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EFFECT OF BIOCHAR ON WATER RETENSION AND LEACHING OF NUTRIENTS IN A SANDY LOAM SOIL

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Abstract: Nutrient leaching causes agronomic and environmental problems in intensively cultivated soils. In this study, the effect of biochar on retension of nutrient in sandy loam soil was evaluated. Upland rice was amended with 3 different sources of biochar in randomized complete design with 4 replications. The treatment included a control (no input), fertilizer, and upland rice either applied alone or in combination with the three different sources of biochar (poultry manure, corn cobs and groundnut shell). Biochar levels were 5 t ha^{-1} each and were incorporated into the soil at the same time. Inorganic fertilizer was applied at a rate of 90, 60, 60 and 45, 30, 30 kg ha^{-1} NPK, as straight fertilizer and then top-dress with nitrogen levels in the form of urea 30 kg ha^{-1} N eight (8) weeks after transplanting. Upland rice was planted in each lysimeter. Leachate from each lysimeter was collected at 3 weeks intervals for 24 months. For the 24 months running biochar significantly decreased the volume of water leached. Control and 90N60P60K treatments showed higher concentrations of NO_3-N and K in the leachate. At a depth of 70 cm leaching significantly reduced with all the three different sources of biochar combined with 45N30P30K and 90N60P60K. The application of three different biochar sources to tropical sandy loam soil may give environmental benefits such as carbon sequestration and reduced nitrate and potassium leaching. Our results indicated that biochar and 45N30P30K combination could be appropriate as a sustainable agronomical approach.

Keywords: lysimeter, leaching, nutrient, biochar, inorganic fertilizer, moisture retention

Introduction

Water flowing through the soil is adequate for nominal crop growth as well as conservational management. The amount and action of drainage have consequences for crop water and nutrition management (Chen et al., 2018;Laird et al., 2010). Biochar integration into agricultural soil is a possible way of increasing nutrient bioavailability of phosphorus and reducing nutrient leaching from soil (Chen et al., 2018). Its integration can decrease inorganic N leaching and increase N retention in the soil (Borchard et al., 2019; Oladele et al., 2019; Sun et al., 2017). It has a high cation exchange capacity (Ding et al., 2016; Yang et al., 2017) and affects the soil pH (Novak et al., 2009), with the shortest-way absorption of and NO_3^- being the most important process. This can happen very quickly in well-drained clayey soils (Renck and Lehmann, 2004). Adding biochar to soil has been demonstrated to enhance crop yield NH_4^+ (Blackwell et al., 2009; Lehmann and Joseph, 2015; Rondon et al., 2007; Steiner, 2008), but its effect on soil hydrology and nutrient leaching has been less explored. Its addition also improves biomass production, which indicates more plant water uptake. Water may reduce through evapotranspiration when it is amended to the soil. A reduced amount of water would then pass through the soil by unsaturated flow in response to changes in matric potential. Its material is very porous (Downie et al., 2009) and has a low density equated with soil.

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It improves negatively charged surfaces as weathering occurs (Sanchez-Monedero et al., 2018; Ventura et al., 2013) and therefore forms relationships with soil minerals (Agegnehu et al., 2017). It has been proven to serve a diversity of molecules in soil, together with pesticides (Khorram et al., 2016; Kookana, 2010), simple hydrophobic organic molecules (Lehmann et al., 2011), and plant leaf extracts (Ding et al., 2016). If applied to soils, it favours the development of microorganisms (Gao and DeLuca, 2018; Pietikäinen et al., 2000), which combined with the influences from minerals and other soil organic matter, may lead to greater soil aggregation. These changes may alter water flow's physical appearance after its application to soil. It can improve the water-holding capacity of the soil and therefore decrease the total volume of leachate (Liu et al., 2017; Ouyang et al., 2013) While its integration into a loam soil had no results, its integration into clay soil condenses water holding capacity. All trends improved or reduced linearly with increasing integration rates. Ayodele *et al*. (2009) testified to augmented infiltration and less runoff in the soils of old charcoal storage sites in Ghana. Major, 2009 recommended some hypotheses for mechanisms and concluded that they could reduce and increase nutrient leaching after adding to soil. Leaching, on the other hand, could be helped by improved nutrient conveyance to charcoal particles or improved saturated instability in soil due to greater soil aggregation with biochar.

The comparative importance of these anticipated mechanisms is not distinct. Because it is said to hold more nutrients, their loss due to leaching could be reduced. This procedure for rising nutrient obtainability has been revealed in laboratory (Faloye et al., 2017; Maxfield, 2017; Scholz et al., 2014) and greenhouse experiments with plants (Budai et al., 2013). Partey et al., 2016 demonstrate that "renewed" biochar addition to an Oxisol soil in Sub-Saharan Africa resulted in a 60% reduction in leaching of applied ammonium (NH_4^+) compared to absolute control over 40 days of cropping rice (*Oryza sativa* L.). Early in that trial, calcium (Ca) and magnesium (Mg) leaching decreased as well, but potassium (K) leaching did not, likely because biochar contains a lot of K (Van Zwieten et al., 2010). However, leaching of K and P usually improved with larger biochar application rates. (Tian et al., 2016) establish more ammonium retention over a longer period, which proposes the evolution of cation exchange sites through oxidation. In a field study, ferric luvisols planted to upland rice species preserved a higher proportion of isotopically tagged nitrogen (N) for two years in the Guinea savanna. After biochar was added, it was likened to compost, even though leaching was not restrained directly (Steiner et al., 2010). Literature searches no work has directly evaluated the effect of biochar application on soil water and nutrient leaching in a field trial over many cropping seasons.

Process-based models not only assist scientists in improving their understanding of various agro-ecosystem components, but they also assist policymakers and farmers in determining farm management opportunities. Such models capture the consequences of various practices on soil dynamics and, therefore, the interactions with crop physiological processes (Holzworth et al., 2014). APSIM (Agricultural Production Systems sIMulator) may be a model that gives a fully-tested framework with a versatile 69-structure that's capable of simulating interactions among weather, soils, crops, and previously known management systems (Keating et al., 2003). In one of the primary efforts to model the consequences of biochar on soils,(Lychuk et al., 2015) by designing an algorithm that accounted for them, biochar's effects on soil properties were incorporated into the EPIC model (Environmental Policy Integrated Climate). Within that algorithm, biochar directly impacts soil CEC, pH, bulk density, and soil organic carbon, and therefore the dynamic interaction between soil organic carbon and biochar also changes because of the change in soil water dynamic and mineral nitrogen in soil. Model performance evaluation revealed a suitable end in replicating field trials of biochar impacts on short-term crop yields and soil properties (Lychuk et al., 2015). A biochar sub-model has been developed for the APSIM model with the aim of providing a dynamic process-based framework for modeling the effect of biochar on soil and crop processes (Archontoulis et al., 2016). This sub-model can simulate carbon decomposition in biochar and assess changes in soil water, bulk density, pH, CEC, organic and mineral nitrogen robotically. The model's calibration results revealed that it can predict soil (pH, bulk density, total carbon, and water content) and crop-related variables (corn grain yield and corn stover) with a mean relative error ranging from -0.4% to 13.10% (Archontoulis et al., 2016). Following recent trials of the APSIM biochar module in Ghana's guinea savanna zone, a recommendation of implementing it on a larger scale and examining the consistency of biochar effects on upland rice productivity as well as NH_4^+, $N0_3$-N, P, pH, EC, and K leaching for different sources of biochar in the same soils. So far, very little study has been published with focus on bigger scale evaluation of biochar effects on upland rice yield and environmental factors using process-based simulation models. APSIM would help to clarify the involvedness of biochar interactions with soil and climate. Over three cropping seasons, this study investigated the effects of three distinct sources of biochar application on poor soils on upland rice yield, soil organic carbon, and NH_4^+, $N0_3$-N, P, pH, EC, and K leaching through saturated sandy soil. The study aims to see if utilizing three distinct sources of biochar as a soil amendment on Guinea savannah agricultural soils improves biomass harvesting sustainability by improving soil quality, sequestering carbon, and boosting nutrient retention and recycling. The specific objective of this study was to see how soil biochar amendments affected nutrient leaching after an inorganic fertilizer application in a typical Guinea savannah agricultural soil.

Materials and methods

Description of study area

The research site was located at the Farming for the Future, University for Development Studies (UDS), Nyankpala near Tamale in the Northern Region of Ghana (latitude 09.246070N and longitude 000.589920W). The area has a unimodal rainfall pattern with an annual rainfall of 800-1100 mm (Kombiok et al., 2012). The dry season starts from November to March with day temperatures ranging from 33 °C to 39 °C, with night temperatures range from 20 °C to 26 °C (Kombiok et al., 2012). The mean annual daytime relative humidity is 54% with altitude of the area is 252 m above sea level. The site is underlain by Upper Voltaian sediments. The area is covered with red and orange-brown drifts partly eroded in places and exposing a layer of shallow ironstone and sandstone (Adu, 1957).

The layer is often separated from the underlying sandstone by a thin stone-lime (Adu, 1995). The soil profile has been classified as Nyankpala series (Ferric Luvisols) (ISSS/ISRIC/ FAO, 1998; FAO-UNESCO (1988). They are shallow to very shallow soils overlying in situ developed iron pan within 55.9 cm. It is also moderately shallow to moderately deep concretionary and or gravelly, heavy to medium textured soils overlying mostly highly weathered granites shales (Obeng, 2000). Characteristically the soils are acidic, with low nitrogen and phosphorus content. They are susceptible to moderate erosion and should not, therefore be left bare. They are inherently infertile and will need to be fertilized to obtain optimum yield (Adu, 1995).

