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ORIGINAL RESEARCH

Influence of sawdust biochar application on the growth, morphological characters and yield of four varieties of sesame (*Sesamum indicum* L.)

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Abstract

Purpose Sawdust, an organic residue abounds in many parts of Nigeria; they often block drainage channels, sometimes burnt to further aggravate the greenhouse gases in the atmosphere. However, it can be harnessed as soil amendment.

Method A field experiment was carried out at the Teaching and Research Farm, University of Ilorin, Nigeria during the 2018 and 2019 wet seasons to evaluate the performance of four sesame varieties using sawdust biochar. The experiment was laid out in a split-plot design, replicated four times. The main plots consisted of four varieties of Sesame (E-8, Ex-Sudan, NCRI-Ben001M, and NCRI-Ben002M), the subplots were sawdust biochar (0, 5, 10, 15, and 20 Mg ha^{-1}). Data were collected on water holding capacity, plant height, and number of leaves, leaf area index, and yield per hectare. Data were subjected to analysis of variance (ANOVA) and means were separated using new Duncan Multiple Range test at 5% level of probability.

Results Results showed significant (p <0.05) effects of variety, and sawdust biochar rates on plant height, number of leaves, leaf area index, crop growth rate and yield per hectare. Variety NCRI-Ben001M gave a yield of 670 kgha^{-1} while the application rate of 15 tha^{-1} sawdust biochar gave a yield of (676 kgha^{-1}) compared to the average yield of sesame in Nigeria.

Conclusion Farmers are therefore encouraged to cultivate NCRI-Ben001M variety and use saw dust biochar at the rate of 15 Mg ha^{-1} for optimum yield.

Keywords Biochar, Varieties, Growth, Yield, Sesame

Introduction

Sesame (*Sesamum indicum* L.), an oilseed crop, is an important economic source of oil for cooking and other industrial applications for mankind. Estimates showed that it provides foreign exchange earnings for Nigeria, contributing about 2.1% to the gross domestic product in 2016 (FAOSTAT 2017). Sesame is cultivated in tropical countries of Asia and Africa (Iwo et al. 2002), and in Nigeria, it is cultivated mainly in the savannah zones by peasant farmers in smallholdings, usually in less than one hectare (Alegbejo et al. 2003). Consequently, the yield of the crop has been on the decline due to poor cultural practices used by farmers that cultivate it at sub-optimum plant population density, soils of low fertility, poor application of fertilizer, use of traditional mixed cropping system, late sowing time, pests and diseases, and the use of unimproved varieties for sowing. Although concerted efforts have been made by the National Cereal Research Institute of Nigeria (NCRI), in breeding and distribution of high yielding varieties to farmers, some of which are fertilizer responsive, but on the farmers' field, the yield has not been impressive due to the aforementioned problems (Eifediyi et al. 2016). In addition, many Nigerian farmers erroneously believe that growing sesame without fertilizer will give consid-

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erable yield. This ideology perhaps, has contributed to low yield experienced in Nigeria (450 kg/ha) compared to those of Ethiopia (825 kg/ha) and Egypt (1,323 kg/ha) (FAO 2009; Eifediyi et al. 2016). To bridge this yield differential, the application of soil amendment is necessary.

It is interesting to note that sawdust, an inevitable by-product in timber processing factories like saw mills has latent value. This by-product often seen as agricultural wastes, abound in many rural and urban centers in Nigeria. Owoyemi et al. (2016) in a study gave an estimate of about 1.8 million Mg of this by-product produced in the country annually. This by-product is often under-utilized as large amount of it is sometimes burnt and in the process, harmful gases such as methane and chlorofluorocarbons are emitted which pollute the atmosphere to further compound the global warming crises. It is the position of this study that saw dust can be processed into compost or biochar to serve as soil amendment. This is plausible as study has shown that saw dust act as a reservoir for plant nutrients, particularly nitrogen, phosphorus, potassium, and micronutrients, and has water and nutrient retention capabilities (Purakayastha et al. 2019). Biochar is a form of organic fertilizer which can be used to improve the fertility of impoverished soil (Yu et al. 2019). The incorporation of biochar into the soil alters physical properties such as structure, pore distribution and density, which leads to good soil aeration, water holding capacity, soil workability and ultimately, plant growth (Joseph et al. 2020; Rehman et al. 2020; Tokova et al. 2020; Nakhli et al. 2020).

