm depth for pre-planting soil analysis. After 9 weeks of treatment application, six bulked soil samples were collected from each treatment plot at 30 cm depth for post sample analysis. These samples were collected using cylindrical metal cores of 5.0 cm internal diameter and 5.0 cm height and air dried at room temperature, sieved with 2mm mesh for laboratory analysis. Two weeks after planting, growth parameters (plant height and number of leaves) were measured and counted at two weeks interval. The weight of fresh maize cob was measured during harvesting using weighing scale.

Laboratory Analysis

Soil physical and chemical properties were determined using the procedures as described in Table 1 below.

Soil Aggregate Stability Using Indirect Erodibility Indices and Organic Carbon Stock

Indirect erodibility indices such as clay ratio (CR), modified clay ratio (MCR), critical level of soil organic matter (CLSOM) and clay flocculation index (CFI) were determined according to the procedures of Igwe and Obalum (2013) and Tarafdar and Ray (2006) using the equations as stated below

$$\text{CR} = \frac{\%sand + \%\,silt}{\%\,clay} \quad (3)$$

$$\text{MCL} = \frac{\%sand + \%\,silt}{\%\,clay + \%Organic\ matter} \quad (4)$$

$$\text{CLSOM} = \frac{\%\,organic\ matter}{\%\,clay + \%\,silt} \quad (5)$$

$$\text{CFI} = \frac{\%\,clay\ in\ calgon - \%\,clay\ in\ water}{\%\,clay\ in\ calgon} \times 100 \quad (6)$$

Soil Carbon stock was calculated using the formula adopted by Batjes (1996), and Brown et al., (2004)

$$\text{SCS} = \sum_{k=1}^{n} Dbi * Ci * Di \quad (7)$$

where; SCS = Soil carbon stock, Dbi = bulk density (g/cm^3), Ci = Soil organic carbon (g/kg) and Di = soil depth.

Table 1. Methods used in analysing soil parameters

Soil Property	Methodology
Sand, silt and clay fractions	Water and sodium hexametaphosphate (calgon) were used to disperse soil samples and the fractions were determined by hydrometer method according to Gee and Or (2002) procedure
Bulk Density	Soil bulk density (BD) was determined by core methods as described by Grossman and Reinsch (2002) with the formula $(BD) = \frac{\text{weight of dry soil}}{\text{volume of dry soil}}$ (1)
Total Porosity	This was calculated from the result of bulk density using the formula Total Porosity (TP) = $[1 - \frac{BD}{pd} \times 100]$ (2) where pd = Particle density (2.65 g/cm^3) and BD = bulk density
Soil pH	This was determined in water and in KCl using pH metre in soil / liquid suspension of 1 : 2.5 according to Hendershot et al., (1993)
Organic Carbon	This was determined using chromic wet oxidation method according to Nelson and Sommers (1982).
Total Nitrogen	Total N was determined by Kjeldahl digestion method using concentrated H_2S0_4 and Sodium Copper sulphate catalyst mixture according to Bremner and Yeomans (1988)
C / N Ratio	This was determined by computation of organic carbon and total nitrogen values (Brady and Weil, 1999)
Exchangeable Mg and Ca	These were determined using ethylene diamine-tetra acetic acid (EDTA) (Thomas, 1982).
Exchangeable K and Na	Exchangeable K and Na were extracted using 1 N Neutral ammonium acetate (NH_4OAC) and then determined using flame photometer (Thomas, 1982)
Exchangeable Acidity	This was measured titrimetrically using 1 N KCl against 0.05N Sodium hydroxide (Mclean, 1982)
Effective Cation Exchange Capacity	This was calculated from the summation of all exchangeable bases and total exchangeable acidity
Base saturation	Base saturation was calculated by dividing total exchangeable base by effective cation exchange capacity and multiplying the quotient by 100

Statistical Analysis

Results from soil analysis and growth parameters of maize were statistically analyzed with Genstat discovery software (4th edition). Analysis of variance was used to determine the significant differences among treatment means at 0.05 probability level using least significant difference (LSD). Interaction between soil properties with erodibility indices and soil carbon stock was determined with correlation analysis.

