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Growth attributes and yield of upland rice (*Oryza sativa*L.) as affected by weed management strategies, source and rate of biochar in Northern Guinea Savanna

Tabat, Y. K[1]., D. B. Ishaya[2]., H.N. Kura[2]and I.Y. Amapu[3]

[1]*Department of Agric. Education, Kaduna State College of Education GidanWaya*
[2]*Department of Agronomy, Ahmadu Bello University, Zaria*
[3]*Department of Soil Science, Ahmadu Bello University, Zaria*
Corresponding author: yusuftabat67@gmail.com

Abstract
Field trials were conducted during 2018 and 2019wet seasons on the research farm of the Institute for Agricultural Research (IAR), Ahmadu Bello University Samaru, Zaria (11°11'N, 07°38'E 686m above sea level) in the Northern Guinea Savanna ecological zone of Nigeria. The experiment was carried out to evaluate the performance of upland rice (Oryza sativa L.) as affected by weed management strategies, source and rate of biochar. The treatments consisted of three sources of biochar organic biomass (rice husk, groundnut shell and wood shavings), three rates of the biochar (0, 2 and 4 t ha^{-1}) and three different weed management strategies [chemical weed control (Saflufenacil + Dimethenamid-Pat 0.5 kg a.i/ha applied pre-emergence), integrated weed control method (Saflufenacil + Dimethenamid-P at 0.5 kg a.i/ha applied pre-emergence + one hand weeding at 9 WAS) and cultural weed control method (Hand weeding at 3, 6 and 9 WAS) which is the farmers' practice]. The three rates of biochar and three different weed management strategies were factorially combined and laid out as the main plot treatment. The sub-plot treatments consisted of the three sources of biochar. All the treatments were laid out in a Split-Plot Design and replicated three times. The best weed control was achieved by integrated weed control which enhanced performance of plant height, leaf area index, crop growth rate that gave the best paddy yield. The application of biochar at 2 t ha^{-1} gave the best crop performance for the growth attributes and resultant paddy yield. Incorporation of rice husk biochar enhanced plant height, leaf area index and paddy yield more than other sources of biochar. The results showed that 2 t ha^{-1} rice husk biochar in combination with integrated weed management are most appropriate for growth and yield of upland rice at Samaru in Northern Guinea Savanna ecological zone of Nigeria.
Key words: *weed management, biochar, upland rice, yield*

Introduction

Rice (*Oryza sativa* L.) is the most important food crop in the developing world and the staple food of more than half of the world's population (Rajput, 2016). It is among the major sources of employment, income and food security for farming households (FAOSTAT, 2010). Farmers find rice more adaptable than a high input staple like maize when there is declining soil fertility because of the huge array of varieties they can switch over to every few years (Oikeh, *et al.,* 2006).Rice has the potential of growing in virtually all the agro-ecological zones in Nigeria, as diverse as the Sahel Savanna of extreme end of Borno state and the coastal swamps of the extreme end of southwest and south-south(Selbut, 2003).As a special staple food crop, farmers are always willing to grow it all the times no matter the constraints they are facing.

More than 700 million tonnes of paddy rice is produced annually at global level with nearly 640 million tonnes produced in Asia, representing 90% of global production (The United States Department of Agriculture, 2020). The FAO (2020) reported world milled rice production at 508.7

million tonnes in 2020 which is slightly greater than the 507.3 million tonnes of milled rice reported in 2019. Nigeria is reported as the largest paddy rice producer in sub-Saharan Africa with approximately 8 million tonnes out of the Africa average of 14.6 million tonnes of paddy rice annually (USDA, 2020).

Rice production in Nigeria is limited by factors such as lack of good seeds, attack by birds, high cost and unavailability of fertilizer at the time of need, cost of pesticides and weed interference (Akintayo *et al.,* 2011).Of all the constraints limiting the production of rice, weeds, appear to have the most deleterious effect causing between 80 to 100% reduction in potential paddy rice yield (Akobundu, 2011; Imeokparia, 2011; Lavabre, 2011). Weed control is thus important to prevent losses in yield, reduce productions cost and preserve good grain quality (Rao *et al.,* 2014).However, the choice and use of appropriate weed control method constitutes yet another constraint to farmers in rice producing regions in Nigeria.