Agbede et al. (2019) showed that the interaction of biochar with NPK could result in increased fertilizer efficiency and reduced plant nutrient loss, resulting in cell division and physiological performance in crops. Biochar application has also been shown to improve growth and yield in crops such as lettuce (Frimpong et al. 2016), maize (Mensah and Frimpong 2018), soybean (Lee et al. 2013), tomatoes (Usman et al. 2016), radish (Nabavinia et al. 2015), among others. Many methods had been used by researchers to improve the yield of sesame in Nigeria, but the yield is still below the global average. The use of saw dust biochar could potentially help in bridging this yield gap in Nigeria, for improved food security and sustained livelihoods. The objective of this study therefore was to evaluate the growth and yield of four varieties of sesame using sawdust bio-char amendment.

Materials and methods

The experimental site

Field experiment was conducted at the Teaching and Research Farm, University of Ilorin, Ilorin, Nigeria (8°04'N 4°05'E, 307 m above sea level), during the 2018 and 2019 cropping seasons. The study area is located in the southern Guinea savannah zone of Nigeria on an Alfisol belonging to the Bolodunro Series (Ogunwale et al. 2002). The soil depth of the area ranges from shallow to deep and the surface soils are coarsely textured, low in organic matter content and in some locations, the soils are highly degraded and erosion of the top soil is common, leading to low soil fertility. The rainfall pattern of the location is bimodal, starting in late March to July with the first peak in late July followed by a break in August. The second part of the rainy season usually starts in late August with a peak in late September and ends in late October. The annual rainfall for the location was 991 mm in 2018 and 1432.92 mm in 2019. The mean annual temperature of the study area is 29°C while the average annual relative humidity is about 85%.

Biochar preparation

Ten biochar trenches measuring 45.75 cm wide and 60.96 cm deep were dug and saw dust collected were sun dried and dumped into the trenches lengthwise until the trenches were completely covered and then compacted. Thereafter, the trenches were completely sealed with soil and compacted to form a mound. A small hole was left open to light the saw dust at one end and at the other end a very small opening was left opened and the saw dust was lit. After 24 hours, the saw dust was converted into biochar and the height of the mound was reduced due to pyrolysis. The remaining smoke or embers were quenched with water during biochar removal (Sai Bhaskar 2014).

Experimental layout and sowing

The land was ploughed and harrowed before marking out into plots. The size of each plot was 3 m × 3 m with a 0.50 m avenue between the plots. The seeds of Sesame were obtained from the National Cereal Research Institute of Nigeria, Badeggi, Niger State, Nigeria. Sawdust biochar was applied two weeks before sowing. The seeds were sown on the 15th of June, 2018 and repeated on 15th of June, 2019, using the drilling method at a depth of 1.0 cm; seeds were covered lightly with soil to prevent desiccation by sunlight. The seedlings were later thinned three weeks after sowing to one plant per stand at a spacing of 30 × 50 cm between and within rows to give a plant population of 66,667 plants per hectare. A total of 60 plants constituted the gross plot while 32 plants made up the net plot. A basal application of NPK fertilizer at the rate of 300 kg ha^{-1} was applied at 3 weeks after sowing due to low nutrient composition of the biochar used.

Experimental design

The experiment was laid out in a split-plot design. The main plots were Sesame cultivars (E-8, Ex-Sudan, NCRI-Ben001M, and NCRI-Ben002M) and the subplots were the sawdust biochar (0, 5, 10, 15 and 20 $Mgha^{-1}$ denoted as T0, T5, T10, T15, and T20, respectively) and replicated four times.

