



INFLUENCE OF MYCORRHIZA INOCULATION METHODS AND RHIZOBIAL INOCULANTS ON THE GROWTH AND YIELD OF SOYBEAN (*GLYCINE MAX MERR. L.*) IN CALABAR, NIGERIA

AKPAN, J. F., AFANGIDE, A AND PETER, P. G

Email: joyceakpan60@gmail.com

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ABSTRACT

This study investigated the influence of *Bradyrhizobium japonicum* and two arbuscular mycorrhizal fungi (AMF) inoculation methods (spore and infected roots) on the growth and yield of soybean (*Glycine max Merr. L.*) in Calabar, Cross River State, Nigeria. The land was marked out in three blocks and each block measured 27.5m x 4m. The experiment was laid in a randomized complete block design with six treatments (i. Uninoculated seeds or control, ii. Rhizobial inoculated seeds using mixture of *Bradyrhizobium japonicum* (Br), iii. Mycorrhizal spore inoculants soil (MS), iv. Mycorrhizal infested root inoculant (MIR), v. Dual inoculation with MS and *Bradyrhizobium japonicum* (Br) and vi. Dual inoculation with Mycorrhizal infested root (MIR) and *Bradyrhizobium japonicum* (B). The six treatment were replicated three times to give 18 treatments plots. Soil physico-chemical properties were determined before inoculation showing low nitrogen (0.1%) and phosphorus contents (10.9 mg/kg) and slightly acidic pH (4.9). There was no change in soil textural class before and after inoculation. The inoculation significantly ($P \leq 0.05$) improved plant height with MIR + Br (127.20 cm), nodulation number at blooming stage with MIR + Br (97.00) and maturity stage with MIR + Br (421.00). The percentage of vesicular arbuscular mycorrhiza infection had the highest level with treatment, MIR + Br (71.3%), straw and seeds yield with MIR+Br (4.78 and 3.69 tonnes/ha) respectively. The largest level of phosphorus and nitrogen were with treatments MIR+Br (83.3 mg/kg and 7.53%) respectively. The results emphasize the potential of microbial co-inoculation as a sustainable bio-stimulant strategy for soybean production in Nigeria.

KEYWORDS: *Bradyrhizobium japonicum*, Arbuscular Mycorrhiza, *Glycine max. Merr. L.* Dual inoculation and soil fertility.

INTRODUCTION

Nitrogen is abundant in atmosphere, yet it is the most limiting nutrient for most crops and soil due to leaching of nutrients by rainfall (Akpan *et al.*, 2020). Many researchers have carried out several researches on the improvement of nitrogen fixation and nodulation with rhizobium inoculation and mycorrhizal inoculation on legume crop which have shown efficient nitrogen availability, improvement in nodulation, nitrogen fixation, fruit production, and phosphorus content of the plant due to the symbiotic action (Graham and Vance, 2003). Continuous use of chemical fertilizer and pesticides has contributed to environmental degradation by reducing soil quality through increased soil acidification.

This trend has prompted researchers to intensify investigations into organic soil amendments and biostimulations as sustainable alternatives for improving soil health and mitigation impacts (Udo, 2023). The soil texture of coastal plain soil ranged from sandy loam, loamy sand and sandy clay loam, low organic carbon content below 15mg/kg, ECEC ranging from 2.63 to 5.52 cmol/kg indicating limited nutrient capacity and pH ranged from 4.5-6.5 (Akpan *et al.*, 2023, Akpan-Idiok *et al.*, 2012. Recent investigation on the combination of rhizobium, mycorrhizal fungi and legumes have shown an improvement in nodulation, enhancement of nitrogen fixation along with increased in dry weight from 2,170 kg/ha to 3134 kg/ha and

Akpan, J. F., Department of Soil Science, Faculty of Agriculture, University of Calabar, Nigeria

Afangide, A., Department of Soil Science and Technology, Federal University of Technology, Owerri, Imo State, Nigeria

Peter, P. G., Department of Soil Science, Faculty of Agriculture, University of Calabar, Nigeria

Phosphorus content from 36.1 mg/kg to 58.5 mg/kg in soybean plants due to the symbiotic action (Oladele and Awodun, 2019).

