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ASSESSING COMBINED EFFECTS OF BIOCHAR CONCENTRATIONS AND DIFFERENT FERTILIZER APPLICATIONS ON PHYSICOCHEMICAL PROPERTIES OF A SANDY LOAMY SOIL

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ABSTRACT

Biochar application in the soil is a major strategy for modifying or improving its physicochemical properties, while soil fertility can be boosted by fertilizer application. The process of soil amendment was explored to investigate the impact of combined biochar and fertilizer treatments on soil properties and yield of New Rice for Africa (NERICA 2) upland rice variety. A Randomized Complete Block Design experiment was conducted using three different fertilizer types, three different biochar concentrations, and two sets of control each, with zero biochar and zero fertilizer. The biochar levels were 0 t/ha, 5 t/ha, 10 t/ha, and 15 t/ha, while the fertilizer types were zero fertilizer, liquid organic fertilizer (LOF), solid fertilizer (NPK), and farmyard poultry manure (PM). A drip irrigation system with the completed layout captured the entire set-up, while soil properties were measured before soil treatment, post-season 1, and post-season 2. A significant increase in particle density from 2.51 g/cm^3 to 2.56 g/cm^3 was recorded while bulk density decreased from 1.42 g/cm^3 to 1.41 g/cm^3, and soil textural classification remained relatively unchanged. Organic carbon, organic matter, nitrogen, phosphorus, potassium, cation exchange capacity, and base saturation increased from their respective pre-treatment values. Also, soil pH improved significantly from 6.38 to 6.37. There was a better improvement in soil properties, which resulted in increased paddy rice yield with an average value of 6.36 t/ha obtained using NPK with a biochar concentration of 15 t/ha (NPKB15) treatment. This is an equivalent of approximately 400% increase in yield compared to the zero fertilizer and zero biochar (FOBO) treatment yield of 1.14 t/ha. NPK fertilizer at a biochar concentration of 15 t/ha, gave the best result in the soil's physical and chemical properties and is recommended for rice production.

Keywords: Soil properties, Soil improvement, Rice yield, Plant nutrients.

INTRODUCTION

Modern agriculture is an evolving approach to agricultural innovations and farming practices that help farmers increase efficiency and reduce the number of natural resources needed to meet the world's food demands. Soil, which is one of the natural resources has been declining rapidly due to over-utilization to meet food demand for the burgeoning population (Akinbile *et al.,* 2019). This decline of the soil continues until management practices are improved, additional nutrients are applied, rotation with nitrogen-fixing crops is practiced, or until a fallow period occurs allowing a gradual recovery of the soil through natural ecological development. The most widespread solution to soil depletion is the right application of soil amendments in the form of fertilizer and manure containing the three major nutrients i.e., nitrogen, phosphorus, and potassium (Bot and Benites, 2005; Akinbile *et al.,* 2020). Ray *et al.* (2013) identified poor soil fertility as one of the two critical factors affecting crop production. Hence, there is increasing demand for researchers to evolve strategies that will improve the physical and chemical properties of the soil in areas of low soil fertility, improve water retention in the soil, as well as improve water use efficiency by the plants to increase yield (Ray *et al.,* 2013).

Sustainable soil management requires practices that maintain and improve soil physicochemical properties while sustaining optimum crop yield over time. To maintain soil fertility, there is a need to apply more stable and nutrient-retaining compounds such as biochar (Lehmann, 2007). The addition of biochar as amendment materials to agricultural soils is receiving much attention due to the apparent benefits of biochar to soil quality, crop yields, and carbon sequestration (Oki and Kanae, 2006; Lehmann and Joseph, 2009; Eze *et al.,* 2022). Sohi *et al.* (2010) stated that biochar is pyrolyzed biomass, produced to amend agricultural soils. They further stated that adding biochar to the soil has been shown to modify some physical properties of the soil such as bulk density, porosity, texture, and particle size distribution, and impact the soil structure. IBI (2011) defined biochar as carbonized biomass obtained from sustainable sources and sequestered in soils to sustainably enhance their agricultural and environmental value under present and future management. Shackley and Sohi (2010) defined biochar as 'the porous carbonaceous solid produced by the thermochemical conversion of organic materials in an oxygen-depleted atmosphere, which has physiochemical properties suitable for the safe and long-term storage of carbon in the environment and potentially, soil improvement'. Biochar is highly recalcitrant due to its condensed structure (Spokas *et al.,* 2012) and is derived from the thermal decomposition of biomass in an environment with low or no oxygen at moderately low temperatures. Several studies have shown that biochar can ameliorate soil nutrients status, cation exchange capacity in the soil, soil structure, nutrient use efficiency, water-holding, nutrient-holding capacity, and saturated hydraulic conductivity, while decreasing soil acidity (Lehmann *et al.,* 2006; Asai *et al.,* 2009; Karhu *et al.,* 2011; Akingbola *et al.,* 2021, 2022). Increases in yield with biochar application have been reported for crops such as cowpea (Yamato *et al.,* 2006), soybean (Tagoe *et al.,* 2008), maize (Yamato *et al.,* 2006; Rodríguez *et al.,* 2009), upland rice (Asai *et al.,* 2009), paddy rice (Shackley *et al.,* 2011; Sokchea and Preston, 2011) and water spinach (Southavong *et al.,* 2012).