Result and Discussion

Properties of Soil at the Study Location and Chemical Composition of Biochar Materials

Some physicochemical properties of soil before the study are presented in Table 2. Soil at the experimental site was texturally sandy with low content of organic matter, total nitrogen and exchangeable bases. The soil was strongly acidic while base saturation and available phosphorus was low according to FAO (2006) soil fertility rating. The C/ N ratio of the soil was high indicating inherent nitrogen deficiency. Selected chemical nutrient compositions of biochar materials are presented in Table 3. The biochars had high pH and therefore could help to reduce the acidity of the acidic soil. The biochars had high organic carbon and exchangeable bases which are expected to improve the quality of the eroded soil for optimum crop production.

Effect of Biochars and NPK Fertilizer on the Physical Properties of Soil

Application of biochars did not significantly ($p \leq 0.05$) influence the textural class and silt clay ratio of the soils when compared to plots treated with only N. P. K fertilizer or control plot (Table 4). However, biochar significantly influenced soil bulk density and total porosity when compared to N. P. K fertilizer or control plots. Application of 10 t/ha palm bunch biochar reduced bulk density by 19% and increased total porosity by 19.3% recording the lowest bulk density value and highest total porosity when compared to other treatments.

Reduction in soil bulk density and increase in soil total porosity on soils amended with biochars could be attributed to the porous nature of biochar (Nyambo et al., 2018). Adekiya et al. (2018) made similar observation and attributed the increase in the porosity of the soil to the porous nature of biochar. The significant increase in soil total porosity and reduction in soil bulk density could be due to the formation of soil macro pores that rearranges soil particles (Hseu et al., 2014). Ndor et al. (2015) and Mukherjee and Lal (2013) reported an increase in soil porosity, gravimetric moisture retention, and decrease in soil bulk density on soils that were amended with rice mill husk biochar.

Table 2. soil physico-chemical properties before the study

Soil Property	Value
Sand (g/ kg)	922.4
Silt (g/ kg)	67.6
Clay (g /kg)	10.0
Textural class	Sand
Silt/clay ratio	6.76
Bulk density (g/cm^3)	1.48
Clay activity	0.37
pH (1:2.5 H_2O)	5.26
pH (1:2.5 KCl)	4.38
Total Nitrogen (g /kg)	0.39
Organic Carbon (g /kg)	9.97
C/N ratio	25.6
Available Phosphorus (mgkg^{-1})	10.32
Exchangeable Acidity ($H^{++}Al^{3+)}$ (Cmolkg^{-1})	1.28
Exchangeable calcium (Cmolkg^{-1})	1.50
Exchangeable Magnesium (Cmol/kg)	0.62
Exchangeable Sodium (Cmol/kg)	0.188
Exchangeable Potassium (Cmol/kg)	0.15
Effective cation exchange capacity (Cmol/kg)	3.74
Base saturation	65.6

Table 3. Chemical properties of the Biochar used in the study

Chemical properties	PBB	RMHB	SDB
Organic carbon (g/ kg)	46.55	56.3	73.2
Total Nitrogen (g /kg)	5.57	4.31	4.11
C/N ratio	8.36	13.06	17.81
Available Phosphorus (g /kg)	0.51	0.41	0.41
pH (1:10 H_2O)	10.48	8.67	9.52
Exchangeable Calcium (%)	0.76	5.7	0.57
Exchangeable Magnesium (%)	0.36	0.85	0.31
Exchangeable Sodium (%)	0.2	0.31	0.18
Exchangeable Potassium (%)	0.15	0.18	0.13

PBB= palm bunch biochar, RMHB= rice mill husk biochar, SDB= saw dust biochar

Table 4. Effect of biochar and NPK fertilizer on soil physical properties

Treatment	Sand (g/ kg)	Silt (g /kg)	Clay (g /kg)	Textural Class	Bulk Density (g/cm^3)	Total Porosity (%)	Silt/Clay ratio
T1	841	60	92	Loamy sand	1.33	49.6	0.65
T2	841	66	92	Loamy sand	1.39	47.5	0.71
T3	834	60	99	Loamy sand	1.46	44.9	0.61
T4	828	67	99	Loamy sand	1.54	41.9	0.68
T5	848	69	83	Loamy sand	1.59	40.0	0.78
F-LSD($P<0.05$)	Ns	Ns	Ns		0.21	5.52	Ns