In the tropical region, crops such as bean, clover and soybean can symbolically fix nitrogen through mycorrhizal and rhizobial symbiotic relationship. Inoculating soybean with mycorrhiza provide adequate number of bacteria in the soybean root zone for effective nodulation to take place (Ibrahim *et al.*, 2024 and Udo *et al.*, 2023). According to Omeke *et al.*, 2022, it was reported that nodulation did not take place mostly until P content were at 0.18%. Co-inoculation increased plant height of soybean by 25%, weight of dry seeds by 30% and weight of dry root by 40% compared to non-inoculated seeds (control) (Barea *et al.*, 2005).

The combination of rhizobium and mycorrhizal fungi has been shown to significantly enhance nitrogen uptake in soil, producing increase ranging from 28.6% to 93.07% compared to single inoculants or non-inoculated (control). Similarly, microbial biomass increased by 67.7% to 72.80% and mycorrhizal inoculation increased by 35.55% to 43.89% relative to single inoculation. It was reported by Zhang *et al.*, 2022 that AMF and crop yield had a significant positive effect on grains yield with an average increase of 15.9%. Co-inoculation strategies combining rhizobia with arbuscular mycorrhizal fungal (AMF) can enhance soybean nodulation from 4 to 23 by Ishaq *et al.*, 2023, Igiehon and Babalola, 2021. Co-inoculation improves nitrogen and phosphorus uptake, mitigates drought-induced stress and enhances root water status. According to Ishaq *et al.*, 2023, co-inoculated of rhizobium and AMF in soybean grown in Ultisol significantly increased nodules from 8 to 48, soil total nitrogen from 19.0mg/kg to 58.5mg/kg and grain yield from 1.5ton/ha to 2.8ton/ha compared to single inoculation or un-inoculated which served as control.

The efficacy of rhizobial inoculation is influenced by optimal results observed in a well-drained soil with exhibiting a pH of 6.0-7.0 (Brockwell *et al.*, 1995). Also, temperature, organic matter accumulation, available P, soil moisture and soil texture can also affect the inoculation of rhizobia. Rhizobial and mycorrhizal activities in soil reduce acidic level in soil from 4.9 to 7.6 (Berthán *et al.*, 2020).

Globally, soybean (*Glycine Merr. L.*) is highly valuable crop with high protein content. It can fix nitrogen from air into the soil thereby reducing the need for synthetic fertilizer.

It is used in crop rotation system, improving soil health and reducing pests and diseases (Omeke *et al.*, 2022 and Cummings *et al.*, 2009). It is however very important to evaluate the influence of *Bradyrhizobium japonicum* and two mycorrhizal

inoculation methods of *Rhizophagus irregularis* on the growth and yield of soybean (*Glycine max Merr L.*) in Calabar, Cross River State.

MATERIALS AND METHODS

The experiment was conducted at Faculty of Agriculture Research and Teaching Farm, University of Calabar, Nigeria at 2024, cropping season. The area has latitude 5°00'1" and 5°40'1"N and longitude 8°04'1" and 8°62'1"E and 39m above, sea level. The soil is classified as ultisol, typical of the humid tropics with low nitrogen and phosphorus (Enwezor *et al.*, 1989). The land was marked out into three blocks and each block measured 27.5m x 4m. It was divided into 18 plots (6 treatments by 3 replication). Each plot measured 4m by 3m (12m²) with each plot separated from each other by an alley of 1metre. The field maintenance was carried out using hoe and machete for weeding of grasses. The planting distance was 70 cm by 10 cm with 142,857 plants per hectare. Each row had 40 plants and each plot consisted of 6 rows with a total of 240 plants per plot.