Achieving optimum production of crops has not been possible without external input of inorganic fertilizers and organic materials (Niehues *et al.,* 2004; Stewart *et al.,* 2005; Mohamed *et al.,* 2008). Generally, fertilizer application is often unaffordable for poor farmers thus they depend on the organic manures whose amendment properties are generally short-lived in the soil due to the rapid decomposition of soil organic matter under high temperatures and aeration of the tropics. The organic matter is usually mineralized within some days after planting (Sander and Tarek, 2012). Therefore, conventional fertilization has been instrumental in not only maintaining but also improving crop yield, especially in the tropics (Major *et al.,* 2010a).

Despite all these benefits, there are some limitations associated with the effective usage of biochar in improving soil fertility. They include the challenge of fluctuating rainfall patterns, soil acidity, and low soil fertility, especially in Nigeria, and require a systematic yet sustainable integrated strategy. To overcome these limitations, a management strategy needs to be urgently developed not only to improve crop yield and quality but also to enhance soil fertility status. Agegnehu *et al.,* (2014) suggested that an integrated soil fertility management approach may have more sustainable agronomic and economic benefits than the use of inorganic fertilizer alone. This study examined the effects of soil amendment using biochar and fertilizer combination treatment on soil physical and chemical properties, and on an upland rice yield.

METHODOLOGY

Description of the study area

The study was conducted at the teaching and research farm of the Department of Agricultural and Environmental Engineering, the Federal University of Technology, Akure, Nigeria. Akure is located at latitudes 7° 14'N and 7° 17'N and within longitude 5° 08'E and 5° 13'E. The soil of the study area is sandy loam according to the United States Department of Agriculture (USDA) soil textural classification (Akinbile *et al.,* 2019). The pattern of rainfall is bimodal, the first peak occurring between June and July, and the second in September, with a little dry spell in August. The mean annual rainfall ranges from 1300 mm to 1500 mm (Akinbile and Sangodoyin, 2012). The soils are light textured, fine sandy loam (Akinbile *et al.,* 2019). The average temperature of the area is 27.5 °C. The relative humidity ranges between 85% and 100% during the rainy season and less than 60% during the harmattan period. The area is about 651 m above sea level and the major occupation of the people are farming and business (Akinbile *et al.,* 2019). The soil moisture holding capacity was described as moderately good (Akinbile and Sangodoyin, 2012).

Experimental set-up and field operations

The design was laid out in a Randomized Complete Block Design (RCBD) of four fertilizer types with four levels of biochar application. The total plot size for the experiment was 10 x 10 m with a 1 x 1 m treatment size and the treatments were factorially combined of 4 x 4 x 3, making a total of 48 experimental plots. Pathways between the treatments and replicates were 1 m x 1 m alleyway with 25 stands of upland rice stand per plot (rice's plant spacing of 20 cm x 20 cm). Four types of fertilizers applied were: Liquid Organic Fertilizer (LOF) -GNLD, NPK 15:15:15 (NPK) inorganic (synthetic), Poultry Manure (PM), and Zero Fertilizer (F0), while the four concentrations of biochar applied were 0 t/ha, 5 t/ha, 10 t/ha, and 15 t/ha. The application rates were consistent with that of previous investigations (Major *et al.* (2010b; Ndor *et al.* 2015).

Rice straw was used as the biomass material for the biochar. It was pyrolyzed using the standard laboratory procedure at the Central Laboratory, FUTA at 400 °C with a heating rate of 2.08 °C/min over a residence time of 55 mins based on the fixed-bed batch type pyrolysis system. The methodology adopted was similar to those previously described (Weixiang *et al.,* 2012; Jiang *et al.*, 2015; Kamara *et al.,* 2015; Yakout 2017).

