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ORIGINAL RESEARCH

Rice husk biochar and inorganic fertilizer amendment combination improved the yield of upland rice in typical soils of Southern Guinea Savannah of Nigeria

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Abstract

Purpose Rice is a staple food in Nigeria, but its cultivation faces constraints of soil acidity, low soil fertility and rainfall variability. Research has shown that biochar has the potential to alleviate the effects of these conditions, but responses vary depending on soil and climate factors. Therefore, this study was conducted to evaluate the effects of different application rates of rice husk biochar on upland rice growth and yield.

Method Two field experiments were conducted within two years in Kwara State located in the southern Guinea savanna agroecological zone of Nigeria. Four biochar rates (0, 5, 15 and 25 t/ha) were used and replicated thrice in a randomised complete block design set up on three soils in three locations. Agronomic data were subjected to analysis of variance (ANOVA) to quantify variations in treatment responses, followed by a separation of significantly different means using the least significant difference (LSD) at $p \leq 0.05$.

Results Better growth was recorded in the first year compared to the second year. Percentage decreases of 9.4 and 11.4% were recorded in plant height (12 weeks after planting), and tiller productivity from the first to the second year, respectively. Biochar amendment significantly ($p \leq 0.01$) improved rice seedling emergence (34.6%) and seed weight (5.8%) relative to control. The highest grain yield of 5.24 t/ha was recorded under 15 t/ha biochar application rate compared to 2.37 t/ha under control.

Conclusion The application rate of 15 t/ha increased rice yield by 55.0% relative to the control, whereas at 25 t/ha the rice growth and yield were reduced.

Keywords Alfisols, Biochar, Entisols, Savanna soils, Upland Rice

Introduction

Rice is identified as a staple food for over 3.5 billion world population (Ricepedia 2013). Nigeria, according to PricewaterhouseCoopers (PwC) (2018) is the single largest rice importer in Africa and the world's third-largest. As a predominant staple crop in the country, it is produced in more than 18 of the 36 states (GEMS4

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2017). Nigeria's rice yield is however one of the lowest globally at an average of 2 tons per hectare, relative to 4 – 7 tons per hectare in Asia (Ricepedia 2013). In 2019, Nigeria, the highest rice producer in Africa produced about 8 million metric tonnes (MT) in comparison to about 144 MT produced by China around the same period (ThriveAgric 2020).

In the past decade, rice consumption has increased by 4.7% in Nigeria, representing about four times the global consumption growth (PwC 2018). The demand for the crop reached 6.4 million tons in 2017, of which only 3.7 million tons were produced locally leaving a gap cushioned by importation. Also, more than 80% of Nigeria's rice is produced by small-scale farmers (PwC 2018) who are characteristically poor. Fageria and Baligar (2001) reported that major yield constraints in upland rice production systems include water limitation due to rainfall variability, low soil organic matter (SOM) content and poor soil nutrient availability. As biochar has been proven to have the potential to alleviate these constraints, its use in rice production is attractive.

Rice has been used as a test crop in some previous biochar field studies. Asai et al. (2009) in an investigation of the effect of biochar on upland rice grain yield and soil physical properties in northern Laos reported that the effect of biochar treatment on rice yield varied, with improved yield than control recorded in some plots while the opposite was the case in others. In their study, biochar application generally did not significantly improve rice yields. In another study, Zhang et al. (2010) reported that biochar amendment resulted in rice yield increases. Zhang et al. (2010) reported that sole biochar amendment at 10 and 40 tons per hectare increased rice yields by 12 and 14%, respectively, and by 8.8 and 12.1% in biochar-nitrogen combination treatments. Another study has also reported improved rice yields following biochar amendment in comparison to control treatments (Zhang et al. 2012). Seeing that rice responses to biochar amendment have varied widely in literature, it is obvious that there is a need for localized studies on its efficacy for improved crop productivity.

According to AgronoMag (2017), to ensure food security, reduce poverty and help populations adapt to the effects of climate changes in areas where rice is traditionally cultivated, profitable rice cultures must survive on less land, and with less water. Large quantities of rice residues are produced annually in rice cropping systems in the country, and most of these residues are regarded as waste after some of it is used for animal feed among other uses. They are thus either burnt or piled and abandoned on rice fields. Burning of this residue result in substantial loss of nutrients such as nitrogen and sulphur, and contribute to air pollution (IPNI Canada 2017). One possible approach to addressing the general soil fertility constraints to agricultural productions in Nigeria thus is the conversion of rice residues into biochar, for reincorporation into the soil as an amendment in an integrated approach.