The treatments were; (i) uninoculated seeds (control) (ii) Rhizobial inoculated seeds using mixture of *Bradyrhizobium japonicum* (BR) (iii) Mycorrhizal spore inoculated soil (MS), (iv) Mycorrhizal infested root inoculate (MIR), (v) Dual inoculation with MS and *Bradyrhizobium Japonicum* (BR) and (vi) Dual inoculation with Mycorrhizal infested root (MIR) and *Bradyrhizobium japonicum* (BR). The soil samples for physical and chemical properties were sampled with the use of soil uger at a depth of 0-15cm from five different points on the field and bulked to have one composite sample. The sample was placed in a well-labeled polythene bag and transported to the Department of Soil Science Laboratory for particle size analysis following the procedures outlined by the International Institute of Tropical Agriculture (IITA), 1979. The soil was also sampled after harvesting based on different treatment conditions, using standardized sampling procedures. The soil designated for inoculation was oven-dried for 24 hours and subsequently allowed to cool prior to inoculants application. This step ensured the removal of potential contaminants and provided a controlled medium for inoculation. The inoculated seeds were inoculated with *Bradyrhizobium inocula* containing viable *rhizobial* cells in amount of 10⁵ cell per ml to enhance good nodulations while *mycorrhizal* inoculation was carried out just before sowing with the rate of 15-30 spores per seed and 9g of MIR for each gram of seeds.

The following plant parameters were taken (i) plant height at 2,4,6,8,10 and 12 weeks after planting (ii) number of fruits and leaves at 2,4,6,8,10 and 12 weeks after planting (iii) number of nodules at blooming stage and maturity (iv) mycorrhizal inoculation methods and *Bradyrhizobium* inoculation on percentage of VAM infection (v) Mycorrhizal inoculation and *Bradyrhizobium* on straw yield in kg/ha and seeds yield in kg/ha (v) content of nitrogen and phosphorus based on *Bradyrhizobium japonicum* and arbuscular mycorrhizal inoculation (vi) physical and chemical properties of the soil before planting.

Data collection was subjected to statistical analysis means were separated using least significant difference at 5% probability level using analysis of variance (ANOVA). Significant

Results and Discussion

Table 1: Physical properties of the soil before and after planting

Before (inoculation)				
Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
0-15	85.0	5.0	10.0	LS
10 weeks after inoculation				
Treatments	Sand (%)	Silt (%)	Clay (%)	
Control (uninoculated)	84.0	6.0	10.0	LS
B. japonicum (BR)	79.0	13.0	6.0	LS
MS	80.0	13.0	7.0	LS
MIR	80.0	12.0	8.0	LS
MS +B. japonicum (MS +BR)	78.0	13.0	9.0	LS
MIR B. japonicum (MIR + BR)	78.0	13.0	7.0	LS

B. japonicum (BR)=Rhizobial inoculated seeds with mixture of *Bradyrhizobium japonicum* (Nodumax), MS=Mycorrhizal spore inoculated soil, MIR=Mycorrhizal infected root inoculated soil, MS + BR = Dual inoculation with MS and *Bradyrhizobium japonicum*, MIR + BR= Dual inoculation with MIR and *Bradyrhizobium japonicum*, control (uninoculated) and Loamy sand (LS).

Table 2: Chemical properties of the experimental plot in University of Calabar Research and Teaching Farm

Treatments	Depth (cm)	pH (H ₂ O)	Organic %	Orgn %	T.N %	Avail P mg/kg	Ca ²⁺	Mg ²⁺	K+	Na+ Cmol/k	H+	Al ³⁺	ECEC	BS %
Before application of treatment														
	0-15	4.9	1.5	2.57	0.1	10.9	2.0	0.2	0.1	0.1	0.4	1.2	4.0	60.0
After application of treatment														
Control (Uninoculated)		4.9	1.5	2.59	0.1	27.7	2.1	0.2	0.1	0.1	0.3	1.1	3.9	64.1
B. japonicum (BR)		6.1	1.6	2.76	0.4	28.1	2.3	0.5	0.3	0.3	0.2	0.4	4.0	85.0
MS		5.8	1.7	2.93	0.2	21.5	2.3	0.6	0.3	0.3	0.2	0.3	4.0	87.0
MIR		5.9	1.7	2.93	0.3	21.3	2.3	0.5	0.4	0.3	0.2	0.4	4.1	85.4
MS + BR		6.7	2.2	3.79	0.5	28.5	2.7	0.6	0.3	0.3	0.1	0.5	4.5	86.7
MIR + BR.		6.8	2.4	4.14	0.6	32.8	2.9	0.9	0.4	0.4	0.1	0.3	4.6	92.0