Soil and biochar analyses

Soil samples from the experimental plot were collected at a depth of 0 – 30 cm from a 2.5 x 2.5 m grid, bulked; then a composite was taken for physical and chemical analyses before sowing and at the end of the cropping season, soil samples were collected from individual plots for physical and chemical analyses. The soil samples collected were air-dried, ground, and passed through a 2 mm sieve. The sieved soil samples and biochar were analyzed as described by Carter and Gregorich (2007). Soil pH was measured (soil: water ratio, 1:2) using a glass electrode; Particle-size analysis was done using the hydrometer method (Gee and Or 2002). Soil organic carbon was determined by the procedure of Walkley and Black using the dichromate wet oxidation method (Nelson and Sommers 1996). Organic matter was estimated by multiplying carbon (C) by 1.724. Total nitrogen was determined by Micro-Kjeldahl digestion and distillation techniques, and available phosphorus was determined following Bray No 1 (1N NH4F + 0.5N HCl) extracting by vanadomolybdophosphoric acid method (Kuo 1996), Textural class was determined using a textural triangle (Brady and Weil 1999; Hunt and Gilkes 1992) and extraction of exchangeable bases was done by using IN ammonium acetate, exchangeable potassium and sodium were determined by using flame photometry while calcium and magnesium were analyzed by atomic absorption spectrophotometry. The soil moisture content was determined at critical periods of water requirement (establishment and flowering stages) using the Gravimetric method.

Data collection and analysis

Data were collected on growth (plant height, number of leaves, leaf area index, crop growth rate) and yield parameters. The plant height was measured from the ground level to the terminal point of the plant using a measuring tape, while the number of leaves was determined visually by counting the green leaves of the fifteen tagged plants in the net plot whereas the leaf area was calculated based on the work of Silva et al. (2002) using $S = 0.3552 * C^2$, where S = leaf area in cm^2 and C = leaf longitudinal length x breadth while the leaf area index was estimated as leaf area/ground cover. The data on yield components were collected on 1000 seed weight, seed weight per net plot and seed weight per hectare. Data on yield per plot was carried out by measuring the weight of seeds from the net plot (32 plants) by using a sensitive balance whereas the yield per hectare was extrapolated from the yield per net plot and the data collected were subjected to analysis of variance (ANOVA) using GENSTAT statistical software (17th edition) and significant means were compared using new Duncan Multiple Range test at 5% probability level.

Result and discussion

The physical and chemical properties of soil and sawdust biochar are presented in Table 1. The soil of the experimental site was loamy, slightly acidic, and low in organic matter, total nitrogen, available phosphorus, potassium, calcium and magnesium. The sawdust biochar was strongly alkaline, high in organic matter and magnesium but low in phosphorus and calcium but very high in potassium, and low in total nitrogen. Following Horneck et al. (2011), nutrients rating, the sawdust biochar was strongly alkaline, high in organic matter and magnesium, phosphorus and calcium but very high in potassium, and low in total nitrogen. This low nutrient composition of the biochar can be attributed to the high lignin content of the feedstock material, the temperature and the method of pyrolysis used. This was in agreement with the findings of Guo et al. (2019) who reported that biochar produced from lignocellulosic material; generally have low nutrient content and hence low capacity to increase soil fertility. Dieguez-Alonso et al. (2018) also reported that the physical and chemical properties of a biochar material are dependent on the biomass type and processing conditions.

The soil of the experimental site was loamy sand and slightly acidic in soil reaction. Soil organic matter, total nitrogen, available phosphorus, potassium, calcium and magnesium were all low, based on soil data interpretation (Horneck et al. 2011). The low nutrients status of the soil can be attributed to intensive and continuous cultivation of the land without adequate application of soil amendments to replenish lost soil nutrients. Research has shown that biochar improves soil nutrient availability and the number of nutrients that can be absorbed by plants from the soil. Nielsen et al. (2018) stated that because of its neutral to alkaline pH, biochar increases the ability of plants to absorb most nutrients, though this is dependent on the feedstock type, soil type, and application rate. The alkaline nature of the biochar used in this study might have resulted in the improvement in the soil reaction status and enhanced the ability of the plants to absorb these nutrients. This was in agreement with the findings of Yu et al. (2019) who reported that biochar can reduce soil acidity, hence the ability of plants to absorb nutrients from the soil. Biochar application has also been shown to improve available soil K due to the addition of K in an available form for plants (Agegnehu et al. 2015; Radin et al. 2018; Sadegh-Zadeh et al. 2018). Furthermore, by improving water retention, biochar could optimize conditions for nutrient ions to move from minerals into soil solution where plants can absorb these nutrients (Nielsen et al. 2018).