Recently, the use of biochar (a carbon-rich substance) in agriculture is gaining global acceptance because of its variously reported significant benefits which include the potential to reduce current global carbon emissions by about 10 percent thereby mitigating climate change (Woolf, 2008), improved soil fertility leading to reduced need for additional fertilizer, improved water and nutrient retention in sandy soils, reduced nutrient leaching (Atkinson *et al.,* 2010, Downie and Van Zwieten, 2013; Pühringer, 2016), reduced weed seed viability and germinability (Major *et al*., 2005; Arif *et al*., 2012) among other benefits. Despite these attributes, utilization of biochar in Nigerian agriculture especially in the savanna region [which is characterized by very low nutrient content (Uyovbisere and Lombin, 1988] is still low. Upland rice production under the different sources and rates of biochar and weed management systems is yet to be established in the savanna region of Nigeria which this research undertook to determine the best source and optimum rate of biochar and most efficient weed management strategy for upland rice production.

Materials and Methods

Field trials were conducted during 2018 and 2019 wet seasons on the research farm of the Institute for Agricultural Research (IAR), Ahmadu Bello University Samaru, Zaria (11°11'N, 07°38'E 686m above sea level). The experiment was carried out to evaluate the performance of upland rice (Oryza sativa L.) as affected by weed management strategies, source and rate of biochar. The treatments consisted of three sources of biochar organic biomass (rice husk, groundnut shell and wood shavings), three rates of the biochar (0, 2 and 4 t ha^{-1}) and three different weed management strategies [chemical weed control (Saflufenacil + Dimethenamid-P at 0.5 kg a.i/ha applied pre-emergence), integrated weed control method (Saflufenacil + Dimethenamid-P at 0.5 kg a.i/ha applied pre-emergence + one hand weeding at 9 WAS) and cultural weed control method (Hand weeding at 3, 6 and 9 WAS) which is the farmers' practice]. The three rates of biochar and three different weed management strategies were factorially combined and laid out as the main plot treatment. The sub-plot treatments consisted of the three sources of biochar. All the treatments were laid out in a Split-Plot Design and replicated three times. The gross plot size was 3m x 3m ($9m^2$), while net plot size was 3 x 1.5m ($4.5m^2$).

The biochar was produced locally under low oxygen condition based on the procedure described by Srinivasarao *et al.* (2013).The composite of the sampled soil at land preparation and at harvest were analyzed for physical and chemical properties. Land was harrowed twice and demarcated into main-plots and sub-plots. NERICA 8 (FARO 59) variety was used and dressed with Dress Force (Imidacloprid 20%, Metalaxyl-M 20%, Tebuconazole 2% WS)at the rate of 10g/2.5kg of rice seeds. The rice seed were sown manually by dibbling at an intra and inter-row spacing of 20 x 20cm on flat land. The herbicide Saflufenacil+ Dimethenamid-Pat 0.5kg a.i. /ha was applied at one day after sowing according to the pre-emergence treatments at a pressure of $2.1kg/cm^2$ using discharge volume of 200L/ha. Half recommended rate of fertilizer for rice (i.e. half of $80kgNha^{-1}$, $30kgP_2O_5ha^{-1}$ and

30kgK_2Oha^{-1}) was used for this research applied under 2 split applications at planting and at 5 WAS. Three hand weedings were carried out in the hand-weeded treatment at 21, 42 and 63 DAS and one hand pulling in the integrated weed control treatment at 63 DAS. Matured panicles were harvested manually using sickle at physiological maturity prior to grain shattering. Data were collected on plant height, leaf area index, crop growth rate and paddy yield per hectare as indicated below:

Plant height (cm)

Five plants were tagged from each plot and their height measured from the base of each plant to the tip of flag leaf at 9 and 12 weeks after sowing using metre rule. Their heights were added and average per plant determined.

Leaf area index (LAI)

Leaf area index (LAI) was measured using AccuPAR/LAI Ceptometer Model LP-80. Five (5) measurements for the incident PAR were taken under the rice canopy in each plot. The sensor was placed diagonally across the two inner rows at ground level so that the ends of the sensor coincide with the line of the plants in each row. The displayed LAI for the plot was also recorded. Observations were taken under cloud free conditions between 12:00 noon and 14:00 hours.

Crop Growth Rate (CGR)*(gcm^{-1}wk^{-1})*:

This is the dry matter accumulation of the crop per unit area per time. This was calculated using the equation below as described by Happer (1999):

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} (gcm^{-1}wk^{-1})$$ where:

W_1 = Dry matter taken at initial period t_1 = Time when W_1 was taken

W_2 = Dry matter taken at second sampling period t_2 = Time when W_2 was taken

Paddy yield (t ha-^{1}):

The paddy yield was obtained from the net plot area of each sub plot. The rice paddies were threshed, winnowed to remove chaff and the clean paddies were weighed using mettler balance (Toledo SB 16001) and the yield expressed in tonnes per hectare(t ha-^{1}).