B. japonicum (BR)= Rhizobial inoculated seeds with mixture of *Bradyrhizobium japonicum* (Nodumax), MS=Mycorrhizal spore inoculated soil, MIR=Mycorrhizal infected root inoculated soil, MS + BR = Dual inoculation with MS and *Bradyrhizobium japonicum*, MIR + BR= Dual inoculation with MIR and *Bradyrhizobium japonicum*, control (uninoculated) and loamy sand (LS).

Table 3: Plant height of soybean in relation Bradyrhizobium japonicum and mycorrhizal inoculation method

Treatments	PH2 WAP (cm)	PH 4 WAP (cm)	PH 6 WAP (cm)	PH 8 WAP (cm)	PH 10 WAP (cm)	PH 12 WAP (cm)
Control	20.47	36.10	60.40	70.73	86.17	89.37
B japonicum	22.70	39.40	68.93	72.60	89.27	90.43
MS	23.23	45.23	65.50	75.63	85.13	89.30
MIR	25.43	53.10	69.70	76.00	88.60	91.30
MS +BR	25.73	58.10	11.27	84.17	90.60	104.23
MIR + BR	29.27	59.30	74.53	88.37	94.30	127.20
F-stat	21.29	157.79	100.38	31.13	1093.38	3128.50

B. japonicum (BR)= Rhizobial inoculated seeds with mixture of *Bradyrhizobium japonicum* (Nodumax), MS=Mycorrhizal spore inoculated soil, MIR=Mycorrhizal infected root inoculated soil, MS + BR = Dual inoculation with MS and *Bradyrhizobium japonicum*, MIR + BR= Dual inoculation with MIR and *Bradyrhizobium japonicum*, control (uninoculated) and loamy sand (LS).

Table 4: Nodulation response of soybean in relation to *Bradyrhizobium japonicum* and mycorrhizal inoculation methods at blooming and matured stage

Treatments	Blooming stage	Maturity stage
Control (inoculated)	2.00	11.00
<i>B. japonicum</i> (BR)	23.00	311.00
MS	40.33	262.00
MIR	62.67	130.00
MS + BR	72.33	386.00
MIR + BR	97.00	421.00
F-stat	1389.05	21.12

B. japonicum (BR)= Rhizobial inoculated seeds with mixture of *Bradyrhizobium japonicum* (Nodumax), MS=Mycorrhizal spore inoculated soil, MIR=Mycorrhizal infected root inoculated soil, MS + BR = Dual inoculation with MS and *Bradyrhizobium japonicum*, MIR + BR= Dual inoculation with MIR and *Bradyrhizobium japonicum*, control uninoculated and loamy sand (LS).

Table 5: Influence of mycorrhizal inoculation method and *Bradyrhizobium japonicum* on vesicular arbuscular mycorrhiza infection percentage at blooming stage

Treatments	Percentage (%)
Control (uninoculated)	27.0
<i>B. Japonicum</i> (BR)	51.0
MS	54.0
MIR	62.0
MS + BR	68.9
MIR + BR	71.3

B. japonicum (BR)= Rhizobial inoculated seeds with mixture of *Bradyrhizobium japonicum* (Nodumax), MS=Mycorrhizal spore inoculated soil, MIR=Mycorrhizal infected root inoculated soil, MS + BR = Dual inoculation with MS and *Bradyrhizobium japonicum*, MIR + BR= Dual inoculation with MIR and *Bradyrhizobium japonicum*, control (uninoculated) and Loamy sand (LS).

