



**INFLUENCE OF RHIZOBIUM INOCULATION AND GENOTYPE ON SOYBEAN
[*GLYCINE MAX* (L.) MERRILL] PERFORMANCE UNDER CONTRASTING SOIL
CONDITIONS IN THE SUDAN SAVANNA OF NIGERIA**

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ABSTRACT

The study evaluated the interactive effects of *Rhizobium* inoculation and soybean genotypes on growth, nodulation, and yield across two locations of Gaya and Bayero University Kano (BUK), with contrasting soil fertility profiles during the 2021 rainy season. The treatments consisted of two soybean varieties (TGX1447-2E and TGX1885-10E) and two inoculation levels (inoculated and uninoculated), factorially combined and laid out in a randomized complete block design with three replications. Pre-planting soil analysis revealed that Gaya had higher organic matter (45 g kg⁻¹) and nitrogen (11 g kg⁻¹), while BUK was nitrogen-deficient (1.4 g kg⁻¹) but phosphorus-rich (188 mg kg⁻¹). *Rhizobium* inoculation significantly ($P < 0.05$) enhanced nodulation, pod weight, 100-seed weight, and grain yield at both sites. At Gaya, inoculation increased grain yield from 4,000.6 to 13,638.6 kg ha⁻¹ and 100-seed weight from 11.09 g to 13.67 g. At BUK, yield rose from 5,796.7 to 7,770.3 kg ha⁻¹ with inoculation, despite lower organic matter. TGX1885-10E performed best at Gaya, producing 11,833.1 kg ha⁻¹, while TGX1447-2E yielded 7,727.3 kg ha⁻¹ at BUK, indicating superior adaptation to low-nitrogen conditions. Although no significant interaction was observed between variety and inoculation, both factors independently improved performance of the crop. These findings underscore the importance of site-specific agronomic strategies, where inoculation combined with appropriate varietal selection can significantly boost soybean productivity and soil fertility in low-input farming systems across the Sudan savanna.

Keywords: Soybean, Rhizobium, Inoculation, Nitrogen, Fixation.

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is an economically and nutritionally important legume crop in Sub-Saharan Africa, particularly valued for its high protein (approximately 40%) and oil (about 20%) content, making it an essential component of both human diets and animal feed systems (Djanta *et al.*, 2020). Globally, soybean is the most important oilseed crop, predominantly cultivated for edible oil extraction and as a protein-rich meal for livestock feed (Pawlowski *et al.*, 2021). One of the major constraints to soybean production in the Sudan savanna of Nigeria is low soil fertility, especially inadequate nitrogen levels due to limited biological nitrogen fixation (BNF). Although soybean can fix atmospheric nitrogen through symbiosis with *Rhizobium* spp., the efficiency of this process depends on the compatibility between soybean varieties and rhizobial strains, as well as the presence and effectiveness of native rhizobia in the soil (Mu'azu *et al.*, 2019). This limitation is particularly problematic in low-input systems where indigenous rhizobia are often ineffective.

Inoculating soybean seeds with effective *Rhizobium* strains has consistently enhanced nodulation, plant growth, and grain yield in nitrogen-deficient soils (Ewusi-Mensah *et al.*, 2021). Moreover, integrating inoculation with balanced nutrient management, including micronutrient applications, can further improve plant performance and support sustainable food production in the region (Kabiru *et al.*, 2024). Despite growing evidence supporting rhizobial inoculation, data on the response of different soybean varieties to inoculation in the Sudan savanna agro-ecology remain limited. This knowledge gap hinders the development of location-specific recommendations for



enhancing soybean productivity. Therefore, this study aims to evaluate the effect of *Rhizobium* inoculation on the growth and yield of selected soybean varieties under the environmental conditions of the Sudan savanna of Nigeria. The findings will help guide best practices for biological nitrogen fixation and sustainable soybean production in this and similar agro-ecological zones.

MATERIALS AND METHODS

The experiment was conducted during 2021 cropping season at the Teaching and Research Farm of Aliko Dangote University of Science and Technology Wudil located in Gaya (Latitude: 11.9331° N, Longitude: 8.5216° E with an elevation of 472.45m above sea level) and at Teaching and Research Farm of Bayero University Kano (Latitude: 12.0027° N, Longitude: 8.5914° E with an elevation of 415 m above sea level). Both locations are situated in the Sudan savanna agro-ecological zone of Nigeria. Prior to the commencement of the trial, composite soil samples were collected randomly at different points within the experimental field at a depth of 0 - 30 cm. the samples were bulked, labelled and taken to a laboratory for analysis using standard soil laboratory procedures as described by AOAC.