Data collected were subjected to statistical analysis of variance (ANOVA) as described by Steel and Torrie (1997) using Statistical Analysis Software package. Treatment means were compared using Duncan Multiple Range Test (DMRT)(Duncan, 1955) at 5% level of probability.

Results

Plant height (cm)

Plant height of upland rice as affected by weed management strategies, rate and source of biochar at 9 and 12 WAS at Samaru during 2018 and 2019 raining seasons is significant only at 9 WAS (Table 1). At 9 WAS in both years, hand weeded treatment significantly produced taller plants than other weed management strategies but were comparable to integrated weed control in 2018.

Application of 2 t ha^{-1} of biochar significantly produced taller upland rice at 9 WAS in both years beyond which there was no further significant increase plant height.

Rice husk biochar significantly produced taller plants of upland rice than groundnut shell biochar which was comparable to wood shavings biochar at 9 WAS in 2019.The interaction among all the treatments evaluated was not significant in both years and the mean (Table 1).

Leaf Area Index

The effect of weed management strategies, rate and source of biochar on leaf area index of upland rice at 9 and 12 WAS at Samaru in 2018 and 2019 wet seasons is significant (Table 1).In both years and sampling stages, integrated weed control significantly recorded the highest LAI of upland rice plants than only chemical weed control except at 12 WAS in 2019 where integrated weed control and hand weeded treatments significantly recorded the highest LAI of upland rice plants than chemical weed control.

Application of 2 t ha^{-1} of biochar significantly increased LAI value of upland rice plants beyond which there was no further significant increase in LAI value in both years but LAI value comparable to the control was recorded at 9 WAS in both years.

Rice husk biochar significantly recorded the highest LAI value of upland rice plants than other source of biochar at 12 WAS in 2018.None of the interactions among the factors evaluated on leaf area index were found to be significant (Table 1).

Crop growth rate ($gcm^{-1}wk^{-1}$)

Table2 shows the effect of weed management strategies, rate and source of biochar on crop growth rate (CGR) of upland rice at 9 and 12 WAS at Samaru in 2018 and 2019 wet seasons. Integrated weed control exhibited crop growth significantly higher than chemical weed control at both sampling stages in 2018 only.

Application of 2 t ha^{-1} of biochar significantly increased CGR of upland rice more than the lower and higher rates of the biochar at 12 WAS in both years beyond which there was significant increase in crop growth more than the control at 9 WAS in 2018.The interaction among all the treatments evaluated was not significant in both years and the mean (Table 2).

Paddy yield

Paddy yield per hectare as affected by weed management strategies, rate and source of biochar at Samaru in 2018 and 2019 wet seasons is significant (Table 2). Integrated weed control consistently and significantly gave the highest paddy yield per hectare more than other weed management strategies while chemical weed control treatment consistently and significantly gave the lowest paddy yield of upland rice per hectare in both years.

Application of 2 t $ha^{-1}$of biochar significantly increased paddy yield per hectare more than all other rates in both years. Rice husk biochar significantly produced higher paddy yield per hectare than only wood shavings biochar in 2018.

The interaction between rate of biochar and weed management strategies on paddy yield per hectare (t ha^{-1}) of upland rice was significant at Samaru in 2018 (Table 3). It was observed that integrated weed control treated with 2 t $ha^{-1}$of biochar significantly produced the highest paddy yield per hectare while chemical weed control without biochar produced the least paddy yield per hectare.

Discussion

Effect of weed management strategy:

The significantly higher records of plant height, leaf area index and crop growth rate obtained by upland rice plants in the integrated weed control and hand weeded treatments could be attributed to the reduced competition for water, nutrients, light and space between the plants and weed species compared to the intensive competition for these resources of the rice plants with weed species in the chemical weed control treatment. This has led to the enhancement of physiological activity which in turn increased the leaf area, light interception, photosynthetic activity and dry matter accumulation of the crop. Kolleh (2006) pointed out that, weeds compete with rice by growing faster and by shading rice with large, horizontal leaves thereby affecting light interception for improved photosynthate production and dry matter accumulation.