Table 6: Response of straw and seeds yield in kg/ha to mycorrhizal and rhizobial inoculation

Treatments	Seed yield	Seeds tones/ha	Straw kg/ha	Straw yield in tones
Control (uninoculated)	1,663	1.66	2,047	2.00
<i>B. Japonicum</i> (BR)	1,820	1.82	2,195	2.20
MS	1,921	1.92	2,416	2.42
MIR	2,370	2.37	3,128	3.13
MS + BR	3,563	3.56	3,574	3.51
MIR + BR	3,694	3.69	4,975	4.98

B. japonicum (BR)= Rhizobial inoculated seeds with mixture of *Bradyrhizobium japonicum* (Nodumax), MS=Mycorrhizal spore inoculated soil, MIR=Mycorrhizal infected root inoculated soil, MS + BR = Dual inoculation with MS and *Bradyrhizobium japonicum*, MIR + BR= Dual inoculation with MIR and *Bradyrhizobium japonicum*, control (uninoculated) and loamy sand (LS).

Table 7: Influence of inoculation with mycorrhiza and *Bradyrhizobium japonicum* on phosphorus and nitrogen uptake by soybean (*Glycine max*)

Treatments	Phosphorus Mg/kg	Nitrogen content %
Control (uninoculated)	18.0	2.87
<i>B. japonicum</i> (BR)	43.2	5.31
MS	58.5	3.54
MIR	71.1	3.61
MS + BR	69.4	5.82
MIR + BR	83.3	7.53

B. japonicum (BR)= Rhizobial inoculated seeds with mixture of *Bradyrhizobium japonicum* (Nodumax), MS=Mycorrhizal spore inoculated soil, MIR=Mycorrhizal infected root inoculated soil, MS + BR = Dual inoculation with MS and *Bradyrhizobium japonicum*, MIR + BR= Dual inoculation with MIR and *Bradyrhizobium japonicum*, control uninoculated and loamy sand (LS).

Soil physical properties of the soil before and after inoculation.

Before the application of mycorrhizal inoculation treatments and *Bradyrhizobium japonicum* inoculants, the soil texture had sand (85.0%), silt (5.0%) and clay 10.0%. based on this particle size distribution, the soil was classified as loamy sand. After the inoculation of different treatments, there was no change in the soil texture as shown in Table 1 (Akpan et al., 2023). There was a change in pH value from 4.9 to the range of 5.8-6.8 after the application of the treatments. The initial value of organic carbon was 1.5% but increased to the range of 1.6 -2.4% with MIR + BR having the highest value (2.4%) as shown in Table 2. Dual inoculation of MS + BR (0.5%) and MIR + BR (0.6%) enhanced growth due to synergistic nutrient uptake with nitrogen fixation by rhizobia and phosphorus acquisition with Ms +Br (28.5mg/kg) and MIR +Br (32.8mg/kg) by AMF (Kabiru et al., 2024). At 12 WAP, treatment with MIR + BR (127.20cm) statistically ($P \leq 0.05$) had higher plant height than other treatments and control or uninoculated (89.37cm) as shown in (Table 3). At maturity stage, dual inoculation with MIR +BR (421.00) produced the highest nodulation, followed by treatment with MS + BR (386.00) and single inoculation of *B.japonicum* (Br) with 311 which enhanced nitrogen fixation (Table 4). Single application with treatment MIR and MS produced nodules of 130 and 262 respectively at maturity slightly increased nodulation by improving phosphorus availability (Akpan et al., 2020 and Adeshina et al, 2024). At Bloming stage, the percentage of vesicular arbuscular mycorrhiza infection varied significantly among treatments with the MIR + BR (71.3%)> Ms + BR (68.9%)> MIR (62.0%)> MS (54.0%) >BR (51.0%)> control (27.0%) as presented in Table 5.

