Efficacy of Corncob and Rice Husk Biochar as Liming Agent and Phosphorus Source for Growth of Soybean in Two Acid Soils

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Abstract

Soil acidity, unavailability and high cost of conventional liming materials are major constraints to soybean production in the Western Region of Ghana. Research has shown that biochar produced from agricultural waste has high concentration of basic cations and available P that could be exploited for use as liming material and/or P source. However, the biochar type that will provide an ideal soil pH and P availability for soybean production in acid soils has received little attention. Therefore, for this study, two acid soils namely; Ankasa Series (Typic Hapludox) and Tikobo Series (Typic Hapludult) were amended with corncob and rice husk biochar types charred at 500 and 700 °C at a rate of 80 tons/ha in a pot experiment in a screen house to ascertain the efficacy of the biochar types as agricultural lime and P sources for soybean growth. The Ca equivalent of the biochar types from $CaCO_3$ was amended to the soils to serve as realistic control. The soils were arranged in a completely randomized design in a screen house to allow for pH equilibration. After pH equilibration, inoculated soybean seeds were sown at stake. Nitrogen was applied at rates of 0 kg/ha and 10 kg/ha. Phosphorus from TSP was applied at 0 and biochar P equivalent to the non-biochar-amended soils. Extra 30 kg P/ha from TSP was applied to some of the biochar amended soils to ascertain if any, the combined effect of synthetic and biochar P on soybean growth. At flower initiation, the crops were harvested, root volume and P uptake determined. Amended with rice husk biochar charred at 700 °C, the shoot P uptake was 1.3 times more in both the Typic Hapludox and the Typic Hapludult than the same soils amended with conventional lime with equivalent biochar P from the synthetic source.

Introduction

The Western Region has a total land area of about 23,921 km^2 with 75% of its vegetation estimated to be in the Evergreen Rainforest (MoFA, 2012). The area is characterized by high rainfall (2200 mm/annum), moderate temperature (26 ^{0}C) and high humidity (80%). As a result of the high rainfall, almost 80% of soils in the area are acidic with pHs mostly below 5. These soils have toxic levels of aluminium and manganese with low phosphorus content (MoFA, 2012). The region has a total population of about 1,924,577 which is estimated to double by the year 2020 (GSS, 2010).

The rapid population growth in the region is expected to increase demand for dietary protein and general food crops. However, the main sources of dietary protein in the region include fish whose catches are diminishing due to illegal fishing methods such as pair trawling, use of unapproved nets and use of light (Nunoo et al., 2015). Fresh water fish catches have equally dwindled mainly because of the menace of illegal mining activities referred to as ‘’galamsey’’, which tend to pollute river bodies. Eutrophication has also resulted in the growth of aquatic weeds depleting fish stocks in fresh water bodies (Naylor et al., 2000). The production of ruminants is also low due to high incidence of tsetse flies, poor animal husbandry and the sparse grassland in the region. Meat from game which could have been an alternative source of protein is not a reliable source because the population of animals in the wild have declined over the years due to illegal methods of hunting game among other factors. Additionally, there is contamination due to the use of poisonous baits in trapping these game (Ogada, 2014). Production of plants-based protein could,

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therefore, be the panacea to the region's insufficiency in dietary protein.

Soybean is an oilseed, and the only legume which has significant amounts of all the essential amino acids, minerals and vitamins for human nutrition (Adu - Dapaah et al., 2004). Soyabean has on the average, 40% protein, 30% carbohydrate and oil content of 20% (Adu - Dapaah et al., 2004; MoFA and CSIR, 2005). Its high protein content coupled with the fact that it contains all the essential amino acids may, in part, be the reasons behind the recent advocacy for its wide-scale cultivation in the Western Region and use as substitute for animal protein.

According to Ugwu and Ugwu (2010), the benefits of soybean over other grain legumes include lower susceptibility to pests and diseases, better storage quality and larger leaf biomass which translates into soil fertility benefit to subsequent crops. Soybean has the ability to fix between 60 kg and 168 kg of nitrogen per hectare per year under favourable conditions (Rienke and Joke, 2005).

Growth and nodulation of soybean are affected by soil acidity, soil available P and presence of efficient rhizobia strains. Production of soybean requires among others, adequate water supply; between 350 – 750 mm per annum, ideal temperature ranges between 20 °C and 30 °C, phosphorus requirement of 80 – 120 P_2O_5 kg/ha and pH from 5.5 to 7.0 with an optimum of 6.0 (Assuming-Brempong et al., 2013). With the large expanse of soils in Western region being acidic, it is evident that yields of soybean would be low. Thus, there has to be a conscious effort to manage these soils to create favourable pH for sustainable and high productivity of soybean.

The use of agricultural lime may be an option among others, for sustainable management of acidic soils of Western Region to ensure the restoration of their health and fertility. Agricultural lime plays a great role in reducing soil acidity and hence favours plant nutrition. Application of agricultural lime reduces Al and Mn toxicity, increases Ca, Mg, Mo and P uptake and improves on plant rooting system (Weil and Brady, 2016). Calcite, dolomite, quick and slaked lime are liming materials commonly used.

Although soils in the Western Region are mostly acidic, the use of agricultural lime by farmers is low due to high acquisition cost. The material is also not readily available on the market when needed and when available, it is mostly not of pure grade. There is also the problem of high haulage cost to remote farm lands because it is not normally available at fertilizer sales and distribution centres. It is imperative therefore, that a suitable alternative is provided to farmers in the region to encourage production of soybean and other crops that do not tolerate acidic conditions. Any alternative material that would be appealing to farmers for liming soils for soybean production should be relatively cheap, readily available and preferably be in close proximity to their farms.

Biochar is a carbon rich material produced by pyrolysing biomass under limited oxygen (Sohi et al., 2010). The molecular structure of biochar makes it chemically and biologically more stable compared to the application of the same un-charred biomass amended directly to soil (Lehmann and Joseph, 2009).

Earlier works by these authors have shown that application of rice husk and corn cob charred at 500 and 700 °C to a Tikobo Series (Typic Hapludult) of the Western Region of Ghana increased pH by two pH units and reduced Al saturation from 24.5% to undetectable levels. Aluminium saturation reduced from 54% in the Ankasa Series (Hapludox) to 20%, 5% above the critical limit for soybean production. This culminated in a unit increase in pH. These reduction in Al saturation and increase in pH should enhance P availability and improve growth and nodulation of soybean. It is, therefore, imperative to evaluate how the reduction in Al saturation and increase in pH would affect growth and nodulation of soybean.

This work therefore seeks to determine the liming potential and the suitability or otherwise of biochar as a P source and liming material for the growth of soybean on the two typical acid soils of the Western Region of Ghana.

