

World News of Natural Sciences

An International Scientific Journal

WNOFNS 66 (2026) 74-85

EISSN 2543-5426

Influence of Rhizobium and NPK on Some Microbial Properties and Yield of Soybean (*Glycine max* L.) in Calabar, Cross River State, Nigeria

Esther Eyo* and Elijah Edet

Department of Soil Science, Faculty of Agriculture, University of Calabar,
Cross River State, Nigeria

*E-mail address: eyoesthereffi@gmail.com

ABSTRACT

This study evaluated the effects of Rhizobium inoculation and organic substrate amendments on soil properties and the growth performance of soybean under controlled conditions. A factorial experiment arranged in a Completely Randomized Block Design (CRBD) was conducted using different substrate treatments and inoculation levels. Soil samples were analyzed before planting, and data were collected on selected soil chemical properties as well as plant growth parameters over a period of twelve weeks. Statistical analysis was carried out using analysis of variance (ANOVA), and significant means were separated using Duncan Multiple Range Test (DMRT) at 5% probability level. The results revealed that the application of Rhizobium inoculation and organic substrates significantly improved soil fertility indicators, including soil pH, organic matter content, and essential nutrients. Similarly, soybean growth parameters such as plant height, number of leaves, and biomass production showed significant improvement under treated conditions compared to the control. The interaction effects between Rhizobium inoculation and substrate types were also significant, indicating the synergistic role of biological and organic inputs in enhancing soil productivity and crop performance. The study concludes that the combined application of Rhizobium inoculation and suitable organic substrates can serve as an effective strategy for improving soil fertility and soybean productivity. It is therefore recommended that farmers adopt integrated soil fertility management practices involving biofertilizers and organic amendments for sustainable agricultural production.

Keywords: Rhizobium inoculation, Soybean, Soil fertility, Organic substrates, Crop productivity, Biofertilizer, Sustainable agriculture, Soil chemical properties, *Glycine max*

1. INTRODUCTION

Soybean (*Glycine max* L.) is one of the most important leguminous crops globally due to its high protein content and its significant role in improving soil fertility through biological nitrogen fixation.

It serves as a major source of plant protein for both human consumption and livestock feed, while also contributing to sustainable agricultural systems. In many developing countries, including Nigeria, soybean production has gained increasing attention as a means of enhancing food security and soil productivity. However, low soil fertility, particularly nitrogen deficiency, remains a major constraint to optimal soybean yield (Sanginga & Woomer, 2009; Vanlauwe et al., 2015).

The use of chemical fertilizers has been widely adopted to address soil nutrient deficiencies, but their high cost, limited accessibility, and environmental implications have raised concerns about their sustainability. Excessive use of inorganic fertilizers has been associated with soil degradation, nutrient imbalance, and environmental pollution (Tilman et al., 2002; Zhang et al., 2015).

Consequently, there is a growing need to explore environmentally friendly and cost-effective alternatives for improving soil fertility and crop productivity. One promising approach is the use of biofertilizers, particularly *Rhizobium* inoculation, which enhances the symbiotic relationship between legumes and nitrogen-fixing bacteria (Babalola, 2010).

Rhizobium species infect the root nodules of legumes and convert atmospheric nitrogen into forms that plants can utilize, thereby reducing the need for synthetic nitrogen fertilizers. Previous studies have shown that *Rhizobium* inoculation significantly improves nitrogen availability, plant growth, and yield in legumes, especially in soils with low native rhizobial populations (Herridge et al., 2008; Giller, 2001).

This makes it a viable strategy for sustainable soil fertility management. In addition to biofertilizers, organic substrates such as compost, manure, and other organic amendments play a crucial role in improving soil structure, increasing organic matter content, and enhancing nutrient availability.

Organic inputs not only supply essential nutrients but also improve soil microbial activity and water retention capacity, thereby creating a favorable environment for plant growth (Lal, 2015; Agegnehu et al., 2017).