The result indicated distinct variations in seed yield (tonnes/ha) among the different treatments (Table 6). The control recorded the lowest mean value (1.66 tonnes/ha), indicating poor growth performance in the absence of microbial inoculation. The inoculation with *Bradyrhizobium japonicum* (BR) alone (1.92 tonnes/ha) enhanced root development and phosphorus uptake. MIR (2.37tonnes/ha) produced a higher response due to improve nutrient availability within the root zone. Combined inoculations with MS + BR (3.56 tonnes/ha) and MIR + BR (3.69 tonnes/ha) gave the highest values, revealing strong synergistic interaction between the microbial treatments (Bobo, 2016). The performance trend was control <BR < MS < MIR< MS + BR <MIR+ BR. These results confirm that dual inoculation significantly enhanced growth compared to single inoculation or control. The synergistic interaction between *Bradyrhizobium japonicum* and Arbuscular Mycorrhizal Fungi (AMF) enhanced nutrient uptake and promoted superior plant vigor.

Phosphorus and nitrogen contents were significantly higher in the inoculated treatments compared with control. The control had the lowest P (18.0mg/kg⁻¹) and N(2.87%) values. *Bradyrhizobium japonicum* alone improved P (43.2 mg/kg⁻¹) and N(5.31%), confirming its role in biological nitrogen fixation (Hungria & Vargas, 2000). Mycorrhizal treatments (MS was 58.5 mg/kg, MIR was 71.1mg/kg^s) also enhanced nutrient uptake through improved root surface area (Smith and Read, 2008). Combined inoculations resulted in the highest nutrient values, particularly the MIR + BR treatment (83.3mg/kg P, 7.53% N), demonstrating a pronounced synergistic interaction between AMF and *Bradyrhizobium japonicum* (Njeru, 2018). This co-inoculation significantly enhanced phosphorus solubilization and nitrogen assimilation, consistent with the findings (Barea, 2025).

Improved nutrient absorption reflects active microbial, root associations and enhanced soil enzyme activity (Miransari, 2011). These findings confirm that integrated biofertilization significantly improves soil fertility (Adesemoye & Kloepper, 2009).

SUMMARY

This study evaluated the influence of *Bradyrhizobium japonicum* and two arbuscular mycorrhizal fungi (AMF) inoculation methods (spore and infected roots) on the growth and yield of soybean (*Glycine max* Merr L.) under soil condition in Calabar, Cross River State, Nigeria. the experiment was laid in a randomized complete block design (RCBD) comprising six treatments; control (uninoculated soil), rhizobial inoculated seeds using mixture of *Bradyrhizobium japonicum* (BR), Mycorrhizal spore inoculated soil (MS), Mycorrhizal infested root inoculants (MIR), dual inoculation with MS and *Bradyrhizobium japonicum* (MS +BR) and dual inoculation with mycorrhizal infested root and *Bradyrhizobium japonicum* (MIR + BR). Growth and yield parameters including nodulation, vegetative growth and grain yield were evaluated.

Prior inoculation, soil analysis revealed an acidic reaction (4.9) with low total nitrogen (0.1%), available phosphorus (10.9mg/kg) and exchangeable base, indicating low inherent soil fertility. After inoculation, pH ranged from 5.8-6.8, total nitrogen (0.2-0.6%) and available phosphorus (21.3-32.8mg/kg) as shown in Table 2. Dual inoculation significantly ($p \leq 0.05$) enhanced plant height with MIR + BR (127.20cm) at 12 WAP. Similarly treatment (MIR +BR) produced the highest nodule formation of 421.00, VAM infection (71.3%), seeds yield (3.69 t/ha), phosphorus and nitrogen content were 83.3mg/kg and 7.53% respectively.

The synergistic interaction between *B. japonicum* and AMF improved both nitrogen fixation and phosphorus uptake, thereby enhancing soil fertility and crop productivity.