Values are means from five replications, T1 = 10 t/ha palm bunch biochar + 0.25t/ha poultry manure, (T2) = 10 t/ha rice mill husk biochar + 0.25t/ha poultry manure, (T3) = 10 t/ha sawdust biochar +0.25t/ha poultry manure, (T4) = 500kg/ha N.P.K 15:15:15 fertilizer +0.25t/ha poultry manure, (T5) = plot without biochar +0.25t/ha poultry manure (control plot)

Effect of Different Biochars and NPK Fertilizer on Soil Carbon Stock

There was significant effect on soil carbon stocks with application of different biochar materials (Fig.1). Comparing the treatments, the highest value of soil carbon stock was recorded on plots amended with 10 t/ha saw dust biochar which increased the carbon stock of the soil by 95.1%. There was an increased 92.3% soil carbon stock on soil amended with 10t/ha palm bunch biochar while rice mill husk biochar increased soil carbon stock by 92.1%. Amending soil with biochar was more efficient in increasing the carbon storage in the soil than NPK fertilizer or control which had no significant effect on soil carbon stock.

Increase in soil carbon stock on biochar amended soils could be attributed to high organic carbon in the biochars and the ability of biochar to retain organic carbon due to it recalcitrant nature over time (Olarieta *et* al., 2010). The ability of biochars to retain its organic carbon in soils as a result of its aromatic structure could also attribute to an increase in soil carbon stock in biochar amended soils (Wang et al., 2016).

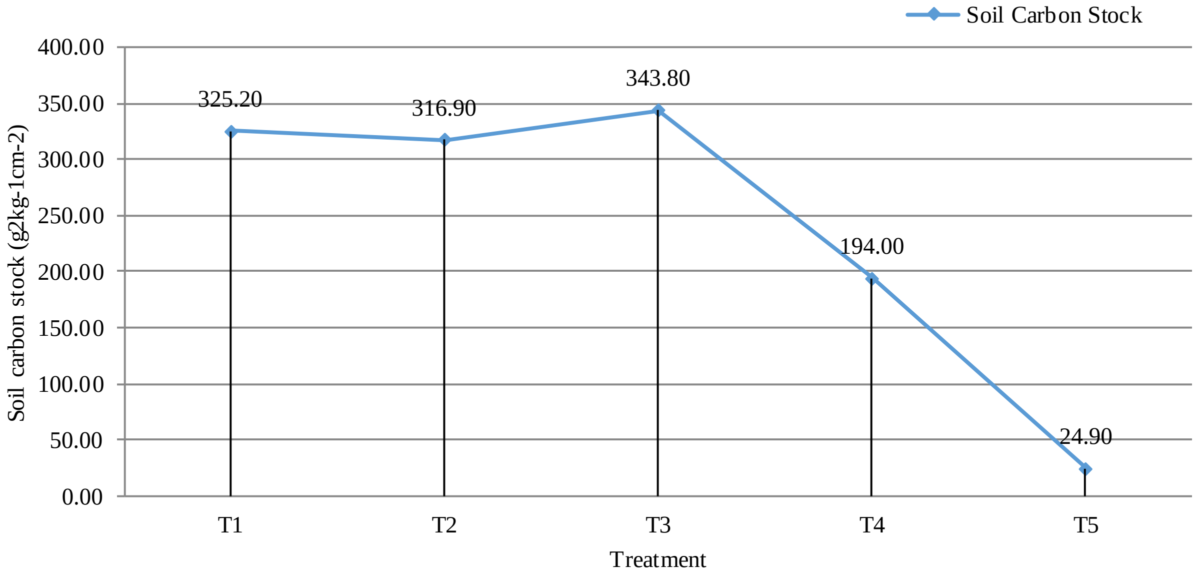

Figure 1. Effect of different biochars and NPK fertilizer on soil carbon stock
T1 = 10 t/ha palm bunch biochar + 0.25t/ha poultry manure, (T2) = 10 t/ha rice mill husk biochar + 0.25t/ha poultry manure, (T3) = 10 t/ha saw dust biochar +0.25t/ha poultry manure, (T4) = 500kg/ha N.P.K 15:15:15 fertilizer +0.25t/ha poultry manure, (T5) = plot without bio char +0.25t/ha poultry manure (control plot)