A drip irrigation system installed over the field was connected with a fertigator (HI 5000 Mini-fertigator - Hanna Instrument) which mixed the fertilizer with irrigation water at the rate of 2500 mL per hectare inside the fertigation tank. The water source was from a borehole sunk for the study located about 30 m from the field. The summary of the treatments is shown in Figure 1, with a legend describing the annotations.

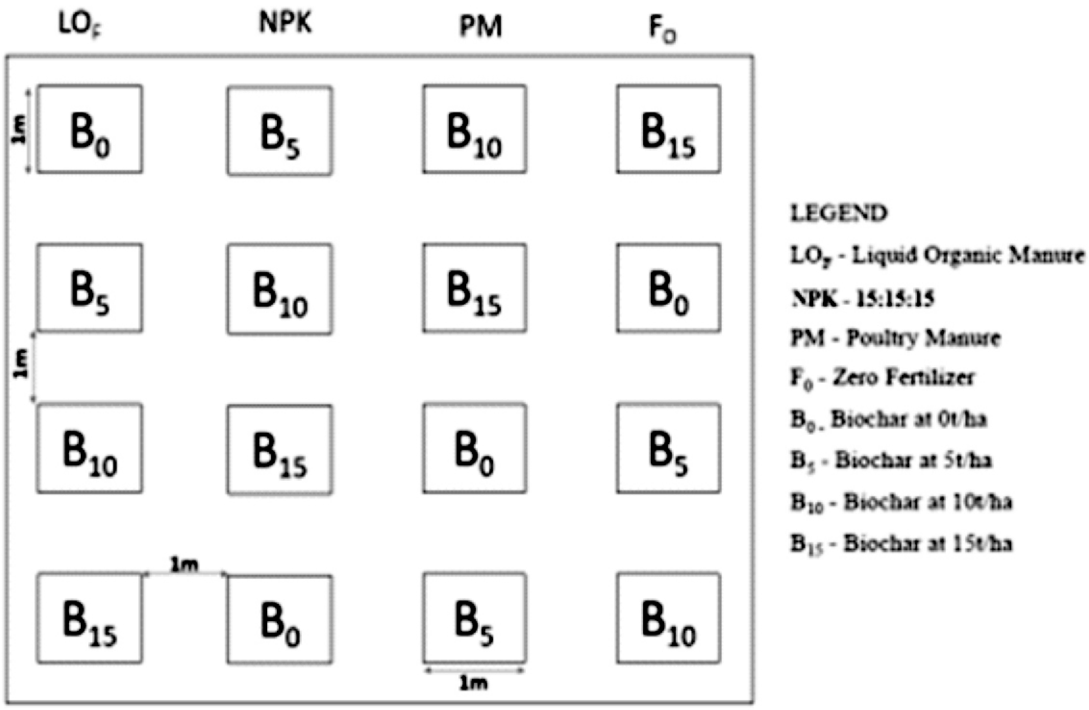

Figure 1: Schematic representation of field layout and set-up.

Conventional field operations were conducted before planting for season 1 occurring between October 2018 and April 2019. The process was repeated at the end of planting season 1 approximately 50 weeks after the commencement of season 1 in the same field i.e., October 2019 to April 2020. Field data measurements and soil samplings and processing were carried out according to standard environmental procedures within the 2 seasons of the experiment. The initial moisture content was raised through drip irrigation to the field capacity before planting. The layout and configuration (plot treatment) of season 1 were retained for season 2.

Biochar was incorporated into the top 15 cm and was evenly mixed with the soil at different rates manually. The first application was before planting, except for the liquid fertilizer which was applied at 3 WAP (Weeks After Planting) through the fertigator. NPK fertilizer was applied using the ring method at a rate of 60 kg/ha while the PM was applied via the broadcasting method at a rate of 5 t/ha after curing for seven days. The plant population was close to recommended plant population of 250,000 stands per hectare by IITA (2014) which is obtainable with a plant spacing of 20 cm x 20 cm at one stand per hole. The second fertilizers and manure application were at the rice tillering/booting stage (9 WAP).