The combined use of organic substrates and *Rhizobium* inoculation has been reported to produce synergistic effects, leading to improved soil health and increased crop productivity. Despite these benefits, the adoption of integrated soil fertility management practices involving biofertilizers and organic amendments remains limited in many parts of Nigeria. This is partly due to inadequate awareness, limited access to quality inputs, and insufficient research on their combined effects under local conditions.

Therefore, there is a need for empirical studies that evaluate the effectiveness of these practices in improving soil properties and crop performance (Herridge et al., 2015).

This study was therefore designed to assess the effects of *Rhizobium* inoculation and selected organic substrates on soil chemical properties and the growth performance of soybean. Specifically, the study aims to determine the individual and interactive effects of these treatments on soil fertility indicators and plant growth parameters, with a view to providing sustainable and practical recommendations for improving soybean production.

2. MATERIALS AND METHODS

2. 1. Description of the study area

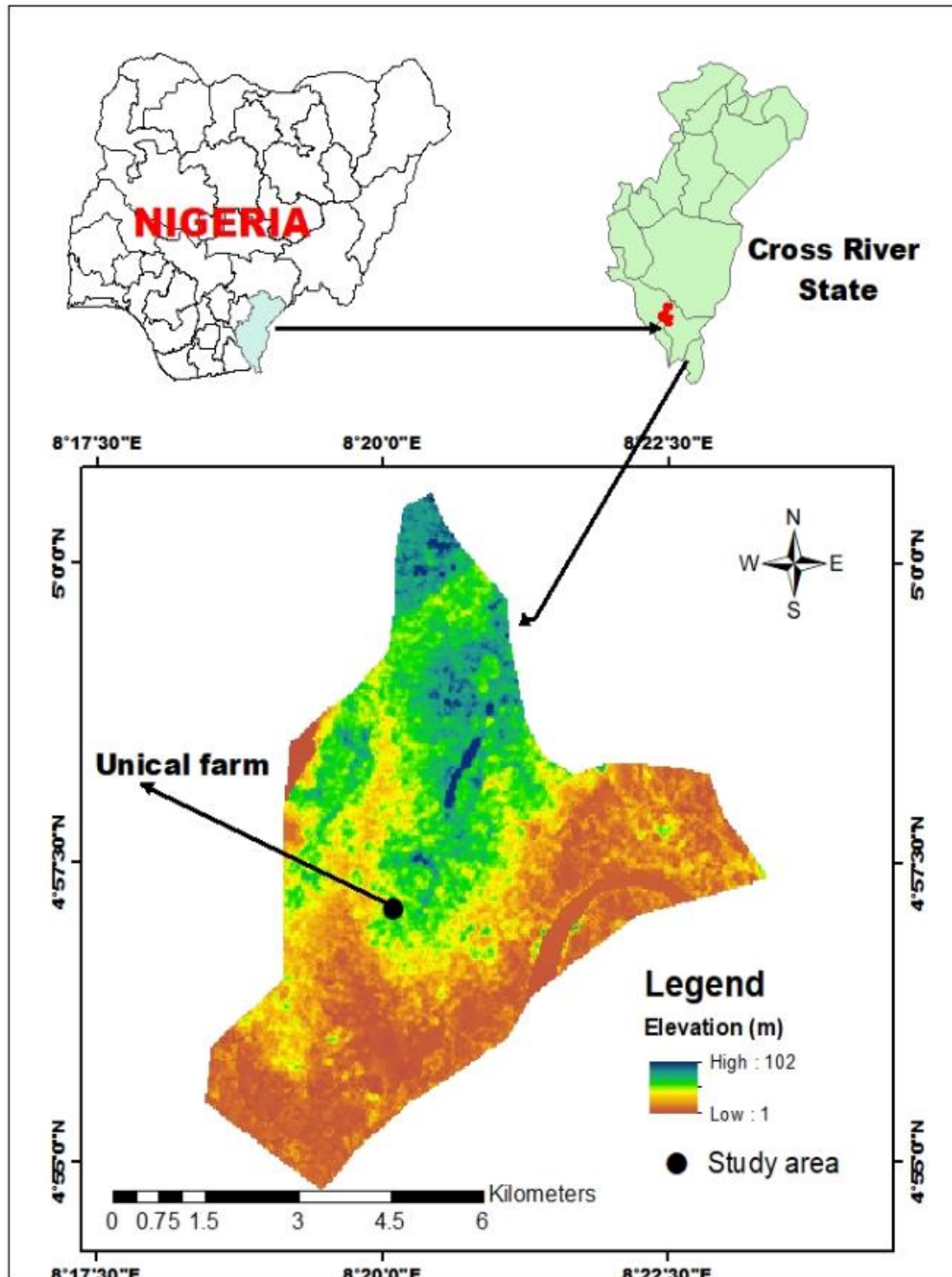


Figure 1. Geological Map of the Study Area.

The experimental site was at University of Calabar Teaching and Research Farm as shown on Figure 1. below. The University of Calabar lies in the tropical rainforest agroecology of the equatorial climate belt of Nigeria (latitude 5° and 5° 40'N, longitude 8° 04' and 8° 62' E) of the Greenwich meridian and altitude of 39 m above sea level. Calabar has a bimodal annual rainfall distribution that ranges from 2,500-3500 mm with several leaching of soil nutrient from the soil. The annual temperature ranges from 22.2 °C - 38.2 °C and relative humidity ranges from 75.90% (NMET 2015). Calabar soils are mainly acidic in nature with low base saturation and high exchangeable aluminium.

2. 2. Soil Sample and Laboratory Analysis

