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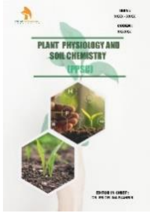

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RESEARCH ARTICLE

EFFECT OF FOUR BIOCHAR TYPES AND INORGANIC PHOSPHATE FERTILIZER ON GROWTH AND NODULATION OF SOYBEAN (*GLYCINE MAX* (L.) MOENCH)

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ABSTRACT

There is a compelling need to explore the use of biochar as a sustainable alternative to the use of chemical or mineral fertilizer amendment in the contexts of soybean cropping system in Sub-Sahara Africa. A pot experiment was conducted to evaluate the effects of poultry manure biochar (PB), swine dung biochar (DB), maize cob biochar (MB), saw dust biochar (SB) and inorganic phosphate fertilizer (single supper phosphate) applied singly on the growth and nodulation of soybean in Minna, southern Guinea savanna zone of Nigeria. The biochars were applied at four levels of 0, 5, 10, and 15 t ha^{-1} while single supper phosphate (SSP) was applied at 30 kg P ha^{-1}. The experimental design was a completely randomized design (CRD) with three replications. The results showed that soybean plant parameters of height, number of leaves, number and dry weight of nodules, shoot, root and total dry biomass increased in all treatments that received animal waste biochars (PB & DB) over the non-treated control (0 t ha^{-1}) except the plant root length and shoot/root ratio. However, the difference was statistically significant ($p<0.05$) only at the higher application level of 10 t ha^{-1}. Plant-based biochars (MB & SB) were less beneficial to soybean plant, and their influence on soybean parameters did not differ significantly from non-treated control. Soybean plant also responded positively to the application of SSP but was significantly better than the control only for plant height. The results showed that animal waste-derived biochars were more beneficial to soybean plant in terms of nodulation and growth than the plant-based biochars and SSP fertilizer. Evidence that soyabean growth, biomass accumulation and nodulation benefit more from amending soil medium planted to soyabean with manure based biochars applied at 10 tons ha^{-1} compared to the plant-based biochar showed that, manure base biochars are more suitable as soil amendments for legumes like soyabean that require more P and less amount of N in their nutrition.

KEYWORDS

Feedstocks, Optimization, Poultry manure, Saw dust, Swine dung.

1. INTRODUCTION

Soybean (*Glycine max* (L.) Merr.) is an annual legume which belongs to the legume family *fabacae*. It has contributed greatly to human nutrition since it contains about 40% protein, 20% oil and 30% carbohydrate, and also played a significant role in world agriculture (Tefera, 2011). The world supply of oil which can be taken by humans comes largely from soybeans. It is also a major source of protein when included in human, livestock and fish feeds (Tefera, 2011). Growing soybean is beneficial to rural farmers as it has capacity to fix atmospheric Nitrogen (N) in soil through biological N fixation. However, this benefit depends more on whether there are favourable atmospheric and environmental conditions (Adekanmbi et al., 2019a). According to a study, soybean production in Nigeria is concentrated on the savannah ecologies where soils are characteristically low in organic matter and plant nutrients (Agboola and Moses, 2015). Although production of soybean is reported to be taking a centre place among cereals and grain legume production in the moist savanna of Nigeria, poor soil condition in this area is a major limiting factor to its growth, yield and nodulation, hence the need to enhance the quality of soils planted to soybean in the area (Okogun et al., 2004).

Over the years, farmers in Nigeria have long been applying organic manures solely or in combination with inorganic fertilizers to improve the fertility of their soils for crop production (Fagbenro et al., 2012). However, inorganic fertilizers are now costly to be procured by resource-poor farmers in the country while their continuous application without a corresponding application of organic manures, particularly animal waste manure, is depleting the native soil organic matter (Madeley, 1990). On the other hand, availability of organic manures for farmer's use can only be guaranteed if the farmer is into animal husbandry. Besides, the organic materials decompose very fast under the prevailing tropical condition, whether applied singly or in combination with inorganic fertilizers, such that their benefits are often short-lived (Jenkinson and Ayanaba, 1977; Bol et al., 2000).