The treatment consisted of two soybean varieties (TGX1447-2E and TGX1885-10E) and two levels of *Rhizobium* (un-inoculated and inoculated). The experiment was laid out in a Randomized complete block design (RCBD) with three replications. Plot size was 3 m x 3m consisting of four ridges.. An alley of 0.5m and 1.0m was maintained between plots and replication, respectively, to facilitate easy movement within the experimental field. Data were collected on number of leaves per plant, number of branches per plant, plant height (cm), days to 50% flowering, number of effective nodules, number of ineffective nodules, fresh weight of nodules, dry weight of nodules, number of pod per plant, pod weight per plant (g), shelling % per plot, 100 seed weight, yield per plant and yield per hectare using standard agronomic procedures. Data collected were subjected to analysis of variance and means were separated using Duncan multiple Range Test (DMRT) at 5% level of probability.

RESULTS

The physical and chemical properties of the soils at the two experimental sites (BUK and Gaya) during the 2021 rainy season is presented in Table 1. The result indicates that the soil texture at BUK was sandy loam, while Gaya exhibited a loamy sand texture, both of which are suitable for soybean cultivation due to good drainage and root penetration capacity.

The soil pH (H₂O) values were moderately acidic, 5.9 at BUK and 6.1 at Gaya, within the acceptable range for soybean growth (5.5–6.5). Organic matter (OM) content was significantly lower at BUK (4.3 g kg⁻¹) compared to Gaya (45 g kg⁻¹), indicating better organic fertility at the latter. The nitrogen (N) content at BUK (1.4 g kg⁻¹) was low, potentially limiting plant growth, whereas Gaya had sufficient nitrogen levels (11 g kg⁻¹) to support healthy soybean development. Conversely, phosphorus (P) availability was high at BUK (188 mg kg⁻¹), suggesting luxury levels, while Gaya's phosphorus content (63 mg kg⁻¹) was marginal, possibly limiting yields.

Potassium (K) levels were adequate at BUK (2.56 cmol kg⁻¹) but lower at Gaya (1.74 cmol kg⁻¹), potentially affecting crop quality. Gaya, however, showed higher calcium (21.92 cmol kg⁻¹), sodium (2.12 cmol kg⁻¹), and zinc (31.04 mg kg⁻¹) levels, enhancing overall nutrient diversity.

Table 1: Physical and Chemical Properties of Soil of the Experimental Sites during 2021 Rainy Season at BUK and Gaya

Physical properties	BUK	Gaya
Particle size distribution (g kg⁻¹)		
Sand	688	760
Silt	180	200
Clay	130	40
Textural class	Sandy loam	Loamy sand
Chemical properties		
pH (H ₂ O)	59	61
pH (CaCl ₂)	63	60
Organic matter k kg ⁻¹	4.3	45
Nitrogen N g kg ⁻¹	1.4	11
Phosphorus mg kg ⁻¹	188	63
Exchange Cations (Cmol kg⁻¹)		
K	2.56	1.74
Na	0.72	2.12
Ca	4.25	21.92
Mg	7.29	3.76
Zn	22.06	31.04
Bo ₄	71.54	87.26
E.A	3.33	3.34
CEC	28.16	32.88

Source: As analysed at Soil Science Laboratory, BUK

Nodule Fresh and Dry Weight and Number of Pods per Plants

The result revealed a significant difference among the treatments at both Gaya and BUK locations. The effect of inoculum at both locations showed that the inoculated produced the highest values as compared to non-inoculated for fresh weight, dry weight and number of pods per plants. The effect of variety showed that variety TGX 1885-10E had more of fresh weight, dry weight and number of pods per plant also as compared to TGX 1448-2E. At BUK location however, no significant ($P>0.05$) effect observed between the varieties for nodule fresh weight. TGX 1448-2E significantly ($P<0.05$) had higher nodule dry weight (0.35g) than TGX 1885-10E (0.29g). Similarly, TGX 1448-2E produced a greater number of pods per plants (68.58) as compared to TGX 1885-10E (52.04).

