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Preliminary investigation of effects of rhodic lixisol soil and biochar types on Soybean inoculated with *Bradyrhizobium japonicum*: A field trial study

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ABSTRACT

In our previous study, biochars derived from poultry manure (PMB) and rice husk (RHB) where shown to be promising sources of nutrients to the soybean crops that were grown in the ferric acrisol soils. Furthermore *Bradyrhizobium japonicum* inoculated soybean seeds were concluded to be advantageous. However, no field study was found for the rhodic lixisol soil types. Here we report effects of such biochars on soybean crops grown in rhodic lixisol soils were examined in terms of root dry weight (unit), shoot dry weight (g plant^{-1}), total plant dry weight (g plant^{-1}), seed weight (g), grain yield (Mg ha^{-1}), number of nodules (nodule number plant^{-1}), nodule dry weight (g plant^{-1}) and harvest index (unit). Our results showed 4 kg Mg ha^{-1} PM had a superior effect on the grain yield of the soybeans coated with *B. japonicum*. In this study *B. japonicum* coated seeds produced both high numbers as well as dry weights of nodules in response to PM and biochars either alone or in combinations. The harvest index of the un-inoculated soybeans upon treatment with 5 kg Mg ha^{-1} RHB + 2 kg Mg ha^{-1} PMB was found to be the highest. We successfully conclude rhodic lixisol soils to be well suited for PM and RHB applications on both inoculated and un-inoculated soybean crops.

KEY WORDS: *Poultry manure biochar*; *Rice husk biochar*; *Soil microbes*; *Soybean crops*

1. Introduction

In Sub-Saharan Africa, the majority of tropical soils are naturally deficient in organic matter due to continuous nutrient mining by growing crops and the presence of kaolinitic clays, which are chemically inert and affect productivity (Adiaha, 2017; Vlek *et al.*, 1997). The current practices of soybean production in the forest-savannah transition agro-ecological zone, especially continuous crop farming without the return of crop residues and fertilizer prior to soybean cultivation, could progressively reduce yields. Limitations of existing practices include nutrient imbalances, reduced soil quality, and increased vulnerability to erosion (Rashmi *et al.*, 2020; Hartemink, 2002). Additionally, soybean seeds require substantial amounts of nitrogen (N), phosphorus (P), and potassium (K), as well as smaller amounts of sulfur (S) and some micronutrients. Although soybean requires

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considerably less P and S than N or K, all these nutrients are essential for plant development.

This study builds on our previous work (Elebiyo & Bachmann, 2024), where poultry manure (PM), poultry manure biochar (PMB), and rice husk biochar (RHB) were prepared, characterized, and applied to soybean seeds inoculated with *Bradyrhizobium japonicum*. However, no field study had previously addressed rhodic lixisol soil types. In the present investigation, rhodic lixisols were used, with the experimental site located in the forest-savannah transition agro-ecological zone. Rhodic Lixisol is a tropical soil classified under the Cutanic, Aric, and Clayic categories. It is one of the most strongly weathered soils, retaining remnant qualities in humid subtropical climates, with low nutrient reserves and low available nutrient levels. Drier regions of the tropics and subtropics are predominantly occupied by rhodic lixisols, covering over 435 million hectares, particularly in East and Sub-Saharan Africa. Literature has shown that biochar applications are especially effective in nutrient-poor and acidic soils (Elias *et al*., 2020; Elebiyo & Bachmann, 2024). All the methods used in this study followed the procedures described in Elebiyo and Bachmann (2024) without modifications unless stated otherwise.

This study hypothesized that biochar addition would enhance soil organic carbon, while short-term agronomic effects would depend on pre-existing organic carbon levels. It was expected that combining poultry manure or poultry manure biochar with rice husk biochar would outperform RHB alone due to better N, P, and K availability, improving soybean growth, nodulation, and yield. Understanding these interactions is essential for optimizing biochar use in sustainable agriculture and environmental management. This research investigated how different biochar combinations and *Bradyrhizobium* inoculation affect soybean growth and yield in tropical rhodic lixisols. The findings are anticipated to guide effective biochar application strategies in improving global food security.

2. Material and Methods

2.1 Raw materials

The raw materials used in the present study were poultry manure (PM) and rice husk (RH), previously collected from local rice millers and poultry farms (Elebiyo & Bachmann, 2024). These materials were then converted into biochars following the procedures described in Elebiyo and Bachmann (2024). The chemical profile of the resulting biochars has also been previously reported (Elebiyo & Bachmann, 2024).