The effect of sawdust biochar application on the water holding capacity (WHC) of four varieties of sesame at 5, 7 and 9 weeks after sowing (WAS) in the two seasons is presented in Table 2. The response of the varieties to WHC at 5 and 9 weeks after sowing (WAS) was negligible in both seasons. Although the response of the varieties to WHC was not significant, the NCRI-Ben001M produced more roots (data not shown) and was able to scavenge for more water compared to other varieties. This superior trait may have contributed to the improved growth and yield which was recorded by the variety. The response to biochar application showed that at 5 WAS, in the first season, there was a 70% increase in the WHC between the control and T15 application rate while in the second season, the increase was about 72% whereas, at 9 WAS, in the first year, the difference between the WHC of the T15 and the control was about 69%, which increased to 71% in the second year.

The increased water holding capacity recorded in biochar treated plots can be attributed to the character of biochar as an organic amendment that tends to hold water for optimum utilization by crops for photosynthesis and other metabolic activities. The highest WHC was observed at T15 application rates during the first and second growing seasons. Biochar has been known to increase soil water content by improving the soil texture and pore size distribution and acts as a cementing agent in sandy soils (Ramlow et al. 2019; Tanure et al. 2019). Obia et al. (2016) reported that the application of maize cob biochar to sandy loam and loamy sand soils in maize and soybean intercrop increased the water holding capacity and soil aggregate stability. The water retention capacity of soils treated with biochar had been reported by Zhou et al. (2019). Alkhasha et al. (2018) also reported that amending sandy soil with date palm (*Phoenix dactylifera* L.) biochar increased soil water holding capacity and hydraulic conductivity.

The effect of sawdust biochar application on plant height of four varieties of sesame at 5, 7, and 9 WAS in the two seasons were significantly different ($p<0.05$), with Ben001M variety producing the tallest plants in both seasons at the three periods of sampling (Table 3). The use of saw biochar as an amendment under T15 produced the tallest plants which were significantly different from the other rates at the three sampling periods of 5, 7 and 9WAS in the two years of study. Also, there was a significant interaction between the variety and the biochar. Results from this study showed that the four varieties of sesame differed in treatment responses in morphological parameters throughout the experiment. NCRI-Ben001M (Ben 001M) significantly outperformed other varieties in terms of plant height, number of leaves, leaf area, leaf area index, and crop growth rate. This optimum growth could be attributed to Ben001M being better adapted to Ilorin climatic conditions, higher nutrient absorption capacity through the production of more roots early in the season than the other varieties, a fast growth rate, better leaf display, hence higher interception of light for photosynthesis, thus a superior competitive ability than the other varieties in the absorption of water and nutrients and its utilization in the production of assimilates.

Table 1 Physical and chemical properties of soil and sawdust biochar

Parameters	Soil	Biochar
pH in H_2O	6.70	-
pH in KCl	6.20	8.74
Organic carbon (%)	0.42	0.89
Organic matter (%)	0.75	1.53
Exchangeable acidity (cmolkg^{-1})	0.56	-
Nitrogen (mgkg^{-1})	0.68	0.76
Phosphorus (mgkg^{-1})	0.73	0.68
Calcium (cmolkg^{-1})	0.77	4.86
Magnesium (cmolkg^{-1})	0.13	5.32
Sodium (cmolkg^{-1})	0.21	3.73
Potassium (cmolkg^{-1})	0.14	3.45
Sand (%)	87.34	-
Silt (%)	7.44	-
Clay (%)	5.22	-
Textural class	Sand	

Table 2 Effect of varieties and sawdust biochar application rate on water holding capacity (WHC) (%) at rapid growth (5 WAS) and flowering (9 WAP) stages of sesame in the two seasons

	5 WAS		9 WAS	
Seasons				
Treatments	**1**	**2**	**1**	**2**
Ex- Sudan	30.25	28.12	26.66	26.58
Ben002M	30.13	29.07	26.74	26.32
E-8	30.36	28.38	26.89	26.15
Ben001M	31.06	29.38	26.66	26.33
SE ($p<0.05$)	Ns	Ns	Ns	Ns
Biochar rates (Mgha^{-1})				
0	12.02	10.88	10.51	9.77
5	28.20	24.19	24.24	23.05
10	33.31	31.89	30.37	29.92
15	39.74	38.63	35.26	34.56
20	38.97	38.09	34.56	33.43
SE ($p<0.05$)	0.282	0.574	3.46	0.370
Interaction	Ns	Ns	Ns	Ns

Season 1 = 2018, Season 2 = 2019.