Table 5. Effect of biochar and NPK fertilizer on Soil Chemical Properties

T	pH1	pH2	OC	Total N	Avail. PM	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	TEB	TEA	ECEC	BS
				g /kg	g /kg	←			Cmol /kg			→	%
T1	6.22	5.67	16.30	0.41	16.31	5.74	2.65	0.42	0.33	9.14	1.43	10.57	86.20
T2	6.01	5.59	15.20	0.36	15.82	4.14	2.44	0.38	0.31	7.27	1.44	8.71	83.46
T3	5.97	4.79	15.70	0.23	14.27	3.64	1.85	0.31	0.26	6.06	1.42	7.48	81.00
T4	5.23	4.65	8.40	0.52	17.22	3.54	1.46	0.29	0.16	5.45	1.73	7.18	75.90
T5	5.13	4.25	7.90	0.16	7.25	1.43	0.57	0.25	0.14	2.39	1.79	4.18	57.20
LSD(0.05)	0.49	0.19	0.44	0.07	0.33	0.39	0.19	0.06	0.09	0.19	0.33	0.42	0.31

T: Treatment; pH1: pH (H_2O); pH2: pH (KCl); OC: Organic carbon g/kg; Values are means from five replications, T1 = 10 t/ha palm bunch biochar + 0.25t/ha poultry manure, (T2) = 10 t/ha rice mill husk biochar + 0.25t/ha poultry manure, (T3) = 10 t/ha saw dust biochar +0. 25t/ha poultry manure, (T4) = 500kg/ha N.P.K 15:15:15 fertilizer +0.25t/ha poultry manure, (T5) = plot without biochar +0.25t/ha poultry manure (control plot), Avail. P = available P, Exch. Exchangeable, TEA = total exchangeable acidity, TEB = total exchangeable bases, ECEC = effective cation ex change capacity, BS = base saturation

Effect of Biochars and NPK Fertilizer on Soil Chemical Properties

Biochar application and NPK fertilizer significantly ($p \leq 0.05$) influenced the pH of the soils when compared to control plot (Table 5). Soils amended with 10 t/ha palm bunch biochar significantly increased soil pH by 17% and also increased soil organic carbon by 51.5% with reference to control plot. The highest available phosphorus and total nitrogen was recorded on plots treated with 500kg/ha NPK 15:15:15 fertilizer which increased total N by 69% and available P by 57% when compared to control plot. There was 73% increase in total exchangeable bases and 53% decrease in total exchangeable acidity on soils treated with 10 t/ha palm bunch biochar. Soils amended with biochar recorded a significant increase in effective cation exchange capacity (ECEC) and base saturation than sole application of NPK fertilizer and control. Soil amended with 10t/ha palm bunch biochar increased ECEC by 60% and percentage base saturation by 33%.

The significant effect in the chemical properties of soils with application of biochars could be attributed to the ability of biochars to retain cations and absorb soluble inorganic soil nutrients like ammonium ions over a long period of time because of its recalcitrant nature (Lehmann and Rondon, 2006). The high pH in biochar materials contributed to the increase in the pH of the soil which helped in making exchangeable bases available in the soil for absorption by plants (Laird et al., 2010). Biochars can absorb leachate, phosphates and exchangeable cations and this will influence the chemical characteristics of soils (Jia et al., 2015). Njoku et al. (2015) and Yamato et al. (2006) recorded an increase in the pH of soils treated with biochar and attributed it to the char which acts as lime in raising soil pH. Soils treated with NPK fertilizers recorded higher values of total N and available P because NPK 15:15:15 fertilizer contains more N and P than biochar materials (Table 3).