Paddy yield of upland rice was enhanced by integrated weed control strategy mainly due to the multiple weed suppression achieved with the application of pre-emergence herbicide and hand weeding at 9 WAS which greatly lowered the weeds density. Haefele *et al.* (2002) reported that, herbicides are often used in combination with other control options and most farmers rely on chemical weed control followed by hand weeding for best results.

Effect of rate of biochar:

The significant increases in the plant height, LAI and CGR observed with the incorporation of 2 t ha^{-1} of biochar at Samaru could be due to the improvement in soil nutrients availability and retention that triggered production of taller plants, more number of tillers and leaves and their expansion which contributed to the total leaf area of the crop leading to increased photosynthate production for increased growth and development. Liu *et al.* (2016) and Benyamin *et al.* (2017) found that, biochar application in rice had significant effect on the number of leaves which translated into higher LAI and CGR and in turn higher photosynthetic efficiency for dry matter production.

The highest paddy yield obtained in both years with the application of 2 t ha^{-1} of biochar indicated that the optimum rate for upland rice yield increases has been reached at this particular rate. This finding is in agreement with Reichenauer *et al.* (2009) who found increased grain yield with the application of 2 t rice-husk-biochar ha^{-1}. It is also in line with the earlier report of Abdullahi (2016) who obtained optimum yield of maize with the application of 2 t ha^{-1} of biochar

Effect of source of biochar:

Plant height and leaf area index were significantly enhanced when rice husk biochar was incorporated. This could be due to the high chemical properties of rice husk biochar as revealed by the chemical analysis (Table 4) that led to the improvement in physical and chemical properties of the soil, increase in water retention capacity of the soil, nutrient use efficiency and improved condition for the activity of soil micro-organisms. In corroboration, Mariluz and Sanchez – Monedero (2015) reported that, when the right biochar is added to the right soil, biochar can among other benefits, improve resource use efficiency, remediate and/or protect soils against particular environmental pollution, and become an avenue for green house gas (GHG) mitigation.

The positive response observed in paddy yield of upland rice in 2018 with the application of rice husk biochar could be attributed to the enhanced leaf area index earlier recorded due to application of the rice husk biochar which was later manifested in the development and better performance of yield attributes of the crop and the resultant yield.

Treatments Interaction:

Interaction between rate of biochar and weed management strategies on paddy yield per hectare was significant in 2018. Integrated weed control in combination with the application of biochar rate at 2 t ha^{-1} gave the highest yield of 4.97 t ha^{-1} in 2018. This indicated the importance of employing the right weed management strategy and appropriate rate of biochar for increased yields of upland rice.

Conclusion

The results showed that 2 t ha^{-1} rice husk biochar in combination with integrated weed management is most appropriate for growth and yield of upland rice at Samaru in Northern Guinea Savanna ecological zone of Nigeria.

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Table 1: Effect of weed management strategies, source and rate of biochar on plant height and leaf area index of upland rice at Samaru in 2018 and 2019

Treatment	Plant height (cm)				Leaf area index			
	2018		2019		2018		2019	
	9 WAS[1]	12 WAS	9 WAS	12 WAS	9 WAS	12 WAS	9 WAS	12 WAS
Weed management - W								
Chemical weed control	54.8b[3]	61.6	53.0b	60.1	2.65b	3.01b	2.62b	2.57b
Hand weeding	61.4a	62.0	60.1a	60.4	2.96ab	3.69a	3.00ab	3.62a
Integrated weed control	57.5ab	61.4	56.0b	60.2	3.10a	3.73a	3.04a	3.65a
SE±	1.33	1.20	1.24	1.12	0.14	0.11	0.13	0.10
Biochar rate (t ha^{-1}) - R								
0	54.0b	60.4	52.2b	58.7	2.72b	3.07b	2.66b	2.63b
2	61.0a	62.9	59.7a	61.6	3.14a	3.80a	3.10a	3.72a
4	58.7a	61.7	57.2a	60.4	2.86ab	3.56a	2.90ab	3.49a
SE±	1.33	1.20	1.24	1.12	0.14	0.11	0.13	0.10

Biochar source - S								
Rice husk	60.1	61.7	58.9a	60.5	3.17	3.76a	3.10	3.48
G/nut shell	56.6	61.7	55.1b	60.4	2.87	3.38b	2.94	3.20
Wood shavings	57.0	61.5	55.2ab	59.8	2.68	3.30b	2.62	3.16
SE±	1.23	1.10	1.19	1.06	0.17	0.12	0.17	0.11
Interaction								
R x W	NS[2]	NS	NS	NS	NS	NS	NS	NS
R x S	NS	NS	NS	NS	NS	NS	NS	NS
W x S	NS	NS	NS	NS	NS	NS	NS	NS
R x W x S	NS	NS	NS	NS	NS	NS	NS	NS

1. WAS = Week after sowing
2. NS = Not significant.
3. Means followed by same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT.