Materials and Methods

The soils used for the study were Ankasa Series, a Typic Hapludox and Tikobo Series, a Typic Hapludult all from the Evergreen Rainforest of the Western Region. The physico-chemical properties of the soils and the effect of corn cob and rice husk biochar amendments on pH, Al and Ca concentrations in the two soils have been discussed in an earlier work (Frimpong Manso et al., 2019)

Incubation Study

Preliminary studies using rice husk (RH) and corn cob (CC) biochar types, each prepared at 500 °C and 700 °C revealed that application of 80 tonnes/ha on a typical acid soil raised soil pH by 1 pH unit (Frimpond Manso et al., 2019). Unprocessed bulk soils of the Ankasa Series (Typic Hapludox) and Tikobo series (Typic Hapludult) were thus packed into pots to attain their respective field bulk densities and amended with each of the four biochar types i.e. rice husk and corncob feedstocks charred at both 500 °C and 700 °C (viz CC_{500}, CC_{700}, RH_{500} and RH_{700}) at an application rate of 80 tonnes/ ha. Equivalent amounts of Ca in the biochar types from $CaCO_3$ (Analar) of 99% purity was amended to another set of potted soils as conventional agricultural lime to serve as realistic control. In estimating the amount of $CaCO_3$ added, the Ca equivalent in the biochar with the highest exchangeable and soluble Ca was used. The $CaCO_3$ amended treatments (Li) served as standards to which the biochar treatments would be judged. A treatment with no amendment was also included to simulate local farmers' practice. The moisture contents of the soils in the pots were kept at 80% field capacity in the screen house. All the treatments were replicated four times and arranged in completely randomized design. Average temperature during the period of incubation was between 27 °C and 32 °C. The soils were incubated till there was no apparent change in soil pH (six-week equilibration).

Upon equilibration, soybean (*Glycine max*) seeds of variety Jankuma and of 90% germination were inoculated with Histick Soy, a commercial inoculant from BASF chemical company in Germany and sown at stake at two seeds per pot and later thinned to one seedling per pot. The levels of available P in the four biochar types added as lime were similar and were therefore averaged (2000 mg P/kg). Equivalent amounts of P in the biochar (160 kg/ha) were added from TSP as synthetic P source to half the number of pots receiving $CaCO_3$ as a liming material with the other half receiving no P. To half of the biochar limed pots additional P from TSP at 30 kg/ha was added to evaluate the combined effect of synthetic P and biochar P on soybean performance. Urea as synthetic source of N were applied at a rates of zero and 10 kg N/ha to all the treatments to evaluate the effect of N on growth characteristics of soybean. The inorganic fertilizers were applied two (2) weeks after germination. Thus, the main treatments were two soils, five liming amendments (Rice husk and corncob at 500 and 700 °C biochar types and $CaCO_3$), two N rates from urea and two P rates i.e. zero P and 30 kg P/ha. There were thus 2 soils x 5 amendments x 2 P rates x 2 N rates factorial experiment with four replicated in a completely randomized design as explained in the incubation study. Four replicates each of the two un-amended soils were included in the experiment to serve as controls. The moisture contents of the soils were maintained at 80% throughout the experiment.

Crop Parameters Determined

At flowering, the plants were harvested by cutting off the shoot at the surface of the soil in the pots. The below soil plant biomass was uprooted and the soil adhering to the roots carefully washed off in a bowl of water. The nodules on the roots were detached, carefully counted and the respective volumes of the washed roots measured using the water displacement method. Nodules were oven dried at 65 °C to a constant weight.

The shoots and the roots were then dried separately at 65 °C to a constant weight in the oven and their respective dry weights determined. Part of the oven dried shoots and roots were milled and wet digested with concentrated sulphuric acid and hydrogen peroxide. Total P in the digest was then determined according to the method described by Murphy and Riley (1962) and P uptake in shoot and root estimated.

Phosphorus Use Efficiency

To assess the effectiveness of the liming materials on P availability, the Apparent P Recovery Efficiency (APRE) was calculated according to the formula by Baligar, et al. (2007).

$$\mathrm{APRE} = \frac{\textit{Nutrient uptake,F (mg)}-\textit{Nutrient uptake C(mg)}\times 100}{\textit{Quantity of nutrient applied (mg)}}$$

Where

F = Uptake in soil at specific P application rate and C = Uptake in un-amended soil

Results

Effect of Liming on Root Volume and Root Dry Matter

The effect of liming on root volume of soybean plants in the two soils is presented in Table 1. The table shows that root volume of the soybean plants in the un-amended Ankasa Series (Hapludox) was the least (1.2 cm^3). Amending the soil with $CaCO_3$, increased the root volume of soybean plant 2.7 folds to 3.25 cm^3 over plants from the un-amended soil. Application of the four biochar types also gave significant increases in root volumes compared to the un-amended soil. The root volume of soybean plants in the $CaCO_3$ amended Ankasa Series (Hapludox) was similar to those in the CC_{700}, RH_{500} and RH_{700} amended soil ($p<0.05$). Amendment with CC_{500} biochar had the least effect on root volume of soybean with an increase of only 1.8 fold over those from the un-amended soils.

The root volume of plants in the un-amended Tikobo Series (Hapludult) was 1.45 cm^3. On liming with the conventional liming material, the root volume increased 2.3 folds to 3.3^3 cm^3. Liming with the four biochar types also increased root volume by 2.7 to 4.1 times over the un-amended. The effect of biochar liming on root growth in the Tikobo Series (Hapludult) was in the order RH_{500} > CC_{700}

> CC_{500} > RH_{700}. Root expansion in all the biochar types except RH_{700} were superior to the conventional liming material. In fact, the root volumes of soybean plants from the RH_{500} limed pots were almost 1.8 times better than those from the Tikobo Series (Hapludult) amended with conventional lime.

The root dry mass of soybean in the un-amended Ankasa Series (Hapludox) was the lightest at 0.21 g (Table 1). On amendment with $CaCO_3$, the mass increased by 48% to 0.31 g. Amending the soil with RH_{500}, although produced root mass superior to the un-amended soil did not increase the root mass significantly compared to that of the $CaCO_3$ amendment. Increases of root mass between 0.39 and 0.42 g over that of the $CaCO_3$ amended Ankasa Series (Hapludox) were, however, recorded for the other biochar liming materials.

In the un-amended Tikobo Series (Hapludult), the 0.14 g root mass of the soybean plant was the least (Table 1). On amending the soil with $CaCO_3$, a six-fold increase in mass (0.84 g) was observed. The biochar amended Tikobo Series (Hapludult), however, showed only a 2 to 4.5-fold increase in root mass over the un-amended soil with the highest of 0.63 g from the RH_{500} treatments.

