International Academy Journal of Agribusiness and Agricultural Science Annals

Volume 6, Issue 2, PP 15-28, ISSN: 2382-9025, December, 2022 DOI: 272142522721622
Double Blind Peer Reviewed International Research Journal
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Effect of Legume Inoculant and Biochar on Growth and Yield of Soybean

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Abstract: *The experiments were conducted at the Teaching and Research Farm, Faculty of Agriculture, Shabu -Lafia Campus, Nasarawa State University, Keffi, during 2018 and 2019 cropping seasons to evaluate the effects of legume inoculant and biochar on growth and yields of soybean. The experiments were laid in Randomized Complete Block Design (RCBD) with three replications. Biochar at the rates of 0, 4, 8 and12 tons/ha was incorporated into the ridges at planting. Four seeds of soybean were planted as uninoculated (without legume inoculant) and inoculated (coated with legume inoculant). All data collected were subjected to analysis of variance (ANOVA) using GENSTAT Statistical Package while least significant different (LSD) was used to separate treatment means at 5% level of probability. The results showed that inoculated plots recorded significantly ($P<0.05$) taller plant, highest number of branches per soybean plant and highest grain yields (1201.7 and 1212.3kg/ha) against the uninoculated plots in 2018 and 2019 cropping seasons respectively. The results also showed that biochar at the rate of 8 tons/ha recorded the tallest plants, highest number of branches per plant and highest grain yields (1304.0 and 1316.7kg/ha) against other rates of biochar in both cropping seasons. The combination of biochar at the rate of 8 tons/ha with inoculants recorded the tallest plants, highest number of branches per plant and grain yield (1420 kg/ha) in 2018 and 2019. However the highest dose of biochar (12 tons/ha) applied did not influence and increased any soybean parameters tested.*

Keywords: *Biochar; combined; inoculants; soybean; sustainable yield*

Introduction

Inoculation of soybean seeds with appropriate strains of rhizobia improves soybean growth, nodulation and yields (Abbasi *et al.,* 2008, Kubota *et al.,* 2008, Botir, 2018, Gebrehana and Dagnaw, 2020). Rhizobial inoculation has been reported to increase the vegetative (stems and leaves) growth of soybean (Tahsin, 2006). Zerihun *et al.* (2017) reported that rhizobial inoculation increased growth performance and shoot dry weight of soybean. Bahati (2015) reported that rhizobia inoculants improved soybean growth under both greenhouse and field conditions. Biochar is a heterogeneous and chemically complex materials made by pyrolysis which is the heating of biomass under the exclusion of air (Wilson, 2014a; Wang *et al.* 2016). It is one of the oldest soil amendments in the history of agriculture (Wilson 2014b). Wu *et al.* (2022) reported that biochar significantly promoted the growth of soybean. Suppadit *et al*. (2012) reported that application of biochar to soil improved soybean growth and production. Glodowska *et al*. (2017) reported that biochar solid inoculants positively affected soybean plant growth. Liu *et al*. (2020) reported that biochar significantly improved soybean growth and productivity. Numalasari *et al*. (2022) reported that rice husk biochar at the rate of 20 t ha^{-1} increased soybean plant height by 14.6%, while at the rate of 15 t ha^{-1} it increased the number of leaves by 11.35% and number of branches by 36.63%. Soybean (*Glycine max* L.Merrill) is a species of legume, widely grown for its edible bean which has numerous uses (Dugje *et al.,* 2009). It is classified as an oil-seed rather than a pulse crop (FAO, 2016). Soybean contains more than 36% protein, about 30% carbohydrates and 20% oil. It is an excellent source of dietary fibre, vitamins and minerals and the only available crop that provide an inexpensive and high quality source of protein comparable to meat, poultry and eggs (Dugje *et al*., 2009, Mawiya, 2016, Atli, 2019). It improves soil fertility by adding nitrogen from the atmosphere through biological nitrogen fixation which is a major benefit in African farming systems where soils have become exhausted by the need to produce more food for increasing population and where fertilizers are hardly available (scarce) and expensive for farmers (Fairhust, 2012). Soybean as a legume crop provides itself with nitrogen through biological nitrogen fixation for its growth and for succeeding crop especially cereal crops (Dugje *et al.,* 2009, Fairhust, 2012, Mawiya, 2016). The decomposed leaves of soybean improve soil fertility and increase yields of subsequent crop (Dugje *et al.,* 2009, Fairhust, 2012). It provides excellent fodder for livestock (Fairhust, 2012). Soybean grown in rotation with cereal crops, serves as catch crop in controlling weeds especially *striga hermonthica* in maize farms (Dugje *et al.,* 2009). There is increasing economic importance and uses of soybean as it is being converted and made into various traditional food products such as soy-milk, soy-cake (Wara), soy-soup, soy-oil, etc. but the use of legume inoculants and biochar to improve poor soil for cultivation of the crop has not received much attention in the study area. Hence the need for this study to encourage local farmers to increase the production of the crop to meet the increasing demands. Therefore this study aimed at evaluating the effects of legume inoculant and biochar on growth and yield of soybean in Lafia, Southern Guinea Savanna of Nigeria.