This could help sequester carbon, improve soil nutrient retention and release, reduce synthetic fertilizer needs, and possibly abate the emissions of GHG (carbon dioxide (CO_2)). To date, however, very few researches have been conducted on biochar influence in Nigerian soils, which makes studies such as this important. Because of the diversification drive of the Federal Government of Nigeria into agriculture which has recently informed the ban on rice importation to encourage local production, it is imperative to engage in studies to promote the sustainable and efficient production of rice, for improved food sufficiency and economic growth of the country. The objective of this study, therefore, was to assess the growth and yield responses of upland rice to biochar and inorganic fertilizer amendment.

Materials and methods

Description of the study area

This study was carried out in three locations in Kwara State (Ilorin, Shonga and Patigi), in the southern Guinea Savannah (SGS) agroecological zone of Nigeria (Fig. 1). Geographically, the state is located between latitudes 7° 45' and 9° 30' North of the Equator, and Longitudes 2° 30' and 6° 25' East of the Prime meridian.

The SGS zone has a mean annual rainfall of 100–150 cm and a wet season that lasts for 6–8 months between March and October. The climate is tropical and is characterized by double rainfall maxima; tropical wet and dry climate. Temperature is uniformly high and ranges between 25 and 30 °C in the wet season, and dry season temperature ranges between 33 and 34 °C. Relative humidity in the wet season is between 75 to 80% while in the dry season it is about 65% (Olaniyan and Ogunkunle 2007).

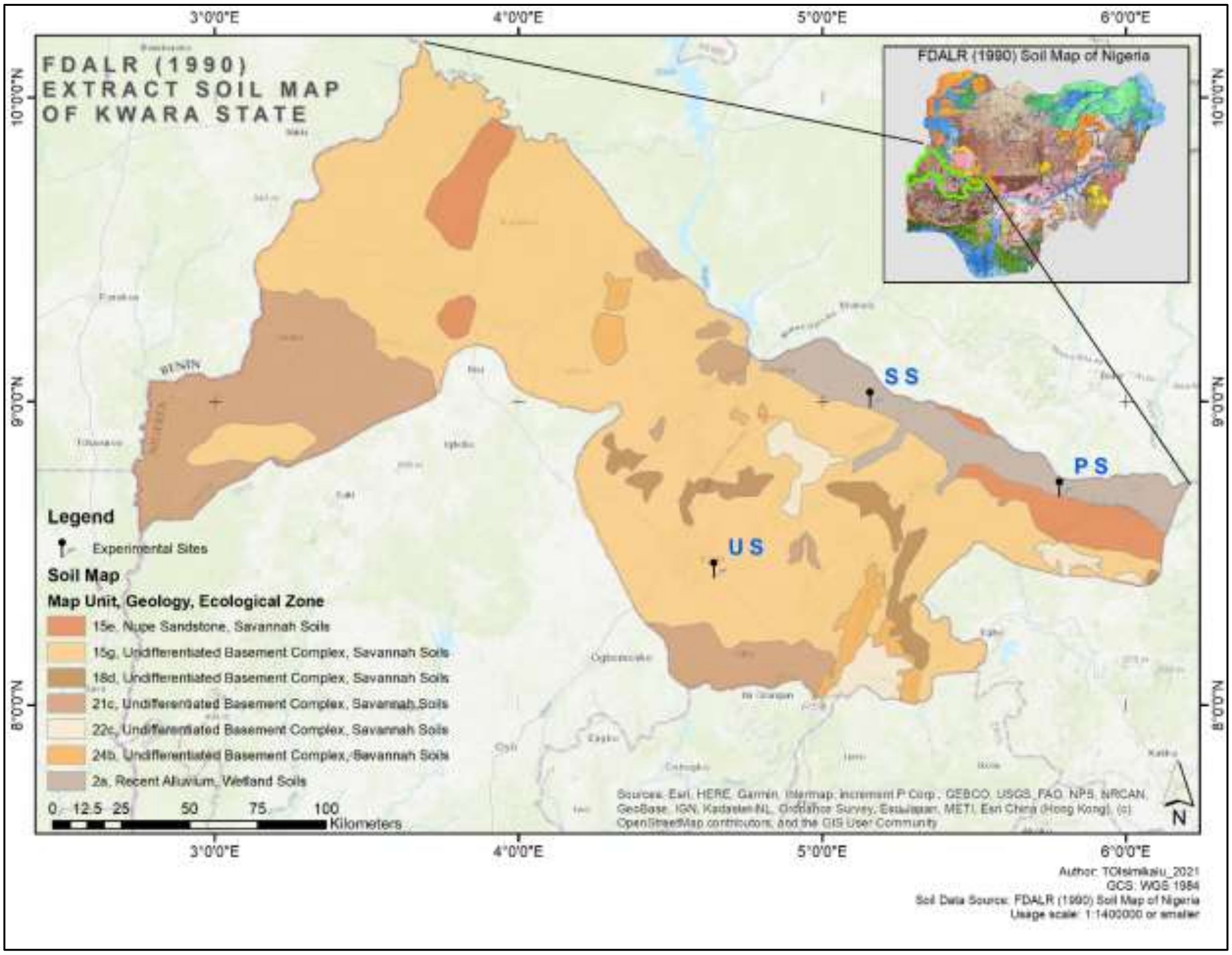

Fig. 1 Map showing the study area and experiment locations

The state is considered one of the most important rainfed agricultural areas in semi-arid regions of the country and could be defined as dependent mainly on rainfall for crop production. Food crops produced are mostly maize, rice, sorghum, yam, cassava, water yam and sweet potato which constitute the main staple foods (Ajadi et al.