The study was conducted under controlled experimental conditions to evaluate the effects of Rhizobium inoculation and organic substrate amendments on soil properties and the growth performance of soybean. Soil samples used for the experiment were collected from the topsoil (0–15 cm depth) of an agricultural site, air-dried, crushed, and sieved using a 2 mm mesh to remove debris and ensure uniformity. Pre-planting soil analysis was carried out to determine baseline physicochemical properties using standard laboratory procedures. The experiment was arranged in a 2 × 3 factorial layout within a Completely Randomized Design (CRD).

The treatments consisted of two levels of Rhizobium inoculation (inoculated and uninoculated) and three types of organic substrate amendments. Each treatment combination was replicated three times to ensure reliability of results.

The substrates were thoroughly mixed with the soil at appropriate proportions before planting to ensure even distribution. Certified soybean seeds were used for the experiment. Prior to planting, seeds designated for inoculation were treated with an appropriate Rhizobium inoculant following standard inoculation procedures to ensure effective nodulation. Planting was carried out in prepared containers filled with treated soil, and the plants were maintained under uniform environmental conditions throughout the duration of the study. Data collection was carried out over a period of twelve weeks.

Growth parameters measured included plant height, number of leaves, and biomass yield at specified intervals. At the end of the experiment, soil samples were collected from each treatment for post-harvest analysis to determine changes in soil chemical properties such as pH, organic matter content, and essential nutrients. Laboratory analyses of soil samples were conducted using standard methods. Soil pH was determined using a pH meter in a soil-water suspension, organic carbon was determined using the Walkley-Black method, while total nitrogen, available phosphorus, and exchangeable cations were analyzed using appropriate standard procedures. The data obtained were subjected to statistical analysis using analysis of variance (ANOVA) to test for significant differences among treatment means. Where significant differences were observed, Duncan Multiple Range Test (DMRT) was used to separate the means at 5% level of probability. All statistical analyses were carried out using appropriate statistical software.