Effect of Liming on Shoot Dry Matter

Shoot dry matter of soybean plants harvested from the un-amended Ankasa Series (Hapludox) was similar to its root dry mass of 0.21 g (Table 2). Liming with $CaCO_3$ gave the highest shoot dry matter of 0.53 g representing a 2.4-fold increase over plants from the un-amended soil. On amending

TABLE 1

Response of Root Volume and Root Dry Matter to Liming*

TREATMENT	ROOT VOLUME (cm^3)		ROOT DRY MATTER (g)	
	Hapludox	Hapludult	Hapludox	Hapludult
Un-amended	1.20 ±0.04a	1.45 ±0.09a	0.21 ±0.02a	0.14 ±0.01a
LiN0P0	3.25 ±0.05c	3.33 ±0.06b	0.31 ±0.05b	0.84 ±0.02e
CC_{500}	2.15 ±0.03b	3.98 ±0.08bc	0.42 ±0.04c	0.21 ±0.01b
CC_{700}	3.38 ±0.018c	4.63 ±0.19c	0.39 ±0.04c	0.23 ±0.01b
RH_{500}	3.28 ±0.98c	5.99 ±0.04d	0.28 ±0.01b	0.63 ±0.03d
RH_{700}	3.15 ±0.08c	3.89 ±0.04bc	0.41 ±0.02c	0.35 ±0.02c

*Li = $CaCO_3$; N0 = zero N application; P0 = zero P application, CC = corn cob, RH= rice husk

TABLE 2

Response of Shoot Dry Matter to Liming*

TREATMENT		**SHOOT DRY MATTER (g)**	
		Hapludox	Hapludult
Un-amended		0.22 ±0.02a	0.26 ±0.03a
LiN0P0		0.53 ±0.03e	0.63 ±0.02d
CC_{500}		0.35 ±0.02c	0.34 ±0.03b
CC_{700}		0.44 ±0.04d	0.53 ±0.02c
RH_{500}		0.34 ±0.03c	1.10 ±0.05f
RH_{700}		0.28 ±0.01b	0.72 ±0.02e
CV%	16.40		

*Li = $CaCO_3$; N0 = zero; N application; P0 = zero P application, CC= corn cob, RH= rice husk the Ankasa Series (Hapludox) with the four biochar types, shoot dry matter was in the order of $CC_{700} > CC_{500} = RH_{500} > RH_{700}$. The least shoot dry matter was from the RH_{700} pot; however, it was significantly heavier than that of the un-amended soil ($p < 0.05$). Amending the soil with the CC_{500} and CC_{700} biochar types increased shoot dry matter of soybean plants by 59% and 100%, respectively over those from the un-amended soil. The RH biochar types when amended to the Tikobo Series (Hapludult) produced soybean plants with shoot dry matter yield significantly higher than those from the $CaCO_3$ amended treatments. Shoot dry matter yield from the RH_{500} soils were approximately 1.7 times higher than their counterparts from the $CaCO_3$ amended soil. The dry matter yield of shoots harvested from plants from the CC biochar types were, however, inferior to those from the $CaCO_3$ amended soils ($p < 0.05$).

Effect of P on Root Volume and Root Dry Matter

The root volumes when the P equivalent from biochar was added from synthetic P source (TSP) to the lime amended Ankasa Series (Hapludox) (LiN0BEP) was 2.5-fold over the un-amended. This root volume was however, not significantly different from that of the soil amended with only $CaCO_3$ (LiN0P0) (Table 3). When synthetic P at the rate of 30 kg P/ha (P30) was added to the biochar amended Ankasa Series (Hapludox), root volume did not generally significantly differ from biochar amended soils with no synthetic P addition.

When synthetic P from TSP was added to the $CaCO_3$ limed Tikobo Series (Hapludult) at the biochar P equivalent rate, root volume increased from 1.45 cm^3 to 4.19 cm^3, statistically similar to when only conventional lime was applied (Table 3). An addition of synthetic P at the rate of 30 kg P/ha (P30) to the biochar amended Tikobo Series (Hapludult) did not generally show any significant change in root volumes of the soybean plants compared to their biochar amended counterpart plants just as was observed in the Ankasa Series (Hapludox) (Table 3).

When synthetic P at the biochar equivalent was applied to the $CaCO_3$ amended Ankasa Series (Hapludox) (LiN0BEP), root mass increased

TABLE 3

Response of Root Volume and Root Dry Matter to P Source*

TREATMENT	**ROOT VOLUME (cm^3)**		**ROOT DRY MATTER (g)**	
	Hapludox	**Hapludult**	**Hapludox**	**Hapludult**
Un-amended	1.20 ±0.04a	1.45 ±0.09a	0.21 ±0.04a	0.14 ±0.01a
LiN0P0	3.25 ±0.48c	3.33 ±0.06b	0.31 ±0.05bc	0.84 ±0.02h
LiN0BEP	3.05 ±0.51c	4.19 ±0.22bc	0.30 ±0.07b	0.53 ±0.09e
CC_{500}N0P0	2.15 ±0.03b	3.98 ±0.08bc	0.42 ±0.04d	0.21 ±0.1b
CC_{700}N0P0	3.38 ±0.18c	4.63 ±0.19c	0.39 ±0.04cd	0.23 ±0.01b
RH_{500}N0P0	3.28 ±0.98c	5.99 ±0.04d	0.28 ±0.01b	0.63 ±0.03f
RH_{700}N0P0	3.15 ±0.08c	3.89 ±0.04bc	0.41 ±0.02c	0.35 ±0.02c
CC_{500}N0P30	2.75 ±0.02bc	4.03 ±0.21bc	0.26 ±0.02ab	0.46 ±0.03d
CC_{700}N0P30	2.80 ±0.20bc	3.38 ±0.06b	0.36 ±0.04c	0.69 ±0.03g
RH_{500}N0P30	2.95 ±0.67bc	4.83 ±0.20c	0.27 ±0.02b	0.50 ±0.03d
RH_{700}N0P30	3.18 ±0.20c	5.75 ±0.05d	0.54 ±0.02e	0.94 ±0.04i
CV%	15.60		8.60	

*Li = $CaCO_3$;N0 = zero N application; P0 = zero P application; P30 = 30 kg P/ha application; BEP = Biochar Equivalent P application from TSP by 43% compared to the un-amended soil (Table 3). However, this increase was not significantly different from that of the $CaCO_3$ limed soil with no external P application. On addition of synthetic P at 30 kg /ha to the biochar amended Ankasa Series (Hapludox), an increase in root mass was observed only in the RH_{700} amended soil (RH_{700}N0P30) in which root mass increased by 32% compared to same treatment without synthetic P (Table 3).

Addition of synthetic P to the conventionally limed Tikobo Series (Hapludult) (LiN0BEP) produced soybean plants with lower root mass as shown by a 37% decrease when compared to the unfertilized conventionally limed soil (LiN0P0) (Table 3). In general, the addition of synthetic P to the biochar amended Tikobo Series (Hapludult) produced heavier roots than their counterparts which were not amended with synthetic fertilizer. The highest root dry matter of 0.94 g was observed in the RH_{700} amended soil with 30 kg/ha application of TSP.

Effect of P on Shoot Dry Matter and Nodulation

The effect of P from biochar and synthetic sources on shoot dry matter of soybean plants grown in the two soils are shown in Table 4. Addition of TSP at biochar equivalent P to the $CaCO_3$ limed Ankasa Series (Hapludox) produced shoot that was significantly lower than its counterpart that received $CaCO_3$ without P fertilization. The soybean plants in P fertilized RH_{700} (RH_{700}P30) biochar amended soils recorded the highest shoot dry matter of 0.80 g among the treatments.