Recently, there has been a global interest in using biochars as soil amendments to improve and maintain soil organic matter and fertility for crop production. Biochar has been reported to boost soil fertility, enhance crop yield on poorly buffered soils like we have in Nigeria, and act as an effective carbon sink in the soil for several years to address the challenge of rapid mineralization of soil organic matter (Fagbenro, 2017). Biochar is a term used to designate a carbon-rich product obtained when a biomass like crop residues or saw dust is heated in a closed container with little or no oxygen (Lehmann and Joseph, 2009). But currently, biochars are not

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used for crop production in Nigeria (Fagbenro et al., 2015). Moreover, there is little or no information on how various biochar types influence the growth and yield of legume crops like soybean in the southern Guinea savanna agro-ecological zone of Nigeria.

The hypothesis of this study is whether all biochars enhance the growth and nodulation of soybean in the type of savanna soil being used for this experiment. The aim of the study was to evaluate the effects of four biochars derived from different feedstocks on the growth and nodulation of soybean in Minna, Nigeria. The decision to undertake the study came from the ever-increasing reported beneficial effects of different biochars on different agricultural crops (Uzoma et al., 2011; Arif et al., 2012; Fagbenro et al., 2018). Also, there is lack of empirical research data on the possible effect of biochar on the growth and nodulation of soybean plant and how it compares with that of 30 kg P ha^{-1} recommended for soybean cultivation in the experimental area (Dugje et al., 2009; Afolabi et al., 2014).

2. Materials and Methods

Soil samples were collected at 0–20 cm layer from an unfertilized plot from the Federal University of Technology Minna Teaching and Research Farm (latitude 9⁰31′2.736″N, longitude 6⁰26′22.548″E and altitude 189.60 m). It was air-dried, crushed, sieved through a 2-mm sieve and analysed for key physical and chemical properties (Table 1). Particle size distribution was determined by Bouyoucos hydrometer method (Bouyoucos, 1962). Soil pH was determined potentiometrically in a 1: 2.5 soil to water and soil to $CaCl_2$ suspension with a glass electrode pH meter. Organic carbon was determined using the wet oxidation method. Total N was determined using the micro Kjeldahl method of while available P was determined colorimetrically after Bray-P1 extraction (Walkley-Black, 1934; Keeney and Bremner, 1966). Exchangeable bases were extracted with neutral 1.0 N ammonium acetate. Calcium and Magnesium were determined by titrating with Na_2EDTA, while Potassium and Sodium were read with flame photometer.

The soil effective cation exchange capacity (ECEC) was determined from the summation of both the exchangeable bases and exchangeable acidity. Saw dust feedstock, which was a mixture of wood waste sawn from indigenous hardwoods of *Triplochiton sceleroxylon, Milletia excelcia*, Terminalia species and *Acacia siame*, was collected from a sawmill located within Iwo municipality where it was constituting an environmental nuisance. Maize cob feedstock was from maize crop residues and poultry manure feedstock were collected from Bowen University Research Farm, while swine dung was procured from a private farm located within Oluponna town near Iwo, Nigeria. All the feedstocks were separately converted to biochars by heating at temperature of 400⁰C using an engineered gas-ignition pyrolyser. Key chemical properties of the biochars (Table 2) were determined following standard routine procedures (IITA, 1982).

Table 1: Some physical and chemical properties of the soil used for the experiment

Parameters	Values
Sand (g Kg^{-1})	809.4
Silt (g Kg^{-1})	56.4
Clay (g Kg^{-1})	134.2
Textural class	Loamy sand
pH (1:2.5) H_2O	6.2
pH (1: 2.5) $CaCl_2$	5.83
Organic Carbon (g Kg^{-1})	2.72
Total Nitrogen (g Kg^{-1})	0.003
Available phosphorus (mg Kg^{-1})	12
Na^+	0.68
K^+	0.33
Ca^{2+}	3.34
Mg^{2+}	2.33
Exchangeable acidity (cmol Kg^{-1})	0.022
Effective Cation Exchange Capacity (cmol Kg^{-1})	6.70

Soybean seed of TGX 1951-3F variety and single supper phosphate fertilizer were sourced from the International Institute of Tropical Agriculture (IITA), Ibadan and agrochemical supper market in Minna, respectively

The experimental design was a completely randomized design (CRD with three replications. Two and a half kilograms (2.5 kg) of air-dry soil per pot was used. Biochar samples were applied at four levels of 0, 5, 10, and 15 t ha^{-1} while single supper phosphate (SSP) was applied at 30 kg P ha^{-1}. Each amendment type was thoroughly mixed with the soil and then transferred quantitatively into black polythene pots having holes at the bottom for aeration and draining of excess water. The holes were plugged lightly with absorbent wool to prevent loss of soil and leaching of nutrients. The soil-biochar mixture was moistened to 40% water holding capacity (WHC) while inorganic fertilizer (single super phosphate) was dissolved in 200ml water (the same volume of water added to other treatment at 40% WHC) before it was mixed with soil. Polythene pot containing soil to which neither biochar nor mineral fertilizer was added served as the non-treated control. All pots containing the soil-amendment mixture and the control were set on a polythene sheet to prevent roots of the growing plant getting into the ground and were left to equilibrate for 3 days before seed sowing while random numbers were used to determine the position of each pot on the polythene sheet.