3. RESULTS

The effects of Rhizobium inoculation and organic substrate amendments on soil chemical properties and soybean growth parameters are presented in Tables 1. The results showed that both treatments, applied individually and in combination, significantly influenced soil fertility

indices and plant growth performance as shown also in Figure 2. The pre-planting soil analysis indicated that the soil was moderately acidic with relatively low levels of essential nutrients, particularly nitrogen and organic matter, suggesting the need for fertility improvement. Following the application of treatments, significant improvements were observed in soil chemical properties. Soil pH increased across treated plots compared to the control, indicating a reduction in soil acidity. Similarly, organic matter content and nutrient levels, including nitrogen and available phosphorus, were significantly enhanced in soils amended with organic substrates and *Rhizobium* inoculation. *Rhizobium* inoculation had a notable effect on nitrogen availability in the soil, with inoculated treatments recording higher nitrogen levels than uninoculated treatments.



Figure 2. Overview of the Agricultural farm.

Table 1. Effect of Treatments on Soil Physicochemical Properties at 2 and 12 Weeks After Planting (WAP).

Treatment	Sand (%)	Silt (%)	Clay (%)	pH (H ₂ O)	OC	TN	Av. P (mg/kg)	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	Al ³⁺	H ⁺	ECEC	BS (%)
2 WAP															
NR ₀	77.35	11.10	11.75	4.90	0.77	0.065	10.75	3.75	1.65	0.11	0.085	0.77	0.81	7.15	78.15
NR ₁₅	69.25	7.15	23.65	5.65	0.61	0.055	13.12	3.17	1.35	0.08	0.075	0.27	1.21	6.03	75.05
NR ₂₅	76.45	13.35	10.65	5.85	0.77	0.055	9.86	4.65	1.55	0.11	0.085	0.36	1.04	7.49	82.15
R ₁₅	74.25	13.05	12.65	5.55	0.75	0.065	12.25	3.55	1.75	0.11	0.085	1.45	1.05	8.04	70.15
R ₂₅	74.25	15.05	10.65	5.55	0.72	0.055	14.05	4.55	1.15	0.12	0.10	0.52	0.73	7.34	82.33
R ₀	60.32	5.15	34.67	5.25	0.37	0.025	11.45	2.62	1.75	0.14	0.11	0.72	0.75	6.17	75.43
F _{cal}	***	***	***	***	***	**	***	***	***	***	***	***	***	***	***
12 WAP															
NR ₀	77.12	15.15	6.75	5.85	1.16	0.33	14.25	3.75	0.61	0.10	0.085	0.17	0.64	5.36	85.13
NR ₁₅	78.20	14.57	7.72	5.92	0.81	0.068	11.40	3.42	0.75	0.10	0.08	0.21	0.77	5.36	78.90
NR ₂₅	73.43	19.15	7.75	6.25	0.75	0.055	18.62	4.75	0.67	0.11	0.08	0.00	0.74	6.38	87.05
R ₁₅	78.90	13.45	7.65	6.07	1.03	0.075	19.34	4.25	0.75	0.11	0.072	0.46	0.43	5.73	84.15
R ₂₅	72.35	15.15	12.65	6.15	3.65	0.315	11.25	4.35	0.75	0.36	0.085	0.00	0.87	6.27	84.55
R ₀	61.25	13.16	25.59	6.25	1.21	0.115	15.86	3.55	0.65	0.11	0.92	0.00	0.93	5.33	83.30
F _{cal}	***	***	***	***	***	NS	***	***	NS	NS	***	***	***	***	***

NR₀ = No rhizobium and no NPK 15:15:15; NR₁₅ = No rhizobium with 15 kg NPK 15:15:15; NR₂₅ = No rhizobium with 25 kg of NPK 15:15:15; R₀ = rhizobium inoculated with no NPK 15:15:15; R₁₅ = rhizobium inoculated with 15 kg NPK 15:15:15; R₂₅ = rhizobium inoculated with 25 kg of NPK 15:15:15; Note: *** and ** denote means significant at 1 and 5 % level of significant; NS = not significant; means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT)

The combined application of Rhizobium and organic substrates resulted in the highest improvement in soil fertility parameters, suggesting a synergistic interaction between biological and organic inputs. The growth performance of soybean was also significantly affected by the treatments. Plant height, number of leaves, and biomass production increased progressively across the treatment combinations compared to the control as presented in Table 3, 4 and 5. Inoculated plants generally exhibited superior growth performance, reflecting the positive impact of biological nitrogen fixation on plant development.