2011). The soils are formed majorly from basement complex rocks (metamorphic and igneous rocks), and sedimentary rocks, to a lower extent. The metamorphic rocks include biotite gneiss, banded gneiss, quartzite augite gneiss and granitic gneiss. The intrusive rock includes pegmatite and vein quartz (Olaniyan and Ogunkunle 2007).

Soil characteristics

Three soil types, a basement complex-derived Anthraquic Ustorthent (Ilorin), recent alluvium-derived Grossarenic Kandiustalf (Shonga) and Nupe sandstone-derived Ustic Quartzipsamment (Patigi) were used for the experiment and denoted as US, SS and PS, respectively. Soil classification was done following USDA Soil Survey Staff (2014) guidelines. Detailed characteristics of these soils have been published in Olaniyan et al. (2020).

Soil and biochar analysis

Top (0-130 cm) composite soil samples from the sites were air-dried, 2 mm sieved, and subjected to physical and chemical analyses following procedures outlined in Table 1. The biochar used was made out of rice husk, using a top lift reactor at ~350 ºC (Joseph et al. 2016). Biochar samples were ground (using a ceramic mortar and pestle) and sieved using a 0.5 mm mesh before analyses. Analyses procedures are presented in Table 1. The physical and chemical properties of the soils are presented in Tables 2 and 3, respectively, and biochar properties in Table 4.

Experiment setup

Upland rice variety (New Rice for Africa (NERICA 8)) was grown for two growing seasons (July-October, 2017 and 2018). Four biochar rates (0, 5, 15 and 25 t/ha) were used denoted as B_0 (control), B_5, B_{15} and B_{25}, respectively. Treatments were replicated thrice and were set up in a randomised complete block design (RCBD). Treatment plots measured 2 x 3 m with a 1 m alley in-between.

Seed preparation, planting and agronomic management

Seeds were planted by dibbling 4 seeds/ hill, to a depth of 2-3 cm at 20 x 20 cm spacing, and thinned to 2 plants/ stand at 14 days after planting (DAP). General fertilizer application recommendation for soils of low to medium fertility under upland rice cultivation, of 80 kg N, 30 kg P_2O_5 and 30 kg K_2O/ha (Oikeh et al. 2008) was uniformly applied to all treatments including control using NKP 15:15:15 and urea fertlizers. Pre-emergence herbicide Butachlor was applied after planting. Hand and hoe weeding was done at 30 and 55 DAP, respectively. Preventive pest control measures were carried out as necessary, and Carbofuran at 2.5 kg a.i. per hectare was incorporated into the planting rows by mixing with sand at a ratio of 1 part to 4 parts of sand. Harvest was carried out at 98 DAP when > 80% of seeds had turned golden brown. Treatment plots were amended with biochar at the start of the experiment in the first year only. Other agronomic management practices (i.e, fertilizer application, pest control and weeding) were the same for the 2 growing seasons. The systematic sampling technique was used to select sampling units (50-stand sampling size) from each plot from which data was collected according to Gomez and Gomez (1984). Agronomic data collected on rice germination percentage (taken as the number of emerged plants stands relative to total stands planted, counted at 7 DAP), plant height (measured from ground surface to the tip of the longest leaf at 4, 8 and 12 weeks after planting), number of tillers/ hills (taken as the number of tillers on each stand at harvest), number of productive tillers/ hill (taken as the number of seed-bearing tillers on each stand), the weight of 1000 seeds (evaluated by counting threshed seeds and weighing), percentage filled spikelet (obtained from the number of filled and unfilled grains per stand), and grain yield (taken as weight of threshed seeds after drying, in hectare equivalents). The meteorological data for the two years in which the study was carried out is presented in Fig. 2.