The effect of sawdust biochar application on the number of leaves of the four varieties of sesame at 5, 7, and 9 WAS in the two seasons is presented in Table 4. The results showed that no significant difference was found among the four varieties in terms of the number of leaves per plant except at 5 WAS in the second season where the Ex Sudan variety produced the highest number of leaves which was significantly different from the other varieties; however, at 7 and 9 WAS Ben 001M variety produced the highest number of leaves. Furthermore, biochar rate of T20 produced the highest number of leaves in both seasons and at the three sampling periods which was significantly ($p<0.05$) different from the control and there was also a significant interaction in the second season at 5 WAS. The advantage of T20 application rate on leaf production could not be translated into higher yields as the plants enjoyed luxury consumption of the nutrients and the assimilates produced may have been partitioned to other uneconomic parts, such as the vegetative parts of the plants rather than on the reproductive parts. The number of leaves increased as the application rates increased. This was due to an increase in water holding capacity and better nutrient utilization in amended treatments, which supported plant morphological growth (Tokova et al. 2020). The leaves were well displayed, with no mutual leaf shading and hence better light interception. This is also in consonance with the findings of Agbede et al. (2019).

The effect of sawdust biochar application on leaf area index (LAI) of four varieties of sesame at 5, 7 and

Table 3 Effect of varieties and sawdust biochar application rate on the plant height (cm) of sesame at 5, 7, and 9 WAS in the two seasons

	5 WAS		7 WAS		9 WAS	
	Season					
Treatments	**1**	**2**	**1**	**2**	**1**	**2**
Ex-Sudan	61.93b	54.63b	79.80b	76.46b	86.60b	85.97b
Ben002M	58.84b	51.54c	80.50b	77.24b	89.70b	87.12b
E-8	58.49b	51.19c	81.30b	77.99b	89.70b	89.35b
Ben001M	68.51a	61.21a	94.20a	90.91a	104.10a	101.46a
SE ($p<0.05$)	2.475	2.475	3.96	3.964	4.94	4.936
Biochar rates ($Mgha^{-1}$)						
0	58.35c	51.05c	79.70b	76.44b	90.50b	87.92c
5	61.12bc	53.82bc	82.20b	78.86b	92.0bb	89.39bc
10	61.71b	54.41b	83.30b	79.95b	92.40b	89.83bc
15	61.94b	54.64b	86.90a	83.60a	96.0a	93.38ab
20	66.58a	59.98a	87.70a	84.40a	96.90a	94.34a
SE ($p<0.05$)	2.909	2.909	3.72	3.718	4.10	4.104
Interaction	5.762	5.762	7.74	7.742	8.85	8.846

Season 1 = 2018, Season 2 = 2019.

Means followed by the same letter (s) are not significantly different from each other.

Table 4 Effect of varieties and sawdust bio-char application rate the number of leaves of sesame at 5, 7 and 9 WAS in the two seasons

	5 WAS		7 WAS		9 WAS	
			Season			
Treatments	**1**	**2**	**1**	**2**	**1**	**2**
Ex-Sudan	61.40	57.10a	84.47	80.10	95.40	90.70
Ben002M	51.27	46.97c	82.27	78.10	93.07	88.37
E-8	57.13	52.83b	84.27	80.10	95.20	90.50
Ben001M	52.00	47.70c	85.87	81.70	98.07	93.37
SE ($p<0.05$)	Ns	4.213	Ns	Ns	Ns	Ns
Biochar rates ($Mgha^{-1}$)						
0	42.00c	37.70c	70.08d	65.90d	81.42c	76.20c
5	55.00b	50.70b	83.00c	78.80c	96.83b	92.13b
10	57.50b	53.20b	86.75b	82.60b	96.92b	92.22b
15	60.00ab	55.70ab	87.08b	82.90b	97.67b	92.97b
20	62.75a	58.45a	94.17a	90.0a	104.33a	99.63a
SE ($p<0.05$)	2.878	2.878	3.375	3.37	3.028	3.028
Interaction	Ns	6.653	Ns	Ns	Ns	Ns

Season 1 = 2018, Season 2 = 2019.