Data collection

Biochar physicochemical characterization

Biochar samples were taken to the university's central laboratory where their physical and chemical properties were determined following the International Biochar Initiative (IBI, 2011) procedure. Biochar bulk density was determined using the standard described by ASTM E873-82 (2013). Chemical properties analyzed include nitrogen (N), Phosphorus (P), Potassium (K), sodium (Na) contents, organic carbon, cation exchange capacity (CEC) and pH. They were determined following standard laboratory procedures, as described previously (Weixiang *et al.,* 2012; Jiang *et al.,* 2015; Kamara *et al.,* 2015; Yakout 2017) while the pH was measured as described by Naeem *et al.,* (2014). CEC was determined by Na saturation as described by Gaskin *et al.* (2008) except that Na was determined by flame photometry instead of atomic absorption spectroscopy. Available phosphorus and cations (Na, K, Mg and Ca) were determined by AB-DTPA extraction (1 M NH_4HCO_3 + 0.005 M DTPA) as described by Naeem *et al.* (2014). Na, K, Mg and Ca were analyzed while Phosphorus (P) concentration was measured on a UV-visible spectrophotometer after developing yellow colour by the vanadate-molybdate method (Kuo, 1996).

Physical characterization of soil in the experimental field

Soil's physical properties of the experimental field such as bulk density, particle size distribution, moisture content, and organic matter were determined in the University Central laboratory at the beginning and end of each of the two experiments (two seasons). Soil samples were collected at depths 0 – 30 cm from 12 locations, four from each of the treatments using the core sampler, and bulked before taking it to the laboratory for measurements. The particle size distribution of the samples from different locations was determined using the hydrometer method (Akinbile and Yusoff, 2011) and gravimetric water content on wet basis (wb) as the mass of water in the soil sample per mass of the oven-dried soil (kg/kg).

The same process was repeated for the chemical characterization of soil at the beginning and end of each of the two experiments (two seasons) to determine nutrient reduction or build-up as a result of the use of biochar and different fertilizer types. Chemical characterization of samples analyzed included soil organic matter (SOM), soil organic carbon (SOC), cation exchange capacity (CEC) at pH 7.0, base saturation, and soil pH. Six samples were collected at each location for soil chemical characterization. The organic carbon was determined using Walkley – Black wet oxidation procedure and the soil organic matter content was determined from the organic carbon. The cation exchange capacity (CEC) at pH 7.0 was determined following the procedure of Vogelmann *et al.* (2010). Available phosphorus (P) and exchangeable cations were determined also by bray-1 extraction followed by molybdenum blue colorimetry. The exchangeable potassium (K^+) and sodium (Na^+) were extracted with an HCl solution and their levels were determined by flame photometry (Vogelmann *et al.,* 2010) and exchangeable magnesium (Mg^{2+}) and Calcium (Ca^{2+}) by atomic absorption spectrophotometer (Senjobi and Ogunkunle, 2010). Soil pH was determined using a pH meter (HI99121, Hanna Instruments, Slovenia) according to standard procedure.

Yield estimation and statistical analysis

Rice yield was estimated based on harvested rice which was estimated per treatment combination type to identify which treatment had the best effect on yield. The total paddy rice yield (without biomass) in tonnes/ha was compared following a manual harvesting operation carried out 16 weeks after planting and at 15% moisture content (dry basis). All the rice yield parameters determined were subjected to statistical analysis using tools such as Analysis of Variance (ANOVA), version

9.1, Statistical Analysis Systems (SAS), and Duncan Multiple Range Test (DMRT) at a 95% significant level.

RESULTS

Biochar Characterization

The biochar produced from rice straw was analyzed to determine its physical and chemical properties (Table 1). The biochar bulk and particle densities were 0.54 g/cm^3 and 0.54 g/cm^3, respectively. The chemical analysis carried out showed that the pH value of the biochar was 7.62, and the composition of other elements is as follows: nitrogen (0.94%), phosphorus (22.62 mg/kg), and organic carbon content (65.22%). The potassium and calcium contents were 28.81 cmol/kg and 8.90 cmol/kg, respectively, while sodium content was 3.67 cmol/kg. The yield of the biochar was 36.8% of the original mass of the rice straw used, with an ash content of 35.7%.

Table 1: Physical and chemical properties of biochar.

Parameters	Value
Physical Properties	
Bulk Density (g/cm^3)	0.54
Particle Density (g/cm^3)	0.54
Ash Content (%)	35.7
Chemical Properties	
pH	7.62
Nitrogen (%)	0.94
Organic Carbon (%)	65.22
P (mg/kg)	22.62
K (cmol/kg)	28.81
Na (cmol/kg)	3.67
Ca (cmol/kg)	8.90
Mg (cmol/kg)	3.40
CEC (cmol/kg)	37.10

Soil characterization

Physical properties

The result as presented in Table 2 showed that the application of biochar had positive effects on the physical properties of the soil as most of the properties improved significantly from their initial, post-season 1, and post-season 2 values. Soil bulk density decreased from 1.42 g/cm^3 initial value to 1.41 g/cm^3 in season 1 and further decreased to 1.40 g/cm^3 in season 2, which are within the FAO range of 1.4 - 1.7 g/cm^3, while particle density increased from 2.51 g/cm^3 initial value to 2.56 g/cm^3 in season 1. It maintained the same value in season 2, and both values were around the FAO recommended average value of 2.65.