Sowing of seed was carried out immediately after equilibration period at the School Horticultural Garden. A planting stick was used to make hole in the mixture contained in the polythene pot and 3 seeds per pot was made. Thinning was carried out at emergence (2 weeks after planting) to one plant per pot. At harvest, 8 weeks after plant emergence (flower initiation stage), soybean shoots for each treatment were cut off from the soil level using a pair of sharp scissors. After shoots have been cut off, the root and the nodules were washed, removed, counted and the number recorded followed by drying in the oven at 70°C. The shoots and roots were oven dried at 70°C to a constant weight to obtain the shoot and root dry weight in (g plant^{-1}). The dry weight of both the root and the shoot were added together to obtain the total dry biomass. Overall, plant height, number of leaves, root length, shoot dry weight, root dry weight, ratio of shoot to root weight, number and dry weight of nodules assessed after the 8th week of growth were reported in this study.

2.1 Statistical Analysis

All the data collected were subjected to one-way analysis of variance (ANOVA) using Minitab 18.0 version. Differences between the treatment means were separated by Fishers least significance difference at 5% level of significance.

Table 2: Some chemical properties of biochar made from different feedstocks

Parameters	Feedstocks			
	Swine dung	Poultry manure	Sawdust	Maize cob
pH (1: 2.5) H_2O	7.1	9.59	7.38	8.93
pH (1: 2.5) Ca_2Cl	5.82	9.25	6.62	9.04
Available Phosphorous (mg Kg^{-1})	2.01	1.8	0.42	0.84
Total Nitrogen (g Kg^{-1})	0.97	0.98	0.07	0.94
Exchangeable bases (cmol Kg^{-1})				
Na^+	1.14	9.6	1.73	1.09
K^+	19.02	37.7	16.52	28.87
Ca^{2+}	3.58	4.1	15.72	3.41
Mg^{2+}	16.04	12.63	6.81	12.71

Source: Adekanmbi et al., 2019b

3. Results

3.1 Effect of Biochar and Phosphate Fertilizer on Height, Number of Leaves and Root Length of Soybean Plant

Table 3 presents the effects of four biochars and inorganic phosphate fertilizer on the height, number of leaves and root length of 8-week soybean seedlings. Plant height and number of leaves increased in all treatments that received biochars derived from animal wastes (poultry manure biochar (PB) and swine dung biochar (DB)) over the non-treated control. The difference was statistically significant ($p < 0.05$) only at the higher application level of 10 - 15 t ha^{-1} for DB and at all levels of application rate for PD for plant height. Numerous leaves was supported by higher application rate of 10 or 15 t ha^{-1} of PD or 15 t ha^{-1} of DB respectively. Application of 30 kg P ha^{-1} was also significantly higher than the non-treated control. While application of 30 kg P ha^{-1} showed statistically similar plant height, it produced few numbers of leaves compared to the animal-based manures applied at 10 t ha^{-1}. But PB and DB applied at 5 t ha^{-1} have similar effects on soybean plant as Maize cob biochar (MB) and saw dust biochar (SB) applied at any level which were statistically at par with the non-treated control. However, the plant root length did not differ significantly among the amendments.

Table 3: Effect of different rates (t ha^{-1}) of biochar derived from different feedstocks and phosphate fertilizer (kg P ha^{-1}) on height, number of leaves and root length of 8-week soybean plant

Treatment	Plant height (cm plant^{-1})	Number of Leaves (plant^{-1})	Root length (cm plant^{-1})
Control (No fertilizer & no biochar)	22.22cde	9.67d	27.89a
30 Kg P	29.30ab	23.89c	30.02a
Maize Cob 5	22.27cde	10.00d	28.07a
Maize Cob 10	23.23b-e	9.00d	23.10a
Maize Cob 15	21.13de	14.33cd	26.23a
Poultry 5	27.83abc	26.00bc	27.63a
Poultry 10	32.27a	44.00a	26.33a
Poultry 15	28.67abc	47.33a	26.80a
Sawdust 5	23.70b-e	12.67cd	30.20a
Sawdust 10	20.4e	9.67d	29.87a
Sawdust 15	24.53b-e	14.00cd	32.03a
Swine 5	24.67b-e	19.67cd	30.80a
Swine 10	31.60a	39.33ab	27.87a
Swine 15	27.87abc	25.00c	24.60a

Values followed by the same letter(s) in a column are not significantly different at $P < 0.05$.