Table 1 Methods of soil and biochar samples analyses

Parameters	Methods of Analyses	
	Soil	**Biochar**
Soil particle size fractions	Gee and Or (2002)	-
pH	Thomas (1996)	In 0.1 N KCl solution (1:10 wt/wt) ratio
Total nitrogen	Bremner (1996)	Enders and Lehmann (2012)
Organic carbon	Walkley and Black (1934)	Enders and Lehmann (2012)
Available phosphorus (Bray 1-P):	Bray and Kurtz (1945)	Enders and Lehmann (2012)
Exchangeable bases (Ca, Mg, K, and Na)	1 N ammonium acetate (NH_4OAc) extraction	Enders and Lehmann (2012)
ECEC	Juo et al. (1976)	-
Exchangeable acidity	Peech et al. (1962)	-
Percentage base saturation	Summation of total exchangeable bases expressed as a percentage of CEC	-
Water holding capacity	-	-
Bulk density	-	-
Porosity	-	-
Moisture content	-	ASTM E871-82 (2013)
Volatile matter	-	ASTM E871-82 (2013)
Ash	-	ASTM E871-82 (2013)
Fixed carbon	-	ASTM E871-82 (2013)

- = not analysed

Table 2 Physical properties of the soils

Pedon	Gravel	Sand (%)	Silt	Clay	Textural Class	Bulk Density (g/cm^3)	Total Porosity	Water Holding Capacity (%)
US	2.12	66.24	26.00	7.760	Sandy loam	1.51	0.09	27.23
SS	2.15	84.24	5.00	10.76	Loamy sand	1.13	0.15	25.0
PS	6.11	75.24	17.0	7.760	Sandy loam	0.46	0.12	28.79

Table 3 Chemical properties of the biochar

Fixed C	Ash	VM (%)	Moisture	pH (H_2O)	N (%)	Ca	Mg	Na (cmol (+)/kg)	K	P (mg/kg)	Yield	C	H (%)	O	S
12.3	15.8	65.7	6.2	7.9	9.8	1.92	0.74	0.12	1.02	8.75	34.2	40.24	5.1	44.5	0.4

Table 4 Chemical properties of the soils

						Exchangeable								**Extractable**	
Pedon	pH 1:1 H_2O	pH 1:1 KCl	Total N	OC (%)	OM	Ca^{2+}	Mg^{2+}	Na^{+} (cmol (+)/kg)	K^{+}	EA	Av. P (mg/kg)	ECEC (cmol (+)/kg)	BS (%)	Fe (mg/kg)	Zn^{2+} (mg/kg)
US	5.11	4.80	0.12	0.34	0.58	1.21	0.76	0.10	0.52	0.10	1.59	2.69	96.28	4.29	0.36
SS	5.46	4.12	0.26	0.30	0.52	1.58	0.61	0.08	0.16	0.10	1.05	2.53	96.05	4.16	0.13
PS	6.82	5.02	0.32	0.78	1.34	3.00	1.00	0.20	0.10	0.10	1.90	4.40	97.73	4.62	0.93

Data analysis

Agronomic data were subjected to analysis of variance (ANOVA) to quantify variations in treatment means in an RCBD design with soil type, treatment and year as blocking factors. Significant differences were compared using the LSD = Least Significant Difference at $p = 0.05$ using Genstat Data Analysis Software (20th Edition) (VSNi 2020).

