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Soybean Nutrient Management Through *Bradyrhizobium japonicum* Inoculation: A Pathway to Sustainable Agriculture.

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Abstract

Field experiments were conducted to study the impact of *Bradyrhizobium japonicum* inoculation on soybeans in the 2020, 2021, and 2022 cropping seasons at the Research Farm of the Faculty of Agriculture, University of Abuja, Gwagwalada. The experiment included three soybean varieties (TGX 1485-1D, TGX 1448–2E and TGX1987–10F) and two levels of inoculant arranged in a randomized complete block design in 54 plots. Standard agronomic practices were followed, data collected for growth and yield parameters, and analyzed using ANOVA ($P \leq 0.05$) with significant means separated using Duncan's multiple range test (DMRT) with 'agricolae' package in R (version 4.2.2). The mean yield obtained ranged from 2685kg/ha to 3038.5kg/ha for the three different varieties. Inoculated plots performed better in terms of growth and yield parameters compared to the control and is recommended as it is eco-friendly, enhances soil fertility, and positively affects grain yield.

Keyword: Rhizobium, Inoculation, Sustainable Agriculture, Soil fertility and Yield

1. Introduction

Soybean (*Glycine max* (L.) Merrill) is a vital crop with substantial nutritional and economic importance globally. Due to its high protein content and oil, it is essential for food, feed, and industrial use. Soybean is widely grown in Nigeria's middle belt or savannah zone. The production of soybeans has expanded beyond the traditional areas of the middle belt to encompass additional regions in Northern and Southern Nigeria previously considered unsuitable or marginal for soybean cultivation (Otaiku *et al*., 2022). However, constraints such as soil nutrient depletion and deficiencies, low pH, and environmental impacts of chemical fertilizers pose threats to sustainable production, potentially reducing crop yield therefore achieving sustainable soybean production requires efficient nutrient management strategies (Salvagiotti *et al*., 2024).

Soybeans and other leguminous plants can acquire Nitrogen through a biological process known as biological nitrogen fixation (BNF). In this process, the nitrogen-fixing bacteria in the root nodules establish a symbiotic relationship with legumes to fix nitrogen in the soil (Htwe *et al*., 2019). Biofertilization (Rhizobia inoculation) is the process of introducing rhizobium bacteria into the soil before or during the planting of soybeans. This is done using an inoculant with a high concentration of the bacteria to improve biological nitrogen fixation (BNF) (Adeshina, 2023). *Biofertilizers* are natural, non-chemical soil amendments, which are cultures of

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microorganisms packed in a carrier material; they contain live or latent cells of efficient strains of phosphate solubilizing, biocontrol microbes, nitrogen-fixing, or cellulolytic organisms applied to seeds, soil, or composting areas, which are helpful for the accessibility of nutrients that plants can readily assimilate. Applying biofertilizer in Soybean cultivation can manipulate the root growth and rhizosphere processes to improve nutrient use efficiency, biological nitrogen fixation, and crop productivity simultaneously (Daud *and Zahir*, 2021). This research explores recent advancements in using *B. japonicum* inoculation in Soybean cultivation, examining its impacts on soybean growth, yield, and its role in promoting sustainable agriculture.