Table 2. Effect of *Bradyrhizobium japonicum* and NPK fertilizer on nutrient concentration (%) in plant tissue of soybeans.

Treatments	2WAP					12WAP				
	Ca	Mg	K	N	P	Ca	Mg	K	N	P
NR ₀	1.30	0.95	2.615	3.05	0.072	1.91	0.42	1.41	1.96	0.11
NR ₁₅	1.32	0.61	1.41	3.07	0.045	0.86	0.52	1.55	2.37	0.33
NR ₂₅	1.71	0.81	1.61	3.07	0.085	1.21	0.52	1.41	1.96	0.11
R ₁₅	1.61	1.06	2.41	3.63	0.085	1.21	0.81	1.55	2.37	0.33
R ₂₅	1.41	0.71	2.85	4.47	0.155	1.91	0.81	2.71	3.37	0.11
R ₀	1.35	0.65	1.55	4.21	0.12	1.21	0.28	1.44	2.94	0.33
Fcal	122.53***	45.33***	37.17***	1854.49***	75.22***	3150***	1017.90	14603.44***	9847.35***	NS

NR₀ = No rhizobium and no NPK 15:15:15; NR₁₅ = No rhizobium with 15 kg NPK 15:15:15; NR₂₅ = No rhizobium with 25 kg of NPK 15:15:15; R₀ = rhizobium inoculated with no NPK 15:15:15; R₁₅ = rhizobium inoculated with 15 kg NPK 15:15:15; R₂₅ = rhizobium inoculated with 25 kg of NPK 15:15:15; Note: *** denote means significant at 1 and 5 % level of significant; NS = not significant; means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT)

Table 3. Effects of *Bradyrhizobium japonicum* and NPK fertilizer on number of leaves of soybeans.

Treatments	2WAP	4WAP	6WAP	8WAP	12WAP
NR ₀	4.75	5.0	19.25	8.50	30.25
NR ₁₅	6.75	12.25	16.50	8.0	25.75
NR ₂₅	6.25	15.25	29.75	43.25	58.0
R ₁₅	7.5	6.50	22.50	33.25	47.75
R ₂₅	6.25	15.25	29.75	43.25	58.0
R ₀	6.75	12.0	21.25	32.50	36.50
Fcal	NS	26.01***	50.19***	1213.07***	42.66***

NR₀ = No rhizobium and no NPK 15:15:15; NR₁₅ = No rhizobium with 15 kg NPK 15:15:15; NR₂₅ = No rhizobium with 25 kg of NPK 15:15:15; R₀ = rhizobium inoculated with no NPK 15:15:15; R₁₅ = rhizobium inoculated with 15 kg NPK 15:15:15; R₂₅ = rhizobium inoculated

with 25 kg of NPK 15:15:15; Note *** denote means significant at 1 and 5 % level of significant; NS = not significant; means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT)

Table 4. Effects of *Bradyrhizobium japonicum* and NPK fertilizer on plant height (cm) of soybeans.

Treatments	2WAP	4WAP	6WAP	8WAP	12WAP
NR ₀	9.75	8.50	17.25	24.9	32.0
NR ₁₅	13.60	11.50	18.57	44.9	51.5
NR ₂₅	18.15	24.30	33.72	61.8	81.0
R ₁₅	16.67	23.32	29.42	42.8	70.5
R ₂₅	18.15	24.30	33.72	61.8	81.0
R ₀	16.05	17.87	25.75	33.2	50.23
Fcal	745.06***	209.58***	47.42***	43.05***	2234.34***

NR₀ = No rhizobium and no NPK 15:15:15; NR₁₅ = No rhizobium with 15 kg NPK 15:15:15; NR₂₅ = No rhizobium with 25 kg of NPK 15:15:15; R₀ = rhizobium inoculated with no NPK 15:15:15; R₁₅ = rhizobium inoculated with 15 kg NPK 15:15:15; R₂₅ = rhizobium inoculated with 25 kg of NPK 15:15:15; Note: *** denote means significant at 1 and 5 % level of significant; NS = not significant; means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT)

Table 5. Effects of *Bradyrhizobium japonicum* and NPK fertilizer on yield of soybeans.