Biochar preparation

Three different sources of feedstocks were produced from slow and high pyrolysis of groundnut shells, corn cobs, poultry manure at 400°C - 700°C with a dwelling time of 24 hours in oxygen-limited conditions in a reactor, followed by water and air cooling of charred feedstock to room temperature and grind the biochar. The synthesized biochar was ground. Chemical characteristics of the biochar are shown in Table 1. Organic carbon was determined by the wet combustion method according to (Walkley and Black, 1934). Total nitrogen was determined by the kjeldahl method. Phosphorus and potassium were determined in plant ash using the Gallenkamp flame analyzer method (Bremner, 1996). Available phosphorus was determined according to (Bray and Kurtz, 1945).

Biochar Types

Table 1: Basic biochar properties used for simulations

Feedstock	Pyrolysis	pH 1:5	C.E.C me100g-1	N %	P %	K %	C/N ratio (-)	Fraction C (0-1)
Biochar Corn cobs	High	6.67	118.26	0.95	0.21	0.45	11.0	0.129
Biochar Poultry manure	Low	9.29	125.63	2.19	0.5	0.47	10.5	0.324
Biochar Groundnut shells	Low	11.13	85.52	1.34	0.13	0.74	12.3	0.243

Source: Frimpong-Manso and Ganiyu (2021)

Experimental design and data collection

Biochar levels were 5 t ha^{-1} each and were incorporated into the soil in June 2017. The experiment was in randomized complete blocks design (RCBD) with 4 replications. The crops were Nerica 14 (African upland rice) with 85 days of maturity for the rice (*Oryza sativa* L.). Nerica 14 seeds were soaked in water to separate unfilled grains from filled grains and then dried at room temperature for 24 hours prior to sowing. The seeds were drilled in rice husk biochar at 3 cm below the biochar surface in rows 30 cm apart to maintain moisture for good germination. Weeds were controlled by hand twice before transplanting. Transplanting was done on 28th July, 2018 and 21st July, 2019 at a rate of two seedlings per hole. Planting distance was 20 cm x 20 cm for the transplanted rice seedlings. The arrangement of the rice and cowpea was in a 3:1 ratio. A week after transplanting, fertilizer was applied at a rate of 90N:60P:60K and 45N:30P:30K kg ha^{-1} Nitrogen(urea), Phosphorus (triple super phosphates and Potassium (muriate of potash) respectively, as straight fertilizer and then top-dressed with nitrogen levels in the form of urea at 30 kg ha^{-1} N at tillering and booting stage respectively when it was eight (8) weeks after transplanting. Weeds were controlled by hand four counts during the season. Weeding was done manually by hand picking and with the use of hand hoe, two weeks after transplanting and as and when weeds reappeared. Weeding and loosening of the soil surface was done four times in the sole rice plots and two times in the rest of the treatments for both intercrop experiments. The weeds that were found on the plots were the usual weeds associated with rice. Weeds occurrence in sole rice was high (50 % coverage of plot area), while that of intercrop was moderate (30-40 % coverage of plot area) and sole cowpea recording low occurrence (10-30 coverage of plot area. The common weeds observed were the grasses (*Rottboellia cochichinensis, Oryza barthii* and *Paspalum orbiculare*); broad leaves (*Ageratum conyzoides, Hibiscus* spp and *Ipomoea acquatica*) and sedges (*Commelina Africana* and *Cyperus diformis*).

The data used in the current study cover the main crop and soil processes. Soil profile was carried out at the initial stage of the experiment (Table 2). Soil sampling was done at depth of 0-30 cm for characterization of both chemical and physical properties. Bulk density and porosity were determined weekly till harvesting Table 5. Agronomic data was collected every week from 30 days after transplanting to heading. Ten plants were randomly selected on each plot and plant height at maturity, number of panicles, number of tillers and number of grains per panicle determined. At maturity 1 m^2 in each plot were harvested for yield. Data collected at maturity included measurements plant height for rice, number of panicles, and number of plants within 1 m area. Five panicles were randomly selected for number of spikelet's, panicle length, number of grains per spikelet on a panicle, weight of unfilled and filled grains, total grain weight and 1000 grain weight for rice and straw weight. Data were determined by APSIM modules version 7.

Installation of instruments and leachates measurement

Thirty-two (32) lysimeters were installed in thirty-two plots. A 70 cm deep hole was dug to install the lysimeters, and back filling was carried out in such a way to provide good soil contact and also prevent excess rain water running into the hole of the installed lysimeters. The soil around the lysimeters was filled up to help prevent ponding around them and preferential flow down the backfilled hole. Leachates were sampled from thirty-two (32) plots and measured with a graduated measuring cylinder. Collection of leachate sampling and hydrological monitoring were performed every three weeks until the plants were harvested. The number of sampled leachates for each individual lysimeter was recorded and transferred into a labelled storage bottle. The sampled leachates were conveyed to the laboratory in an iced chest with some ice cubes for chemical analysis. Figure 2 presents the flowchart of constructing lysimeters, collection and measurement of leachate at the field.

Table 2. Soil profile parameters used in this study

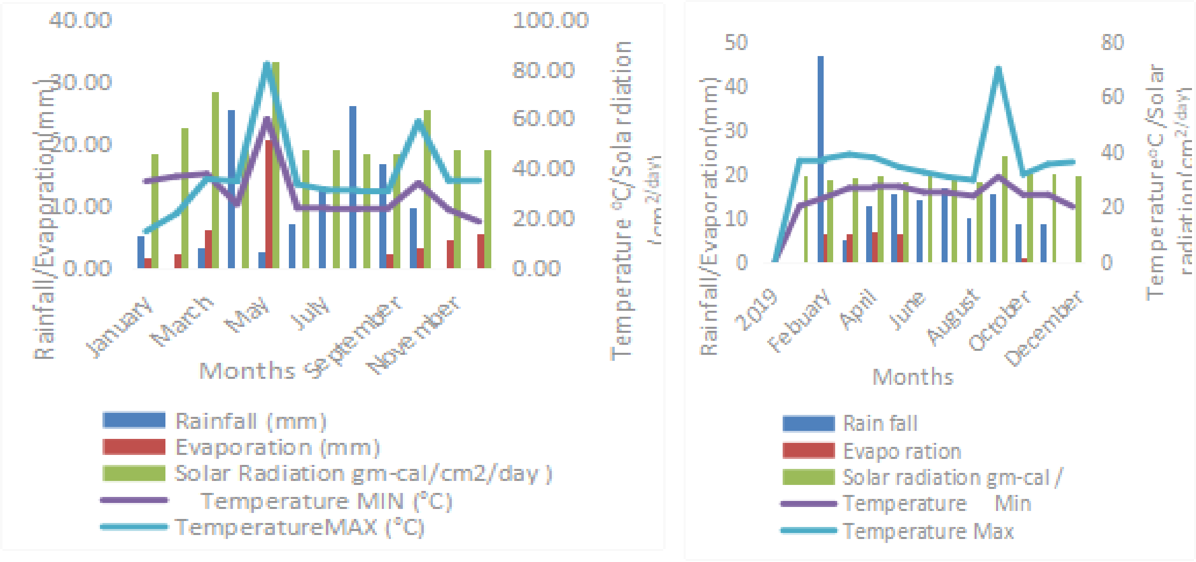
Soil Layer	1	2	3	4	5
Layer thickness (cm)	0-15	15-30	30-60	60-90	90-120
Soil water parameters					
BD (g cm^{-3})	1.58	1.62	1.57	1.59	1.57
SAT (mm^{-1})	0.354	0.358	0.368	0.342	0.339
DUL (mm-^{1})	0.202	0.204	0.201	0.198	0.132
LL15 (mm^{-1})	0.050	0.106	0.153	0.128	0.198
Soil-C parameters					
OC (%)	0.47	0.41	0.33	0.38	0.33
pH(H20)	4.66	4.66	4.66	4.56	4.56
Finerta	0.36	0.36	0.70	0.90	0.90
Fbiomb	0.016	0.02	0.02	0.01	0.01
Soil P parameter					
Labile P (Mg kg^{-1})	11.6	5.8	5.0	2.0	1.0
P sorption (mg kg-1)	60	80	150	180	200

Source: Frimpong-Manso and Ganiyu (2021)

Soil parameterization of ferric Luvisols at farming for the future, UDS experimental farm to specify APSIM simulations. LL, lower limit; DUL, drained upper limit; SAT, saturated volumetric water content; BD, bulk density; OC, organic carbon; Fbiom, non-inert fraction of microbial C; and Finert, inert fraction of organic C.

Climatic weather during the cropping Season 2018-2019

The rainy season's peak happened in July for the current time slice, while a change in the rainfall peak toward August was predicted for the future time slice. The months of August, October, and November are expected to see significant increases in monthly rainfall in the future. The month with the most rainfall was August (Figure 1). Since sandy loam soils dry out rapidly due to their low permanent wilting point, accessible water, and water storage capacity, good crop yields are strongly dependent on a well-distributed rainfall pattern. In the wet season of 2018-2019, Figure 1 depicts the study area seasonal water balance. In 2018-2019, the total rainfall was 133.29 mm, while the total evapotranspiration was 37.10 mm. The upland rice was planted in June of 2018 and 2019, and harvested in November of the same month. From July through October, 61.81 mm of rainfall, while 3.07 mm of evapotranspiration fell (Figure 1). During the rice growth phase, from July to August, the table shows a favorable moisture balance. From July to August, rainfall increased and evapotranspiration decreased dramatically. However, because the September rainfall was lower, there was a slight water deficit after August. During the upland rice growing season, there was drought. As a result, biochar amended had a higher yield than non-biochar amended. The significant drop in average temperatures during the upland rice's growth phase (Figure 1) also contributed to a decrease in evapotranspiration, which favoured the rice plant.