2.2 Experimental site

This study was conducted at the College of Agriculture, Ejura's Research Farm in Ghana between May and August 2017. The site is situated at a latitude of 07°23′04″ N and longitude 01°21′32″ W, with an elevation of approximately 249 m above sea level (see Fig. 1). The experimental site lies in the forest-savannah transition agro-ecological zone. The criteria for site selection were consistent with those used in Elebiyo and Bachmann (2024).

2.3 Weather

Weather data were obtained from the Ghana Meteorological Agency (GMet). The region experiences a bimodal rainfall pattern, with the major rainy season from mid-March to July and a minor rainy season from September to November.

The average annual rainfall is approximately 1439 mm. Monthly average temperatures range between 21.2℃ and 31.2℃. Relative humidity during the major cropping season averages 86%, while it drops to about 55% during the minor season.

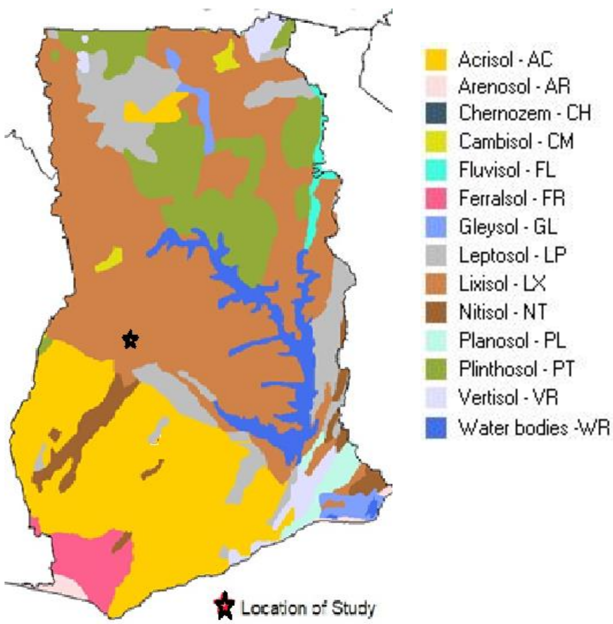

Fig. 1: Soil map of Ghana based Harmonised World Soil Map version 1.21. The dominant soil group at the study site is predicted to be Lixisol

2.4 Soil testing

Standard soil testing procedures were employed to determine key soil properties. Soil pH was analyzed using the method of McLean (1982), and electrical conductivity followed the standard protocol outlined by Rayment and Higginson (1992). Soil organic carbon (SOC) was estimated using the method of Nelson and Sommers (1982). Available phosphorus was assessed using the Bray and Kurtz (1945) method, and total nitrogen was measured according to Bremner and Mulvaney (1982). Exchangeable minerals including calcium, magnesium, and sodium were analyzed as per Brown and Lilleland (1946) and Moss (1961). Total exchangeable acidity (hydrogen and aluminum ions) was determined following the methods outlined by Page *et al*. (1982). Soil texture was determined using the hydrometer method described by Bouyoucos (1962).

2.5 Soil sampling and treatments

Soil sampling and treatment application were conducted following the methods described by Elebiyo and Bachmann (2024). Briefly, poultry manure biochar (PMB) was applied at rates of 2 and 4 Mg ha^{-1}, while rice husk biochar (RHB) was applied at 5 and 10 Mg ha^{-1}. Some RHB treatments were enriched with either dry PM or PMB. Control plots received no biochar amendments and were maintained with plain soil at 10 kg Mg ha^{-1}.

2.6. Soybean seed inoculation

Soybean seed inoculation followed the method described in Elebiyo and Bachmann (2024). Seeds were moistened using gum arabic and inoculated with *Bradyrhizobium japonicum* (SoyCap) at a rate of 10 g per kg of seeds. Each seed was estimated to carry between 10^4 and 10^6 viable rhizobial cells.

2.7 Soybean seed planting

Soybean seeds were planted on June 6, 2017, in the forest-savannah transition zone. Planting was done by placing three seeds per hole at a depth of 5–7 cm. Row spacing was maintained at 60 cm, and intra-row spacing at 10 cm.