Table 2: Variations in the physical properties of the soil.

Parameters	Initial	Post Season 1	Post Season 2	FAO Standard
Bulk density (g/cm^3)	1.42±0.01^a	1.41±0.01^a	1.40±0.02^a	1.4 - 1.7
Particle density (g/cm^3)	2.51±0.02^a	2.56±0.01^b	2.56±0.02^b	2.65
Sand (%)	45.00±1.58^d	43.50±0.65^d	43.75±0.63^d	-
Silt (%)	21.00±0.41^b	22.25±0.48^c	22.50±0.29^b	-
Clay (%)	30.25±0.48^c	31.50±0.25^e	31.75±0.50^c	-

**Means that do not share the same letter are significantly different*

Chemical properties

It was observed that most of the essential soil nutrients such as Nitrogen (N), Phosphorus (P), Potassium (K), Organic Matter (OM), Soil pH, Base Saturation (BS), and others recorded a decrease in treatment F0B0 (control) from their initial values compared with their final values in post-seasons 1 and 2 indicative of the rice uptake of the nutrients (Table 3). This might be attributed to the non-application of fertilizer and biochar to the treatment. On the other hand, the essential soil nutrients improved significantly in the other treatments where fertilizer and biochar were applied, an indication that fertilizer and biochar impacted positively on the soil nutrients which supported rice growth. The soil was mildly acidic in the control treatment (F0B0) as soil pH decreased from 6.38 to 6.37 in season 1 and further to 5.37 in season 2, whereas the soil pH tended towards neutral in other treatments.

Organic Carbon (OC) increased from 1.69% to 1.79% in season 1 and further to 1.86 % in season 2 for LOF with Biochar treatment, and from 1.51% (1.47%) to 1.65% (1.66%) in season 1 and further to 1.73% (1.74%) in season 2 in PM (NPK) with Biochar treatment. Organic Matter (OM) increased from 2.90% to 2.91% in season 1 and further to 2.92% in season 2 in LOF and from 2.51% to 2.84% and then 2.86% for PM with biochar treatment. However, in the NPK with biochar, OM increased from 2.49% to 2.79% in season 1, but decreased again to 2.61% in season 2.

Nitrogen (N) content increased from 0.11% to 0.14% in season 1 and then to 0.16% in season 2 for LOF with biochar treatment, from 0.11% to 0.14% in season 1 and 0.19% in season 2 for PM with biochar treatment, and from 0.12% to 0.16% in season 1 and then to 0.21% in season 2 for NPK with biochar treatment. Phosphorus (P) content increased from 6.84 mg/kg initial value to 8.28 mg/kg in season 1 and increased from season 1 value to 8.66 mg/kg in season 2 in LOF. On the other hand, P increased from 6.69 mg/kg to 8.45 mg/kg in season 1 and further to 8.53 mg/kg in season 2 in PM with biochar treatment. It also increased from 7.11 mg/kg to 8.88 mg/kg in season 1 and further to 8.97 mg/kg in season 2 in NPK with biochar treatment. Potassium (K) content increased from 0.63 cmol/kg to 0.86 cmol/kg in season 1 and further to 0.89 cmol/kg in season 2 in LOF with biochar treatment and from 0.63 cmol/kg to 0.81 cmol/kg in season 1 and further to 0.84 cmol/kg in season 2 in PM with biochar treatment. It also increased from 0.78 cmol/kg to 0.95 cmol/kg in season 1 and further to 0.97 cmol/kg in season 2 in NPK with biochar treatment.

Cation Exchange Capacity (CEC) increased from 6.36 cmol/kg to 8.04 cmol/kg in season 1 and further to 8.39 cmol/kg in season 2 in LOF with biochar treatment and from 6.46 cmol/kg to 7.69 cmol/kg in season 1 and further to 7.97 cmol/kg in season 2 in PM with biochar treatment. CEC also increased from 6.36 cmol/kg to 8.06 cmol/kg in season 1 and further to 8.42 cmol/kg in season 2 in NPK with biochar treatment. Base Saturation (BS) increased from 90.56% to 93.47% in season 1 and further to 93.64% in season 2 in LOF with biochar treatment and from 80.37% to 90.15% in season 1 and further to 90.35% in season 2 in PM with biochar treatment. BS also increased from 81.43% to 90.86% in season 1 and further to 91.74% in season 2 in NPK with biochar.