There was about 1.65 times increase in shoot dry matter when the $CaCO_3$ limed Tikobo Series (Hapludult) was fertilized with TSP over their unfertilized $CaCO_3$ counterpart (Table 4). On TSP fertilization of the CC limed Tikobo Series (Hapludult), shoot dry matter increased about 1.59 and 1.23 times, respectively in the CC_{500} and CC_{700} amended soils compared to the unfertilized counterparts. The converse was observed in the RH amended Tikobo Series (Hapludult)

TABLE 4

Response of Shoot Dry Matter, Nodule Number and Nodule Dry Matter to P Source*

TREATMENT	SHOOT DRY MATTER (g)		NODULE NO.	NODULE DM(g)
	Hapludox	Hapludult	Hapludult	Hapludult
Un amended	0.22 ±0.02a	0.26 ±0.03a	0	0
LiN0P0	0.53 ±0.03cd	0.63 ±0.02c	0	0
LiN0BEP	0.35 ±0.17b	1.04 ±0.11e	0	0
CC_{500}N0P0	0.35 ±0.02b	0.34 ±0.03a	0	0
CC_{700}N0P0	0.44 ±0.04c	0.53 ±0.02b	0	0
RH_{500}N0P0	0.34 ±0.03b	1.10 ±0.05e	0	0
RH_{700}N0P0	0.28 ±0.01ab	0.72 ±0.02cd	11	0.011
CC_{500}N0P30	0.44 ±0.03c	0.54 ±0.10bc	4	0.004
CC_{700}N0P30	0.46 ±0.02c	0.65 ±0.04c	5	0.004
RH_{500}N0P30	0.55 ±0.04d	0.57 ±0.05bc	5	0.004
RH_{700}N0P30	0.80 ±0.01e	0.78 ±0.15d	7	0.016
CV%	9.18			

*Li = $CaCO_3$;N0 = zero N application; P0 = zero P application; P30 = 30 kg P/ha application; BEP = Biochar Equivalent P application from TSP, CC = corn cob, RH = rice husk, NO. = number, DM = dry matter where 93% decrease in shoot dry matter was observed in the TSP fertilized RH_{500} compared to the unfertilized counterpart. However, similar values of shoot dry matter were observed when the TSP fertilized RH_{700} and the unfertilized counterpart were compared.

The effect of P on nodulation is presented in Table 4. All the plants grown in the Ankasa Series (Hapludox) did not produce any nodules when the amendments were applied to the soil. Apart from RH_{700} amended Tikobo Series (Hapludult) which had 11 nodules weighing 0.011 g, all plants did not nodulate in either the conventionally limed or biochar amended soils (Table 4). On addition of TSP at the rate of 30 kg P/ha to the Tikobo Series (Hapludult), however, soybean plants which did not produce any nodules in the CC_{500}, CC_{700} and RH 500 amended soils nodulated with average nodule numbers and mass of 5 and 0.004 g, respectively. The unfertilized RH_{700} amended Tikobo Series (Hapludult) which produced soybean plants with 11 nodules had a reduction in nodule numbers to 7 with an average mass of 0.016 g on addition of 30 kg P/ha from TSP.

Effect of N on Shoot Dry Matter and Root Volume

The sole effect of N on shoot dry matter of soybean grown on the $CaCO_3$ limed Ankasa Series (Hapludox) and Tikobo Series (Hapludult) are presented in figure 1. Generally, with the exception of the RH_{700} amended Ankasa Series (Hapludox), all the amended soils did not show any response to N application. When N from urea was applied at 10 kg/ha to the RH_{700} amended Hapludox, shoot dry matter increased by almost 2.1 times from 0.28 g to 0.58 g.

The effect of N application on root volume of the two soils is presented in figure 2. It is apparent from the figure that N application at 10 kg N/ha generally had no effect on root volume as unfertilized limed soils and fertilized limed soils both produced plants with statistically similar root volumes.

Interactive Effects of Biochar Liming, Synthetic P and N Application on Growth Characteristics

The interactive effects of biochar as a liming material and synthetic P and N on some growth

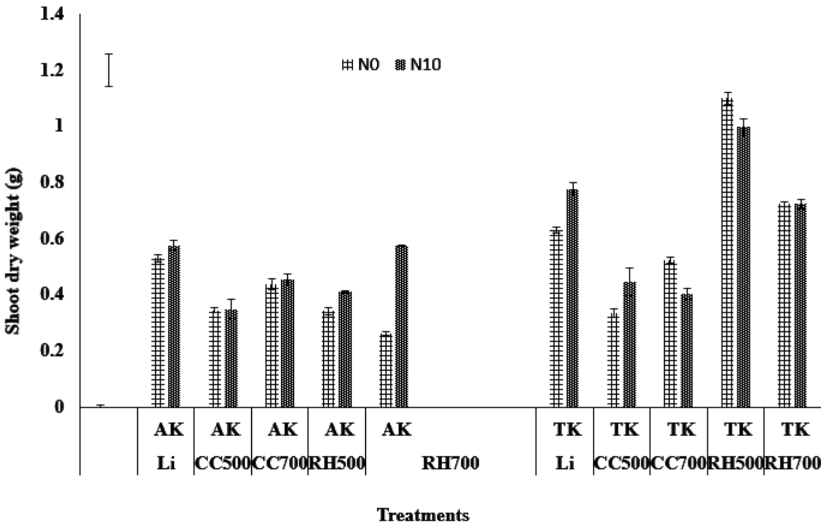

Figure 1: Response of shoot dry mass to N application

AK = Ankasa series (Hapludox), TK = Tikobo series (Hapludox), Li = Lime ($CaCO_3$), RH = Rice Husk, CC= Corn Cob, 500 & 700 = charring temperatures (oC), N = Nitrogen, N0 = 0 N kg/ha rate & N10 = 10 kg/ha N rate

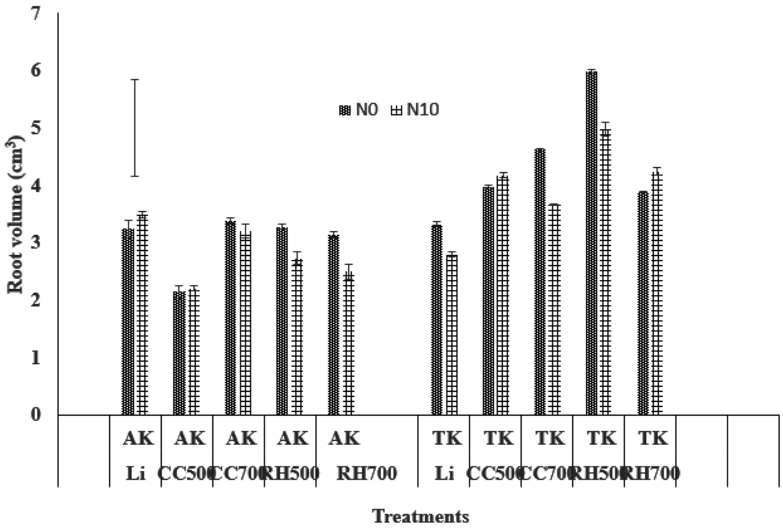

Figure 2: Response of root volume to N application

AK = Ankasa series (Hapludox), TK = Tikobo series (Hapludox), Li = Lime ($CaCO_3$), RH = Rice Husk, CC= Corn Cob, 500 & 700 = charring temperatures (oC), N = Nitrogen, N0 = 0 N kg/ha rate & N10 = 10 kg/ha N rate

characteristics of soybean are presented in Tables 5 and 6. The RH amended Ankasa Series (Hapludox) that had been fertilized with both urea and TSP at respective rates of 10 kg N/ha and 30 kg P/ha (RH$_{500}$N10P30, RH$_{700}$N10P30) produced plants with higher root volumes than their CC amended counterparts (CC$_{500}$N10P30, CC$_{700}$N10P30). The RH 500 and 700 with both P and N fertilization had root volumes that were 77% and 92% respectively heavier than their CC counterparts. The RH amended soils which had been fertilized with both N and P had significantly higher root volumes than those that had been fertilized with only N. Addition of P from TSP did not however, increase root volume in the CC amended Ankasa Series (Hapludox) significantly.