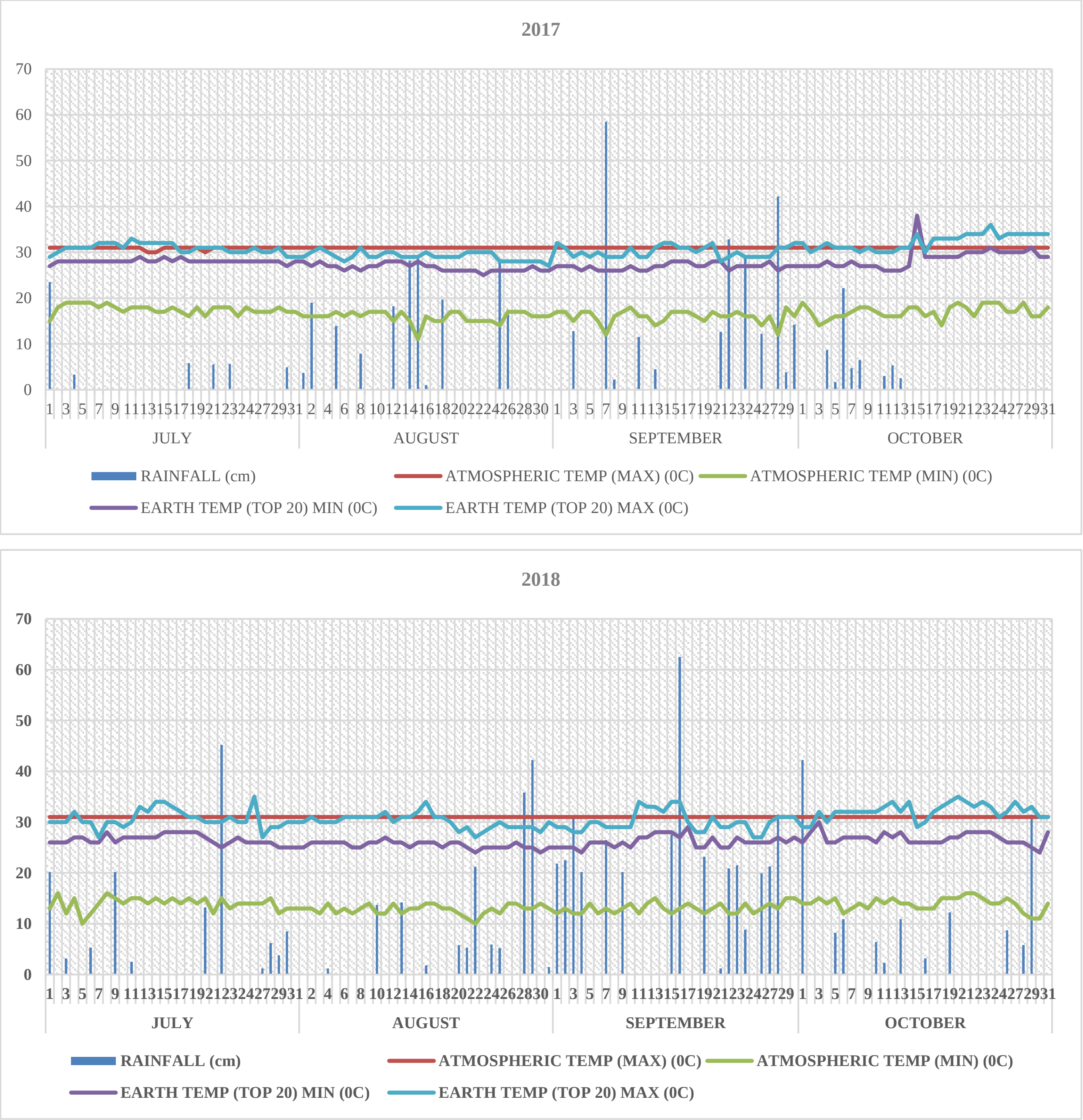

Fig. 2 Meteorological data of the study area during field experimentation

(Source: University of Ilorin Teaching and Research Farm Weather Station)

Results and discussion

Rice growth performance

Analyses results showed that there were significant interactions between experimental year, soil type and biochar rates on rice growth indices (Table 5).

Rice growth indices in the two growing seasons

Table 5 shows the means of rice growth parameters in the three soils and four biochar rates in the two years. Rice growth indices significantly ($p \leq 0.05$) differed between both years. Overall, better growth performance was recorded in the first year, with a percentage decrease of 9.4 and 11.4% recorded for plant height at 12 weeks after planting (WAP) and tiller productivity from 2017 to 2018, respectively. The mean tiller counts also decreased significantly ($p \leq 0.05$) from 13% in 2017 to 12% in 2018 (Table 5). The reduction in rice performance in the second year may have resulted from the reduced effect of biochar as a direct nutrient-supplying material. This is inferable, as earlier research by Lehmann and Joseph (2009) shows that the majority of nutrients in biochar materials are readily utilizable by plants and may be leached into soil within a short period. The fact that weather factors for the two years under the study were similar as shown in the meteorological data (Fig. 2) buttresses this inference.

Effect of soil type on rice growth indices

Soil type significantly affected rice growth performance in all evaluated indices except tiller productivity (Table 5). The maximum plant height was significant ($p \leq 0.05$) 4, 8 and 12 WAP in SS, and the lowest was recorded in the same weeks in PS (Table 5). The highest seed germination percentage was recorded in SS (61.41%), which was significantly ($p \leq 0.05$) higher than that recorded in PS. The tiller number per stand was the same (13) in US and SS, which was significantly ($p \leq 0.05$) higher than PS (12). The different results among soils likely resulted from the differences in their physical and chemical properties, which will affect biochar soil conditioning mechanisms of nutrient retention and release.

Effect of biochar treatments on rice growth indices

Biochar amendment consistently resulted in better growth performance, with a biochar application rate of 5 t/ha consistently resulted in better performance than the control treatment in all measured indices. Growth generally increased with increasing levels of biochar application, but it decreased at the highest application rate of 25 t/ha. The seed germination percentage decreased significantly ($p \leq 0.05$), about 13.8% at the highest application rate of biochar. According to Wang et al. (2022), soil reaction (pH) may inhibit seed germination. Thus, biochar amendement at 15 t/ha may have resulted in optimal soil pH conditioning for seed germination in comparison to the control, B_5, and B_{25} treatments which had lower germination percentages than B_{15}. Rice height at 12 WAP and tiller productivity were highest under biochar rate of 15 t/ha and lowest under control, with percentage differences of 10.5% and 25% respectively (Table 5).