Similar trends were observed in the other treatments for all the soil nutrients tested, such as calcium (Ca), magnesium (Mg), and sodium (Na) contents. An increase in the soil nutrients was recorded with an increase in biochar levels in both season 1 and season 2. It should also be noted that for the zero fertilizer with biochar treatments, the pattern of higher nutrient content in season 1 and season 2 was repeated for most of the properties tested as shown in Table 3.

Table 3: Variations in soil chemical properties in each treatment.

Soil Parameters	Season	LOF with Biochar	NPK with Biochar	PM with Biochar	F0 with Biochar	FAO Range
PH	0	6.76±0.04^{a}	6.23±0.00^{b}	6.32±0.00^{b}	6.38±0.34^{a}	
	1	6.79±0.04^{e}	6.45±0.12^{c}	6.65±0.11^{b}	6.37±0.36^{bcd}	6.5-8.5
	2	6.86±0.00^{g}	6.45±0.12^{c}	6.67±0.11^{b}	5.37±0.00^{bcd}	
OC (%)	0	1.69±0.00^{a}	1.47±0.00^{b}	1.51±0.00^{c}	1.39±0.00^{d}	
	1	1.79±0.04^{bcd}	1.66±0.08^{a}	1.65±0.05^{a}	1.64±0.09^{ab}	2.0
	2	1.86±0.05^{bc}	1.74±0.09^{ab}	1.73±0.07^{a}	1.65±0.14^{ab}	
OM (%)	0	2.90±0.00^{a}	2.49±0.00^{b}	2.51±0.00^{b}	2.21±0.00^{c}	
	1	2.91±0.03^{cf}	2.79±0.10^{a}	2.84±0.11^{a}	2.69±0.16^{abc}	2.0++
	2	2.92±0.03^{cd}	2.81±0.10^{b}	2.86±0.11^{a}	2.65±0.26^{abc}	
N (%)	0	0.11±0.00^{a}	0.12±0.00^{a}	0.11±0.00^{ab}	0.02±0.00^{c}	
	1	0.14±0.01^{ab}	0.16±0.01^{a}	0.14±0.01^{a}	0.11±0.06^{a}	0.2
	2	0.16±0.02^{a}	0.21±0.03^{a}	0.19±0.02^{a}	0.14±0.05^{a}	
P (mg/kg)	0	6.84±0.00^{b}	7.11±0.00^{a}	6.69±0.00^{c}	5.44±0.00^{d}	
	1	8.28±0.63^{g}	8.88±0.84^{b}	8.45±0.80^{b}	7.79±0.92^{d}	20.0
	2	8.66±0.93^{f}	8.97±0.85^{d}	8.53±0.84^{b}	7.86±0.96^{d}	
Ca (cmol/kg)	0	2.00±0.00^{a}	1.50±0.00^{b}	1.20±0.00^{c}	0.80±0.00^{d}	
	1	1.90±0.23^{cdef}	1.65±0.18^{a}	1.80±0.20^{a}	1.48±0.29^{ab}	10-20
	2	1.98±0.19^{bc}	1.68±0.18^{ab}	1.83±0.22^{a}	1.45±0.32^{ab}	
Mg(cmol/kg)	0	1.00±0.00^{a}	0.70±0.00^{b}	0.60±0.00^{b}	0.70±0.00^{b}	
	1	2.18±1.28^{def}	0.73±0.09^{a}	0.85±0.12^{a}	0.73±0.10^{a}	3-8.0
	2	0.83±0.13^{ab}	0.73±0.09^{ab}	0.84±0.08^{a}	0.68±0.12^{a}	
K (cmol/kg)	0	0.63±0.00^{b}	0.78±0.00^{a}	0.63±0.00^{b}	0.13±0.00^{c}	
	1	0.86±0.09^{a}	0.95±0.07^{a}	0.81±0.08^{a}	0.68±0.19^{a}	0.61.2
	2	0.89±0.09^{ab}	0.97±0.07^{ab}	0.84±0.12^{a}	0.72±0.22^{a}	
Na(cmol/kg)	0	0.19±0.00^{d}	0.27±0.00^{a}	0.22±0.00^{c}	0.25±0.00^{b}	
	1	0.29±0.04^{abc}	0.36±0.05^{a}	0.35±0.05^{a}	0.33±0.03^{a}	0.7-1.2
	2	0.33±0.04^{ab}	0.40±0.04^{a}	0.36±0.05^{a}	0.35±0.03^{a}	
CEC (cmol/kg)	0	6.36±0.00^{b}	6.36±0.00^{b}	6.46±0.00^{a}	3.41±0.00^{c}	
	1	8.04±0.65^{g}	8.06±0.61^{b}	7.69±0.48^{b}	6.67±1.18^{cd}	10.00
	2	8.39±0.64^{f}	8.42±0.60^{cd}	7.97±0.49^{b}	6.90±1.25^{cd}	
BS (%)	0	90.56±0.00^{a}	81.43±0.00^{b}	80.37±0.00^{b}	70.01±0.00^{c}	
	1	93.47±1.20^{h}	90.86±3.21^{c}	90.15±3.36^{c}	87.25±5.80^{e}	60–80
	2	93.64±1.51^{g}	91.74±2.51^{e}	90.35±3.38^{c}	87.33±5.87^{e}	++