2. Materials and Methods

The research was carried out during the rainy seasons of 2020, 2021, and 2022 at the Research Farm (Lat 9° 32N and Long 50° 10E) of the Department of Crop Sciences, Faculty of Agriculture, University of Abuja, Gwagwalada, Federal Capital Territory. Gwagwalada is located in the North Central Zone of the Southern Guinea Savanna in Nigeria, bordered by Niger, Nasarawa, Kogi, and Kaduna (Ishaya and Abaje, 2009).
The study used three improved Soybean varieties: TGX 1485-1D (early maturing), TGX 1448 – 2E (medium maturing), and TGX 1987-10F (medium maturing) and Nodumax, an inoculant designed for soybeans and containing *Bradyrhizobium japonicum,* which were sourced from the International Institute of Tropical Agriculture, Ibadan (IITA). The Nodumax product results from a collaboration between the IITA Business Incubation Platform and the N2Africa comprise more than 1 x 109 *Bradyrhizobium japonicum* strain USDA 110 per gram and was conveniently packaged in an alumino-laminate bag, including Gum Arabic adhesive and detailed user instructions (N2Africa, 2015).
The experimental treatments were laid in a 3 x 2 x 3 factorial of the three soybean varieties (TGX 1485-1D, TGX 1448- 2E, and TGX 1987-10F**)**, two levels of inoculant (without, with inoculant), and three levels of Phosphorus fertilizer (0kg/ha, 20kg/ha, 40kg/ha) in a Randomized Complete Block Design with three replicates. Each replicate consisted of 18 plots; the total plots were 54 plots. The gross plot size was 3m x 3m ($9m^2$) each, while the net plot was 2m x 2m (4m2) each. Data were collected for growth and yield parameters which were subjected to analysis of variance (ANOVA) using the ‘agricolae’ package in the R Statistical Programme (R version 4.2.2), Duncan Multiple Range Test (DMRT) and Standard error (SE) were used to separate significant means at ($P \leq 0.05$) between various traits, yield and among different yield components.

3. Result and Discussion

3.1 Impact of *Bradyrhizobium japonicum* Inoculation on Soybean Growth and Yield

Results obtained from field experiments showed that all inoculated varieties showed higher yields when the inoculants were applied above the control. Producing significantly higher yields in 2020, 2021, and 2022, and in the mean years, showing a significant grain yield difference above the control. This interaction of the varieties and Inoculation (V x I) on the yield (Kg/ha) for the mean year analysis is presented in Table 1. Variety TGX 1987-10F recorded the highest yield at 3038.5kg/ha, TGX 1448-2E with 2842.3kg/ha, and TGX 1485-1D with 2685kg/ha, respectively.
This may be attributed to the abundant rhizobia introduced, which positively increased the biological nitrogen fixation and made nutrients more available to the soybean for efficient growth. This position was supported by Abdelrahman *et al*., 2020), who demonstrated that *B. japonicum* inoculation significantly enhances soybean growth parameters, including root development, biomass accumulation, and chlorophyll content. Furthermore, Daud and Zahir (2021) also reported that enhanced nitrogen availability from BNF results in improved pod formation and seed yield. They stated that inoculated soybean plants often exhibit increased nodulation, higher tissue nitrogen content, and greater overall productivity than non-inoculated controls.
Observed results from Table 1 also showed varying yields with the individual varieties used for the study. This finding was consistent with findings by Rabbani *et al*. (2023), who reported that Rhizobium inoculation could

increase soybean yield, but soybean genotypes influence its performance. Kamara *et al*. (2022) supported this view as they reported that despite the varietal improvements in soybeans, selecting the most appropriate varieties for a region was important. They emphasized the need for improved soybean varieties to attain maximum yield and promote revenue generation for the farmers. According to Otaiku *et al*. (2022) Soybean yield has been characterized by high instability within and between species at different sites and seasons. It is pertinent to use stable genotypes for high seed yield, which are well suited to the agroecological zone and inoculants for sustainable soybean production.

Table 2 presents the practical implications of *Bradyrhizobium japanicum* inoculation from studies conducted in selected countries. The results indicate that inoculation treatment of Soybeans with phosphorus amendment can lead to a significant reduction in chemical fertilizer usage, improved soil health, and increased profit from enhanced yield. These findings offer a compelling case for soybean farmers to consider adopting this practice, not only for its potential economic benefits but also for its positive environmental impact.

The positive effects of *B. japonicum* inoculation on soybean growth and soil health can be attributed to the symbiotic relationship it forms with Soybean roots. This relationship leads to nodule formation, where biological nitrogen fixation (BNF) occurs. The bacteria convert atmospheric nitrogen into ammonia, which is then assimilated by the plant (Hungria *et al*., 2022). This process not only supplies essential nitrogen to the soybean but also enriches the soil with organic nitrogen, thereby improving soil health and benefiting subsequent crops. The synergistic effect of *B. japonicum* inoculation and optimal phosphorus application can maximize soybean yield, making it a promising strategy for sustainable soybean production (Mensah and Ajayi, 2023).