2.8 Experimental design

The study employed a randomized complete block design (RCBD) as previously used in Elebiyo and Bachmann (2024). A total of 3 blocks were established, each consisting of 18 plots. In half of the plots, soybean seeds were not inoculated with *B. japonicum*, while the other half received inoculated seeds. In total, the experiment comprised 54 plots, covering a land area of 1295 m². Plots measured 5 m × 3 m, with 2 m spacing between blocks and 1 m between individual plots. The complete layout is summarized in Table 1.

2.9 Fertilizer

Triple superphosphate and potassium (K) were from muriate of potash. Fertilizers were applied to all soybean plots one week after planting using the band method. The application rate for phosphorus was 30 kg P per hectare (ha^{-1}) and potassium was also 30 kg K per hectare (ha^{-1}) respectively (Elebiyo & Bachmann, 2024).

2.10 Measurement of crop parameters

The soybean crops were analysed for dry biomass (shoot, root and total) weight, nodulation, grain yield and harvest index in accordance with methods described in Elebiyo and Bachmann (2024).

2.11 Statistical analysis

The data obtained for nodulation, growth, and yield parameters of soybean were subjected to statistical analysis using GENSTAT (2012 Edition). Analysis of variance (ANOVA) was performed to determine significant differences

Table 1: Soil treatments at experimental site of the forest-savannah transition agro-ecological zone. Values are on Mg ha^{-1} basis (Elebiyo & Bachmann, 2024).

Main plot number	Treatment	Main plot	Split plot		
		B. japonicum	PM	PMB	RHB
1	Plain soil	+	-	-	-
	Plain soil	-	-	-	-
2	10RHB	+	-	-	10
	10RHB	-	-	-	10
3	4PM	+	4	-	-
	4PM	-	4	-	-
4	4PMB	+	-	4	-
	4PMB	-	-	4	-
5	2PM+10RHB	+	2	-	10
	2PM+10RHB	-	2	-	10
6	2PMB+10RHB	+	-	2	10
	2PMB+10RHB	-	-	2	10
7	4PM+5RHB	+	4	-	5
	4PM+5RHB	-	4	-	5
8	2PMB+5RHB	+	-	2	5
	2PMB+5RHB	-	-	2	5
9	4PMB+5RHB	+	-	4	5
	4PMB+5RHB	-	-	4	5

PM - Poultry manure, PMB - Poultry manure biochar and RHB - Rice husk biochar between treatments after significant mean values were separated using the Duncan Multiple Range Test (DMRT) at the probability level of 5%.

3. Results and Discussion

3.1 Soil characteristics

The general characteristics of the soil at the experimental site were found to be similar to those of our previous study (Elebiyo & Bachmann, 2024). The soil type, however, was found to be rhodic lixisol (FAO/UNESCO Soil Map of the World Legend; Adu, 1992; Sys *et al*., 1993). The pH tests revealed that the chemical characteristics were very acidic (pH = 5.44). The pH is, however, found lower than that reported for ferric acrisol (Elebiyo & Bachmann, 2024). The SOC content was 0.39% and was found marginally appropriate for soybean cultivation; the SOC of a previous study was found to be moderate (Elebiyo & Bachmann, 2024) (Table 2). The characteristics of treated soil at the experimental site are shown in Table 3.

3.2. Growth of Soybeans with biochar-enriched soil and *B. japonicum* on a continuous cropping farm

In the present study, the outcomes of the root dry weight, shoot dry weight, and total plant dry weight of soybeans were not statistically different in their significance ($p < 0.05$) after applying 4 Mg ha^{-1} PM, 10 Mg ha^{-1} RHB and 4 Mg ha^{-1} PMB alone or in combination. Effects of *B. japonicum* coated seed on soybean root, shoot, or total plant dry weights were also found to be statistically similar in their significance ($P > 0.05$) after applying PM, RHB, and PMB alone or in combination. *B. japonicum*-coated seed had no significant ($P > 0.05$) effect on soybean root, shoot, or total plant dry weight (Fig. 2–4).