Materials and Methods

The study comprised of two experiments conducted at the Teaching & Research Farm, Faculty of Agriculture, Shabu--Lafia Campus, Nasarawa State University, Keffi, during the 2018 and 2019 cropping seasons. The study area is located between 08° 29'30" N and 08° 31'0" E, which falls within the Southern Guinea Savannah zone of Nigeria. Rainfall usually starts from April and ends in October. Lafia has mean annual rainfall in the range of 1100-2000 mm and mean monthly temperature range between 20 and 30°C (NIMET 2021). A composite soil samples (0-15 and 15-30 cm depths) were taken randomly at six different locations of the experimental field before ridging. The soil samples were analyzed for the some physical and chemical properties in the Agronomy Laboratory, Faculty of Agriculture, Shabu-Lafia Campus, Nasarawa State University, Keffi. Particle size analysis was determined by Gee and Bauder (1986) method. The textural class was determined from the USDA soil textural triangle.Total Nitrogen was determined by the micro- Kjeldhal method (Bremmer and Mulvaney 1982). Soil pH was determined in 1:25 soil/water extract of the composite samples (Mclean 1982). Soil organic carbon was determined by Nelson and Sommers' (1982) method; this was multiplied by 1.724 to obtain soil organic matter. Available P was determined by Bray 2 extract (Olsen and Sommers 1982). Total exchangeable bases (K^{+}, Ca^{2+}, Mg^{2+} and Na^{+}) were determined after leaching the soils with ammonium acetate. Then, Ca^{2+} and Mg^{2+} were determined from extract by using atomic absorption spectrometry(AAS) (Buck Scientific Model 210), while and K^{+} and Na^{+} were analyzed by flame photometer from the same extract (Thomas 1982). Cation exchange capacity (CEC) of the soil was estimated by summation of the exchangeable bases. Inoculation of soybean seed was done by preparing sugar solution as sticking agent and was used to moist the seed for adherence of inoculant. The soybean seeds were placed in a basin and the sugar solution was sprayed on them and then Nodumax legume inoculant powder was sprayed onthe seeds and mixed thoroughly under shade. Biochar was made locally from cashew woods which were arranged and covered with earth and firewas set through four small openings to allow in littleair. The fire was quenched after about 4-5 hours with water. It was then crushed into pieces and incorporated into the ridges at planting at therates of 0, 4, 8, 12 t ha^{-1}.

The experiment was laid out in randomized complete block design (RCBD) with three replications. Four seeds of soybean were planted per hole without (uninoculated) and with legume inoculants (inoculated) at a planting space of 5 cm between plants on four manually made ridges of 2-m long, spaced approximately 75 cm between ridges. The seedlings were thinned to two plants at two weeks after planting (WAP). Data were collected on plant height, numbers of branches and grain yields were subjected to analysis of variance using GenStat statistical package while least significant difference (LSD) was used to separate treatment means at 5% level of probability.