Effect of Biochars and NPK Fertilizer on Soil Erodibility

There was significant influence in the erodibility indices of the soils with application of biochars and NPK fertilizer (Figure 2). Results showed that apart from control plot that did not receive biochar and NPK fertilizer, there was an improvement in the clay ratio (CR), critical level of soil organic matter (CLOM), modified clay ratio (MCR) and clay flocculation index (CFI). Application of biochars irrespective of the type significantly increased CR, CLOM and MCR and reduced CFI when compared to control plot. Among the treatments, application of 10t/ha palm bunch ash recorded the highest values of CR, CLOM and MCR and lowest value of CFI. According to Kusrel et al. (2018), soils with clay ratio above 15% indicate that the soils are erodible to erosion but if less that 15%, the soils are not erodible. Therefore the soils amended with palm bunch biochar, rice mill husk biochar and saw dust biochar had clay ratio above 15% unlike the control with CR below 15% indication high susceptibility of the soils to erosion. Soil amended with only NPK fertilizer was moderately not erodible. Similarly, soils amended with biochars had CLOM and MCR above 5 which indicated that the soil have high resistance to erosion. Olaniya et al. (2020) reported that CLOM less than 5 means high susceptibility to erosion while MCR and CLOM less than 5 indicates high susceptibility to erosion. Among the biochars, application of 10t/ha palm bunch ash improved the stability of soil to erosion than NPK fertilizer. This is confirmed in the results of clay flocculation index where soils amended with biochar recorded lower CFI than NPK fertilized soils and control. The lower the CFI, the higher the resistant of the soil to erosion while the higher the value the lower the erodibility.

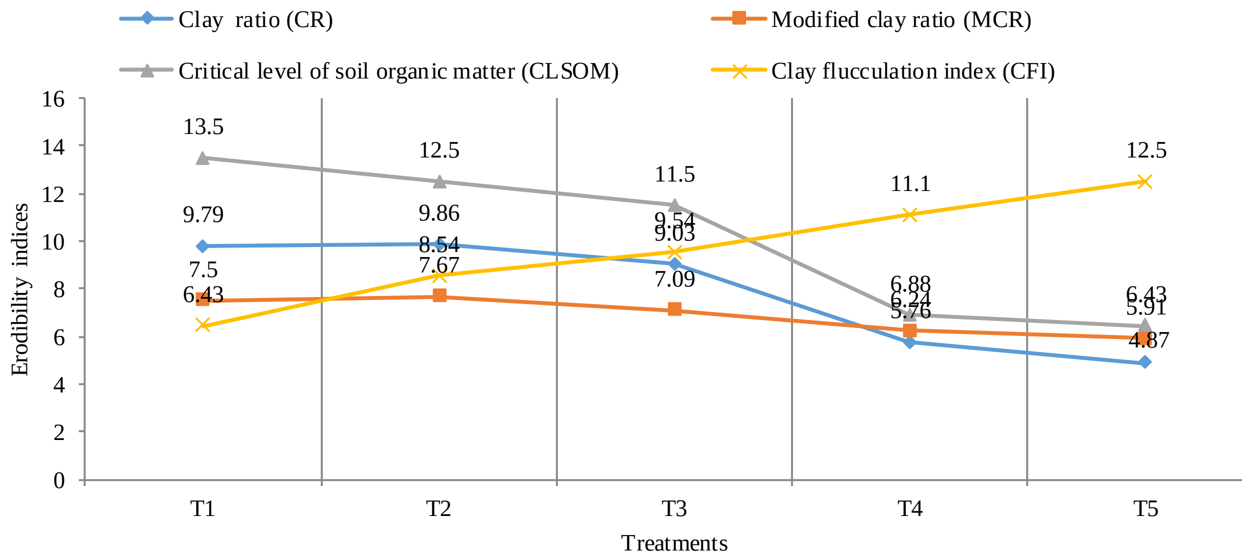

Figure 2. Effect of biochars and NPK fertilizers on the erodibility of soil
T1 = 10 t/ha palm bunch biochar + 0.25t/ha poultry manure, (T2) = 10 t/ha rice mill husk biochar + 0.25t/ha poultry manure, (T3) = 10 t/ha saw dust biochar +0.25t/ha poultry manure, (T4) = 500kg/ha N.P.K 15:15:15 fertilizer +0.25t/ha poultry manure, (T5) = plot without bio char +0.25t/ha poultry manure (control plot)

Effect of Biochars and NPK Fertilizer on the Growth and Yield of Maize

From 2 to 4 weeks after planting, the treatments did not significantly influence the height and numbers of leaves of maize but after 4 weeks of planting, significant effects was observed with soils amended with 10 t/ha palm bunch biochar recording the highest values of maize height (Figure 3) and number of leaves (Figure 4). The trend changed in the fresh cob weight of maize where plots amended with 10 t/ha rice mill husk biochar recorded the highest fresh cob weight against other treatments (Figure 5) even though it was not significantly difference with yield obtained from plots fertilized with 10 t/ha palm bunch biochar and 500kg/ha NPK fertilizer. This could be due to high N in the applied biochars and NPK fertilizer which helped in the vegetative growth and yield of the plant.