*** Difference in the letters of superscript in the same row means there is a significant difference* ($P<0.05$)
Where 0, 1, and 2 represent soil chemical properties at the initial stage (after biochar application but before planting), end of season one, and end of season two respectively.

Yield Characterization

The results of rice yield (without biomass) under different fertilizers and with varying biochar concentrations were presented in Table 4. Paddy rice yield was least in the control (F0B0) treatment at 1.14 t/ha for season one harvest, i.e., H1, attributable to the absence of beneficial soil amendment properties present in the other treatments. The yield was maximum, 6.36 t/ha, in NPKB15 treatment for season two harvest, i.e., H2 which comprised NPK 15:15:15 fertilizer type and 15 t/ha biochar concentration, proving that rice production could benefit significantly from improved soil properties and conditions. In all cases, the H2 yield was more than the H1 yield in all the treatments. Also, the yield was significantly higher for the combined treatments relative to the zero fertilizer treatments albeit with varied performance dependent on fertilizer type.

Table 4: Paddy rice yield without the biomass in tonnes/ha for the different treatment combinations.

Season	Biochar conc.	F0	PMB	NPK	LOF
H1	0	1.14±0.03[b]	2.53±0.23[b]	2.02±0.02[c]	1.92±0.78[b]
H2		2.90±0.07[c]	3.38±0.03[c]	2.38±0.08[d]	2.07±0.22[c]
H1	5	1.51±0.08[d]	2.84±0.38[b]	1.81±0.02[d]	1.90±0.27[c]
H2		3.13±0.07[c]	3.25±0.04[c]	2.86±0.08[c]	3.59±0.04[a]
H1	10	1.74±0.08[c]	4.37±0.05[b]	3.59±0.08[b]	2.88±0.14[b]
H2		3.35±0.02[b]	5.29±0.41[a]	4.60±0.01[b]	4.02±0.04[a]
H1	15	2.50±0.08[a]	5.74±0.03[a]	6.31±0.14[a]	3.51±0.07[a]
H2		3.36±0.01[a]	6.00±0.06[a]	6.36±0.01[a]	4.55±0.02[a]

**Means that do not share the same letter are significantly different*
*** Difference in the letters of superscript in the same row means there is a significant difference* (P<0.05)

DISCUSSION

The values of the physical and chemical properties of the biochar obtained in this research as presented in Table 1 are comparable with previous investigations (Weixiang *et al.,* 2012; Jiang *et al.,* 2015; Kamara *et al.,* 2015; Yakout, 2017) with biochar using rice straw as biomass material. The result obtained showed that the biochar was alkaline in nature, rich in nitrogen, potassium, and sodium, with high organic carbon content and cation exchange capacity. Hence, it is suitable to be applied to the soil according to the International Biochar Initiative recommendations (IBI, 2015). The outcome of the analysis of the biochar agreed with the findings of investigations that biochar contains stable carbon, large specific surface area, and negative surface charge (Mukherjee *et al.*, 2011), and gives beneficial soil amendment properties (Paz-Ferreiro *et al.*, 2011; Vaccari *et al.*, 2011; Ali *et al.,* 2015), improving soil water and nutrient retention, carbon sequestration, greenhouse gas emission reduction and enhancing crop yield (Schulz *et al.,* 2013; Butnan *et al.*, 2015).