Source: Frimpong-Manso and Ganiyu (2021)

1a. climatic weather for 2018

1b. climatic weather for 2019

Figure 1. Summary of climatic weather observed at the study site from 2018 - 2019 Cropping Season

Lysimeters

Flowchart of constructing lysimeters

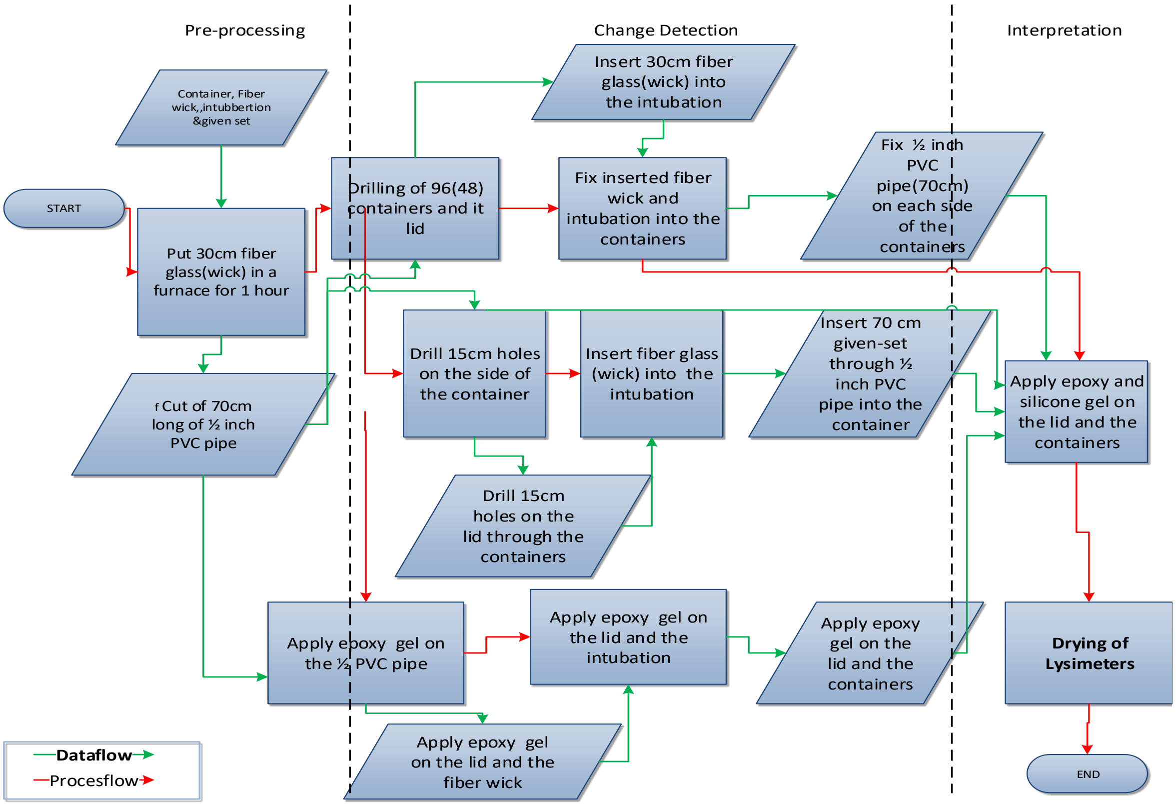


Figure 2. Construction process of Lysimeters used for the experiment.

Leachates nutrient analysis

Leachates Sampling

Leachates were collected from thirty-two (32) pots and measured using a graduated measuring cylinder. The number of leachate samples collected for each individual lysimeter was recorded and transferred to a labelled storage bottle. The sampled leachates were transported to the laboratory in an ice chest containing some ice cubes for chemical analysis. The plants were sampled twice every three weeks until they were harvested.

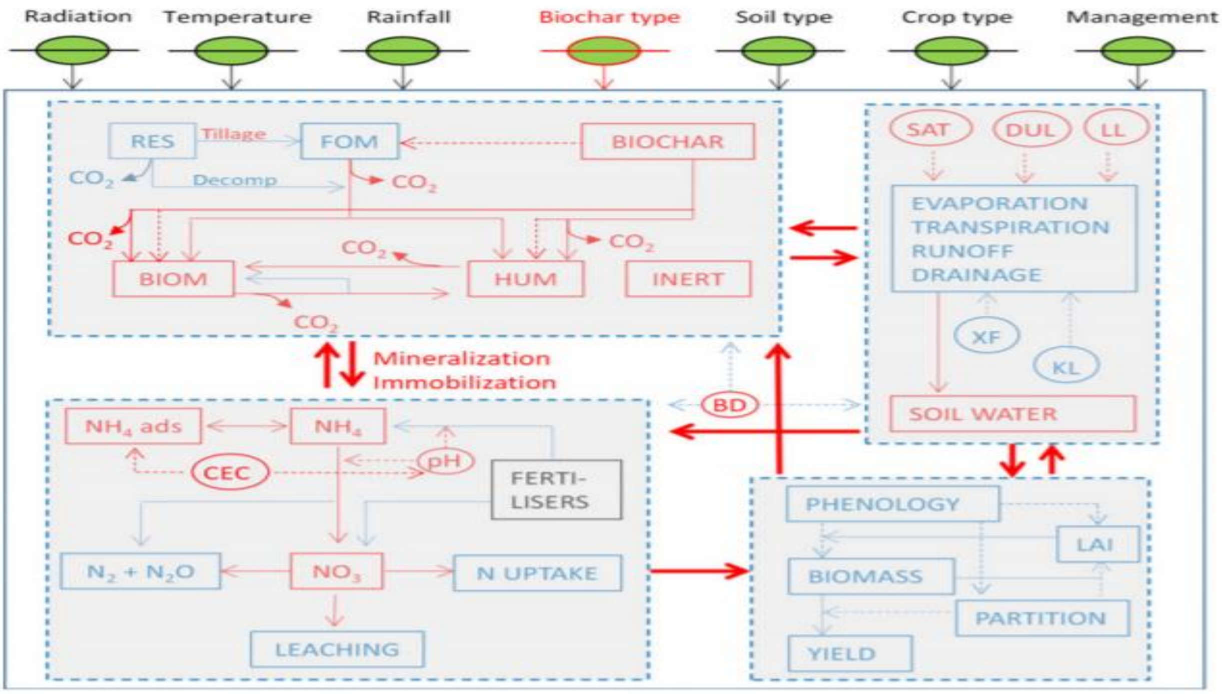


Figure 3: Sources: Adapted from John Wiley and Sons (2015)

A basic diagram demonstrating APSIM's soil carbon: (top left windowpane), soil nitrogen (bottom left window pane), soil water (top right windowpane) and crop (bottom right windowpane) modules. Boxes are state variable, solid arrows are rate variables and shows material flow (e.g. carbon), broken arrows show information flow (e.g. priming), and circles are intermediate variables. Driving variables for the system (green circles at the top) include weather, soil, crop, and management. Those that are indicated in red are the state, rate, and intermediate variables that we assume to be influenced by biochar amendments. RES, surface residue; FOM, fresh organic matter; BIOM, microbial pool; HUM, humic pool; INERT, inert pool; SAT, saturation point; DUL and LL, drained upper and lower limits; KL, parameter defining the capability of the roots to take up water; CEC, cation exchange capacity; and BD, soil bulk density.

A pH meter was used to measure soil pH in a 1:15 w/v soil with a deionized water mixture that was stirred three times over the period of one hour. Electrical conductivity was measured using the Jenway 4510 Conductivity Meter. It was calculated using (Rhoades, 1993) method. PO_4 in the leachates was determined using the malachite green technique (Olsen, 1982). The malachite green procedure was used to determine it (Rao et al., 1997). Nitrate was measured using the Cataldo technique (Cataldo et al., 1975). The Indophenol blue method, as stated by (Koroleff, 1983), was used to determine ammonium in leachates.

Statistical indices for model performance

In SAS, PROC GLM is used (SAS Institute, 2003), $p<0.05$ was considered significant when calculating statistical differences between treatment means. Time was not included as a predictor in the model for measurements collected repeatedly throughout time because measurement weeks were treated as replicates. The data was log-transformed to conform with the model's equal variance assumption after validating diagnostic residual plots from nutrient transport dominated by saturated instability.

Results and discussion

Nutrient leaching

The volume of leached water was affected by the interaction of biochar with inorganic fertilizer and the three distinct biochar sources. The rainwater filled the soil pores, and the rest percolated down, and the water leached away. Crops were cultivated with the majority of the water retained by the earth. During the leaching process, 20 liters of water were provided; the collected water discharge ranged from 2.95 to 6.07 liters in 2018 and 2.57 to 5. 04 liters in 2019 (Table 3a, b). Higher water absorption by rice plants with more vigorous growth induced changes in altered cumulative water percolation at the end of the trial. With the exception of the control, the cumulative amount of water leached from the soil was connected with yield output rather than soil amendments.