Table 2: Effect of Rhizobium Inoculum and Varieties on Fresh Weight, Dry Weight and Number of Pods per Plant of Soybean at Gaya and BUK during 2021 Rainy Season

Treatment	Gaya			BUK		
	Nodule fresh Weight (g)	Nodule dry Weight (g)	Number of Pods plant ⁻¹	Nodule fresh Weight (g)	Nodule dry Weight (g)	Number of Pods plant ⁻¹
Inoculation (I)						
Non-inoculated	0.34b	0.31b	45.85b	0.33b	0.26b	52.88b
Inoculated	0.49a	0.47a	117.50a	0.47a	0.38a	67.75a
LS	**	**	**	**	**	**
SE (±)	0.06	0.03	8.59	0.05	0.03	5.97
Variety (V)						
TGX 1448-2E	0.23b	0.27b	62.14b	0.42	0.35a	68.58a
TGX 1885-10E	0.59a	0.50a	101.21a	0.38	0.29b	52.04b
LS	**	**	**	NS	**	**
SE (±)	0.04	0.03	10.56	0.05	0.03	5.82
Interaction						
I x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter within the same column are not significantly different at 5 % level of probability using Duncan's Multiple Range Test. LS=Level of significance, * = Significant at 5%, NS = Not significant.

100 Seed Weight, Pod Weight per Plant and Seed Yield per Plant

Table 3 presents result of the effects of *Rhizobium* inoculation and soybean varieties on 100-seed weight, pod weight per plant, and grain yield per plant at Gaya and BUK during the 2021 rainy season. The results indicate that *Rhizobium* inoculation had a significant effect ($P < 0.05$) on all yield parameters measured at both locations. Inoculated seeds produced significantly higher 100-seed weights (13.67 g at Gaya and 11.35 g at BUK), greater pod weights per plant (56.15 g at Gaya and 35.36 g at BUK), and increased grain yields per plant (47.36 g at Gaya and 29.16 g at BUK), compared to uninoculated controls.

Among the varieties, TGX1885-10E consistently outperformed others at Gaya by producing significantly ($P < 0.05$) heavier seeds, as well as higher pod and grain yields per plant. However, at BUK, varietal differences in 100-seed weight were not statistically significant. Notably, TGX1448-2E significantly outperformed TGX1885-10E in pod and grain yield per plant at BUK, suggesting location-specific varietal performance. The interaction between inoculation and variety was not significant at either location, indicating that the effects of inoculation and variety were independent of each other.

Table 3: Effect of *Rhizobium* Inoculum and Variety on Pod Weight per Plant, Pod Weight per Plot, Grain Yield per Plant and Pod Weight per Plant of soybean at Gaya and BUK during 2021 Rainy Season

Treatment	Gaya			BUK		
	100 seed weight (g)	pod weight plant ⁻¹ (g)	Grain yield plant ⁻¹ (g)	100 Seed weight (g)	Pod weight plant ⁻¹ (g)	Grain Yield plant ⁻¹ (g)
Inoculation(I)						
Non-inoculated	11.09b	21.10b	16.13b	10.68b	27.60b	21.84b
Inoculated	13.67a	56.15a	47.36a	11.35a	35.36a	29.16a
LS	**	**	**	**	**	**
SE (±)	0.22	3.70	2.94	0.24	3.08	2.69
Variety (V)						
TGX 1448-2E	11.77b	28.26b	24.02b	11.16	35.45a	29.20a
TGX 1885-10E	12.98a	48.99a	39.47a	10.88	27.50b	21.81b
LS	**	**	**	NS	**	**
SE (±)	0.32	4.77	4.16	0.26	3.05	2.68
Interaction						
I x V	NS	NS	NS	NS	NS	NS

Means followed by the same letters within the same column are not significantly different at 5 % level of probability using Duncan's Multiple Range Test, ** = Significant at 1%, NS = Not significant.

Grain Yield per Hectare and Shelling Percentage

The effects of *Rhizobium* inoculation and soybean variety on grain yield and shelling percentage at both locations are presented in Table 4. Inoculation had a significant effect ($P < 0.05$) on both grain yield and shelling percentage at Gaya and BUK. At Gaya, inoculated seeds produced the highest grain yield and shelling percentage. However, at BUK, although inoculation significantly increased grain yield, it had no significant effect ($P > 0.05$) on shelling percentage.