As for the soil's physical properties presented in Table 2, a reduction in bulk density indicates a comparatively better movement of air and water through the soil of the experimental field and that water retention capacity was higher when bulk density was reduced. The reverse was reported by Liu *et al.* (2012) in fields managed with fertilizers alone. The class of the soil as determined using the USDA Textural Classification is sandy clay loam. This result is consistent with the findings of Akinbile *et al.* (2019) who reported that the soil around the experimental field is sandy loam. The soil has more binding strength due to an increased percentage of clay content. Therefore, it has an adsorptive capacity for basic plant nutrients and might not be easily susceptible to erosion. The sandy loam texture of the soil with good aeration favoured crop growth under a drip or sprinkler irrigation system. The improvement in the physical properties of the soil was a result of the incorporation of biochar and improved agronomic management practices adopted in the research. Liu *et al.* (2012) reported a positive interactive effect of the combined application of fertilizers and biochar on soil physical properties under field conditions. Sohi *et al.* (2010) further stated that adding biochar to the soil has been shown to modify some physical properties of the soil such as bulk density, porosity, texture, and particle size distribution; thus, impacting the soil structure. Eze *et al.* (2022) remarked that the modification in these soil's physical properties might be attributed to the physical dilution of the biochar with soil.

From the chemical properties as presented in Table 3, increasing soil nutrient content was matched by increasing biochar levels in all cases presented thus suggesting that higher biochar resulted in higher soil nutrients irrespective of fertilizer type used. The results agreed with the findings of Van *et al.* (2010) who observed that the addition of biochar to soils enhances the soil's chemical properties, improves soil cation exchange capacity, and pH reduces nutrient leaching, and thus improves fertility and nutrient use efficiency. Nitrogen, Potassium, Phosphorus, Soil organic carbon, and soil pH improved significantly and are among the soil properties that are very essential for rice optimum growth. Results also support the findings by Gaskin *et al.* (2010) who observed that two years of biochar application increased soil organic carbon (SOC) and total nitrogen content (TN) without affecting soil available phosphorus (P). Major *et al.* (2012c) reported that the amendment of soil low in fertility with wood biochar at 20 t/ha increased the concentration of nitrate (NO_3-N) in the soil solution. Akingbola *et al.* (2021; 2022) reported that the ability of biochar to retain soil nutrients and improve the water-holding capacity of soil may have direct effects on increasing crop yield and water use efficiency.

For rice yield characterization under different fertilizer types with varying biochar concentrations, a progressive increase was observed as biochar concentrations increased. The results agreed with the findings of Major *et al.* (2010b) which reported that when several rates of biochar (concentration levels) are used, plots with the higher biochar application rate showed better results. Also, the general pattern showed that yield increased with increasing levels of biochar applied corroborating reports that combined fertilizer and biochar applications were very effective in enhancing yield as indicated by Schulz and Glaser, (2012) and Zhang *et al.* (2012).

CONCLUSION

The combined effects of biochar concentrations and fertilizer types on soil's physicochemical properties where rice (*NERICA 2)* was planted under drip irrigation were determined. Results of physicochemical analyses of the biochar used showed that the biochar was naturally alkaline, which makes it very suitable for application to the soil according to the International Biochar Initiative (IBI) standard. The different types of fertilizers (NPK, Poultry Manure, Liquid Organic Fertilizer, and Zero fertilizer) and the biochar levels (0, 5, 10, and 15 t/ha) applied contributed favourably to the improved physical and chemical properties of the soil, as observed. However, a decrease in the bulk density was recorded in the two seasons from 1.42 g/cm^3 to 1.41 g/cm^3 (season 1) and further to 1.40 g/cm^3 (season 2), while the soil aggregation increased as a result of relative volumetric increases in silt and clay composition up to 22.50% and 31.75% from the initial values of 21% and 30.25%, respectively. Similarly, the base saturation of the soil increased significantly across the treatments in the two seasons, which was an indication of the presence of a considerable number of soluble forms of basic cations in soil that enhanced the crop uptake of soil nutrients. Essential soil nutrients such as nitrogen, phosphorus, potassium, magnesium, calcium, and organic carbon, improved significantly in all the treatments where fertilizer and biochar were applied other than in F0B0 (zero fertilizer and biochar application), an indication that the fertilizers and biochar concentrations had positive effects on the soil nutrients which effectively supported rice growth. NPK fertilizer at a biochar concentration of 15 t/ha, which gave the best result in the soil's physical and chemical properties is recommended as the best treatment for soil in rice production under similar conditions if achieving food security is the goal, especially within the study area.

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CONFLICT OF INTEREST

There is no conflict of interest

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