The incremental performance of rice with additional biochar levels supports the proposal of a direct supply of nutrients and soil conditioning by biochar. With higher biochar application, more nutrient is expectedly released. The low performance at the highest application rate of biochar may have resulted from disaggregation of soil structure by high amounts of biochar materials, which could result in high nutrient leaching or immobilization, and possible nutrient toxicity and imbalance. The decreases of rice yield at high biochar application rates have been reported in previous study by Asai et al. (2009) who reported higher rice yields at a 4 t/ha biochar application rate in comparison to 8 and 16 t/ha. Zhang et al. (2013) also found that the correlation between biochar application amount and rice yield was not positive. Chen et al. (2021) however recorded the highest rice yield at the highest application rate of 40 t/ha.

This demonstrates the complexity of biochar's effects on crop growth. Beusch et al. (2019) reported that biochar addition could reduce nutrient retention in soil due to the quick decomposition of biochar C by up to 51% in 16 months following application.

Rice yield

There were significant interactions between experimental year, soil type and biochar rates on rice yield indices (Table 6).

Table 5 Variations in means of growth parameters of rice in three soil types and four biochar treatments in two cropping seasons

Year (Y)	**Height at 4 WAP (cm)**	**Height at 8 WAP (cm)**	**Height at 12 WAP (cm)**	**Seed germination (%)**	**Tiller count/stand**	**Tiller productivity/ stand**
2017	42.71	100.28	112.44	60.86	13	12.99
2018	40.39	96.21	101.85	59.91	12	11.51
LSD	0.20*	1.49	1.55*	0.19	0.10*	0.19*
Soil type (S)						
US	41.44	98.01	107.30	60.24	13	12.06
PS	40.67	96.82	106.00	59.50	12	12.15
SS	42.54	99.91	108.14	61.41	13	12.54
LSD	0.50*	0.66*	0.81*	0.52*	0.17*	0.23
Biochar rates (B)						
B_0	32.87	91.34	101.05	52.14	11	10.85
B_5	36.85	97.71	105.73	58.72	12	11.39
B_{15}	48.97	102.67	111.66	70.16	14	13.56
B_{25}	47.52	101.27	110.14	60.51	13	13.21
LSD	0.80**	0.91**	0.99**	0.56**	0.45**	0.48**
Interaction						
Y x S x B	*	*	*	*	*	*

LSD = Least Significant Difference; ** = p≤0.01; * = p≤0.05

Effect of soil types and biochar treatments on rice yield parameters

Results showed that soil types did not have significant effects on yield parameters except for 1000 seeds weight that was higher in SS and lower in PS with values of 28.97 and 27.72 g, respectively.

At a p≤0.01 significant level, however, biochar treatment had effects on all rice yield parameters (Table 6). Seed dry weight (g) was higher under B_{25}, but the value was not significantly different from that obtained under

B_{15} treatment. Also, biochar application at 5 t/ha did not show any significant difference in rice 1000 seeds weight in comparison to the control. The highest 1000 seed weight (29.52 g) was recorded in the B_{15} treatment, and this was significantly ($p \leq 0.01$) higher compared to other treatments (Table 6). The highest percentage of filled spikelets was also obtained under B_{15} treatment (89.97%) while the lowest (75.63%) was obtained under control. The result recorded under the B_{15} treatment was significantly ($p \leq 0.01$) higher than those recorded from other treatments except for B_{25}.

Table 6 Variation in means of rice yield parameters in soils, treatment rates and years

Year (Y)	**Grains dry weight (g/Stand)**	**Weight of 1000 grains (g)**	**Filled spikelet (%)**	**Grain yield (t/ha)**
2017	41.07	28.43	84	4.04
2018	36.99	28.23	83.56	3.57
LSD	2.67	0.11	0.20	0.23
Soil type (S)				
US	37.59	28.31	83.61	3.67
PS	37.85	27.72	83.8	3.65
SS	41.67	28.97	83.93	4.09
LSD	2.17	0.35*	0.18	0.20
Biochar rates (B)				
B_0	28.27	27.89	75.63	2.37
B_5	29.78	27.46	80.3	4.79
B_{15}	48.36	29.52	89.97	5.24
B_{25}	49.72	28.47	89.22	4.79
LSD	1.63**	0.44**	0.35**	0.14**
Interaction				
Y x S x B	*	*	*	*

LSD = Least Significant Difference; ** = $p \leq 0.01$; * = $p \leq 0.05$

The equivalent rice yield to tons per hectare was higher under B_{15} treatment with a value of 5.24 t/ha, which was significantly higher than those recorded in the other treatments. The differences in yield between B_{25}, B_{15}, B_5, and the control were 102.1, 121.1 and 102.1%, respectively. The increase in rice yield following biochar application as a result of improved soil condition has been reported in earlier research. Kartika et al. (2018) reported that biochar application resulted in a significant increase in filled spikelet number, grain weight per panicle, and 1000 grains seed weight of rice. In their research, however, the biochar amendment rate of 3 t/ha produced the best results, and reduced spikelet filling was observed at an application rate of 4 t/ha.