Results and Discussion

The physical and chemical properties of soil of the experimental site before the experiments (table 1) indicated that soil pH (H_2O) (5.63 and 5.61) and organic matter content (3.04 and 2.97%) of the experimental site at both surface and subsurface soil levels were moderate while the percentage total nitrogen (0.25 and 0.21%), organic carbon (1.77 and 1.73%) and available phosphorous (2.53 and 2.43 ppm) were very low at both surface and subsurface soil levels. The percentage base saturation was high (86.00 and 85.00%) at both surface and surface soil levels. The sand particle (85.80%) was very high at the surface and subsurface soil levels hence the soil textural class was sandy loam. This is in line with the report of Chude *et al*. (2012) who rated and classified soil nutrient status of Southern Guinea Savanna of Nigeria as very low, low, moderate and high depending on the nutrient. The low soil property of the experimental site before the experiments was an indication of the expected response of soybean to the application of inoculants and biochar as reflected in all the parameters tested.

Table 1: Physical and Chemical Properties of Soil of the Experimental Site before the Experiment, 2018

	Soil Depth	
	0-15 cm	15-30 cm
Soil Parameter		
P^H (H_2O)	5.63	5.61
Organic Carbon (%)	1.77	1.73
Organic Matter (%)	3.04	2.97
Total Nitrogen (%)	0.25	0.21
Available phosphorus (ppm)	2.53	2.43
Exchangeable bases (cmol/kg)		
Potassium(k) (cmol/kg)	0.18	0.17
Calcium(ca) (cmol/kg)	2.71	2.59
Magnesium(mg) (cmol/kg)	1.52	1.62
Sodium (Na) (%)	0.15	0.13
Exchangeable acidity (EA) (%)	0.67	0.75
Total exchangeable bases (%)	4.51	4.48
Cation exchange capacity (CEC) (cmol/kg)	5.18	5.23
Base saturation (%)	86.00	85.00
Particle size distribution:		
Sand (%)	85.80	85.80
Silt (%)	4.40	4.40
Clay (%)	9.30	9.80
Textural class	Sandy loam	Sandy loam

The effects of inoculant on soybean plant height (Table 2) showed that the inoculated plots produced significantly $p < 0.05$) taller plants at 8 and 10 WAP than the uninoculated plots in 2018 and 2019 cropping seasons respectively. The positive response of soybean to the application of legume inoculant in this study may be attributed to high competitive ability and performance of the introduced rhizobial inoculants against the indigenous rhizobial in the soil. The results are in line with the findings of Ravellin *et al.* (2000), Diep *et al.* (2002), Abaidoo *et al.* (2007), Abbasi *et al.* (2008), Kubota *et al.* (2008), Tairo and Ndakidemi (2013), Rechiatu *et al*. (2015), Mathenge *et al.* (2019), Folnovic, (2019) and Grossman, (2019) who reported that inoculation of soybean seed with rhizobial improved biological nitrogen fixation, increased soybean growth, nodulation, shoot biomass and grain yields. The results also showed that 8 t ha^{-1} biochar recorded significantly ($p < 0.05$) the tallest soybean plant at 8 and at 10 WAP in 2018 and 2019 cropping seasons respectively. Suppadit *et al*. (2012), Glodowska *et al*. (2017) and Liu *et al*. (2020) reported that application of biochar to soil improved soybean growth and production. Numalasari *et al*. (2022) also reported that rice husk biochar at the rate of 20 t ha^{-1} increased soybean plant height by 14.6%. Similarly, Bayan (2013) also reported that biochar at 2% in pot experiment significantly enhanced soybean growth.

Table 2 Effect of Legume Inoculant and Biochar on Plant Height (cm) of Soybean at 8 and 10 Weeks after planting (WAP) during 2018 and 2019 cropping seasons

	2018		2019	
	8 WAP	10 WAP	8 WAP	10 WAP
Uninoculated	38.8b	43.7b	40.2b	44.9b
Inoculated	40.3a	47.6a	42.1a	49.9b
LSD(0.05)	0.10	0.09	0.15	0.17
Biochar (t ha^{-1})				
0	38.9c	44.1c	39.9c	46.1c
4	40.0b	46.6b	42.1b	48.1b
8	40.4a	48.0a	42.7a	49.2a
12	38.8c	43.8d	40.0c	46.0c
LSD(0.05)	0.14	0.12	0.22	0.12
Interaction (I×B)	*	*	*	*

Values with the same letter within a column are not significant at 5% level of probability; *Significant