Means followed by the same letter (s) are not significantly different from each other.

9 WAS in the two seasons is presented in (Table 5). At 5 WAS in the two seasons, the Ben 001M, E-8 and Ex-Sudan varieties produced similar leaf area index which was significantly different from the Ben 002M variety whereas T15 produced the highest leaf area index at the same period which was significantly different ($p<0.05$) from the other rates except at 5 WAS when it was at par with T20 while the control produced the least leaf area index. At 7 WAS, in the first season, the E-8 variety produced the highest leaf area index which was significantly different from the other varieties, while the Ben 002M produced the least leaf area index. Biochar rate at T15 produced the highest mean values which was at par with the T10 and T20 but different from the control and T5. In the second season, the Ben001M produced the highest LAI which was significantly different from other varieties while the least LAI was produced by the Ex-Sudan variety.

Biochar treatment rate T15 produced the highest LAI which was at par with the T10 and T20, respectively. At 9 WAS, in both seasons, the Ben001M produced the highest LAI which was at par with the E-8 variety. There was an initial increase in leaf area index in the plants, which resulted in a higher photosynthetic surface area. This increase peaked at full flowering and then decreased progressively until the senescence stage. Leaf area index is an essential component of photosynthesis; a higher leaf area index translates to more photosynthesis ability. The higher the leaf area index, the more assimilates will be produced (Jaiswal et al. 2020). The higher leaf area produced by Ben001M assisted the plant variety to intercept more sunlight energy which was utilized for photosynthesis. This was in agreement with the findings of Olowe et al. (2009) who reported that variety of Ben001M produces high leaf area which assists the plant in assimilate production compared to other varieties. This ultimately led to the higher yield produced by it, compared to the other varieties. This was also in agreement with the earlier findings of Umar et al. (2010).

Table 5 Effect of varieties and sawdust biochar application rate on the leaf area index of sesame at 5, 7, and 9 WAS in the two seasons

	5 WAS		**7 WAS**		**9 WAS**	
	Season					
Treatments	**1**	**2**	**1**	**2**	**1**	**2**
Ex-Sudan	0.62a	0.57a	0.96c	0.92c	1.25b	1.13b
Ben002M	0.40b	0.36b	0.73d	0.64d	0.95c	0.85c
E-8	0.67a	0.62a	1.70a	1.04b	1.64a	1.51a
Ben001M	0.67a	0.62a	1.28b	1.15a	1.67a	1.57a
SE ($p<0.05$)	0.051	0.048	0.120	0.108	0.221	0.226
Biochar rates ($Mgha^{-1}$)						
0	0.37c	0.35c	0.73c	0.65c	0.93d	0.85d
5	0.58b	0.52b	0.98b	0.83b	1.23c	1.10c
10	0.62b	0.57b	1.10ab	1.01a	1.44b	1.31b
15	0.73a	0.68a	1.23a	1.16a	1.72a	1.58a
20	0.64ab	0.58b	1.14a	1.02a	1.58ab	1.48a
SE ($p<0.05$)	0.093	0.090	0.139	0.149	0.185	0.177
Interaction	0.174	0.168	0.276	0.288	0.399	0.390

Season 1 = 2018 sowing, Season 2 = 2019 sowing.
Means followed by the same letter (s) are not significantly different from each other.