Chemical weed control (Saflufenacil +Dimethanamid-P); Hand weeding (3, 6, & 9 WAS)
Integrated weed control (Saflufenacil +Dimethanamid-P + Hand weeding at 9 WAS)

Table 2: Effect of weed management strategies, source and rate of biochar on crop growth rate and paddy yield of upland rice at Samaru in 2018 and 2019

Treatment	Crop Growth Rate ($gcm^{-1}wk^{-1}$)				Paddy yield per hectare ($t\ ha^{-1}$)	
	2018		2019			
	9 WAS[1]	12 WAS	9 WAS	12 WAS	2018	2019
Weed management - W						
Chemical weed control	3.32b[4]	8.83b	2.46	9.07	2.033c	1.856c
Hand weeding	3.59ab	9.24ab	2.19	8.74	2.985b	2.687b
Integrated weed control	3.73a	9.42a	2.26	8.97	3.802a	3.419a
SE±	0.10	0.18	0.44	0.46	0.223	0.244
Biochar rate ($t\ ha^{-1}$) - R						
0	3.36b	8.65b	2.20	7.79b	2.078c	1.838b
2	3.60ab	9.72a	2.53	10.9a	3.865a	3.618a
4	3.67a	9.13b	2.18	8.03b	2.878b	2.507b
SE±	0.10	0.18	0.44	0.46	0.223	0.244

Biochar source - S						
Rice husk	3.68	9.00	2.28	8.88	3.257a	3.093
G/nut shell	3.53	9.22	2.27	8.97	2.945ab	2.477
Wood shavings	3.42	9.27	2.35	8.92	2.618b	2.392
SE±	0.09	0.14	0.34	0.36	0.229	0.262
Interaction						
R x W	NS	NS[3]	NS	NS	*[2]	NS
R x S	NS	NS	NS	NS	NS	NS
W x S	NS	NS	NS	NS	NS	NS
R x W x S	NS	NS	NS	NS	NS	NS

1. WAS = Week after sowing
2. * = Significant
3. NS = Not significant.
4. Means followed by same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT.

Chemical weed control (Saflufenacil +Dimethanamid-P); Hand weeding (3, 6, & 9 WAS)
Integrated weed control (Saflufenacil +Dimethanamid-P + Hand weeding at 9 WAS)

Table 3: Interaction between rate of biochar and weed management on paddy yield per hectare of upland rice at Samaru in 2018

Weed management	Rate of biochar (t ha^{-1})		
	0	2	4
Chemical weed control	1.483g[1]	3.167d	1.450g
Hand weeding	2.071f	3.455c	3.430c
Integrated weed control	2.680e	4.972a	3.730b
SE±		0.070	

[1]Means followed by same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT.

Chemical weed control (Saflufenacil +Dimethanamid-P); Hand weeding (3, 6, & 9 WAS)
Integrated weed control (Saflufenacil +Dimethanamid-P + Hand weeding at 9 WAS)

Table 4: Chemical properties of Biochar at Samaru during 2018 and 2019 wet seasons

Chemical properties	2018			2019		
	RHB	GSB	WSB	RHB	GSB	WSB
pH in water (1:2:5)	10.2	9.86	9.16	10.1	9.58	8.91
pH in 0.01M$CaCl_2$	NA	NA	NA	NA	NA	NA
Organic carbon (g kg^{-1})	171.0	153.0	130.0	163.0	159.6	129.3
Total nitrogen (g kg^{-1})	9.5	8.1	6.5	8.15	7.6	5.91
Phosphorus (mg kg^{-1})	2.85	2.52	1.81	2.15	1.82	1.75
Potassium (cmol kg^{-1})	1.21	1.02	0.95	1.01	1.15	1.26
Sodium (cmol kg^{-1})	0.08	0.06	0.02	1.09	1.05	0.08

Source: Soil Analytical Laboratory, Department of Agronomy, Ahmadu Bello University, Zaria.
RHB – Rice husk biochar, GSB – Groundnut shell biochar, WSB – Wood shavings biochar
NA – Not Applicable