Generally, with the exception of RH$_{700}$, addition of both synthetic N and P increased shoot dry matter more than when only N was added to the biochar amended plots. Shoot dry matter in the Ankasa Series (Hapludox) was highest in the P and N fertilized RH$_{500}$ and least in the fertilized CC$_{500}$ amended soil.

Just as was observed in the Ankasa Series

TABLE 5

Interactive Effects of Amendment on Root Volume and Shoot Dry Matter in Hapludox*

TREATMENTS	ROOT VOLUME (cm^3)	SHOOT DRY MATTER (g)
Un-amended	1.20 ±0.04a	0.22 ±0.02a
LiN0P0	3.25 ±0.48cd	0.53 ±0.03fg
CC$_{500}$N0P0	2.15 ±0.03b	0.35 ±0.02c
CC$_{700}$N0P0	3.38 ±0.18cd	0.44 ±0.04de
RH$_{500}$N0P0	3.28 ±0.98c	0.34 ±0.03c
RH$_{700}$N0P0	3.15 ±0.08cd	0.28 ±0.01b
LiN0BEP	3.05 ±0.51c	0.35 ±0.17c
CC$_{500}$N0P30	2.75 ±0.02bc	0.44 ±0.03de
CC$_{700}$N0P30	2.80 ±0.41bc	0.46 ±0.02e
RH$_{500}$N0P30	2.95 ±0.67bc	0.55 ±0.04fg

TABLE 5 cont.

Interactive Effects of Amendment on Root Volume and Shoot Dry Matter in Hapludox*

TREATMENTS	ROOT VOLUME (cm^3)	SHOOT DRY MATTER (g)
RH$_{700}$N0P30	3.18 ±0.20cd	0.80 ±0.01i
LiN10P0	3.50 ±0.29cd	0.58 ±0.03g
CC$_{500}$N10P0	2.21 ±0.04bc	0.35 ±0.07c
CC$_{700}$N10P0	3.20 ±0.29cd	0.46 ±0.04e
RH$_{500}$N10P0	2.73 ±0.34bc	0.41 ±0.01d
RH$_{700}$N10P0	2.50 ±0.10bc	0.58 ±0.01g
LiN10BEP	2.23 ±0.25bc	0.33 ±0.17c
CC$_{500}$N10P30	2.25 ±0.01bc	0.44 ±0.05de
CC$_{700}$N10P30	2.23 ±0.21bc	0.56 ±0.01g
RH$_{500}$N10P30	3.99 ±0.17d	0.63 ±0.05h
RH$_{700}$N10P30	4.28 ±0.41d	0.51 ±0.01f
CV%	18.10	10.70

*Li = $CaCO_3$; N0 = zero N application; P0 = zero P application; P30 = TSP applied at a rate of 30 kg P/ha ; BEP = Biochar Equivalent P application from TSP; N10 = 10 kg N/ha from urea, No.= number, DM = dry matter, Vol = volume

(Hapludox), the RH amended Tikobo Series (Hapludult) produced plants with higher root volumes than their CC counterparts when the soil was fertilized with both urea and TSP (Table 6) and they were generally associated with higher shoot dry matter. Statistically, shoot dry matter upon N and P fertilization in the biochar amended soils was in the order of RH$_{700}$N10P30 > RH$_{500}$N10P30 >= CC$_{700}$N10P30 > CC$_{500}$N10P30. When both fertilizers were applied to the biochar amended Tikobo Series (Hapludult), shoot dry matter, except in the RH$_{500}$N10P30 amended soil was higher than in their counterparts that had received only N fertilization.

Root and Shoot P Uptake

Root P uptake from soybean plants grown in the two soils are presented in Table 7. Root P uptake in the Ankasa Series (Hapludox) limed with $CaCO_3$ was 6.8-fold higher than the un-amended counterpart. Although amending the soil with biochar increased root P uptake significantly compared to that of the un-amended, this was however lower than the uptake in the $CaCO_3$ limed soil. When the biochar equivalent P from TSP was added to the $CaCO_3$ limed soil (LiN0BEP), root uptake increased 4-fold over the un-amended counterpart. This uptake was however not different from the levels observed in the four biochar amended soils. Addition of synthetic P from TSP at the rate of 30 kg P /ha to the biochar amended soils saw a significant increase in P uptake of the soybean roots. Synthetic P addition to the CC$_{500}$, CC$_{700}$ and RH$_{500}$ biochar amended soils saw root P uptake increasing between 1.7 and 1.9 times over their counterparts without any synthetic P additions. The RH$_{700}$ biochar amended soil on addition of the synthetic P had a 2.9-fold increase in root P uptake over its counterpart with no P amendment.

It is apparent from Table 7 that addition of 10 kg N/ha from urea (LiN10P0) did not affect P uptake compared to when no N was applied to the $CaCO_3$ limed soil. However, on application of both N and P to the $CaCO_3$ limed Ankasa Series (Hapludox) (LiN10BEP), P uptake was suppressed by 26% compared

TABLE 6

Interactive Effect of Amendment on Root Volume, Shoot Dry Matter and Nodule Number in Hapludult*

TREATMENTS	ROOT VOL (cm^3)	SHOOT DM (g)	NODULE No.	NODULE DM (g)
Un-amended	1.45 ±0.09a	0.26 ±0.03a	0	0
LiN0P0	3.33 ±0.06bc	0.63 ±0.02e	0	0
CC_{500}N0P0	3.98 ±0.08cd	0.34 ±0.03b	0	0
CC_{700}N0P0	4.63 ±0.19d	0.53 ±0.02d	0	0
RH_{500}N0P0	5.99 ±0.04e	1.10 ±0.05j	0	0
RH_{700}N0P0	3.89 ±0.04cd	0.72 ±0.02f	11	0.011
LiN0BEP	4.19 ±0.22c	1.04 ±0.11i	0	0
CC_{500}N0P30	4.03 ±0.21c	0.54 ±0.10d	4	0.004
CC_{700}N0P30	3.38 ±0.06bc	0.65 ±0.04e	5	0.004
RH_{500}N0P30	4.83 ±0.20d	0.57 ±0.05d	5	0.004
RH_{700}N0P30	5.75 ±0.05e	0.78 ±0.15g	7	0.016
LiN10P0	2.80 ±0.16b	0.78 ±0.04g	0	0
CC_{500}N10P0	4.18 ±0.18cd	0.45 ±0.10c	0	0
CC_{700}N10P0	3.68 ±0.04c	0.41 ±0.04c	8	0.017
RH_{500}N10P0	4.99 ±0.12de	1.00 ±0.06hi	0	0
RH_{700}N10P0	4.25 ±0.05c	0.72 ±0.03f	0	0
LiN10BEP	3.03 ±0.16bc	0.42 ±0.02c	0	0
CC_{500}N10P30	4.43 ±0.38c	0.78 ±0.02g	6	0.006
CC_{700}N10P30	4.93 ±0.07d	0.99 ±0.07h	7	0.006
RH_{500}N10P30	5.25 ±0.01de	0.96 ±0.12h	0	0
RH_{700}N10P30	4.75 ±0.06de	1.08 ±0.10ij	8	0.016
CV%	19.31	10.84		