Rice yield indices in the two growing seasons

Table 6 shows the rice yield parameters in the two years (2017 and 2018). No significant differences were recorded between years and soil types for grains dry weight/stand, the weight of 1000 grains, percentage filled spikelet and the grain yield in tons per hectare. A mean yield of 4.04 t/ha was recorded in 2017, while 3.57 t/ha was recorded in 2018 representing an insignificant decrease of 11.6%. The slight decrease in rice yield parameters from 2017 to 2018 can be attributed to the reduction of direct nutrient supply by biochar for the plant. Research shows that biochar nutrients can be readily available for plant use directly after application to the soil, but at the same time they can be easily lost from the soil by leaching (Lehmann and Joseph 2009).

Interaction effect of year, soil type and biochar treatment on rice tiller productivity

Rice tiller productivity was significantly different ($p \leq 0.05$) between the two years, with better results recorded in the first year (Table 7). The highest tiller productivity was recorded in SS in the first year and the lowest in PS and US in the second year. B_{15} had the highest productivity recorded in the first year, while the lowest productivity was recorded under control in the second year. Soil SS had the best tiller productivity under all treatments and the least performance was recorded in PS (Table 7). This suggests that the potential of biochar to directly supply nutrients for plants was influential on higher tiller productivity in the first year.

Table 7 Year, soil type and treatment interaction effects (Y×S×T) on rice tiller productivity in soils and treatment levels

Year				**T**	
	S	**B_0**	**B_5**	**B_{15}**	**B_{25}**
2017	US	10.80	11.96	14.27	13.87
	PS	11.47	12.09	14.38	13.68
	SS	11.97	12.43	14.63	14.33
2018	US	9.93	11.27	12.40	12.00
	PS	10.23	10.10	12.77	12.50
	SS	10.67	10.50	12.90	1.90
LSD	1.07				

LSD = Least Significant Difference; T: biochar treatment; S: soil; Y: year

Interaction effect of year, soil type and biochar treatment on rice dry grains weight/stand

Table 8 shows the interaction effect of year, soil type and biochar treatment on rice grains weight. Rice grains weight were higher in 2017 in all soils, and the highest weight was recorded in SS (43.43 g/stand). The lowest weight was recorded in the US in 2018 (34.41 g/stand). The best performance was recorded in SS under all treatments including control (Table 8).

These results suggest a likelihood that the poor performance of PS under higher application rates of biochar resulted from nutrient (especially N) toxicity since PS had a high inherent level of N. This assumption is supported by the fact that the soil performed better than the US at a lower biochar application rate of 5 t/ha and control. Higher application rates of the N-rich biochar and additional fertilization likely resulted in excess N, which may have resulted in luxury consumption that caused plants to prioritize growth at the expense of grain yield. Similar observations of poor crop performance resulting from overfertilization have been reported in previous research (Kischel et al. 2011; Albornoz 2016). While N has many functions in crop development which include promotion of rapid growth, increase in leaf size and quality, and enhancement of fruit and seed development, its oversupply can reduce crop quality. Wang et al. (2011) stated that an oversupply of N can result in an osmotic restriction in plants, which limits growth and development. Also, researchers including Mingotte et al. (2013) have reported a reduction in the mass of rice grains with increasing levels of N.

Table 81 Interaction effects of experimental factors (Y×S×T) on rice dry grain weight (g/stand) in soils and biochar rates

Year				**T**	
	S	B_0	B_5	B_{15}	B_{25}
2017	US	28.47	30.43	50.50	53.67
	PS	27.20	30.63	48.97	49.30
	SS	29.80	32.73	55.23	55.97
2018	US	23.30	27.10	44.03	43.20
	PS	29.90	27.53	43.10	46.13
	SS	30.93	30.27	48.33	50.07
LSD	5.03				

LSD = Least Significant Difference; T: biochar treatment; S: soil; Y: year

Interaction effect of year, soil type and biochar treatment on 1000 rice grains weight

There was a significant ($p\leq 0.01$) decrease in 1000 rice grains weight from the first to the second year (Table 9). The highest grains weight was recorded in the first year in SS (29.08 g) while the lowest weight was recorded in PS in 2018 (27.71 g). In soil PS, treatment B_{15} had the best performance, and the lowest was recorded under control. Chen et al. (2021) also observed improved rice productivity in multiple growing cycles. The biochar amendment exerted a significant positive effect on rice yield by 10% in the first cycle and 9.5–29% in the subsequent cycle following the biochar amendment. They attributed this response to the role of biochar in increasing soil pH (H_2O), SOC, total N and decreasing soil bulk density. This explanation is also applicable to the responses recorded in this study.

Interaction effect of year, soil type and biochar treatment on rice spikelet filling

The interaction effect of experimental factors on rice spikelet filling are shown in Table 10. There was a general decrease in performance from the first to the second year, and the control treatment consistently had the lowest values in all 3 soils. Field observations showed that at harvest (98 DAP), many plants under control treatment in all soil types were still very vegetative, with immature panicles in comparison to plants under biochar amendment which had developed grains that were already mature for harvest. This is an indication of improved rice growth and yield under biochar treatment which likely resulted from better utilization of applied inorganic nutrients and conditioning of the soil system in biochar-treated plots. A similar response has been observed in a previous study (Kang et al. 2018).