The mean values of the crop growth rate of sesame are presented in Table 6. Ex Sudan, , E- 8 and Ben001M varieties produced the same rate of growth (0.05) at 5WAS in the first season which was significantly different from Ben 002M variety while T15 treated plots exhibited the fastest growth rate (0.06) which was significantly different from those the other treatments while the control had the slowest growth rate (0.03). In the second season, Ex Sudan, E 8 and Ben002M varieties had similar growth rate value while Ben001M had the slowest growth rate. The application of biochar had no significant effect on the sesame at this stage. At 7WAS, in the first season, Ben 001M had the fastest growth rate which was significantly different from the other varieties, while T15 rate had the fastest rate of growth which was significantly different from the other biochar rates of application.

At 9 WAS, in the first season, E 8 and Ben 001M varieties produced the fastest growth rates which were significantly different from the other varieties. Treatments T15 and T20 produced the fastest growth rates which were significantly different from the other biochar rates. In the second season, no significant variety and biochar application rates were observed. The response of the varieties to biochar application in terms of the pattern of growth rate further illustrates the importance of amendments in the improvement of growth and yield of sesame. This debunks the beliefs of traditional farmers that substantial yield can be obtained from sesame without the application of fertilizers.

Table 6 Effect of varieties and sawdust biochar application rate on the leaf area index of sesame at 5, 7, and 9 WAS in the two seasons

	5 WAS		7 WAS		9 WAS	
				Season		
Treatments	**1**	**2**	**1**	**2**	**1**	**2**
Ex-Sudan	0.62a	0.57a	0.96c	0.92c	1.25b	1.13b
Ben002M	0.40b	0.36b	0.73d	0.64d	0.95c	0.85c
E-8	0.67a	0.62a	1.70a	1.04b	1.64a	1.51a
Ben001M	0.67a	0.62a	1.28b	1.15a	1.67a	1.57a
SE ($p<0.05$)	0.051	0.048	0.120	0.108	0.221	0.226
Biochar rates ($Mgha^{-1}$)						
0	0.37c	0.35c	0.73c	0.65c	0.93d	0.85d
5	0.58b	0.52b	0.98b	0.83b	1.23c	1.10c
10	0.62b	0.57b	1.10ab	1.01a	1.44b	1.31b
15	0.73a	0.68a	1.23a	1.16a	1.72a	1.58a
20	0.64ab	0.58b	1.14a	1.02a	1.58ab	1.48a
SE ($p<0.05$)	0.093	0.090	0.139	0.149	0.185	0.177
Interaction	0.174	0.168	0.276	0.288	0.399	0.390

Season 1 = 2018 sowing, Season 2 = 2019 sowing.
Means followed by the same letter (s) are not significantly different from each other.

The effects of biochar and varieties on the yield components of sesame are presented in (Table 7). Data on 1000 seed weight showed that Ex Sudan variety produced the heaviest seed weight in the two years of assessment, which was significantly different from the other varieties. Biochar rate T15 produced the highest in terms of 1000 seed weight, which was at par with the T20 application rate. These values were significantly different from those of the other treatments in the two years evaluated. No significant interaction was observed. The results of the net plot yield and yield per hectare in the first season showed that the Ben00m1 variety had the highest yield which was significantly different from the Ex Sudan variety. In the second season, however, Ben 001M variety had the highest yield, but not statistically different from the other varieties. The use of biochar applied at T15 produced the highest net yield per plot and yield per hectare in the two years of evaluation but no significant differences were observed.

Studies have shown that plants grown in soils amended with biochar are more effective at accessing and using nutrients than those grown in control soils (Berek et al. 2018; Manolikaki and Diamadopoulos 2019). This is most likely due to the amendments' inherent nutrients, improved nutrient availability from soil pH conditioning, increased soil organic matter content, increased water-holding capacity, and decreased nutrient leaching (Cao et al. 2018; Radin et al. 2018; Zhang et al. 2019). As these properties are improved, inherent constraints to crop production are addressed, which will lead to increase in biomass production (Jeffery et al. 2017). Although Ex Sudan variety out-yielded the other varieties in terms of 1000 seed weight, this could not be translated to the overall yield. This could possibly be attributed to the production of lower number of seeds compared to the Ben 001M variety.