The significant effects on the growth and yield of maize on biochar amended soils could be attributed to improved soil structural stability of the soils as manifested in the modified organic matter, critical level of soil organic matter, clay ratio and clay flocculation index. These helped to reduce nutrient losses and reduce the bulk density of the soil for better root elongation and nutrient absorption. This finding agreed with Katterer et al. (2019) who recorded an increase in the growth and yield of maize with application of biochar in Kenya. However, the work of Adekiya et al. (2019) contradicted this observation where biochar did not significantly improve the yield of *Raphanus sativus* under short duration of application. Most works on acid soils recorded significant improvement in the growth and yield of crops with application of biochar. For example, Njoku et al. (2015) applied 10 t/ha rice mill husk biochar and recorded higher yield of sesame (*Sesamum indicum L.)* in Nasarawa State of Nigeria while Reichenauer et al. (2009) recorded significant increase in the growth and yield of crops even at low rate of biochar application.

Relationship between Erodibility Indices and Soil Properties

There was significant positive correlation between CLOM with available phosphorus, clay fraction, effective cation exchange capacity, exchangeable bases, total porosity, soil pH, total nitrogen and organic carbon. Significant negative correlation existed between CLOM with bulk density and total exchangeable acidity. Similar relationship existed between CR and MCR with the soil properties (Table 6).

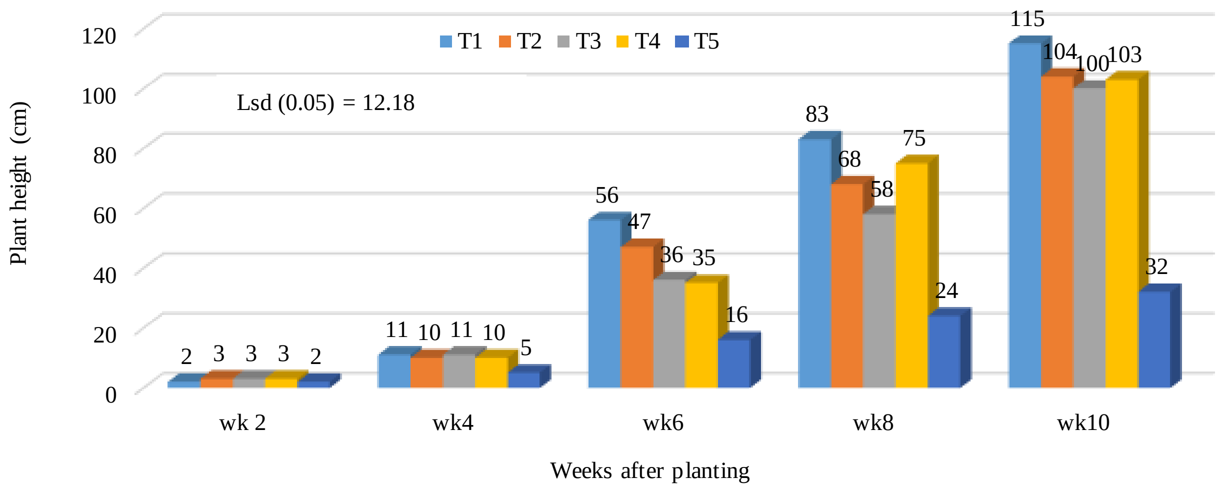

Figure 3. Effect of biochars and NPK fertilizer on the height of maize
T1 = 10 t/ha palm bunch biochar + 0.25t/ha poultry manure, (T2) = 10 t/ha rice mill husk biochar + 0.25t/ha poultry manure, (T3) = 10 t/ha saw dust biochar +0.25t/ha poultry manure, (T4) = 500kg/ha N.P.K 15:15:15 fertilizer +0.25t/ha poultry manure, (T5) = plot without biochar +0.25t/ha poultry manure (control plot)