These findings demonstrate that co-inoculation of soybean with rhizobia and AMF constitutes a sustainable and environmentally sound biofertilization strategy for optimizing legume production in nutrient deficient tropical soils.

CONCLUSION

The study established that dual inoculation of soybean (*Glycine Max* Merr. L.) with *Bradyrhizobium japonicum* and arbuscular mycorrhizal fungi (AMF) significantly improved plant growth, nodulation and grain yield under acidic and nitrogen-poor soil conditions of Calabar, Cross River State, Nigeria. The synergistic interaction between the two symbionts enhanced both biological nitrogen fixation and phosphorus acquisition, thereby improving overall plant nutrition and productivity.

At the adopted planting distance of 70 X 10 cm (142,857 plant/ha), the dual inoculation treatment recorded the highest per plant yield (18.2g) and a 38% increase in total grain yield relative to the uninoculated soil (control). These results demonstrate that microbial co-inoculation offers an efficient, cost-effective and environmentally sustainable biofertilization approach for optimizing soybean performance in nutrient-depleted tropical soils. Continued application of this technology can reduce dependence on synthetic fertilizers and contribute to sustainable agricultural intensification in Nigeria and other sub-saharan African.

RECOMMENDATION

Based on the results of this study, dual inoculation of soybean with *Bradyrhizobium japonicum* and arbuscular mycorrhizal fungi is recommended for improved plant growth, nodulation and grain yield under acidic and nutrient-poor soil conditions. This practice should be encouraged among farmers as a cost-effective and eco-friendly alternative to sole reliance on inorganic fertilizers.

Research institutions and Agricultural Biotechnology centers should prioritize the isolation, characterization and mass production of locally adapted *B. japonicum* and AMF strains for region-specific inoculants formulation.

Dual microbial inoculations should be incorporated into integrated soil fertility management (ISFM) frameworks to promote balanced nutrient cycling and sustain long-term soil productivity.

REFERENCES

- Adesemoye, A. O., and Kloepper, J. W., 2009. Plant-microbes interaction in enhanced fertilizer – use efficiency. *Applied Microbiology and Biotechnology*, 85, 1-12.
- Adeshina, D. A. Chuwang, P. Z., Odoh, N. C. and Adeboye, S. E., 2024. Effect of rhizonal inoculation on nodulation, growth and yield of soybean in the savanna region of Nigeria. *International Journal of Horticulture and Food Science*, 8(2), 10-17.
- Akpan, Idio, A. U. and Ukwang, E. E., 2012. Characterization and classification of coastal plain soils in Calabar, Nigeria, *International Journal of Agricultural Research*, 7(7), 358-366.
- Akpan, J. F., Ijah, C. J., Isong, I. A., Umunnakwe and Aberagi, F. V., 2023. Distribution of soil organic carbon and important soil nutrient ratios along toposequence in human tropics in Nigeria. *Agro- Science*, 22 (4), 51-63.
- Akpan, J. F., Ubi, G. M. and Njokw, R. N., 2020. Influence of Algal biofertilizers on fruit lignifications time interval, DNA concentration and Agro-morphological characteristics in Okro (*Abelmoschus esculentus* Moench. *Annual Research and Review in Biology*, 35(3), 63-73.
- Barea, J. M., Azcon, R. and Azcon-Aguilar, C., 2005. Interactions between mycorrhizal fungi and bacteria to improve plant nutrient cycling and soil structure. In F. Buscot and S. Verima (Eds), *Microorganisms in soils. Soil Biology Series*, 3; 195-212.
- Beitham, M., Lestari, P. and Handayani, S., 2020. Combined inoculation of *Glomus* spp. And *Bradyrhizobium japonicum* improves soybean growth on coastal plain sand. *Journal of Sustainable Agriculture and Environment*, 18(2), 75-86.
- Bobo, B., Asefa, F. and Zebene, A., 2016. Diversity and abundance of arbuscular mycorrhizal fungi under different plant and soil properties in sidama, southern Ethiopia. *Advance in Bioscience and Bioengineering*, 4(3), 16-24.
- Brockwell, J., Bottomley, P. J. and Thies, J. E., 1995. Manipulation of Rhizobia Microflora for improving legume productivity and soil fertility: a critical assessment. *Plant and Soil*, 174, 1430-180.
- Cummings, S. P., Gyaneshwar, P., Vinuesa, P. Farruggia, F. T., Andrews, M. and Janes, E. K., 2009. Nodulation of sesbania species by *Rhizobium* (*Agrobacterium*) strain IRBG 74 and other rhizobia. *Environmental Microbiology*, 11(10), 2510-2525.