*Li = $CaCO_3$; N0 = zero N application; P0 = zero P application; P30 = TSP applied at a rate of 30 kg P/ha; BEP = Biochar Equivalent P application from TSP; N10 = 10 kg N/ha from urea. Means with the same alphabet are not significantly (p>0.05) different, No.= number, DM = dry matter. Vol = volume

TABLE 7

Effect of Amendments on Root and Shoot P Uptake *

TREATMENTS	ROOT P UPTAKE (mg/pot)		SHOOT P UPTAKE (mg/pot)	
	Hapludox	Hapludult	Hapludox	Hapludult
Un-amended	1.45 ±0.19a	1.55 ±0.22a	2.15 ±0.08a	3.46 ±0.35a
LiN0P0	9.93 ±0.90cd	17.13 ±0.59g	6.79 ±0.76cd	12.59 ±2.56cd
CC_{500}N0P0	5.15 ±0.50b	4.56 ±0.22b	9.80 ±0.73e	6.32 ±0.85b
CC_{700}N0P0	5.35 ±0.71b	5.49 ±0.20b	8.72 ±1.65de	12.71 ±2.38cd
RH_{500}N0P0	6.62 ±0.31bc	14.45 ±0.93f	3.76 ±0.89b	18.49 ±1.58ef
RH_{700}N0P0	5.45 ±1.20b	7.97 ±0.48c	8.96 ±1.21de	14.47 ±1.29de
LiN0BEP	5.84 ±1.44b	12.58 ±1.86ef	7.14 ±1.06cd	11.55 ±0.88cd
CC_{500}N0P30	9.17 ±0.42c	11.06 ±0.57d	6.23 ±1.41c	17.3 ±2.514ef
CC_{700}N0P30	9.22 ±0.78c	13.91 ±0.49f	8.44 ±1.35de	12.82 ±1.28c
RH_{500}N0P30	12.44 ±0.41d	12.00 ±0.80e	6.54 ±0.95cd	16.87 ±2.30e
RH_{700}N0P30	16.24 ±0.51e	22.77 ±1.56h	12.75 ±1.78f	14.88 ±2.56de
LiN10P0	9.40 ±0.46cd	8.63 ±0.52cd	12.49 ±1.83f	13.84 ±2.70d
CC_{500}N10P0	7.37 ±0.65bc	4.56 ±0.18b	4.98 ±0.32bc	11.37 ±1.70cd

TABLE 7 cont.

Effect of Amendments on Root and Shoot P Uptake *

TREATMENTS	ROOT P UPTAKE (mg/pot)		SHOOT P UPTAKE (mg/pot)	
	Hapludox	Hapludult	Hapludox	Hapludult
CC_{700}N10P0	9.49 ±0.99cd	8.78 ±0.28cd	8.17 ±0.80d	11.55 ±1.69cd
RH_{500}N10P0	8.74 ±0.66c	12.01 ±1.35e	7.44 ±1.72c	17.15 ±2.10e
RH_{700}N10P0	11.41 ±1.99cd	12.95 ±0.95ef	15.19 ±1.52g	16.44 ±2.81de
LiN10BEP	7.88 ±1.52bc	9.77 ±0.99d	7.24 ±1.92cd	10.02 ±1.55c
CC_{500}N10P30	11.00 ±1.53cd	21.62 ±1.21h	8.33 ±1.25d	20.00 ±3.90f
CC_{700}N10P30	12.87 ±0.70d	14.40 ±0.84f	8.32 ±1.44de	19.21 ±3.60ef
RH_{500}N10P30	12.35 ±0.41d	22.92 ±1.61h	12.86 ±0.52f	19.26 ±3.92ef
RH_{700}N10P30	12.10 ±0.42d	17.42 ±0.91g	7.97 ±1.23d	25.67 ±3.07g
CV%	11.00		16.10	

*Li = $CaCO_3$; N0 = zero N application; P0 = zero P application; P30 = TSP applied at a rate of 30 kg P/ha ; BEP = Biochar Equivalent P application from TSP; N10 = 10 kg N/ha from urea

to when the conventionally limed soil was neither fertilized with N nor P. Root P uptake in the biochar only amended Ankasa Series (Hapludox) was similar to that of the P fertilized $CaCO_3$ limed soil. Addition of both urea and TSP to the biochar amended soils did not generally increase root P uptake compared to when only synthetic P was added to the biochar amended soils. However, addition of both synthetic fertilizers to the biochar amended Ankasa Series (Hapludox) gave higher root P uptake than when only urea was applied to the biochar amended soils.

Root P uptake in the Tikobo Series (Hapludult) was generally higher than in the Ankasa Series (Hapludox) when either of the synthetic fertilizers was added. Liming the soil with $CaCO_3$ increased P uptake 11-fold over the un-amended soil to 17.12 mg/pot which upon addition of the biochar equivalent P from TSP was suppressed by 26% to 12.58 mg/pot. Addition of biochar to the Tikobo Series (Hapludult) although increased root P uptake more than that of the un-amended, led to a significantly lower root P uptake compared to the $CaCO_3$ limed soil. When TSP was added to the biochar amended Tikobo Series (Hapludult) at 30 kg P/ha, P uptake increased more than when synthetic P was not applied. On addition of synthetic P to the biochar amended Tikobo Series (Hapludult)t, root P uptake was in the order RH_{700}N0P30 > CC_{700}N0P30 > RH_{500}N0P30 = CC_{500}N0P30. Nitrogen application to the biochar limed and $CaCO_3$ limed soils did not increase root P uptake compared to their non N fertilized counterparts. However, these P uptake values were expectedly lower than when synthetic P was added to the biochar and $CaCO_3$ only limed soils. On addition of synthetic P and N to the biochar limed Tikobo Series (Hapludult), P uptake of roots was significantly enhanced with the CC_{500}N10P30 and RH_{500}N10P30 treatments having the highest values of approximately 22 mg/pot.

Results of shoot P uptake after harvest are presented in Table 7. Shoot P uptake was significantly ($p < 0.05$) higher in all the amended soils than their un-amended counterparts. Unlike in root P uptake, shoot P uptake was generally higher in the four biochar amended Hapludox and Hapludult than their $CaCO_3$ amended counterparts. Amendment with rice husk biochar charred at 700 °C with the addition of 30 kg P/ha synthetic fertilizer gave the highest shoot P uptake of 12.75 mg/pot in the Ankasa Series (Hapludox). Shoot P uptake was generally higher in the Ankasa Series (Hapludox) amended with the biochar types than the CaCO$_3$ and the un-amended soils.

Addition of N to the soils amended with biochar just as was observed for root uptake did not improve shoot P uptake. Uptake of P in soybean shoots in the biochar amended Ankasa Series (Hapludox) did not generally differ from the same treatments with addition of both synthetic N and P. However, in the Tikobo Series (Hapludult), shoot P uptake of soybean was generally higher in biochar amended soils with synthetic N applications than without the synthetic N.