3.2 Effect of Biochars and Phosphate Fertilizer on Biomass Production and Nodulation of 8-week Soybean Plant

The effects of four biochar types and phosphate fertilizer on shoot, root, shoot: root ratio, total biomass, number and dry weight of nodules produced by soybean plant are presented in Table 4. Generally, amending soil with animal manure (PB and DB) biochars or 30 kg P ha^{-1} increased Shoot, Root and Total dry biomass, number and dry weight of nodules produced by soybean compared to non-treated control. While PB applied at 5- or 10-tons ha^{-1} similar to DB at 10 tons ha^{-1} was statistically superior, shoot biomass produced by plant based biochars (MB and SB) were similar to control treatment. Applying poultry manure (PB) at 5- or 10-tons ha^{-1} produced higher root weight compared to the control treatment and these were similar to DB at 10- and 15-tons ha^{-1} or 30 kg P ha^{-1}. Also, total biomass was significantly higher in soil amended with PB at 5 or 10 tons ha^{-1} compared to control and these were statistically similar to DB at 10 tons ha^{-1}.

However, it was at the application level of 10 t ha^{-1} of both PB and DB that soybean plant produced nodules that were significantly ($p<0.05$) higher and heavier than the control. Overall, applying animal manure biochar at 10 tons ha^{-1} showed superior quality at enhancing soybean Shoot, Root and Total dry biomass, number and dry weight of nodules compared to all other treatment applied. For instance, applying PB at this rate increased Shoot, Root and Total dry biomass, number and dry weight of nodules by 84.8 %, 68.7%, 77.5%, 88.9%, and 94.4% respectively above the non-treated control. Amending soil with 30 kg P ha^{-1} yielded 69 %, 45.2%, 57.3%, 54.7% and 75% increases above the control treatment in terms of Shoot, Root and Total dry biomass, number and dry weight of nodules respectively. Maize cob biochar (MB) and saw dust biochar (SB) applied at every level did not differ significantly from non-treated control for the five plant parameters. The shoot: root ratio was statistically similar irrespective of the soil amendments

Table 4: Effects biochar type and rate on the above and below ground biomass and nodule characteristics of soyabean

Treatment	Shoot dry weight (g plant-1)	Root dry weight (g plant-1)	Shoot-Root Ratio	Total Biomass (g plant-1)	Number of Nodule (plant^{-1})	Nodule dry Weight (g plant^{-1})
Control	0.39d	0.63c	0.69a	1.03d	3.22bc	0.014c
30 Kg P	1.26bcd	1.15abc	1.17a	2.41bcd	7.11bc	0.056c
Maize Cob 5	0.45d	0.60c	0.86a	1.05d	4.33bc	0.004c
Maize Cob 10	0.53d	0.54c	1.03a	1.07d	3.67bc	0.013c
Maize Cob 15	0.58d	0.74c	0.82a	1.31d	6.00bc	0.030c
Poultry 5	1.8abc	1.73ab	0.93a	3.53abc	18.00ab	0.097bc
Poultry 10	2.57a	2.01a	1.42a	4.58a	29.00a	0.250a
Poultry 15	1.14cd	1.47abc	1.10a	2.61bcd	17.33ab	0.187ab
Sawdust 5	0.50d	0.83bc	0.60a	1.33d	5.67bc	0.013c
Sawdust 10	0.37d	0.58c	0.66a	0.96d	1.00c	0.000c
Sawdust 15	0.55d	0.91bc	0.59a	1.46d	9.67bc	0.007c
Swine 5	0.94cd	0.88bc	1.09a	1.83cd	6.00bc	0.023c
Swine 10	2.10ab	1.75ab	1.20a	3.85ab	18.67ab	0.200ab
Swine 15	1.29bcd	1.38abc	1.02a	2.67bcd	4.00bc	0.047c