The combined effect of legume inoculants and biochar on soybean plant height (table 3) indicated that biochar at the rate of 8 t ha^{-1} recorded the tallest soybean plant at 8 WAP (50.7 and 45.4 cm) with and without inoculants respectively while biochar at the rate of 12 t ha^{-1} with and without inoculants recorded the shortest plant height at 8 WAP and 10 WAP respectively in 2018 cropping season. The results of 2019 cropping season indicated that biochar at the rate of 8 t ha^{-1} recorded the tallest soybean plants (41.7 cm) without legume inoculant at 8 WAP while biochar at the rate of 4 t ha^{-1} recorded the tallest plant (52.1 cm) with inoculants at 10 WAP. The positive response of soybean to the combined application of inoculant and biochar in this study revealed benefits of integrating inoculants and biochar in soybean production. This may be due to the plant nutrient contents of biochar as reported by Zhang *et al*. (2015) who stated that biochar generally contains carbon, nitrogen, hydrogen, K, Ca, Na, and Mg. This also indicated that biochar improves soil fertility, releases plant nutrients and increases crop production as reported by Schmidt and Wilson, (2014) and Wang *et al.* (2016). The results also confirmed the finding of Vanzwieten *et al.* (2010) who observed positive effects of biochar and nitrogen fertilizer on the growth of wheat, soybean and radish in an initially acidic, nutrient deficient Australian Ferrosol.

Table 3 Combined Effect ofLlegume Inoculants and Biochar on Plant Height (cm) of Soybean at 8 and 10 Weeks after planting(WAP) 2018 and 2019 cropping seasons

Biochar	2018				2019			
	8WAP		10WAP		8WAP		10WAP	
Tons/ha	Uninoculated	Inoculated	Uninoculated	Inoculated	Uninoculated	Inoculated	Uninoculated	Inoculated
0	37.8c	40.0c	42.5c	45.7c	39.3c	40.6b	43.8b	48.5c
4	39.4a	41.5a	44.4b	48.7b	40.5b	43.8a	46.0a	52.1a
8	39.6a	40.5b	45.4a	50.5a	41.7a	43.8a	46.0a	50.6b
12	38.3b	39.4d	42.4c	45.2d	39.5c	40.4b	43.8b	48.3c
LSD(0.05)	0.20	0.20	0.17	0.17	0.31	0.31	0.24	0.24

Values with the same letter(s) within a column are not significantly different at 5% level of probability.

The effect of legume inoculants and biochar on number of branches (table 4) showed that the inoculated plots produced significantly ($p < 0.05$) more number of branches per soybean plant at 8 and at 10 WAP compared to the uninoculated plots in 2018 and 2019 cropping seasons respectively. The results are in line with the findings of Ravellin *et al.* (2000), Diep *et al.* (2002), Abaidoo *et al.* (2007), Abbasi *et al.* (2008), Kubota *et al.* (2008), Tairo and Ndakidemi (2013), Rechiatu *et al*. (2015), Mathenge *et al.* (2019), Folnovic (2019) and Grossman (2019) who reported that inoculation of soybean seed with rhizobial improved biological nitrogen fixation, increased soybean growth, nodulation, shoot biomass and grain yields. The results also showed that biochar at the rate of 8 t ha^{-1} recorded significantly ($p < 0.05$) the highest number of branches per soybean plant compared to the other levels at 8 and at 10 WAP in both cropping seasons. The increase in number of branches per plant as a result of the application of biochar in this study may be attributed to the plant nutrient contents of biochar which improved soil fertility and influenced plant nutrient availability to the crop (Schmidt and Wilson, 2014, Zhang *et al*. 2015, Wang *et al.* 2016). Numalasari *et al*. (2022) also reported that rice husk biochar at the rate of 20 t ha^{-1} increased soybean plant height by 14.6%, while at the rate of 15 t ha^{-1} it increased the number of leaves by 11.35% and number of branches by 36.63%. Similarly, Bayan (2013) also reported that biochar at 2% in pot experiment significantly enhanced soybean growth by 35% over the control and 5% of biochar applied.