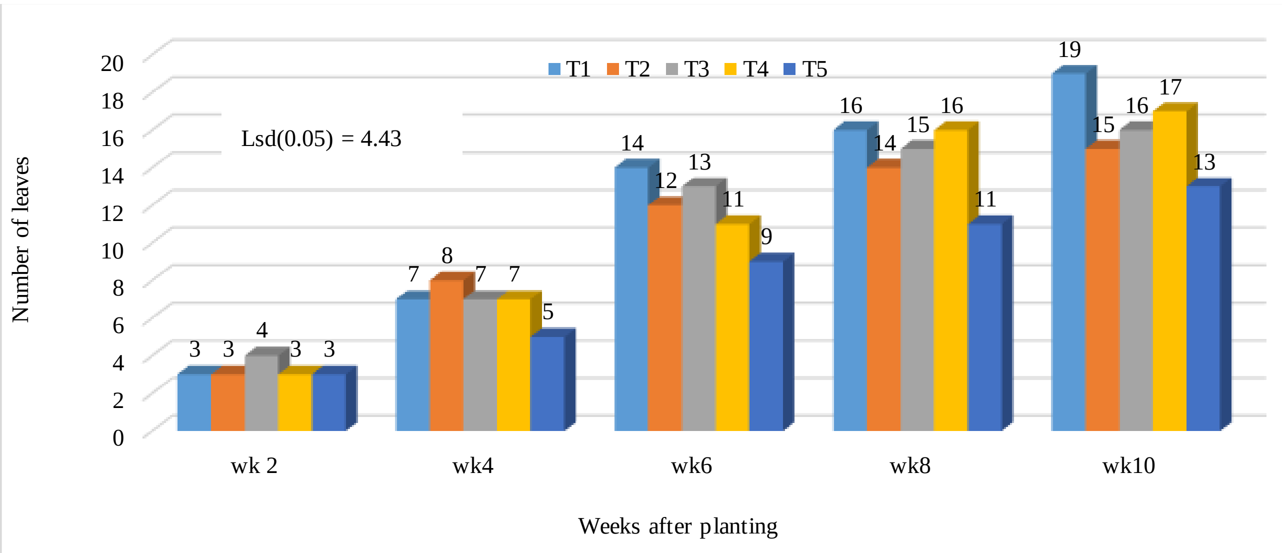

Figure 4. Effect of biochars and NPK fertilizer on the number of leaves of maize
T1 = 10 t/ha palm bunch biochar + 0.25t/ha poultry manure, (T2) = 10 t/ha rice mill husk biochar + 0.25t/ha poultry manure, (T3) = 10 t/ha saw dust biochar +0.25t/ha poultry manure, (T4) = 500kg/ha N.P.K 15:15:15 fertilizer +0.25t/ha poultry manure, (T5) = plot without bio char +0.25t/ha poultry manure (control plot)