Treatments	Nodules	Dry pod	Wet pod	Dry weight	Wet weight
NR ₀	44.5	9.57	57.4	16.45	98.7
NR ₁₅	75.8	14.51	87.1	17.89	107.3
NR ₂₅	111.2	15.40	92.4	60.64	363.9
R ₁₅	217	22.67	136	129.69	778.1
R ₂₅	287.2	15.40	92.4	60.64	363.9
R ₀	151.5	13.93	83.5	85.26	511.5
Fcal	1049***	6.32***	6.32***	7255.29***	7255.29***

NR₀ = No rhizobium and no NPK 15:15:15; NR₁₅ = No rhizobium with 15 kg NPK 15:15:15; NR₂₅ = No rhizobium with 25 kg of NPK 15:15:15; R₀ = rhizobium inoculated with no NPK 15:15:15; R₁₅ = rhizobium inoculated with 15 kg NPK 15:15:15; R₂₅ = rhizobium inoculated with 25 kg of NPK 15:15:15; Note: *** denote means significant at 1 and 5 % level of significant; NS = not significant; means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT).

Among the treatments, the combination of Rhizobium inoculation and organic substrate amendment produced the highest values for all measured growth parameters. Significant interaction effects were observed between Rhizobium inoculation and substrate types, indicating that the response of soybean growth and soil properties depended on the combined influence of both factors as shown on Table 5.

The results as presented on Table 6. consistently showed that integrated application of biofertilizer and organic amendments enhanced both soil quality and crop performance more effectively than single applications. Overall, the findings demonstrate that both Rhizobium inoculation and organic substrates play important roles in improving soil fertility and soybean growth, with the combined treatments producing the most favorable outcomes.

Table 6. Effects of *Bradyrhizobium japonicum* and NPK fertilizer on soil microbial properties.

Treatments	Bacterial count ($\times 10^6$ cfug ⁻¹)	Fungal count ($\times 10^3$ cfug ⁻¹)
NR ₀	160	18
NR ₁₅	111	12
NR ₂₅	74	10
R ₁₅	140	21
R ₂₅	54	21
R ₀	128	14

NR₀ = No rhizobium and no NPK 15:15:15; NR₁₅ = No rhizobium with 15 kg NPK 15:15:15; NR₂₅ = No rhizobium with 25 kg of NPK 15:15:15; R₀ = rhizobium inoculated with no NPK 15:15:15; R₁₅ = rhizobium inoculated with 15 kg NPK 15:15:15; R₂₅ = rhizobium inoculated with 25 kg of NPK 15:15:15

4. DISCUSSION

The results of this study demonstrate that the application of Rhizobium inoculation and organic substrate amendments significantly improved both soil chemical properties and the growth performance of soybean. The observed increase in soil nitrogen content in inoculated

treatments can be attributed to the effectiveness of biological nitrogen fixation, where *Rhizobium* bacteria convert atmospheric nitrogen into plant-available forms. This finding is consistent with previous studies which reported that *Rhizobium* inoculation enhances nitrogen availability and promotes better growth in leguminous crops, particularly in soils with low native fertility (Herridge et al., 2008; Ulzen et al., 2016). The improvement in soil organic matter and nutrient status observed in treatments amended with organic substrates further supports the role of organic inputs in enhancing soil fertility. Organic amendments are known to improve soil structure, increase microbial activity, and enhance nutrient cycling, thereby creating a more favorable environment for plant growth.