It is seen from Fig. 3 that 4 kg Mg ha^{-1} PM alone, and in combination with 5 kg Mg ha^{-1} RHB showed an increase in the dry shoot biomass. The findings were comparable to the un-inoculated soybean control samples. In fact, in this study 5 kg Mg ha^{-1} RHB combined with 4 kg Mg ha^{-1} PM showed the highest dry shoot weight relative to

Table 2: Soil physical and chemical properties prior to the experiment for soybean production in a rhodic lixisol of forest-savannah transition agro-ecological zone

Soil parameter	Unit	Rhodic Lixisol	Soil characteristics	Ferric Acrisol	Soil characteristics
pH (1:2.5 H_2O)		5.44	S3	5.64	S2
Electrical conductivity	(dS/m)	0.6	S1	0.6	S1
Organic carbon	(%)	0.39	S3	1.81	S2
Total nitrogen	(%)	0.01	NA	0.03	NA
Available phosphorus	(mg kg^{-1})	8.71	NA	9.4	NA
Calcium	(g kg^{-1})	2.34	NA	2.23	NA
Magnesium	(g kg^{-1})	0.22	NA	0.11	NA
Potassium	(g kg^{-1})	0.26	NA	0.13	NA

Suitability: S1 (high), S2 (moderate), S3 (marginal), N (unsuitable), NA: Not available

Table 3: Nutrient status of treated rhodic lixisol from the forest-savannah transition agro-ecological zone

Soil parameter	10 t RHB	4 t PM	4 t PMB	2 t PM + 10 t RHB	2 t PMB + 10 t RHB	4 t PM + 5 t RHB	4 t PMB + 5 t RHB	2 t PMB + 5 t RHB
Organic carbon	0.71	0.44	0.41	0.74	0.72	0.57	0.57	0.56
Total nitrogen	0.014	0.017	0.016	0.017	0.017	0.018	0.018	0.015
Available phosphorus	17.4	49.1	38.6	37.4	32.2	42.8	42.8	28
Calcium	2.34	2.54	2.42	2.44	2.38	2.42	2.42	2.38
Magnesium	0.226	0.235	0.231	0.233	0.232	0.234	0.234	0.229
Potassium	0.293	0.327	0.291	0.326	0.308	0.307	0.307	0.292

the control. The application of 4 kg Mg ha^{-1} PM, 10 kg Mg ha^{-1} RHB, 4 kg Mg ha^{-1} PMB, 10 kg Mg ha^{-1} RHB + 2 kg Mg ha^{-1} PM, and 5 kg Mg ha^{-1} RHB + 4 kg Mg ha^{-1} PM to the inoculated soybean seeds showed enhanced dry shoot biomass relative to the controls. The application of Mg ha^{-1} RHB + Mg ha^{-1} PMB in varying formulations on the contrary showed poor results, implying that more organic amendment is required.

From Fig. 4 it can be seen that inoculated soybeans treated with Mg ha^{-1} PM and Mg ha^{-1} RHB alone or in combination yielded high dry root biomass. In Fig. 5 it is obvious that PM and RHB are promising sources of nutrients to the inoculated soybean seeds.

5 kg Mg ha^{-1} RHB + 4 kg Mg ha^{-1} PM (18.02 g plant^{-1}) had the highest dry biomass weight, while 5 kg Mg ha^{-1} RMB + 2 kg Mg ha^{-1} PMB (10.02 g plant^{-1}) had the lowest influence. The findings indicate that PM released nutrients faster than PMB. Technically, PM has a shorter-term effect than PMB on agronomic practices. The findings indicate that the application rate was insufficient to address the nutrient shortfall in a timely manner at the research site, where nitrogen and phosphorus levels were low, organic matter was low, and the soil was acidic. The treatments with *B. japonicum* produced decent but not substantial results. PM is a more effective enhancer than PMB, which releases nutrients slowly. Our findings are congruent with those of Wu *et al*. (2022), who found that an optimum biochar application rate was effective in generating stable yields or yield increases under continuous cropping settings. It was also reported by Wu *et al.* (2022) that biochar applications increased the total root volumes relative to control samples. In the present study, the pH (7.88) of the PM-treated soils is close to the pH (7.39) of one of the biochar-treated soils in Wu *et al*. (2022), which showed about a 28.06% increase in total root volumes compared to control samples.

The study by Yusif *et al.* (2019) is of significance owing to the fact that acidic soils treated with 40 t ha^{-1} of biochar at 8 weeks after sowing resulted in taller plants. Increasing the quantity of biochars to 60 t ha^{-1} led to an improvement in the number of leaves. The optimal biochar rate for the highest shoot dry weight, root dry weight, and nodules was found to be 70 t ha^{-1}, 10 t ha^{-1}, and 50 t ha^{-1} respectively.