Values followed by the same letter(s) in a column are not significantly different at $P < 0.05$

4. Discussion

As reported from studies from other part of Nigeria, and using different test plants, there is growing evidence that biochar of different feedstocks could exert varying effects on the production of arable crops either in combination with inorganic fertilizer or in isolation (e.g. Fagbenro et al., 2015; Fagbenro et al., 2018). The present study has demonstrated that soil amendment with biochar can influence soybean growth and nodulation characteristics depending on their original feedstocks and application rate, and that this effect can be more beneficial to plant than using inorganic source of Phosphorus at the farmer's prescribed rate of 30 Kg P ha^{-1} (Dugje et al., 2009; Afolabi et al., 2014). Possibly because biochar derived from manure contained higher P concentration and can retain most of its P content after pyrolysis even at higher pyrolysis temperature compared to its original feedstock (Ro et al., 2010; Szogi et al., 2015).

The observed positive effects of the four biochars (PB, DB, MB and SB) and phosphate inorganic fertilizer on soybean plant when compared to the control implies that the amendments have potential to enhance the growth and nodulation of soybean, supporting the notion that any plant, whether tree or arable crop, requires nutrient elements for adequate growth (Fagbenro and Aluko, 1987). The positive effects of the biochars on soybean plant confirms the stimulating effect of biochars on tree or arable crops (Zhang et al., 2011; Fagbenro et al., 2015; Fagbenro et al., 2018). The variation in the response of the plant to the application of the biochar types is similar to the various results of studies reported in the literature that biochars produced from different feedstocks applied singly or in combination with inorganic fertilizer could exert varying effects on plants implying that all biochars are not created the same (McLaughlin et al., 2009; Hoshi, 2001; Fagbenro et al., 2013).

The general improvement in soybean parameters with increase in biochar application rate confirms the results reported (Chan et al., 2008; Karhu et al., 2011; Fagbenro et al., 2013). Even though the soyabean response to biochar in the current study is like the plant response earlier documented in literatures, our current study evidenced for the first time in the Guinea savanna of Nigeria differential response of soyabean to biochar derived from plant and animal feedstock. Similar effort has been reported for cowpea in a different paper (Adekanmbi et al., 2019b). The positive effect of the biochars on growth and nodulation of soybean plant may be due to a number of factors which include gradual abiotic and biotic oxidative release of nutrients and humic substances contained in the biochars, liming property of biochar, the high specific surface area, large amount of chemically reactive sites and high porosity of biochars, the nutrient-transforming property of biochar in the soil system and the beneficial effect of biochars on soil water holding capacity and on a variety of agriculturally important soil micro-organisms (Ogawa et al., 1983; Fagbenro and Agboola, 1993; Arif et al., 2012; Fagbenro et al., 2012; Draper, 2018; Petter and Madari, 2012; Gundale and DeLuca, 2006). However, determination of these properties listed here are outside of the scope of this current study.

The variation in the response of soybean to different biochars feedstocks could be due to differences in the inherent properties of the feedstocks from which the biochars were produced such as nutrient content, presence or absence of cellulose, hemicellulose or alkaloid as well as rate of mineralization of the resulting biochar (Fagbenro et al., 2018). This is likely to be the main reason why animal waste-based biochars (PB & DB) were more beneficial to soybean plant than the wood-based biochars (MB & SB). For instance, study by showed that Poultry manure biochar had higher content of both the macro and micronutrients compared to plant-based Coffee husk, Pine bark, Sugarcane bagasse and Eucalyptus Sawdust biochars (Domingues et al., 2017). The nutrient rich Poultry manure however had lower aromatic character, lower C concentration, but higher ash content compared to plant based biochars in their study.

The result obtained in this study indicated that sole application of phosphate inorganic fertilizer for the production of soybean plant was significantly inferior to the application of animal waste-based biochars, implying that animal waste based biochars had properties especially other essential nutrient elements apart from P which soybean plant requires for adequate growth and nodulation. This result suggests the possibility of using animal waste biochars solely as soil conditioner and as fertilizer for soybean production. It may also be possible to use the wood-based biochars complementarily with phosphate fertilizer to enhance the growth of soybean plant. This is because reported research results in the country have indicated that it is the combination of inorganic fertilizers and organic inputs that gives optimum crop production (Lombin et al., 1991). However, there is the need for further optimization studies on the use of the biochars for soybean growth and nodulation and for long-term pot and field experiments on their residual effects on soil and plant.

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