The results obtained in this study agree with findings by Agegnehu et al. (2017) and Adekiya et al. (2020), who reported significant increases in soil nutrient content and crop yield following the application of organic materials. The increase in soil pH observed in treated soils may also be linked to the buffering capacity of organic matter, which helps to moderate soil acidity and improve nutrient availability. The superior growth performance of soybean observed in inoculated and amended treatments, as reflected in plant height as shown on Table 4., number of leaves as shown on Table 3., and biomass production, can be linked to improved nutrient uptake resulting from enhanced soil conditions. Nitrogen, being a critical nutrient for vegetative growth, plays a major role in cell division and chlorophyll formation, thereby contributing to increased plant vigor.

This is in line with the findings of Giller (2001) and Vanlauwe et al. (2015), who emphasized the importance of integrated soil fertility management practices in improving crop productivity. Furthermore, the significant interaction effects observed between *Rhizobium* inoculation and organic substrates indicate a synergistic relationship between biological and organic inputs. The combined application resulted in greater improvements in both soil properties and plant growth compared to individual treatments as shown on Table 5. This suggests that organic substrates not only supply nutrients but also enhance the activity and effectiveness of *Rhizobium* in nitrogen fixation. Similar synergistic effects have been reported in other studies, where the integration of biofertilizers and organic amendments led to improved soil health and increased crop yield (Sanginga & Woomer, 2009; Adesemoye et al., 2009).

Despite these positive outcomes, it is important to consider certain limitations associated with the use of biofertilizers and organic inputs. The effectiveness of *Rhizobium* inoculation may vary depending on environmental conditions, soil type, and the compatibility of the bacterial strain with the host plant. In addition, the quality and composition of organic substrates can influence their effectiveness, which may result in variability in outcomes. These factors highlight the need for proper selection of inoculants and organic materials, as well as site-specific management practices to achieve optimal results. Overall, the findings of this study reinforce the importance of integrating biological and organic approaches in soil fertility management. The combined use of *Rhizobium* inoculation and organic substrates offers a sustainable alternative to sole reliance on chemical fertilizers, contributing to improved soil health, enhanced crop productivity, and environmentally friendly agricultural practices.

5. CONCLUSIONS

This study has demonstrated that the application of *Rhizobium* inoculation and organic substrate amendments significantly improves soil chemical properties and enhances the growth

performance of soybean. The findings revealed that both treatments, applied individually, contributed to increased soil fertility, while their combined application produced the most pronounced effects, indicating a synergistic relationship between biological nitrogen fixation and organic nutrient supply. The improvement in soil parameters such as pH, organic matter content, and essential nutrients translated into better plant growth, as evidenced by increases in plant height, leaf production, and biomass yield.

These results highlight the effectiveness of integrating biofertilizers and organic amendments as sustainable alternatives to sole reliance on inorganic fertilizers. Based on the findings, it can be concluded that the combined use of Rhizobium inoculation and organic substrates is a viable strategy for enhancing soybean productivity and improving soil health under the prevailing conditions of the study area. This approach not only promotes efficient nutrient utilization but also supports environmentally friendly agricultural practices. It is therefore recommended that farmers adopt integrated soil fertility management practices involving the use of Rhizobium inoculants and organic amendments. Further research is also suggested to evaluate the long-term effects of these treatments under field conditions and across different soil types to enhance their wider applicability.