Similarly, Wei *et al*. (2023) reported that inoculation increased beneficial bacteria, minimized the prevalence of crop diseases, facilitated nitrogen fixation, and promoted the absorption of phosphorus and iron, thus enhancing the production of plant hormones that encourage crop growth and increase yields. They stressed the importance of inoculating soybeans with suitable rhizobia to sustain farmland ecosystems as this practice can increase the presence of beneficial microorganisms, leading to improved soil fertility, and should be explored extensively.

Research conducted between 2020 and 2022 in the Northern Guinea savannah of Nigeria by Adeshina (2023) also highlighted the benefits of *B. japonicum* inoculation in combination with phosphorus fertilization, as field trials showed that inoculated soybeans in this region exhibit superior growth and yield compared to non-inoculated counterparts, emphasizing the potential for scaling up this practice to enhance local food security and farmer livelihoods. *B. japonicum* inoculation contributes to sustainable agriculture by reducing the dependence on chemical nitrogen fertilizers, which are associated with environmental issues such as soil acidification and water pollution. Improved soil health from organic nitrogen inputs and enhanced microbial activity support long-term agricultural productivity.

Table 1: Interaction between Varieties and Inoculant on the Yield (Kg/ha) of Soybean in Mean years at the University Research Farm, Gwagwalada, Abuja.

	Yield (Kg/ha) Mean years	
Varieties	**Inoculant Control**	**With Inoculant**
TGX 1485-1D	1988.9e	2685c
TGX 1448-2E	2227.4d	2842.3b
TGX 1987-10F	2359.7d	3038.5a
SE± 48.884		

Means followed by the same letter(s) are not significantly different at 5% level of probability (DMRT), SE=Standard error

Table 2: Environmental and economic benefits of *Bradyrhizobium japanicum* inoculation from studies in some selected countries.

Location	Inoculation treatment	Reduced Chemical fertilizer use	Soil health improvement	Economic benefit
Egypt	B. japonicum + Phosphorus	40% Reduction	Increased Microbial Activity	Increased Profit
Pakistan	B. japonicum + Phosphorus	45% Reduction	Increased Organic Matter	Increased Profit
Brazil	B. japonicum	50% Reduction	Increased Soil Fertility	Increased Profit
Nigeria	B. japonicum + Phosphorus	42% Reduction	Improved Soil Structure	Increased Profit
USA	B. japonicum + Enhanced Phosphorus	48% Reduction	Enhanced Soil Quality	Increased Profit

Culled from Adeshina (2023).

4. Conclusion

Based on the objectives and the results obtained in the current study, there is sufficient evidence showing that *Bradyrhizobium japonicum* inoculation presents a viable pathway to sustainable soybean production by enhancing nitrogen fixation, improving yield, and promoting soil health. The application of biofertilizer in Soybean cultivation can manipulate the root growth and rhizosphere processes to offer an efficient method to enhance nutrient utilization and crop productivity simultaneously by fixing atmospheric nitrogen, promoting root growth by Producing hormones, antimetabolites, soil mineralization, and decomposition of nutrients. Thus, it offers a sustainable solution by reducing dependency on chemical fertilizers and improving soil health, contributing to the broader goals of sustainable agriculture (Otaiku *et al*.,2022)

It is imperative to acquaint farmers with the concept of inoculation using policy support, extension services, and capacity building (Salvagiotti *et al*., 2024). Emphasis should be placed on the manifold advantages, including its cost-effectiveness, eco-friendliness, and positive influence on grain yield. This approach can facilitate the attainment of balanced fertilization, environmental preservation, and resource efficiency objectives in soybean farming, thereby offering a promising outlook for the industry and paving the way for a more sustainable and resilient agricultural future.

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