The biochar treatments of poultry manure+45N30P30K and control produced the most leached water. Application of biochar groundnut shells+45N30P30K, biochar groundnut shells, and biochar corncobs+45N30P30K, biochar corncob (5 t ha^{-1}) resulted in the lowest volume of leached water. This indicates that the water was absorbed by the plant and kept by the soil, resulting in less water being leached Table 3a, b. Yield vs. tillers, spikelets per panicle, and grain per panicle production were calculated using water and nutrients ingested by plants (Figure 5a, b, 6a, b, and 7a, b). Because most of the water was leached from the ground, the absolute control treatments yielded the lowest yields. The results presented in (Tables 3a, b) demonstrate that biochar+45N30P30K was added to the volume of leached water. Biochar reduced drainage water volume by two folds. On days 1–15 after planting, there was no interaction between biochar material and biochar rate on NH_4^+, NO_3-N, P, and K leaching, while on days 15–30 after planting, there was an interaction (Table 3a, b). According to the findings, a similar pattern was observed in eC and pH leaching. Although the levels of pH, NH_4^+, NO_3-N, P, K, and eC were high in the soil, the kind of biochar rate used resulted in less leaching of pH, NH_4^+, NO_3-N, P, K, and eC (Table 3a, b). Biochar groundnut shells, biochar groundnut shells+45N30P30K, and biochar corncobs+45N30P30K treatments had the lowest pH, NH_4^+, NO_3-N, P, K, and eC leaching during rice growth (day 15–30), while biochar poultry manure and biochar poultry manure+45N30P30K treatments had the highest. Mineral fertilizer caused intensive leaching of pH, NH_4^+, NO_3-N, P, K, and eC. However, with increased biochar poultry manure+45N30P30K, pH NH_4^+, NO_3-N, P, K, and eC leaching increased by two folds, and biochar poultry manure was substantially higher in 2019 than in 2018. The increase in pH, NH_4^+, NO_3-N, P, K, and eC appears to be connected to the type of biochar used in the soil. The soil amendments had minimal effect on the proportions of N and P uptake, while pH and eC showed a clear response (Figure 4a, b and e and Table 3a, b).

Biochar+45N30P30K with K was highly effective, increasing SO_4-S and K absorption in a proportional manner (Figure 4c and f). The amount of K uptake from biochar soil reduced as the concentration of NO_3-N increased. Applied N and K were mobile in the soil, and the amount of leaching increased in mineral fertilizer treatments. The absolute control showed high ratios of uptake-to-leaching for all studied nutrients. After the amendment application, however, leaching increased more than uptake, and the proportions decreased. For all nutrients, the proportions of nutrient uptake to leaching increased when biochar was applied to the soil.

Table 3a: Effects of biochar materials and volume of water and Nutrient leached for 2018

						Nutrient leached (mgl^{1})							
Treatment		NO3N Mg l^{-1}		NH4+N mg l^{-1}		K+		P		eCuS /cm		pH	Volume of Water leached (ml)
	15 Days	30 Days	15 Days	30 Days	15 Days	30 Days	15 Days	30 Days	15 Days	30 Days	15 Days	30 Days	30 Day
Control	5.81	4.49	0.76	1.02	4.1	2.5	0.18	0.18	153	161.1	6.56	6.78	5.42
90N60P60K	7.35	6.22	0.51	0.76	3.3	2.7	0.41	0.47	176.2	106	6.76	6.69	6.07
CharGs+45N30P30K	4.77	3.38	1.02	1.02	3.4	1.49	0.30	0.79	124.4	80	6.68	6.81	2.95
CharPM+45N30P30K	6.29	6.01	0.76	1.27	6.2	6.7	1.04	1.60	139.1	129.7	6.72	6.63	4.58
CharCc+45N30P30K	6.74	2.16	0.25	0.76	8	3.3	0.20	0.24	157.4	72.4	6.85	6.66	3.06
Char Gs	3.65	3.79	0.76	1.02	2.7	2.3	0.24	0.16	117.7	91.9	6.81	6.67	4.07
Char PM	5.42	4.13	0.51	0.51	5.2	3.5	0.16	0.12	155.9	104.6	6.72	6.59	3.81
Char Cc	4.02	3.00	0.25	0.51	5.3	1.59	0.30	0.18	137	54	6.63	6.74	4.12

Table 3b: Effects of biochar materials and volume of water and Nutrient leached for 2019

	Nutrient leached ($mg\ l^{-1}$)												
Treatment	NO3-N $mg\ l^{-1}$		NH_4^+N $mg\ l^{-1}$		K^+		P		eCuS /cm		pH		Volume of Water leached (ml)
	15 Days	30 Days	15 Days	30 Days	15 Days	30 Days	15 Days	30 Days	15 Days	30 Days	15 Days	30 Days	30 Days
Control	5.81	4.49	1.78	3.06	4.1	2.5	0.18	0.18	153	161.1	6.56	6.78	5.04
90N60P60K	7.35	6.22	2.04	2.04	3.3	2.7	0.41	0.47	176.2	106	6.76	6.69	4.04
CharGs+45N30P30K	4.77	3.38	1.27	2.04	3.4	1.49	0.30	0.79	124.4	80.0	6.68	6.81	2.57
CharPM+45N30P30K	6.29	6.01	1.53	2.29	6.2	6.7	1.04	1.60	139.1	129.7	6.72	6.63	4.06
CharCc+45N30P30K	6.74	2.16	0.76	3.31	8.0	3.3	0.20	0.24	157.4	72.4	6.85	6.66	4.34
Char Gs	3.65	3.79	1.78	3.82	2.7	2.3	0.24	0.16	117.7	91.9	6.81	6.67	3.83
Char PM	5.42	4.13	1.02	2.29	5.2	3.5	0.16	0.12	155.9	104.6	6.72	6.59	3.30
Char Cc	4.02	3.00	0.51	1.02	5.3	1.59	0.30	0.18	137	54	6.63	6.74	3.86

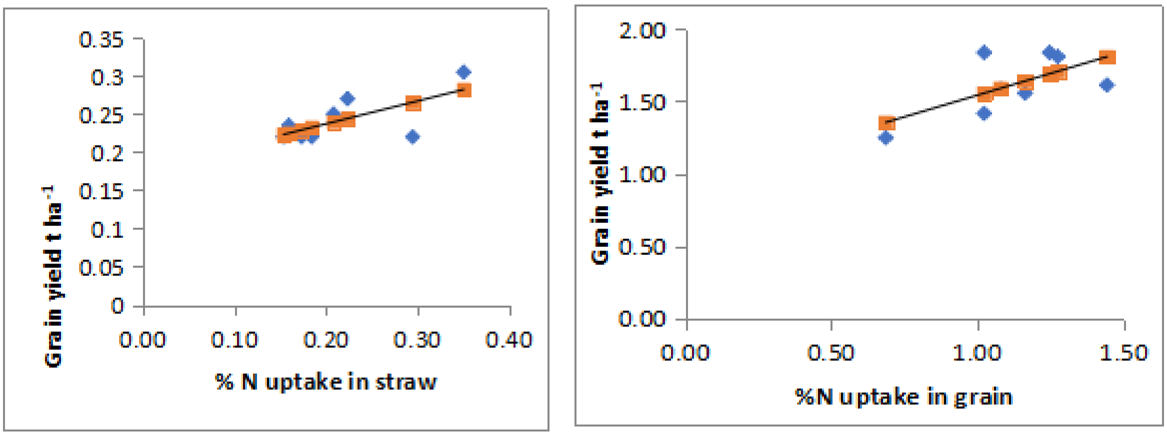
Char-biochar, Gs-groundnut shells, PM-poultry manure, Cc-corn cobs, NPK-nitrogen, phosphorus, potassium, NO3-N-nitrate, NH_4^+N-ammonium, eC-electrical conductivity, P-phosphorus, K^+-potassium

Nitrate (NO3-N) and potassium (K^+) lost as leachate from biochar

Variations in cumulative water percolation and extent of nutrient leaching among treatments were caused by variations in plant water uptake and efficiency of nutrient retention. As expected, leaching of nutrients was significantly lower among the three different sources of biochar amendment compared with the control and mineral fertilized soil. The groundnut shells biochar treatment cumulatively had lower leaching of nutrients than biochar groundnut shells + 45N30P30K, biochar corncobs, and biochar corncobs + 45N30P30K. This could possibly be because of more pore spaces within the sole biochars, and increased sorption capacity through oxidative reactions on the biochar surfaces over time (Figure 8a-d).