References

- [1] Adekiya, A. O., Agbede, T. M., Aboyeji, C. M., Dunsin, O., & Ugbe, J. O. (2020). Effects of biochar and poultry manure on soil characteristics and the yield of radish. *Scientia Horticulturae*, 243, 457–463
- [2] Adesemoye, A. O., Torbert, H. A., & Kloepper, J. W. (2009). Plant growth-promoting rhizobacteria allow reduced application rates of chemical fertilizers. *Microbial Ecology*, 58 (4), 921–929
- [3] Agegnehu, G., Srivastava, A. K., & Bird, M. I. (2017). The role of biochar and organic amendments in soil fertility improvement: A review. *Applied Soil Ecology*, 119, 156–170
- [4] Babalola, O. O. (2010). Beneficial bacteria of agricultural importance. *Biotechnology Letters*, 32 (11), 1559–1570
- [5] Chianu, J. N., Nkonya, E. M., Mairura, F., Chianu, J. N., & Akinnifesi, F. K. (2011). Biological nitrogen fixation and socioeconomic factors for legume production in sub-Saharan Africa. *Agronomy for Sustainable Development*, 31 (1), 139–154
- [6] Foyer, C. H., Lam, H. M., Nguyen, H. T., Siddique, K. H. M., Varshney, R. K., Colmer, T. D., & Considine, M. J. (2016). Neglecting legumes has compromised human health and sustainable food production. *Nature Plants*, 2 (8), 1–10
- [7] Herridge, D. F., Peoples, M. B., & Boddey, R. M. (2008). Global inputs of biological nitrogen fixation in agricultural systems. *Plant and Soil*, 311 (1–2), 1–18
- [8] Hungria, M., Nogueira, M. A., & Araujo, R. S. (2015). Soybean seed inoculation with Bradyrhizobium in Brazil: Technological advances and yield improvements. *Agronomy Journal*, 107 (1), 1–10

- [9] Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, 7 (5), 5875–5895
- [10] Masso, C., Ulzen, J., Abaidoo, R. C., & Nolte, C. (2016). Biological nitrogen fixation and grain legume yield responses to inoculation in sub-Saharan Africa. *Agronomy Journal*, 108 (1), 1–11
- [11] Meena, V. S., Maurya, B. R., Verma, J. P., & Meena, R. S. (2016). Potassium solubilizing microorganisms for sustainable agriculture. *SpringerPlus*, 5 (1), 1–11
- [12] Njeru, E. M., Mburu, M. W. K., & Lesueur, D. (2016). Evaluation of rhizobial strains for soybean production in Kenya. *Applied Soil Ecology*, 108, 81–88
- [13] Sanginga, N., Thottappilly, G., & Dashiell, K. (2000). Effectiveness of rhizobia nodulating recent promiscuous soybean selections. *Soil Biology and Biochemistry*, 32 (8–9), 1279–1286
- [14] Thuita, M., Pypers, P., Herrmann, L., Okalebo, J. R., Othieno, C., Muema, E., & Lesueur, D. (2012). Commercial rhizobial inoculants significantly enhance growth and nitrogen fixation of soybean in Kenya. *Biology and Fertility of Soils*, 48 (1), 87–96
- [15] Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, 418 (6898), 671–677
- [16] Ulzen, J., Abaidoo, R. C., Mensah, N. E., Masso, C., & AbdelGadir, A. H. (2016). Bradyrhizobium inoculants enhance grain yields of soybean and cowpea in northern Ghana. *Frontiers in Plant Science*, 7, 1770
- [17] Vanlauwe, B., Descheemaeker, K., Giller, K. E., Huising, J., Merckx, R., Nziguheba, G., Wendt, J., & Zingore, S. (2015). Integrated soil fertility management in sub-Saharan Africa. *Soil*, 1 (1), 491–508
- [18] Zhang, X., Davidson, E. A., Mauzerall, D. L., Searchinger, T. D., Dumas, P., & Shen, Y. (2015). Managing nitrogen for sustainable development. *Nature*, 528 (7580), 51–59
- [19] Zahran, H. H. (1999). Rhizobium-legume symbiosis and nitrogen fixation under severe conditions. *Microbiology and Molecular Biology Reviews*, 63 (4), 968–989
- [20] Peoples, M. B., Herridge, D. F., & Ladha, J. K. (1995). Biological nitrogen fixation: An efficient source of nitrogen for sustainable agricultural production. *Plant and Soil*, 174 (1–2), 3–28