Table 4 Effect of Legume Inoculant and Biochar on Number of Branches of Soybean at 8 and 10 weeks after planting (WAP) during 2018 and 2019 cropping seasons

	2018		2019	
	8 WAP	10 WAP	8 WAP	10 WAP
Uninoculated	3.2b	3.9b	3.1b	3.8b
Inoculated	3.4a	4.1a	3.5a	4.2a
LSD(0.05)	0.12	0.06	0.21	0.24
Biochar(t ha^{-1})				
0	3.0c	3.8c	3.1c	3.7b
4	3.4b	4.4b	3.7b	4.0b
8	4.5a	4.5a	4.0a	4.4a
12	2.9c	3.3d	3.0c	3.7b
LSD(0.05)	0.18	0.08	0.21	0.24
Interaction(I×B)	*	*	*	*

Values with the same letter within a column are not significant at 5% level of probability.
*Significant.

The combined effect of legume inoculants and biochar on number of branches (table 5) showed that biochar at the rate of 8 t ha^{-1} produced significantly ($p < 0.05$) the highest number of branches per soybean plant (4.2 and 3.4) with and without legume inoculants respectively at 8 WAP. The results also showed that biochar at the rate of 8 t ha^{-} recorded the highest number of branches (4.7) with inoculant in the 2018 cropping season. Conversely, the results of 2019 cropping season showed that biochar at the rates of 4 and 8 t ha^{-1} with and without inoculants recorded similar number of branches per soybean plant but significantly ($p < 0.05$) higher than the other treatment combinations. The results also showed that biochar at the rates of 0.0 (control) and 12 t ha^{-1} with and without inoculants recorded similar and lowest number branches per soybean plant at both 8 and 10 WAP respectively. The positive influence of the combined application of legume inoculants and biochar to soil observed on soybean plant growth parameters tested in this study could be attributed to high competitive ability of the introduced rhizobial inoculants against the indigenous rhizobial in the soil. This may also due to the nutrients released by the biochar which were probably made available to the crop. This is in line with the finding of Zhang *et al*. (2015) who reported that biochar contains plant nutrients such as carbon, nitrogen, hydrogen, K, Ca, Na, and Mg. This revealed the advantages of integrating inoculants with biochar in soybean production. Schmidt and Wilson 2014 and Wang *et al. (*2016) reported that biochar improves soil fertility, releases plant nutrients and improves crop production. Similarly, Mete *et al*. (2015) also recorded 67% increase in total biomass as a result of the combined application of biochar and NPK compared to the control.

Table 5 Combined Effects of Legume Inoculants and Biochar on Number of Branches per Soybean Plant at 8 and 10 weeks after planting (WAP) 2018 and 2019 cropping seasons

	2018				2019			
Biochar	8 WAP		10 WAP		8 WAP		10 WAP	
0	3.0c	3.0c	4.0b	3.7c	3.0a	3.1b	3.6b	3.8b
4	3.3b	3.4b	4.3a	4.4b	3.3a	4.1a	4.0a	4.6a
8	3.4a	4.2a	4.3a	4.7a	3.3a	3.8a	4.1a	4.7a
12	2.9c	2.9c	3.0c	3.7c	2.9a	3.1b	3.6b	3.9b
LSD(0.05)	0.25	0.25	0.11	0.11	0.41	0.41	0.47	0.47

Values with the same letter(s) within a column are not significantly different at 5% level of probability

The results of the effects of legume inoculants and biochar on seed yield of soybean per hectare (table 8) showed that inoculated plots recorded significantly ($P<0.05$) higher grain yield (1201.7 and 1212.3kg/ha) compared to the uninoculated ones (751.0 and 760.0 kg/ha) in 2018 and 2019 cropping seasons respectively. The positive response of soybean to the application of legume inoculant in this study may be attributed to high competitive ability and performance of the introduced rhizobia inoculants against the indigenous rhizobia in the soil The results are in line with the work of Mathenge *et al.* (2019) who reported that inoculated plots produced significantly ($P<0.05$) higher grain yield/ ha of soybean compared to the uninoculated plots. Abbasi *et al.* (2008) and Kubota *et al.* (2008) also reported that inoculation of soybean seeds with appropriate strains of rhizobia improves soybean yields. Similarly, Ukem *et al.* (2019) also reported that mean grain and fodder yields of soybean were significant in response to inoculation compared to the control and other treatments. The results also indicated that application of biochar at the rate of 8 tons/ha recorded significantly ($P<0.05$) the highest grain yield (1304.0 and 1316.7kg/ha) followed by biochar at the rate of 4 tons/ha (1180.0 and 1187.3kg/ha) while biochar at the rate of 0.0 ton/ha (control) recorded the lowest grain yield (739.0 and 745.0 kg/ha) in 2018 and 2019 cropping seasons. The positive response of soybean to the application of biochar in this study may be attributed to the nutrient contents of biochar which positively improved soil fertility and influenced crop yields. The results are in line with the work of Mete *et al.* (2015) who reported that grain yield of soybean increased on average by 67 % as a result of the application of biochar compared to the control.