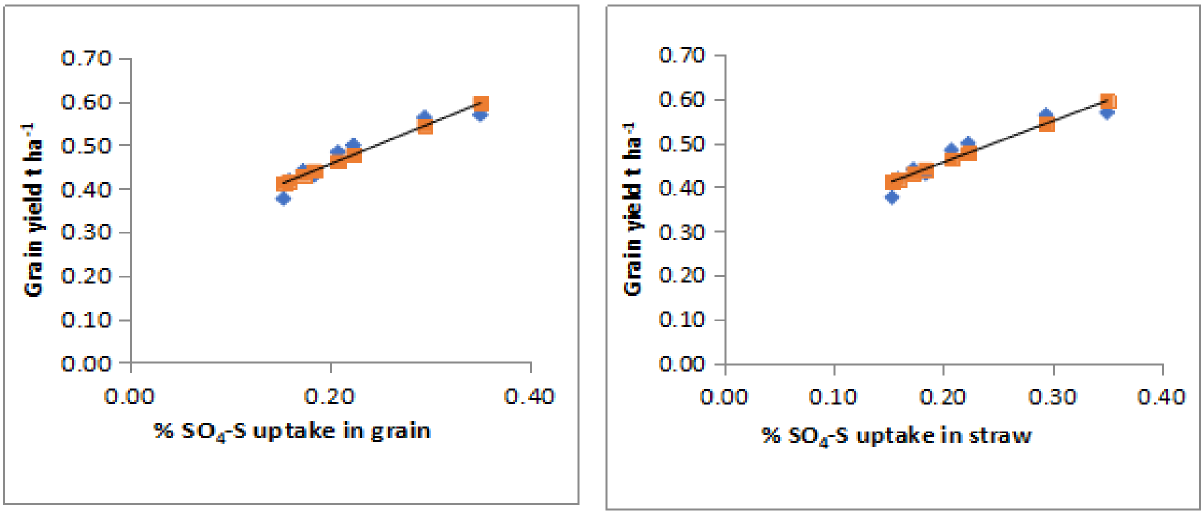
The experiment exhibited the reduction of leaching of NO_3-N by 3.65–4.77 mg l^{-1} per 15 days, while K^+ was 2.7–3.4 mg l^{-1} from the applications of biochar groundnut shells and biochar groundnut shells+45N30K30P on the same soil type (Figure 8a-d) 45% of the applied N fertilizer (Meisinger and Delgado, 2002). Variations were detected among treatments in terms of magnitude of leaching of nutrients. A similar study exhibited that charcoal application reduced the proportion of leached N and Ca on Ferralsols (Lehmann et al., 2003). Although N and K proved very mobile in soil (Figure 8a-d), application of sole biochar and their combination with mineral fertilizer reduced leaching of NO_3-N 5.42 and 6.29 mg l^{-1} and K- 5.2 and 6.2 mg l^{-1}, respectively, compared with soil applied with mineral fertilizer only. For example, biochar poultry manure+45N30P30K reduced leaching. The retention of

N and K should be specifically targeted with additions of slow-releasing nutrients and soil amendments. Leaching happens at a more moderate rate when most of the ions are extant in exchangeable form (Troeh and Thompson, 2005), or when uptake by plants rises (Lehmann et al., 2003). Low leaching at high nutrient availability promotes sustainable soil fertility, which agrees with the findings of (Lehmann et al., 2003). Soils that have been strongly weathered and leached often have low levels of NO_3-N and K^+ and plant growth may be nutrient limited (Glaser *et al*., 2002). According to Sika (2012), biochar significantly decreased leaching of NO_3-N (26–95%), NH_4-N (12–86%), basic cations, P and certain micronutrients. By difference, (Novak et al., 2009) specified higher EC and K concentrations of leachates but lower concentrations of P. Although the initial soil K status was sufficient for plant growth, the ratio of K uptake to initial soil K was the lowest for the control, because K uptake might be limited by the low availability of other nutrients, such as N and P.



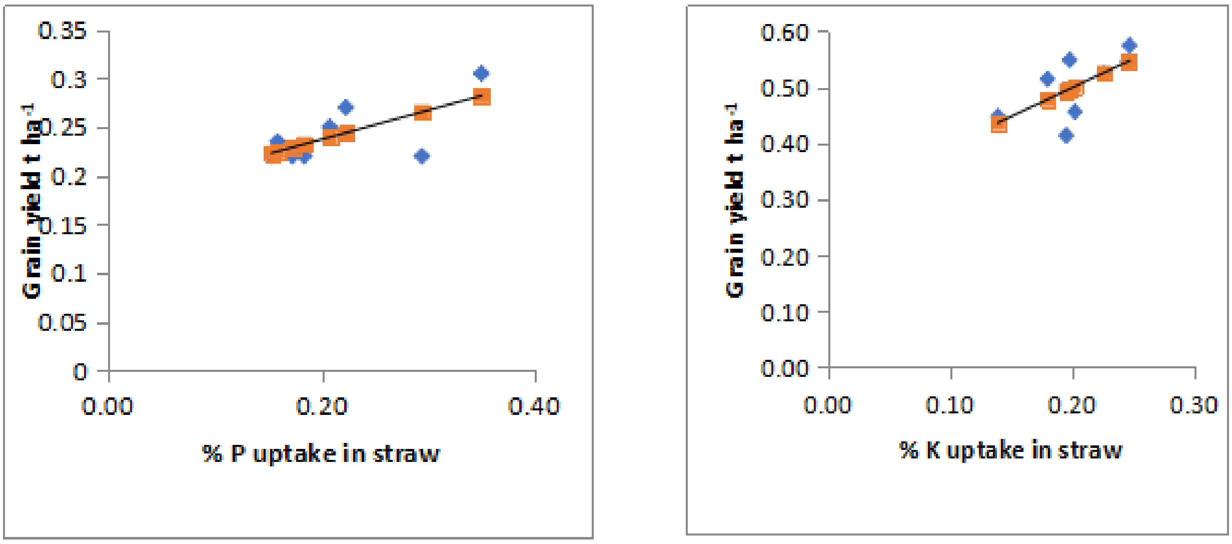
A *B*

Figure 4a, b. Relationship between grain yield kg ha^{-1} and %N uptake in grain and straw



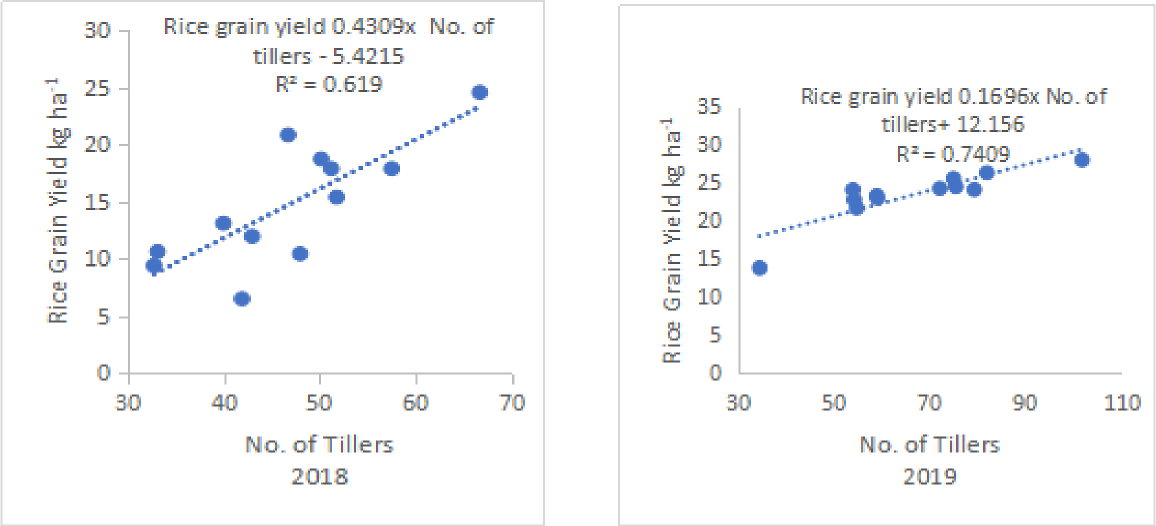
C *D*

Figure 4c, d. Relationship between grain yield kg ha^{-1} and % SO4-S uptake in grain and straw



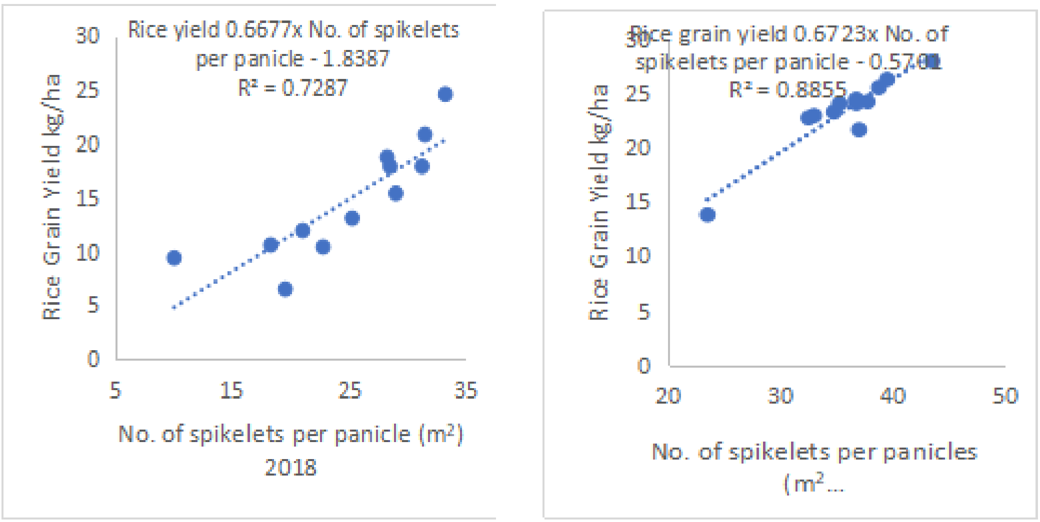
E *F*

Figure 4e, f. Relationship between grain yield kg ha^{-1} and % P and %K uptake in straw