Shoot to Root Ratio

Table 8 shows the shoot to root ratio of soybean plants harvested from the various treatments. From the Table, it is clear that the plants from the Tikobo Series (Hapludult) generally had higher shoot to root ratios than their counterparts from the Ankasa Series (Hapludox) especially in the soils with no synthetic P amendments. With both synthetic N from urea and P from TSP additions to the two soils, the shoot to root ratio was generally higher in the Tikobo Series (Hapludult) than the Ankasa Series (Hapludox). It is worthy of

TABLE 8

Shoot to Root Dry Weight Ratio and APRE on Hapludox and Hapludult*

TREATMENTS	ROOT to SHOOT RATIO		APRE (%)	
	Hapludox	Hapludult	Hapludox	Hapludult
Un-amended	1.05 ±0.20d	1.86 ±0.12l	-	-
LiN0P0	1.71 ±0.20k	0.75 ±0.02a	-	-
LiN10P0	0.92 ±0.12bc	2.17 ±0.11o	-	-
LiN0BEP	1.17 ±0.31ef	1.96 ±0.15m	2.01	5.25
LiN10BEP	1.00 ±0.01d	0.95 ±0.08c	1.68	2.87
CC$_{500}$N0P0	0.83 ±0.01b	1.62 ±0.21j	1.77	5.78
CC$_{500}$N10P0	1.35 ±0.22h	1.55 ±0.15i	2.35	8.40
CC$_{700}$N0P0	1.13 ±0.02e	2.30 ±0.02p	1.81	6.58
CC$_{700}$N10P0	1.15 ±0.11e	1.11 ±0.12d	3.51	7.88
RH$_{500}$N0P0	1.21 ±0.03f	1.75 ±0.05k	3.53	5.83
RH$_{500}$N10P0	1.28 ±0.01g	1.89 ±0.31l	5.00	7.67
RH$_{700}$N0P0	0.69 ±0.02a	2.06 ±0.05n	6.72	6.76
RH$_{700}$N10P0	0.87 ±0.03b	1.29 ±0.21f	2.92	4.55
CC$_{500}$N0P30	1.69 ±0.14k	1.17 ±0.07e	2.69	5.17
CC$_{500}$N10P30	1.26 ±0.13fg	0.85 ±0.01b	3.65	5.25
CC$_{700}$N0P30	1.28 ±0.05g	0.94 ±0.21c	3.31	7.80
CC$_{700}$N10P30	1.56 ±0.20j	1.55 ±0.10i	4.55	7.47
RH$_{500}$N0P30	2.04 ±0.09l	1.14 ±0.09de	4.34	9.09
RH$_{500}$N10P30	1.13 ±0.15e	0.97 ±0.04c	5.19	8.73
RH$_{700}$N0P30	1.48 ±0.30i	0.83 ±0.02	4.95	8.75
RH$_{700}$N10P30	1.50 ±0.04ij	1.42 ±0.12g	4.84	11.67
CV%	2.8			

*CC500= corn cob biochar at 500 oC, CC700= corn cob biochar at 700 ^{o}C, RH500= rice husk biochar at 500 oC, rice husk biochar at 500 ^{o}C, P= phosphorus, N= nitrogen, BEP = biochar equivalent phosphorus, Li= agricultural lime. Means with the same alphabet are not significantly (p>0.05) different and APRE = Apparent Phosphorus Recovery Efficiency note that the highest shoot to root ratios were observed in plants grown in the Tikobo Series (Hapludult) amended with only CC_{700} and RH_{700} biochar.

Apparent Phosphorus Recovery Efficiency

The APRE shows the ability of the plant to obtain P as a nutrient from the soil (Baligar, et al., 2007). In calculating the APRE, the average equivalent available P in 80 Mg/ha of biochar (BEP) applied per pot was used as the amount of P added. This translated to 220 mg P per pot for both biochar and TSP as BEP. The APRE of the various fertilized amendments are shown in Table 8. The APRE in the two soils were generally very low and below 12%. When the Ankasa Series (Hapludox) was conventionally limed and the biochar equivalent P was added from TSP (LiN0BEP), P recovery was 2.01% which decreased marginally to 1.68% when that soil was fertilized further with N. The APREs of the CC_{500} and CC_{700} biochar only amended Ankasa Series (Hapludox) were 1.77 and 1.81%, respectively which increased to 2.35 and 3.51 upon further fertilization with N from urea. When the CC_{500} and CC_{700} biochar amended soils were fertilized with synthetic P at 30 kg/ha from TSP viz. CC_{500}N0P30 and CC_{700}N0P30, APREs of soybean plants increased to 2.69% and 3.31% from when no synthetic P was added. Further fertilization with urea increased the respective APREs to 3.65 and 4.55%. The RH_{500} and RH_{700} amended Ankasa Series (Hapludox), however, had their plants having higher APREs of 3.53% and 6.72% than their counterparts from the conventionally limed soils. Addition of urea to the RH_{500} also saw an increase in APRE of the soybean plant whereas the RH_{700} saw a decrease. Adding TSP to the RH_{500} biochar amended soils also increased APREs of the soybean plants to 4.34% and then to 5.19% when urea was added, Addition of TSP to RH_{700} increased the APREs of the plants to 4.95%.

The APRE in the conventionally limed Tikobo Series (Hapludult) with synthetic P fertilization was 5.25% which decreased just as in the Tikobo Series (Hapludult) to 2.87% when synthetic P was added. Plants from all the biochar amended Tikobo Series (Hapludult), however had higher APREs than those from the LiN0BEP amended soil with values between 5.78 and 6.75%. Further application of P from TSP to the biochar amended Tikobo Series (Hapludult) increased their respective APREs to about 8.75% in the RH_{700}.

Discussion

Effect of Soil Amendments on Plant Growth Parameters

The acidic pH in water of 4.2 and a high Al saturation of almost 55% of the Ankasa Series (Hapludox) (Frimpong Manso et al., 2019) which was above the critical limit for optimum soybean cultivation (Fageria, and Baligar, 2008) coupled with low available P concentration of 1.54 mg/kg, contributed to restricted root development and expansion. It is, therefore, not surprising that the root volume of soybean in the un-amended Ankasa Series (Hapludox) was the least.

Amendment of the Ankasa Series (Hapludox) with the liming agents increased pH in water by about one pH unit to 5.2 with a concomitant improvement in availability of the basic nutrient Ca, Mg, K and Na especially in the biochar amended soil (Frimpong Manso et al., 2019). These improvements in the fertility status of the soil must have culminated in increased root volume of the soybean plants in the biochar and $CaCO_3$ amended Ankasa Series (Hapludox). The fact that root volumes in the biochar amended soils are similar to those in the $CaCO_3$ amended soils implies that the biochar types are as effective as the conventional $CaCO_3$ in enhancing root expansion and hence growth.