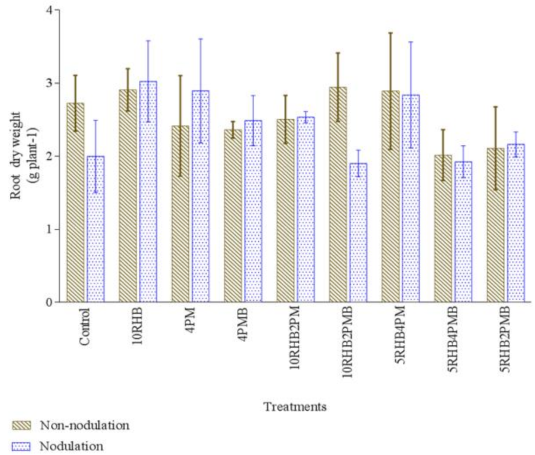

Fig. 2: Root dry weight of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Shoot dry weight is not significantly different (*p<0.05*).

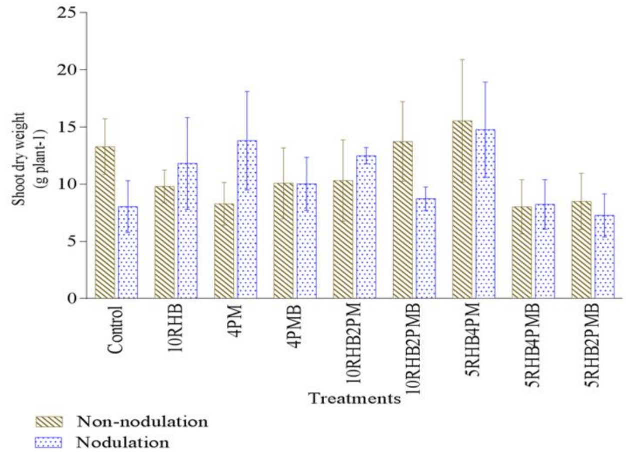

Fig. 3: Shoot dry weight of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Shoot dry weight is not significantly different (*p<0.05*).

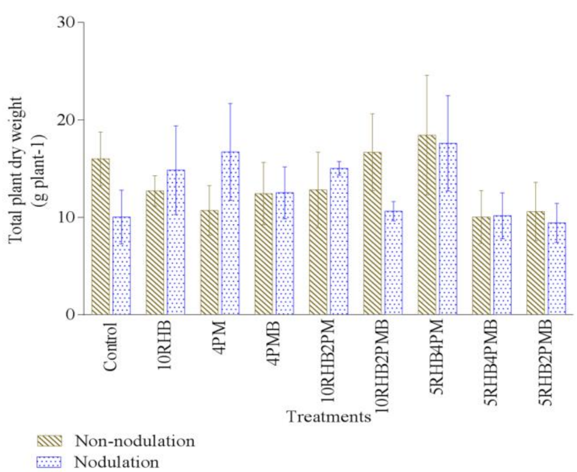

Fig. 4: Total plant dry weight of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Total plant dry weight is not significantly different (*p<0.05*).

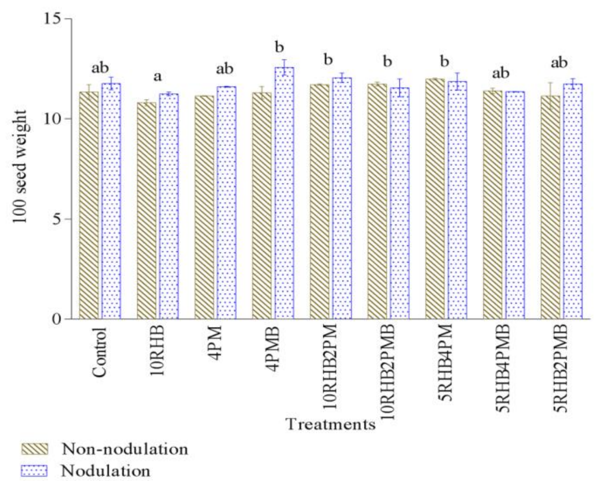

Fig. 5: 100 seed weight of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Total plant dry weight is not significantly different (*p<0.05*).