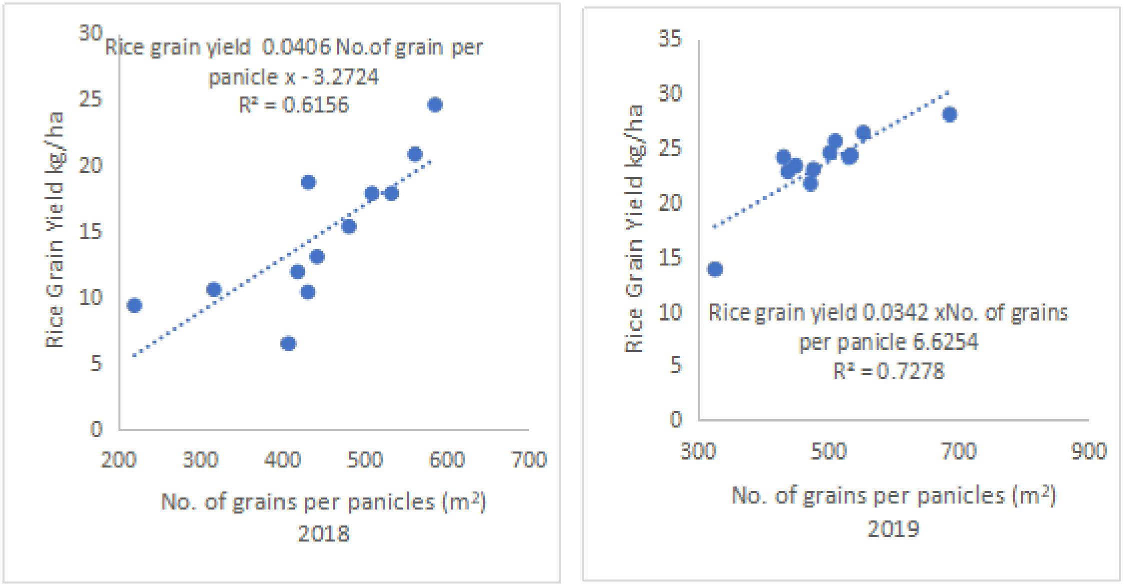
A *B*

Figure 5. Relationship between number of rice grains yield kg ha^{-1} and tillers (2018 and 2019)



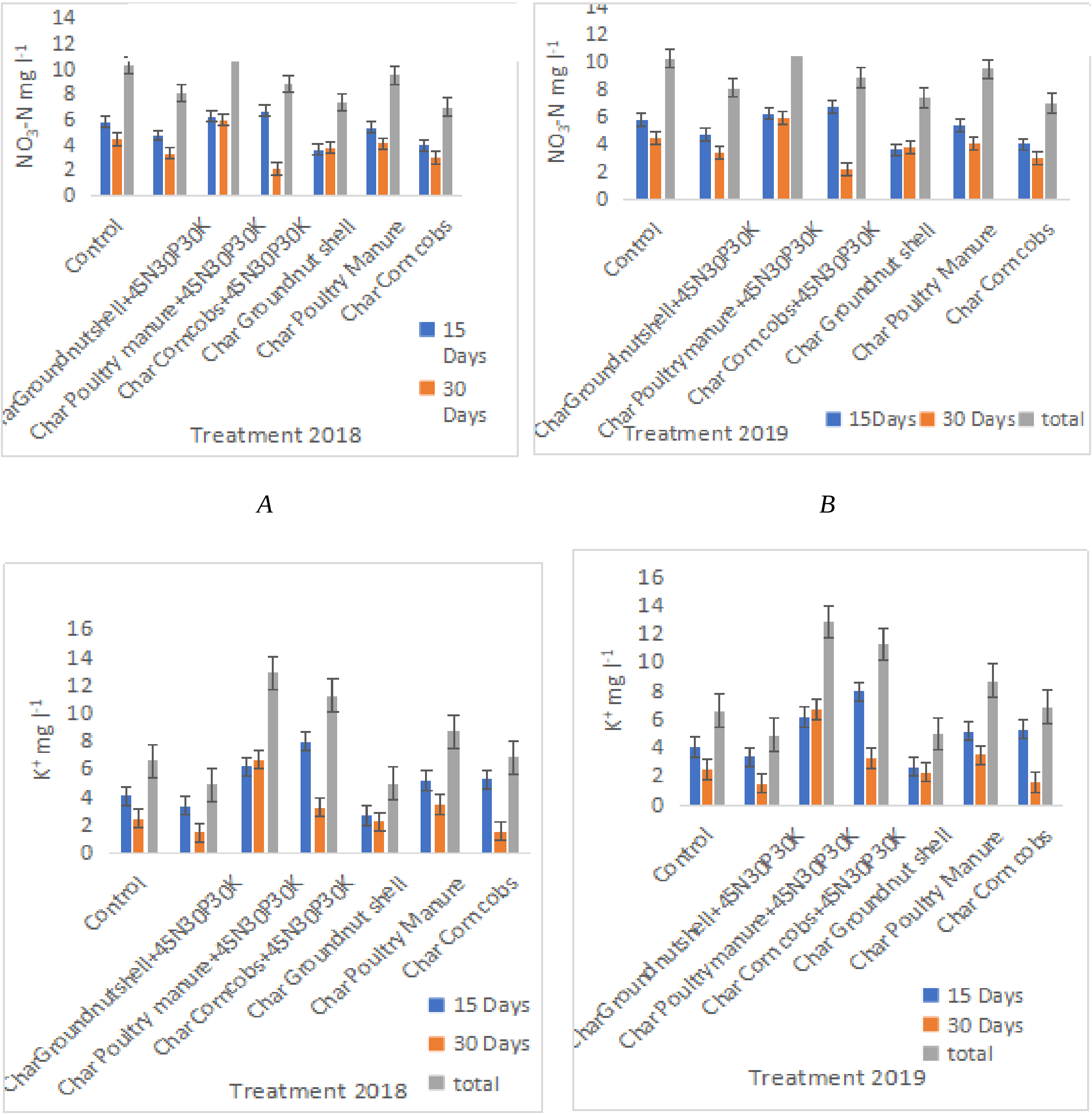
A *B*

Figure 6. Relationship between grain yield and number of spikelets per panicle (2018 and 2019)



A *B*

Figure 7. Relationship between grain yield and number of grains per panicles (2018 and 2019)



A

B

D

E

Figure 8. Days total of nitrate (NO3-N) and potassium (K^+) lost as leachate from soil amended from lysimeter on three different sources of biochar

Mineral fertilizer and biochar effects on plant production

Mineral fertilizers and biochar, as well as three distinct sources of biochar from poultry manure, groundnut shells, and corn cobs, increased plant production based on recommendations. The amounts applied were conventional for plant growth. The longer biochar stays in the soil, the higher the yield (Ali et al., 2020). Experiments have shown that biochar combined with mineral fertilizer may primarily sustain agricultural production (Figure 4a to f). Higher P levels and micronutrient additions are likely to have improved crop performance. The P was applied at a rate which was revealed to be a bit low to meet rice plant demands for nutrients in the soil. In a recent field experiment, large yield increases of 5.5 times of fertilized rice could be found with an application of 60P kg ha^{-1} of inorganic fertilizer (Ahmed, 2018; Musah, 2019) and similar outcomes were presented for a biochar and inorganic fertilizer application in a lysimeter experiment (Lehmann et al., 2003; Major, 2009).

Nitrogen nutrition has been critical for improving crop growth as straw N levels were lower in the crops grown on the ferric Luvisols (Dogbe et al., 2015), while at the same time, biomass production was higher. However, plant development was aided by P and K additions, which is consistent with prior research on the rice-cowpea intercrop in the same area (Baba et al., 2013; Inusah et al., 2013; Musah et al., 2013). Similar work was done by (Oroka and Omoregie, 2007) K was very mobile in soil, with considerable amounts of up to 30% of the quantity present in improved soil being rapidly leached.

Nutrient retention in the soil after application

The increased P availability in biochar compared to inorganic fertilizer was mostly responsible for the higher crop growth. Higher levels of soil SO_4 and micronutrients, particularly Zn and S, may have further aided plant performance. Different phases of the crop require higher levels of P and S (Buri et al., 2012; Dobermann et al., 2002; Krishna, 2013). Various ferric Luvisols of primitive origin have been reported regularly on the Guinea savanna. The total N contents were higher in the mineral fertilizer than the biochar +45N30P30K, but N availability was low due to a high C-to-N ratio. However, the low N availability did not seem to reduce crop growth. In contrast to the potential cation exchange capacity (Lehmann et al., 2003; Steiner, 2008), the effective cation exchange capacity was higher in the mineral fertilizer than in the biochar+45N30P30K, which caused low retention of applied nutrients and high leaching. The primordial ferric luvisols' low fertility may have been due to nitrogen release from sequentially available soil pools rather than high ion levels at exchange locations. In comparison to the mineral fertilizer, the leachate in the biochar experiment showed extremely low nutrient concentrations despite having a high nutritional availability. Soil fertility is maintained via low leaching and high nutrient availability. These findings are consistent with those of (Obodai, 2018; Yeboah et al., 2009), who discovered biochar in Ghana after 40 years of continuous cultivation without fertilization. The features of relict human-caused soils have crucial implications for ferric luvisols soil management, indicating that solo biochar poultry manure applications can be used for sustained crop production in semi-arid environments. These findings, on the other hand, suggest that biochar corncobs and biochar groundnut shell+45N30P30K applications should continue.