Table 9 Interaction effects experimental factors (Y×S×T) on weight of 1000 rice seeds (g) in soils and treatment levels

Year				**T**	
	S	**B_0**	**B_5**	**B_{15}**	**B_{25}**
2017	US	28.13	27.60	29.63	28.57
	PS	27.33	26.43	28.97	28.20
	SS	28.47	28.60	30.30	28.97
2018	US	27.67	27.13	29.60	28.13
	PS	27.30	26.57	28.93	28.03
	SS	28.43	28.40	29.67	28.90
LSD	1.02				

LSD = Least Significant Difference; T: biochar treatment; S: soil; Y: year

Table 10 Interaction effects of experimental factors (Y×S×T) on percentage of filled spikelet in rice

Year				**T**	
	S	**B_0**	**B_5**	**B_{15}**	**B_{25}**
2017	US	75.70	80.53	89.90	89.03
	PS	75.43	80.53	90.17	89.87
	SS	76.63	80.63	90.40	89.17
2018	US	75.00	79.77	90.03	88.90
	PS	75.17	80.00	89.37	89.87
	SS	75.87	80.33	89.93	88.47
LSD	0.81				

LSD = Least Significant Difference; T: biochar treatment; S: soil; Y: year

Interactions effect of year, soil type and biochar treatment on rice grain yield

Rice grain yield generally decreased significantly ($p \leq 0.05$) from the first to the second year (Table 11). The highest yield of 4.31 t/ha was obtained in 2017 in SS, and the lowest yield was obtained in the US in 2018 (3.36 t/ha). There was also a reduction in yeild from the first to the second year, with the highest yield recorded under B_{15} in 2017 (5.63 t/ha) and reduced to 4.86 in 2018. Control treatments consistently gave the lowest yield which was below 2.6 t/ha in all soils with the US having the lowest. The overall the highest yield of 5.9 t/ha was obtained from SS under B_{15} in 2017, and the lowest was recorded in the US in 2018 (1.9 t/ha). US which has the lowest content of N and OM recorded the lowest yield performance under control treatment.

This indicated that the positive rice performance and productivity under biochar amendment could be attributed to the improvement of soil physical properties, P availability and nutrient uptake efficiency following biochar amendment.

Liu et al. (2016) reported similar observations under biochar amendment to lowland rice and attributed responses to improved availability of phosphorus and potassium, soil pH conditioning and improved organic carbon in the soil. The decrease in productivity in the second year is attributable to the reduction of direct nutrient supply capacity by biochar, after the majority of the nutrients may have been consumed or leached in the first year. The effect of biochar on soil conditioning and quality has been reported in the literature (Zhang et al. 2012; Chen et al. 2021), which supports the current study's outcome. A previous study by Kang et al. (2018) showed that biochar can improve nitrogen availability and its uptake by plants, and stimulate nitrification. The slight enhancement recorded in the first evaluation year compared to the second year suggests that biochar served as a direct source of nutrients for the plants, and the majority of the nutrients maybe had been leached or consumed by the second year. Lehman and Joseph (2009) reported that nutrients in biochar may be readily available for plant uptake directly after application, but when water leaching occurs their availability will be reduced.

Table 11 Interaction effects of experimental factors (Y×S×T) on rice grain yield (t/ha)

Year		T			
	S	B_0	B_5	B_{15}	B_{25}
	US	2.37	2.87	5.50	5.20
	PS	2.33	2.77	5.50	4.67
2017	SS	2.53	3.23	5.90	5.57
	US	1.90	2.53	4.83	4.17
	PS	2.53	2.43	4.73	4.23
2018	SS	2.53	3.00	5.00	4.93
LSD	0.45				

LSD = Least Significant Difference; T: biochar treatment; S: soil; Y: year

Conclusion

In the current study, biochar amendment positively influenced rice seeds germination, spikelet sterility, grain mass and yield, with the highest performance and yield recorded at 15 t/ha. A decrease in rice performance and yield was recorded at a biochar rate beyond 15 t/ha in both sandy and loamy surface soil textures. Overall, biochar addition resulted in higher rice yields in the two years, with an average yield increase of about 55% at 15 t/ha relative to control. There was a non-significant decrease in rice yield and growth from year 1 to year 2. This showed that rice husk biochar application can enhance rain-fed upland rice productivity. The observed increase in rice yields in these weathered and nutrient-poor soils possibly resulted from the effects of soil properties and their interactions with the biochar material, which improved soil structure and its ability to hold and release nutrients and water for rice growth, as well as direct supply of nutrients.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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