Table 6: Effect of Legume Inoculants and Biochar on Seed Yield (kg/ha) of Soybean during the 2018 and 2019 Cropping Seasons

Treatments	2018	2019
Uninoculated	751.0b	760.0b
Inoculated	1201.7a	1212.3a
LSD(0.05)	0.11	0.13
Biochar (tons/ha)		
0	739.0d	745.0d
4	1180.0b	1187.3b
8	1304.0a	1316.7a
12	1053.7c	1066.0c
LSD(0.05)	0.16	0.19
Interaction (I × B)	*	*

Values with the same letter within a column are not significant at 5% probability.
*= Significant

The combined effect of legume inoculant and biochar on soybean grain yield (table 7) showed that biochar at the rate of 8 tons/ha with legume inoculants recorded significantly ($P<0.05$) the heaviest weight of grain of soybean per hectare (1420.0kg/ha) in the 2018 while biochar at the rate of 4 tons/ha with legume inoculants recorded the heaviest grain yield of soybean (1433.7kg/ha) in 2019 cropping season. The results also showed that biochar at the rate of 0.0 ton/ha (control) with and without legume inoculants recorded the lowest grain yield in both cropping seasons. This revealed the advantage and benefit of integrating inoculants with biochar in soybean production. The positive response of soybean to the combined application of inoculant and biochar in this study could be explained that the introduced rhizobia inoculants competed and performed better than the indigenous rhizobia in the soil of the study area. It also showed that biochar contains plant nutrients which improved soil properties and increased the yields of soybean. The results confirmed the finding of Agboola and Moses (2015) who reported that the combined application of biochar and cow dung significantly increased soybean yield parameters. Ukem *et al.* (2019) also reported that the combination of inoculant with P, K, micronutrient and manure had the best response as reflected in mean grain and fodder yields of soybean per hectare compared to other treatment combinations. Similarly, Mete *et al.* (2015) recorded 54% increase in seed yield of soybean as a result of the combined application of biochar and NPK compared to the control. Ali *et al.* ((2021) also reported that integrating biochar with compost considerably enhanced soybean yield probably as a result of positive effect of biochar-compost interaction on the soil and the crop.

Table 7: Combined Effects of Legume Inoculants and Biochar on Weight of Seed (kg/ha) of Soybean during the 2018 and 2019 Cropping Seasons

	2018		2019	
Biochar (tons/ha)	Uninoculated	Inoculated	Uninoculated	Inoculated
0	735.3d	934.0d	740.0d	939.7d
4	854.3c	1271.3b	863.3c	1433.7a
8	1187.0a	1420.0a	1190.7a	1278.7b
12	1066.7b	1123.0c	1078.3b	1133.3c
LSD (0.05)	0.23	0.23	0.35	0.35

Values with the same letter within a column are not significant at 5% probability.

Conclusion and Recommendation

The results of this study showed that the application of legume inoculants and biochar significantly ($P<0.05$) and positively influenced growth and yield parameters of soybean against other treatments in the 2018 and 2019 cropping seasons respectively. The results also showed that biochar at the rate of 8 tons/ha showed better and significant ($P<0.05$) performance compared to other treatments as reflected in all the variables measured. The results also showed that the integration of biochar at the rate of 8 t ha^{-1} with legume inoculant consistently recorded the tallest plant, highest number of branches per soybean plant and highest grain yield in both cropping seasons. However, the highest dose ofbiochar (12 t ha^{-1}) with and without inoculants in this study did not significantly influence and increased the parameters tested. Therefore, the combination of legume inoculant and biochar at therate of 8 t ha^{-1} is hereby recommended for both small and large scale soybean farmers in the study area forsustainable production of the crop.

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