Biochar amendments for increasing soil fertility

Biochar application resulted in decreased N availability due to high C-to-N ratios, similar to ferric Luvisols soil. Direct nutrient additions with the addition of three different sources of biochar, especially of K^+, but also of P, NH_4-N, and NO_3-N, result in improved biomass production and nutrient uptake. Nutrient losses were modest at the same time. The soil K content increased by an order of magnitude, surpassing that of inorganic fertilizer soils, whereas leaching losses in biochar augmented soils were less than half of those in inorganic fertilizer soils. Furthermore, biochar and biochar+45N30P30K condensed the leaching of applied inorganic fertilizers NH_4-N and NO_3-N, as well as NH_4-N, NO_3-N, P, K, pH, and eC in the first 15 days, and the ratio of uptake to leaching increased for all nutrients after biochar+45N30P30K application, demonstrating a high efficiency of nutrients applied with biochar+45N30P30K. Biochar+45N30P30K amendments have not been proven to help with nutrient retention. There are numerous possibilities, including: (a) establishing places for electrostatic adsorption; (b) retaining soil water and nutrients. Biochar and biochar+45N30P30K additions did not reduce water percolation, and nutrient retention was then activated by adsorption to an exchange complex generated by biochar+45N30P30K additions. The study found that biochar made from poultry manure, corn cobs, and groundnut shells boosted high cation exchange capacity by as much as 125.63, 118.26, and 85.52 m g^{-1}, respectively (Table 1). It's important to remember that the surface properties of biochar vary a lot depending on the organic matter used to make it and the charring environment, such as temperature and oxygen supply (Budai et al., 2014; Kammann et al., 2017; Lehmann, 2007).

Particle size of biochar

The size of the biochar pieces amended to soil had only minor effects on nutrient uptake and biomass production of upland rice. This could indicate that either the surface area or the amount of nutrients provided by the three distinct biochar sources (poultry manure, groundnut shells, and corn cobs) were sufficient with larger pieces, or that neither of the two factors was significant in increasing crop growth in the studied soil. We can accept that nutrient retention was a significant reason for the rise in nutrient uptake and growth of upland rice, since nutrient leaching was insignificant from the lysimeter and the contents of those nutrients that could be supplied by the three distinct biochar were high. This may change after some cropping seasons and more intense leaching, and should be tested in long-term field experiments. Furthermore, the amount of nutrients supplied by three distinct sources of biochar pieces may have been sufficient for plant growth, either because the total amount of three distinct biochar pieces already exceeded plant demands or because nutrients were contained inside the three distinct biochar pieces. Plant roots were found to be huddled around the three distinct biochar pieces, or even grow into the three distinct biochar pieces, demonstrating nutrient availability in the three distinct biochar pieces. Nutrients may have been leached or diffused into the rhizosphere from the inside of the three distinct biochar pieces.

Effect of the amount of biochar on soil fertility

The amounts of the three distinct sources of biochar from poultry manure, groundnut shells, and corn cob additions were obviously critical for the effects on crop growth and nutrition. Plant growth was significantly improved with the addition of 5 t ha^{-1} of three distinct sources of biochar, and higher quantities added further increased biomass production. This quantity corresponds to a CEC contribution of 126.63 m g^{-1} by biochar poultry manure, 85.52 m g^{-1} by biochar groundnut shells, and 118.26 m g^{-1} by corncobs, which falls within the larger range of possible biochar yields (0.324 kg ha^{-1} C) estimated by the aboveground biomass in (Table 1). Additional inorganic fertilizer nutrients must be used to ensure consistent and long-term development and yields. The land use approach of producing and applying three distinct sources of biochar to soil is only feasible if the three distinct sources of biochar are formed from charred agricultural waste materials. Lysimeter trials were conducted to test the positive results of this field experiment for plant nutrition and growth. Furthermore, as a result of human-caused or natural fires in our forest, biochar can be found in many soils of the refuse dump and farmlands. As a result, biochar is abundant in such large quantities in farmland soils that we can expect an effect on plant development and nutrition. Biochar does not only exist as large pieces in soil but also as fine particles of less than 20 m (Glaser et al., 2000; Glaser et al., 2001), providing an indication that a large portion of the stable carbon pool in soil is present as supposed black carbon and may have derived from charred organic matter. According to (Liang et al., 2008; Czimczik and Masiello, 2007; Glaser et al., 2002), there is a lot of stable black carbon in grassland soil that has been burned a lot. Because of its potential importance in the global biogeochemical C cycle (Schulze *et al*., 2001), black carbon has become a major research topic (Glaser et al., 2002; Nguyen et al., 2004; Schmidt et al., 2011). Long-term research on the effects of biochar treatments on soil fertility and nutrient dynamics is required.

Effects of Treatments on Soil Properties

The differential impacts of inorganic fertilizer and three different sources of biochar on soil parameters and agronomic characteristics of the rice-cowpea intercrop were evident in the results of this study, as expected, and reflected their apparent chemical composition disparities. The results of the analysis revealed that the treatments had a substantial impact on the soil parameters that were measured. The use of the three different sources of biochar in combination considerably improved the pH of the soil used, in contrast to fertilizer application (Table 4a and b). The liming impact of biochar on soils has been widely reported (Wang et al., 2021), and the findings of our study are consistent. While the mechanism underlying biochar’s lime effects is unknown, the liming effect has been explored in the literature as one of the most plausible reasons for increasing plant production following biochar application (Nguyen et al., 2018). When the three different sources of biochar and inorganic fertilizer were combined with cowpea intercrop, the pH dramatically improved compared to when inorganic fertilizer was applied alone. It is practical to accept that biochars with higher liming potential can help liming required arable soils more by being applied more frequently at lower rates or in combination with cowpea intercrop (Xiao et al., 2018).

Furthermore, in all treatments, mineral N levels increased, except control. Mineral N was comparable between inorganic fertilizer treatments either applied alone or in combination with three different sources of biochar and inorganic fertilizer (Table 4a and b). These findings reveal that in areas where inorganic nitrogen fertilizers are scarce, high-quality cowpea could be planted alongside three different biochar sources. Except in control soils, biochar amended treatment application improved phosphorus availability. The soils that received biochar poultry manure plus inorganic fertilizer treatments, either alone or in combination with inorganic fertilizer and biochar groundnut shells, had the highest phosphorus availability. Meanwhile, inorganic fertilizer had similar impacts on available P when used alone or in combination with the three biochar sources. High-quality organic residues, such as those found in rice straw diversifolia, have been proven to be comparable to inorganic fertilizers in terms of nutrient supply (Chimouriya et al., 2018; Kiboi et al., 2019). The effects of biochar on mineral N and P availability were either comparable or significantly higher than inorganic fertilizers, as established in this study. This finding backs up previous research that found high-quality plant wastes to be feasible alternatives to inorganic fertilizers (Mahmud et al., 2018; Reyes-Cabrera et al., 2019). The quantities of extractable C recorded were found to be strongly associated (Table 1) with nitrogen availability in soil (Figure 4), confirming soil nitrogen contributions from N released during the decomposition of the plant materials employed in the experiment (Table 4a and b). Because of the slow decomposition and mineralization patterns of the three different sources of biochar, the nutrient supply contributions from the three different sources of biochar when applied with inorganic fertilizers may only be apparent in the long term (Farhangi-Abriz et al., 2021; Stagnari et al., 2017). It’s high carbon content, applying biochar to soil is likely to raise the soil's C:N ratio, potentially resulting in initial net N immobilization by microorganisms (Table 1). Although higher mineral N levels were observed in biochar-amended soils (Figure 3a to e), this finding could only be explained by a hypothetical priming effect of the biochar on N mineralization from already existing organic matter in the soil. Chang et al., 2020 from already existing organic matter in the soil. Several experimental studies (Fischer et al., 2018; Whitman et al., 2015) have verified the priming effect of biochar in triggering C and N mineralization. The results were attributed to the conditioning effect of the biochar in limiting nutrient losses, mainly through leaching, rather than N mineralization from the biochar itself, in some cases where biochar application had a significant effect on nutrient availability (Antonangelo et al., 2021; Gao and DeLuca, 2016; Major, 2009). Furthermore, enhanced nutrient availability in soils treated with a combination of biochar and inorganic fertilizer or biochar and green manure could have been attributed to the conditioning effects of biochar in enhancing soil structural and chemical properties. Sohi *et al*. (2010) wrote a review that explains these mechanisms. CEC rose as a result of treatment, having the greatest influence in soils treated with biochar (Table 1). The effect of biochar treatment on CEC is well recognized (Ren et al., 2020; Yadav et al., 2019; Šimanský et al., 2018), but the mechanism behind it is still being researched. It's important to note, however, that improving CEC with biochar is critical in many semi-arid areas dominated by low-cation-exchange-capacity soils, such as high-acidity sandy soils, which can quickly lose their fertility if fallow periods, or something similar to fallow conditions, aren't imposed (Ren et al., 2020). The application of 5 t ha^{-1} of three different sources of biochar did not change the particle size distribution in the top 0–30 cm of the soil ($p > 0.05$). Only at 1.0-0.97g cm^3, where the density of absolute control soil (1.05 g cm^3) was greater than three different sources of biochar altered soil (1.01-0.96 g cm^3), were significant changes in bulk density ($p<0.05$) detected (Table 5).