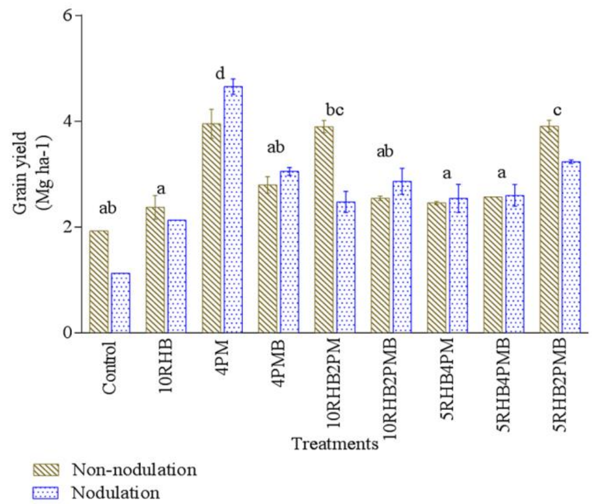

Fig. 6: Grain yield of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Bars with the same letters are not significantly different (*p<0.05*).

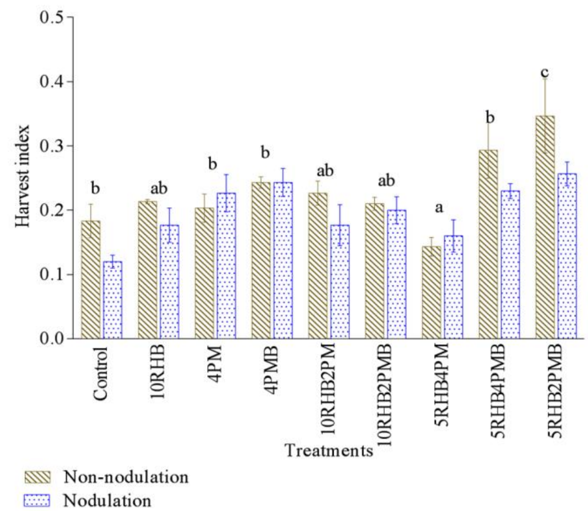

Fig. 7: Harvest index of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Bars with the same letters are not significantly different (*p<0.05*).

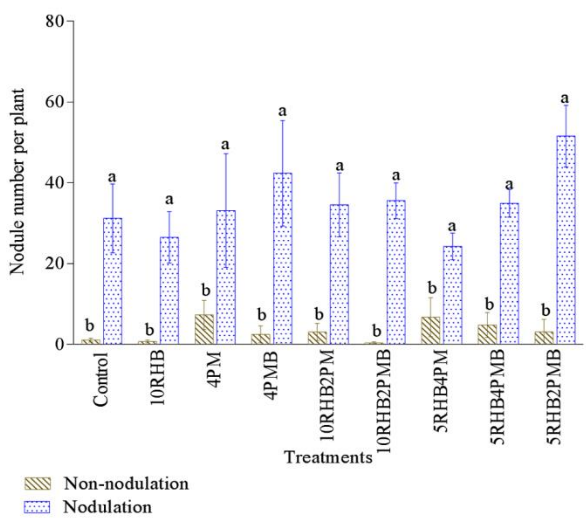

Fig. 8: Nodule number per plant of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Bar with the same letters are not show significantly different (*p<0.05*).

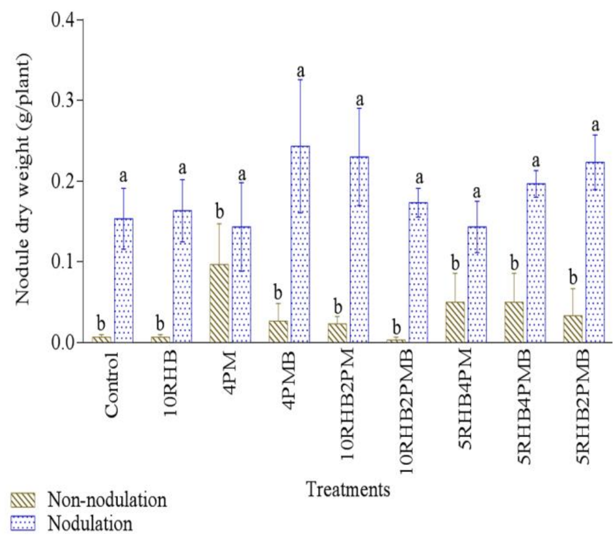

Fig. 9: Nodule dry weight per plant of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Bars with the same letters are not significantly different (P<0.05).