Amendment of the Tikobo Series (Hapludult) with conventional liming material also increased root volume due to improved pH. Amendment with the four biochar types resulted in improved soil pH from 4.9 to between 5.9 and 6.2, reduced Al concentration from 0.4 cmol/kg to almost zero and increased soil available P. The fact that the synthetic P at the biochar P equivalent when applied to the $CaCO_3$ amended Ankasa Series (Hapludox) gave statistically similar root volumes as the soil amended with biochar shows that the P in the biochar was as effective as synthetic P in root growth.

The shoot dry matter of the soybean plants harvested from the un-amended Ankasa Series (Hapludox) and Tikobo Series (Hapludult) were relatively low, mainly because of their lower root volumes which might have hindered exploitation for nutrients culminating in lower root and shoot uptake.

On amendment with $CaCO_3$, shoot dry matter in the Ankasa Series (Hapludox) increased and this can be attributed to the increased root volume and hence root P uptake. When Ankasa Series (Hapludox) and Tikobo Series (Hapludult) were amended with biochar, shoot dry matter also increased because of the liming effect which increased root volume. A plot of shoot dry matter against root volume showed a positive correlation coefficient of 0.783 (Figure 3) implying that as root volume increase shoot dry matter also increase.

Amending the Tikobo Series (Hapludult) with the biochar types also increased shoot dry matter. As reported in our earlier work, (Frimpong Manso et al., 2019) the $CaCO_3$ limed soils had readily more available Ca released than their biochar counterparts. This faster release of Ca helped in root division and expansion culminating in more shoot in the plants from the conventionally limed amended than the biochar amended soils

The Ankasa Series (Hapludox) with lower shoot to root ratio especially in the biochar only amended soils implies that relatively more P as a nutrient was channeled into root

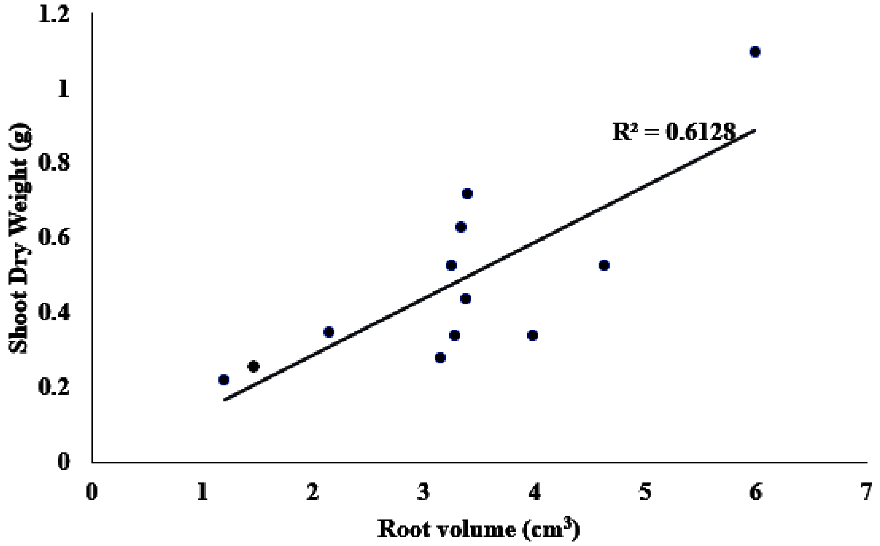

Figure 3. Relationship between root volume and shoot dry weight

development. This result is corroborated by the relatively higher P uptake in the roots than the shoots of the soybean plants grown in the Ankasa Series (Hapludox). This might be the response of the soybean plant to stress imposed by the presence of relatively high Al concentration of between 0.5 and 1 cmol/kg in the Ankasa Series (Hapludox) compared with the near zero in the Tikobo Series (Hapludult) (Martinez et al., 2005). Addition of N to the limed soils irrespective of liming material increased shoot to root ratios indicating the effect of N on leaf production (Marschner, 2011)

Addition of extra 30 kg P/ha from TSP to the biochar amended Hapludult did not increase root volume more than that in the biochar amended soil implying that the P in the biochar was adequate for root growth in this soil. The extra P may have been used in producing higher root mass as shown in the TSP fortified biochar amended Tikobo Series (Hapludult). This is also reflected in the higher root P uptake in the plants grown on the TSP-biochar amended Tikobo Series (Hapludult).

The fact that on addition of TSP to the biochar amended Tikobo Series (Hapludult) and Ankasa Series (Hapludox), only the RH_{700} treatment showed positive response of shoot dry matter to P could be an indication that the RH_{700} biochar type is the ideal material for soybean cultivation should inorganic fertilizer be amended as a supplement. This is further supported by the fact that it is only the RH_{700} amended soils that increased tremendously in shoot dry matter especially in the Tikobo Series (Hapludult) compared to its unfertilized counterpart upon addition of both synthetic N and P. It is thus clear that on amendment of the two soils with the corncob biochar types and RH_{500}, it is not prudent to further add any synthetic N or P.

Effect of P on Nodulation

Nodulation of legumes is favoured by near to neutral pH and high P availability (Alexander 1977) Soybean nodulation occurred only in the Tikobo Series (Hapludult). Nodules formation in this soil could be attributed to the increase in pH from 4.9 to 5.3 in the conventionally limed soil, and between 5.9 and 6.2 in the biochar amended soils shown at the end of the six-week incubation period (Frimpong Manso et al., 2019). These increases in pH led to a reduction in Al concentration to undetectable levels and a corresponding increase in Ca availability promoting nodulation in the biochar amended Tikobo Series (Hapludult). The RH_{700} also proved to be a superior amendment for soybean nodulation as without external P supplementation, it was the only amendment which produced soybean with nodules. The nodulation in the RH_{700} biochar amended Tikobo Series (Hapludult) could be due to its superior pH of 6.2 and high exchangeable Ca of 1.8 cmol/kg from that of the un-amended at the end of the six weeks of incubation with the biochar type (Frimpong Manso et al., 2019).

All the four biochar types had similar available P concentrations. On addition of extra 30 kg P/ha from TSP, there was suppression of nodulation in the RH_{700} amended Tikobo Series (Hapludult) whilst the other three biochar types which hitherto could not promote nodulation had soybean plants nodulating. Factors such as Mo concentration, microbial population and diversity, presence of nitrogenase enzyme (Alexander 1977) which were not investigated in this study and addition of urea could have played major roles in nodulation. Nodule numbers in the RH_{700} reduced upon urea fertilization at 10 kg/ha showing the negative effect of readily available N addition on nodulation (Alexander 1977).

Phosphorus Use Efficiency

The low APRE of below 12% might be as a result of low recovery of phosphorus by soybean plants due to soil P fixation (Nartey, et al., 1997). Recoveries were slightly higher in the Tikobo Series (Hapludult) because of its relatively higher pH. This higher pH and undetectable levels of Al in solution especially from the RH_{700} (Frimpong Manso et al., 2019) may have in part led to lower fixation of added P and improved uptake as evident in the RH biochar amended Tikobo Series (Hapludult).

Conclusion

Amending the soils with the liming materials resulted in significant increase in root volume, root and shoot dry matter than in the un-amended counterparts. Root volume which was significantly enhanced in the biochar amended soils than the conventionally limed soils seemed to control shoot dry matter implying that biochar especially rice husk charred at 700 °C could be used as liming agent and P source with or without synthetic fertilizer to enhance growth of soybean on acid soils of the Western Region.

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