Table 4a: Soil properties as affected by biochar and inorganic fertilizer for 2018 -2019 cropping season

Treatment	pH 2018	pH 2019	N 2018	N 2019	O.M 2018	O.M 2019	Av. P 2018	Av. P 2019	Ca 2018	Ca 2019	Mg 2018	Mg 2019
			%				Mg kg^{-1}		cmol (+) kg^{-1}			
90N60P60K	4.86	4.96	0.06	0.05	0.80	0.88	17.15	25.82	1.70	1.28	0.85	1.07
ChCc+45N30P30K+C	5.33	5.55	0.04	0.05	0.80	1.02	12.42	33.32	1.70	1.92	1.07	1.07
Control	4.32	4.32	0.05	0.05	0.20	0.20	9.22	9.86	0.08	0.08	0.75	0.75
Ch Cc	5.63	5.62	0.04	0.03	0.66	0.73	10.45	16.76	1.17	1.49	0.43	0.96
Ch Gs	5.65	5.67	0.04	0.05	0.59	0.80	17.15	13.21	1.28	1.57	0.75	0.85
ChGs+45N30P30K+C	5.46	5.66	0.06	0.06	0.73	0.88	15.18	13.21	1.28	1.69	0.75	1.28
ChPM+45N30P30K+C	5.92	5.98	0.05	0.04	0.80	0.95	24.25	42.38	1.28	1.69	0.75	1.07
Ch PM	5.58	5.63	0.04	0.06	0.80	0.88	12.42	33.71	1.49	2.13	0.43	1.07
Sole cowpea	4.33	4.38	0.04	0.05	0.66	0.80	12.42	13.80	1.23	1.49	0.48	0.64

Ch-biochar, Gs-groundnut shells, Cc-corn cobs, PM-poultry manure, C-cowpea, Nitrogen (N), Phosphorus (P), Potassium (K) and Cowpea (C)

Table 4b: Soil properties as affected by biochar and inorganic fertilizer for 2018 and 2019 cropping season

Treatment	K 2018	K 2019	Na 2018	Na 2019	Ex. Acidity 2018	Ex. Acidity 2019	ECEC 2018	ECEC 2019	BS 2018	BS 2019
				cmol (+) kg^{-1}						%
90N60P60K	0.14	0.18	0.01	0.04	0.80	1.20	3.48	3.79	65.49	78.91
ChCc+45N30P30K +C	0.20	0.28	0.01	0.03	0.80	0.85	3.83	4.10	77.79	80.48
Control	0.07	0.07	0.01	0.03	1.20	1.10	3.20	3.50	65.69	65.71
Ch Cc	0.15	0.19	0.02	0.03	0.95	1.30	3.26	3.43	70.84	62.08
Ch Gs	0.14	0.18	0.02	0.04	1.00	1.25	3.28	3.29	69.60	61.86
ChGs+45N30P30K +C	0.14	0.19	0.03	0.05	0.95	1.00	3.47	3.68	74.15	71.20
ChPM+45N30P30 K+C	0.17	0.20	0.01	0.02	0.85	1.00	3.32	3.37	74.78	69.89
Ch PM	0.15	0.17	0.02	0.03	0.85	0.90	3.59	3.64	75.30	76.36
Sole cowpea	0.14	0.18	0.01	0.05	1.20	1.35	3.26	3.56	58.43	66.27

Ch-biochar, Gs-groundnut shells, Cc-corn cobs, PM-poultry manure, C-cowpea, Nitrogen (N), Phosphorus (P), Potassium (K) and Cowpea (C)

Table 5. Model Parameters and measured bulk density, porosity and particle size distribution in the top 0-30cm of the soil for all treatments

					2018		2019	
Treatment	Sand	Silt	Clay	Texture	Bulk Density	Porosity	Bulk Density	Porosity
		%			gcm^{-3}	%	gcm^{-3}	%
90N60P60K	82.00	14.00	4.00	LS	1.01	60.00	1.49	61.25
charCorncob+45N30P30K	80.00	16.00	4.00	LS	1.01	63.25	3.93	61.13
Absolute Control	78.00	18.00	4.00	LS	1.05	60.63	0.93	61.13
CharCorncob cobs	80.00	16.00	4.00	LS	0.97	64.25	6.44	63.50
CharGroundnut shell	82.00	14.00	4.00	LS	0.87	67.88	4.57	59.63
CharGroundnut shell+45N30P30K	84.00	12.00	4.00	LS	1.00	63.13	2.06	62.88
CharPoultryManure+45N30P30K	82.00	14.00	4.00	LS	1.07	63.00	4.92	62.50
Char Poultry Manure	80.00	16.00	4.00	LS	1.08	61.38	2.48	63.63
Sole cowpea	81.00	15.00	4.00	LS	0.96	64.88	6.99	63.13
Grand Mean	81.00	15.00	4.00		1.00	63.54	3.99	61.75

Biochar-Char, LS-loamy soil, SL-sandy loam

Upland rice yield

Short-term rice yields are difficult to model. The seasonal yield differences in both treatments were difficult to predict. Short-term environmental events, such as high temperatures and moisture stress during key periods, flood damage, high winds, and occurrences of pests, diseases, or birds in the field, can be used to induce measured yields that the model cannot deliberate. A comparable study on short-term rain-fed upland rice simulation also found that extreme short-duration weather events not considered by the model are the reason behind imprecise short-term upland rice simulation (Reynolds et al., 2018). The planting date is known to influence rice yield (Jalota et al., 2012; Karim et al., 2012; Yao et al., 2007), and in this simulation, the planting dates over the years were not known but only based on a managing regulation that originated planting in a pre-defined planting. Other considerations, like the availability of planting materials and labor, can influence the planting date more than the weather. For the 90N60P60K treatment, yield overrating between 1990 and 2019 may be an effect of varieties cultivated in those years not being as vigorous as calibrated Nerica 14, which was used for the entire simulation. Another explanation for the control's erroneous yield estimate could be the model's mentioning of N and insufficient moisture yields. Other factors not well thought-out by the model have previously influenced the measured yields. Previously, yield quantities were calculated by multiple people, which could be another source of error in yield measurements. All of these considerations showed that, in the vast majority of situations, poor statistical outcomes may be attributed to the incorporation of poor model performance and possible inconsistencies in measured data when secondary data is employed.

Soil organic matter

The amount of soil organic matter (SOM) was generally adequately approximated by APSIM, which had previously demonstrated its usefulness by being able to estimate comparable patterns with observed data. The slow, steady waning of modeling capacity from the start could indicate that the decomposition of SOM on barren ground is undervalued. According to popular belief (Fageria, 2012; Kekeli, 2015; Lemenih, 2004), tilling of land causes SOM loss in cropping systems, with considerable initial soil organic matter loss when virgin vegetation is replaced by cropping systems. Organic inputs and the degree of decomposition, which is heavily influenced by management techniques, influence variations in SOM content. SOM is normally stable in natural vegetation when humus is generated and degraded at the same rate. This steadiness is then bothered by human actions like tilling and bush burning, which create favorable environments for oxidation that result in SOM waning and the ultimate decline in plant nutrient reserves like N, P, and S, which are essential parts of organic matter. Higher SOM in biochar+45N30P30K than in the control treatment is attributed to a higher stable C pool in the biochar input (Table 2) as an effect of the amendment raising biomass production in the mineral fertilizer treatment. Soil tilling and low C inputs from residues reduce control. However, soil tilling and N treatment can lead to significant mineralization of organic inputs despite low C inputs for mineral fertilizer. Clough et al., 2013 stated that the higher mineralization rate of biochar inputs in mineral fertilizer treatments was due to N fertilization improving the decay process by raising the availability of essential microbes. Biochar integration has been shown in several studies to reduce inorganic nitrogen leaching and increase soil N retention (Borchard et al., 2019; Major et al., 2012; Oladele et al., 2019; Sun et al., 2017; Yao et al., 2012). The mechanisms underlying biochar's impacts on soil N retention are not completely understood, but some potential advancements have been suggested; in (Table 1), biochar has a high cation exchange capacity (Ding et al., 2016; Nelissen et al., 2014; Yang et al., 2017) and changes the soil pH (Novak et al., 2009), foremost by the shortest way of absorption of NH_4^+ and NO_3-N. As crop yields were not precisely simulated at all times, it is likely that biomass was not precisely simulated at all times, and this capacity persuaded the SOM level assessments.

Conclusion

The experiment shows that the soil in the lysimeters was not deficient in plant-available nutrients, consistent with control treatments in general observation that Luvisols are nutrient-depleted and suboptimal for plant growth without additions of organic and inorganic amendments. Applications of the three different sources of biochar+45N30P30K were more efficient in improving soil organic carbon, soil water storage capacity, and nutrient-retention capacity and nutrient-use efficiency than mineral fertilizer alone. The use of three different sources of biochar as soil amendments reduced the loss of some nutrients through leaching, with nutrient leaching of NO_3-N, P and exchangeable bases significantly decreased as the growth of plants progressed. Application of 5 t ha^{-1} of the three different sources of biochar resulted in the highest yield production, number of grains per panicle, number of grains per spikelets, number of tillers. Although the sole application of the three different sources of biochar did not perform in terms of biomass yield and nutrient uptake, the combined application of biochar+45N30P30K improved and sustained soil biophysical and chemical properties, because most of the mineral fertilizer will dwindle over time through decomposition, whereas the biochar will stay in the soil for years.

The findings of this study strongly suggest that adding three different sources of biochar to Guinean savannah agricultural soils will increase the soil's ability to retain nutrients and thus reduce nutrient leaching. Increased nutrient retention in the soil profile should increase the likelihood of nutrients being taken up by plant roots, reducing the risk of them being leached and transported to surface or groundwater reservoirs. The net effect of these processes should be improved nutrient use efficiency, reducing the need for fertilizer and lime amendments in production agriculture while also improving water quality. The use of three different sources of biochar and one soil for a short period of time was a limitation of the current study. Biochar properties vary greatly depending on the properties of the pyrolyzed biomass, the conditions under which it is pyrolyzed, and the degree of aging of the biochar. Biochar surfaces are expected to oxidize as they age in the soil, forming carboxylate groups and thus active sites for the adsorption of various compounds. The longer biochar remains in soils, however, the more likely its surfaces will become saturated with metals, oxyanions, and organic compounds. As a result, biochar's function in soils will almost certainly change over time. However, the Terra Preta soils' high fertility and capacity to retain nutrients today, more than 500 years after the practices that led to their development, suggest that biochar's beneficial effects on soils are long-lasting.

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