In line with our previous experiment (Elebiyo & Bachmann, 2024), biochar greatly increased the growth and yield of soybean crops in the ferric acrisol of Ghana's Guinea savanna agro-ecological area, where organic carbon levels were moderate, and provided a concept for soybean cultivation. It indicates that more organic amendment may be required in this area.

In the study by Howard (2011), dry root mass of soybeans was found to depend on whether the seeds were grown in sand or soil. For example, in sand, an increase in dry root biomass was observed at 1.5% biochar compared to control. However, a decrease in dry root biomass was found when biochar application increased to 3.0%. The opposite effects were observed for dry root biomass grown in soils. Biochar at 3% produced the highest dry root biomass in soil, while comparably low results were observed at 1.5% and 6% biochar usage.

In the study by Zhu *et al.* (2018), biochar applications at 1.5% increased total root volumes by 52.1% relative to control samples. Similarly, a 31.5% increase in total root surface area was also evident. Root vitality was found to increase by 225.7–384.7% compared to controls at 7 days after germination. At 10 days after germination, root vitality was 92.7% higher than in the control samples.

In the study by Shekedir (2022), applications of 10 t ha^{-1} biochar and *Rhizobium* were found to boost root dry mass by 1.6-fold (2.06 g) compared to control (1.30 g). Total root volumes were also improved by such applications.

3.3 Soybean 100 seed weight, grain yields, and harvest index using biochar-enriched soil and *B. japonicum* on a continuous cropping farm

Using PM, RHB, and PMB alone or in combination significantly boosted soybean seed weight, grain yield, and harvest index ($p < 0.05$). *Bradyrhizobium* coated soybean seeds had a substantial impact ($P < 0.05$) (Fig. 5–7). Shekedir (2022) showed that for common beans treated with 10 t ha^{-1} biochar + *Rhizobium*, the number of nodules increased by 221.2% compared to the control samples. When lowering the application rate to 10 t ha^{-1} biochar + *Rhizobium*, a 36.52% increase in nodule number was reported compared to controls.

The highest 100-seed weight of soybean was measured with the application of 4PMB (11.94), while the lowest weight was recorded for 10RHB (11.03). The greatest grain yield at harvest was obtained under the application of 4PM (4.306), whereas the lowest was reported for 5RHB4PMB (2.433). The greatest impact on harvest index was recorded for 5RHB2PMB (0.3036), while 5RHB4PM gave the lowest value of 0.1527 PM was more impactful on nutrients due to its stronger response in terms of grain yield.

The increase in soybean grain yield and harvest index might be attributed to both single and combined treatments of PM, RHB, and PMB, as the control showed the lowest yield. The impact was stronger for RHB enriched with PM and PMB than for RHB alone. The results are consistent with Elebiyo and Bachmann (2024), although the yield observed in this study was lower than in a similar experiment conducted on ferric acrisol in a semi-deciduous forest in Ghana, where organic matter was higher. This suggests that additional organic matter is required on rhodic lixisols to improve grain yield and harvest index. It also implies that there is room for further improvement in yield outcomes.

Bradyrhizobium was able to influence 100-seed weight and harvest index, likely due to enhanced P and K availability from the organic amendments aiding nitrogen fixation, although this was insufficient to significantly affect overall yield. *Bradyrhizobium* inoculation, in combination with or separate from applications of PM, RHB, and PMB, has the potential to substantially enhance soybean grain yields.

According to Shekedir (2022), the combination of biochar and *Rhizobium* inoculation had a significant ($P < 0.01$) effect on nodule number, dry biomass, root volume, pod count, and seed yield. When compared to *Rhizobium* inoculation alone, a combined application of 10 t ha^{-1} biochar and *Rhizobium* significantly increased pod and seed production. Similarly, Sun *et al*. (2020) validated that both biochar type and inoculation influenced seedling growth performance. Their findings demonstrated that combined application of 10 t ha^{-1} biochar and *Rhizobium* improved pod number and seed yield compared to *Rhizobium* alone.

Ayalew *et al.* (2021) further reported that inoculation of cowpea with strain CP-24 significantly increased 100-seed weight by 13% relative to the control, although this did not translate into a significant improvement in overall yield.