- Enwezor, W. D., Udo, E. J. and Sobulu, R. A., 1989. Fertility status and productivity of the acid sand in south eastern Nigeria. Monograph I. Soil Science Society of Nigeria, 56-73.
- Graham, P. H. and Vance, C. P., 2003. Legumes: importance and constraints to greater use. *Plant physiology*, 131(3), 872-877.
- Hungria, M. and Vargas, M. A. T., 2000. Environmental factors affecting N₂ fixation in grain legumes in the tropics. *Field crops research*, 55: 151-164.
- Ibrahim, M., Ahmad, A., Ezra, A. G. and Nayaya, A. J., 2024. Effect of Arbuscular mycorrhizal fungi on the growth and yield of soybean (*Glycine max* L. Merrill) in Bauchi, *Nigerian Journal of Global Agriculture and Ecology*, 16(3): 30-40.
- Igiehon, N. and Babalola, O. O., 2021. Rhizobium and Mycorrhizal fungal species improved soybean yield under drought stress condition. *Current Microbiology*, 78, 1615-1627.
- International institute tropical agriculture (IITA), 1979. Selective methods for soil and plant analysis. Manual sense No.1: Ibadan, International Institute of Tropical Agriculture (117A).
- Ishaq, L. F., Manehat, I. J. A., Tae; A. S. and Benggu, Y. I., 2023. Dual inoculation of Rhizobium and Arbuscular Mycorrhizal fungi increases soil-total nitrogen, available phosphorus and yield of soybean in vertisols. *Journal of Penelitian Pendidikan*,
- Kabiru, M. R., Buerner, A. B., Dahhani, S., Hafidi, M., Jibrin, J. M. and Jemo, M., 2024. Soybean yield variability and predictability from applied phosphorus sources and rhizobia inoculation in North Nigeria. *Frontiers in sustainable food systems* 8,214-223.
- Miransari, M., 2011. Arbuscular mycorrhizal fungi and nitrogen uptake. *Achievers of microbiology*, 19(2), 77-81.
- Njeru, E. M., 2018. Exploiting diversity to promote arbuscular mycorrhizal symbiosis and crop productivity in organic farming systems, *Journal of AIMS Agriculture and Food* 3(3), 280-294.
- Oladele, S. O. and Awodun, M. A., 2019. Response of maize (*Zea Mays* L.) to mycorrhizal inoculation and organic nutrients sources in a tropical Alfisol. *Nigerian Journal of Soil Science*, 29 (2), 119-129.
- Omeke, J. O., Uzoma, K. C. and Akpan, J. F., 20. Multivariate analysis of soil productivity indicators in the northern guinea savanna agroecology of Nigeria. *Ukrainian Journal of Ecology*, 12(11), 12-22.
- Smith, S. E. and Read, D. J., 2008. *Mycorrhizal/biulowsis* (3rd ed.). Academic press, London UK.
- Udo, I. A., Akpan, J. F., Bello, O. S. and Otie, V. O., 2023. Arbuscular mycorrhizal fungus species different in bio-control potential on pepper genotype infested with *meloidgyne incognita*. *International Journal of Vegetable Science*, 29, 261-274.
- Zhang, L., Zhou, J., George, T. S., Limpens, E. and Feng, G., 2022. Arbuscular mycorrhizal fungi conducting the hyphosphore bacterial orchestra. *Trends in Plant Science*, 27(4), 402-411.