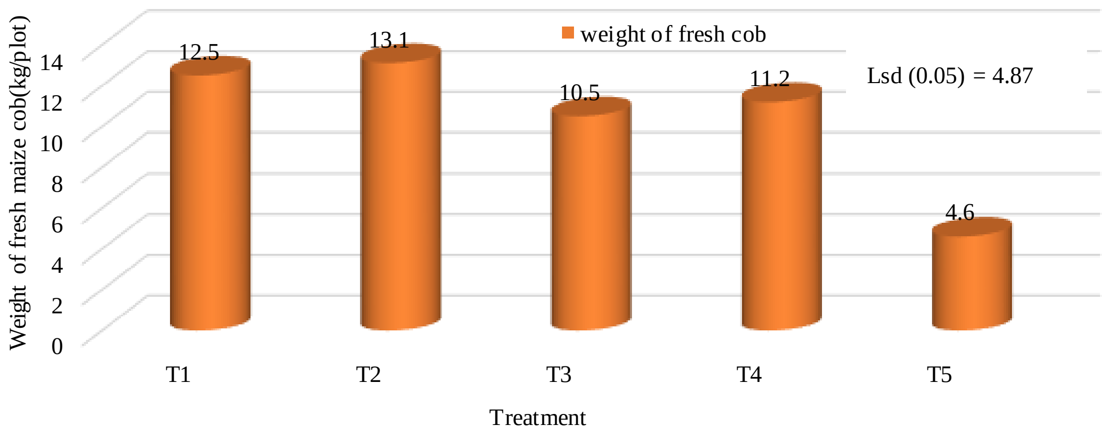

Figure 5. Effect s of biochars and NPK fertilizer on the weight of fresh maize cob
T1 = 10 t/ha palm bunch biochar + 0.25t/ha poultry manure, (T2) = 10 t/ha rice mill husk biochar + 0.25t/ha poultry manure, (T3) = 10 t/ha saw dust biochar +0.25t/ha poultry manure, (T4) = 500kg/ha N.P.K 15:15:15 fertilizer +0.25t/ha poultry manure, (T5) = plot without bio char +0.25t/ha poultry manure (control plot)

Table 6. Interaction between soil erodibility indices, soil carbon stock and soil physicochemical properties

Soil Property	CLSOM	CR	CFI	MCR	Soil Carbon Stock
AP	0.51*	0.57*	-0.64*	0.60*	0.77**
BS	0.11	0.18	-0.05	-0.28	0.02
Bulk Density	-0.97**	-0.94**	0.99**	-0.95**	-0.84**
Clay	0.23	0.33	-0.26	0.28	0.66*
ECEC	0.86**	0.85**	-0.97**	0.86**	0.86**
Exch. Ca	0.83**	0.81**	-0.95**	0.82**	0.84**
Exch. K	0.91**	0.88**	-0.98**	0.91**	0.77**
Exch. Mg	0.93**	0.94**	-0.96**	0.95**	0.91**
Exch. Na	0.99**	0.98**	-0.96**	0.98**	0.87**
pH H20	1.00**	0.99**	-0.94**	0.96**	0.90**
Sand	0.07	-0.02	0.02	0.00	-0.39
Silt	-0.43	-0.37	0.77**	-0.66*	-0.81**
TEA	-0.97**	-0.98**	0.86**	-0.95*	-0.94**
TEB	0.88**	0.87**	-0.97**	0.88**	0.88**
Total N	0.11	0.15	-0.36	0.22	0.34
Total Porosity	0.96**	0.94**	0.99**	-0.95**	-0.84**
Organic carbon	0.98**	0.98**	-0.89**	0.95**	0.91**

*and ** = significant at 0.05 and 0.01 probability levels respectively

However, different trend was observed in the relationship between CFI and the soil properties where significant negative relations occurred between CFI with available P, base saturation, clay, effective cation exchange capacity, exchangeable bases, total N and organic carbon. This is because clay flocculation index is inversely related to CLOM, CR and MCR (Igwe and Obalum, 2013). Soil carbon stock significantly correlated positively with available P, clay fraction, effective cation exchange capacity, exchangeable base and organic carbon. Soil organic matter helps in the stability of soil aggregates and soil with high organic matter content will accommodate high soil microbes whose activities in the soil will improve soil structure and stability of soil aggregates. Bearing in mind also that organic matter acts as a reserviour for soil nutrients (Onwudike et al., 2016), it is expected that the high organic matter in biochar will significantly influence CLOM, CFI, CR and MCR in the soil. Increasing the content of soil organic matter will increase the pH, exchangeable bases, CLOM, CR and MCR while it will decrease the value of CFI (Zeeshan et al., 2004).

Conclusion

Palm bunch biochar, rice mill husk biochar and saw dust biochar are rich in plant nutrients and applying them on acid and eroded soil has shown to increase the pH, soil carbon stock and exchangeable bases more than application of inorganic fertilizer. This study showed that biochar applications on soil has the ability to improve the stability of soil aggregates by improving the modified clay ratio, critical level of soil organic matter and reducing the clay flocculation index more than inorganic fertilizer, these help to reduce soil loss through erosion and increases the resistance of soil to erosion. These attributes contributed positively by increasing the growth and yield of maize as proved in this study.

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