3.4 Soybean nodule number and nodule dry weight with biochar-enriched soil and *B. japonicum* on a continuous cropping farm

Bradyrhizobium japonicum-coated soybean application significantly increased nodule number and the dry weight ($P < 0.05$) (Fig. 8 and 9). The sole and combined application of PM, RHB, and PMB did not significantly ($P < 0.05$) improve nodule number but caused variation across the treatments. Fig. 8 and 9 revealed that the performance of *B. japonicum* depends on the availability of organic matter and nutrients.

The lowest number of nodules was found in 10RHB (13.60) and control (16.13) plots, while the plot with 5RHB2PMB (27.33) and PMB (22.42) had the most. The control (0.0802) and 10RHB (0.0847) had the lowest dry weights, but the plot amended with 5RHB2PMB (0.1282) and PMB (0.1345) had the greatest.

Overall, the result indicated that inoculation treatments outperformed non-inoculated therapies. This result revealed that the application of *Bradyrhizobium japonicum* stimulates nodulation, particularly in tropical soils with a low native *Bradyrhizobium* strain population, which may be insufficient, and so increased the plant's response to *Rhizobium* strain inoculation (Abaidoo *et al*., 2007). Moretti *et al*. (2018) found that *Rhizobia* inoculation increased soybean nodule dry weight compared to the control. When *B. japonicum* inoculant was applied to soybean, the nodule dry weight and number increased by two to three times compared to the control. The positive increase in nodule number in soybean plants is consistent with the findings of Głodowska *et al*. (2017). Biochar improved nodulation performance, but not significantly. Ofori (2017) found that mixing rock phosphate and *Bradyrhizobium* spp. promoted nodulation in soybean and cowpea by around 61.5%. According to Shamim *et al*. (2015), nodulation increased when biochar and NPK fertilizer were applied together, with the combined application having the greatest influence. Shikha *et al.* (2023) demonstrated that biochar-based *Rhizobium* inoculants boosted nodulation, root weight, shoot weight, nut yield, and soil nutrient uptake in groundnut.

In conclusion, our data show that utilizing alkaline biochars and *B. japonicum*-inoculated seeds in soils without a history of soybean farming can increase the number of nodules. 4PMB and 5RHB2PMB will be effective organic additives for improving soybean nodulation.

4. Conclusion

The findings from the rhodic lixisol in the forest-savannah transition agro-ecology imply that soil pH and organic matter levels should be increased for improved legume yield and nodulation.

PMB outperformed PM in terms of soybean nodule formation. It indicates that nodulation requires slow-release nutrients. The results suggest that nutrient release from PM was faster than that of PMB on soybean crop growth biomass. As a result, PM is more effective in enriching RHB and has a shorter time effect than PMB, which informs agricultural applications. Under a sufficient soil pH, the combined application of PM or PMB could result in a short-term improvement in overall performance.

The soybean's root, shoot, and total plant dry mass remained unchanged ($p > 0.05$) after applying PM, RHB, and PMB alone or in combination, likewise the application of *B. japonicum*-coated seed. Using PM, RHB, and PMB alone or in combination significantly boosted soybean seed weight, grain yield, and harvest index ($p < 0.05$). *Bradyrhizobium japonicum* application resulted in a significant ($P<0.05$) increase in nodule number and dry weight (Fig. 8 and 9). This confirms the study's alternate hypothesis that nutrient-enriched biochar has a higher fertilization potential than RHB or non-biochar. The application of *B. japonicum* coated soybean seeds considerably boosted nodule number and dry weight in a ferric acrisol of the semi-deciduous agro-ecological zone.

The addition of 4 Mg PM and 5RHB2PMB resulted in the maximum number of nodules and grain yield when compared to 10 Mg RHB and 4 Mg PMB because the pH, phosphorus, and potassium levels in the soil were highest. Available phosphorus and potassium were shown to be connected with root, shoot, and total plant dry weight, but NPK in soil appeared to be somewhat correlated with grain ($R2 > 0.46$).

This study illustrates the feasibility of employing PM or 5RHB2PMB as an alternative or addition to synthetic inorganic fertilizer for soybean growth. PMB generated at 350°C should be used instead of PM to reduce odour and weight while retaining nutrients. PMB can also address nutrient shortages in RHB".

The results obtained from the rhodic lixisol in the forest-savannah agro-ecological zone show that there is a need to boost soil pH and organic matter content to improve the production and nodulation of legumes

5. Reference

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