The yield of sesame in the first growing season was higher than that of the second growing season. This observation could be attributed to the short-term effect of biochar nutrients release in soil. Although the carbon content in biochar is expected to be largely stable in soil, its nutrients, which are large components of the ash content are easily leached. Quilliam et al. (2012) reported that after three years of applying 50 Mgha^{-1} biochar to a loamy Cambisol, there was no longer any observable effect on soil nutrient concentrations, which increased after repeated biochar application. With the decrease in the direct nutrient supply capacity of biochar, crop yield is reduced in subsequent cropping seasons under similar conditions. Besides, the results of the first growing season cannot answer the question of long-term impacts of biochar on crop yield, as the biochar itself could only have changed a little in the soil during this short period.

Table 7 Effect of varieties and sawdust biochar application rate on the yield components of sesame in the two seasons

	1000 seed weight (g)		Yield per net plot (g)		Yield per hectare (kg)	
Treatments	**1**	**2**	**1**	**2**	**1**	**2**
Ex-Sudan	4.03a	3.38a	291.0b	259.2	606b	539.98
Ben002M	3.97a	3.32a	310.6a	278.8	647a	580.78
E-8	3.58b	2.93b	313.5a	281.7	653a	586.83
Ben001M	3.89a	3.24a	321.5a	289.7	670a	603.60
SE ($p<0.05$)	0.143	0.143	16.51	Ns	34.4	Ns
Biochar rates (Mgha^{-1})						
0	3.42c	2.77b	278.4	246.6	580	513.73
5	3.83b	3.18a	308.6	276.8	643	576.61
10	3.87b	3.22a	311.7	279.9	649	583.05
15	4.13a	3.38a	324.6	292.8	676	609.94
20	4.08a	3.24a	322.5	290.7	672	605.65
SE ($p<0.05$)	0.236	0.236	Ns	Ns	Ns	Ns
Interaction	ns	0.445	Ns	Ns	Ns	Ns

Season 1 = 2018, Season 2 = 2019

Means followed by the same letter (s) are not significantly different from each other.

Although there are many reports on the effect of biochar application on crop yield (Usman et al. 2016; Rab et al. 2016), it is difficult to compare results, as experiments differ in terms of biochar properties, soil, and agronomic management. Major et al. (2010) in illustrating the impact of long term biochar application stated that in a 4-year field experiment on an Oxisol with biochar applied at 0, 8, and 20 Mg ha^{-1}, biochar did not significantly increase maize grain yield in the first year, but the yield at 20 Mg ha^{-1} increased by 28, 30, and 140% over the control for the following 3 years, respectively. Another study on wheat in the Mediterranean region also showed a positive effect on crop yield with biochar at 60 t ha^{-1} during two consecutive seasons (Vaccari et al. 2011). These results are in contradiction with the outcome of this study, as a reduction in crop yield was recorded from the first to the second growing season. This contradiction may be associated with soil type, soil pH, and nutrient status of the soil before application of biochar (Jeffery et al. 2017).

Many researchers have recently become interested in biochar because of its potential as a soil amendment to increase crop growth (Jeffery et al. 2011; Singh et al. 2010, El-Naggar et al. 2019, Zhang et al. 2019). In the current study, biochar rates of 5, 10, 15, and 20 Mg per hectare improved the growth and yield of sesame compared to the control, which was consistent with the findings of Lee et al. (2019) and Luyima et al. (2019) who reported that adding biochar to soil increased plant growth. Ali et al. (2017) also reported that the use of biochar improved plant growth, biomass, and yield, as well as photosynthesis, nutrient absorption, and gas exchange characteristics of *Brassica rapa*.

Conclusion

This study has shown the effects of low soil fertility on the cultivation of sesame crop in the Guinea savannah zone of Nigeria, could be improved by the use of saw dust biochar as amendment. The work further demonstrates the dual processes of preparing saw dust into biochar and the application of the biochar which improves the physical and chemical properties of the soil, especially the water holding capacity and hence a reduction in leaching of soil nutrients and their availability to sesame plants. This resulted in an improvement in the growth and yield attributes of the crop. *Ben001M* and E- 8 varieties had the highest growth and yield attributes, in comparison to the other varieties. Farmers should therefore be encouraged to plant these two varieties using biochar at the rate of 15 Mg ha^{-1} for improved yield.

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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