Varietal effects revealed that TGX1885-10E produced higher grain yield and shelling percentage than TGX1447-2E at Gaya. In contrast, at BUK, TGX1447-2E significantly ($P < 0.05$) outperformed TGX1885-10E in grain yield. Shelling percentage at BUK was not significantly affected by variety.

Table 4: Effect of Rhizobium Inoculum and Variety on Yield Parameters of Soybean during 2021 Rainy Season at Gaya and BUK

Treatment	Gaya		BUK	
	Grain yield (Kg ha ⁻¹)	Shelling (%)	Grain yield (Kg ha ⁻¹)	Shelling (%)
Inoculum (I)				
Non-inoculated	4000.6b	71.47b	5796.7b	78.16
Inoculated	13638.6a	84.17a	7770.3a	79.07
SE (±)	1439.32	1.42	703.88	1.95
LS	**	**	**	NS
Variety (V)				
TGX 1448-2E	5805.6b	74.55b	7727.3a	79.81
TGX 1885-10E	11833.1a	81.09a	5839.6b	77.41
SE (±)	1762.90	1.79	710.47	1.96
LS	**	**	**	NS
Interaction				
I x V	NS	NS	NS	NS

Means followed by the same letters within the same column are not significantly different at 5 % level of probability using Duncan's Multiple Range Test, ** = Significant at 1%, NS = Not significant.

DISCUSSION

Impact of *Rhizobium* Inoculation on Growth Parameters

Rhizobium inoculation significantly increased plant height, leaf number, and branch count at both Gaya and BUK, with more pronounced effects at BUK, where native nitrogen levels were lower. This confirms that inoculation is particularly beneficial in nitrogen-deficient soils due to enhanced nitrogen availability through symbiotic fixation, which supports vegetative growth. Similar trends were reported by Gao *et al.* (2018), who found that inoculated soybeans exhibited greater nodule biomass and nitrogenase activity, resulting in improved plant height and leaf area. Santos *et al.* (2019) also observed enhanced plant vigor and biomass in inoculated plants. More recently, Wei *et al.* (2023) reported that long-term *rhizobium* inoculation increased soybean yield by 32% and significantly improved vegetative biomass in nitrogen-poor soils. Likewise, Kamau *et al.* (2021) documented substantial gains in shoot dry weight and plant height following inoculation in acidic, low-nutrient soils.

Effect of *Rhizobium* Inoculation on Nodulation and Nitrogen Fixation

Inoculation significantly increased both the number and biomass (fresh and dry weight) of nodules across both sites, with a stronger response at BUK, where lower organic matter and nitrogen levels likely limited native *Rhizobium* effectiveness. This aligns with Farhat *et al.* (2020), who reported that inoculation enhances nodule efficiency, nitrogen fixation, and plant nitrogen uptake in low-fertility soils. The improved nodulation observed in this study indicates sustained nitrogen availability, which is vital for reproductive development and yield. Supporting this, Debela *et al.* (2021) found that combining inoculation with organic amendments significantly improved nodule performance and contributed to a higher harvest index in nutrient-poor conditions. Similarly, Adeshina *et al.* (2024) reported increased nodulation and yield across soybean varieties following *Bradyrhizobium* inoculation in Nigerian savanna soils.

Yield Improvements

Inoculation significantly increased pod weight, 100-seed weight, and grain yield per plant at both Gaya and BUK. While Gaya's higher baseline fertility particularly in nitrogen and organic matter supported higher absolute yields, the relative yield gains from inoculation were more pronounced at BUK, where native nitrogen was limited. This suggests that inoculation was especially beneficial under nutrient-deficient conditions. These results are consistent with findings of Tufail *et al.* (2018) who reported yield improvements of 15–25% from inoculation, particularly under low-nitrogen conditions. Similarly, Budiastuti *et al.* (2025) found that inoculation enhanced seed weight and yield



even when nitrogen fertilizer was applied, especially in low-fertility soils. Ishaq *et al.* (2023) also demonstrated that dual inoculation strategies improved seed yield by enhancing nodulation and nutrient uptake. Additionally, increased shelling percentage in inoculated plots further indicates improved seed development and quality due to enhanced biological nitrogen fixation and nutrient availability.

Genotypic and Environmental Interactions

The location-specific varietal responses to inoculation align closely with the underlying soil properties of Gaya and BUK. Gaya's higher organic matter and elevated micronutrient levels (Zn, B, K, and Ca) support enhanced biological nitrogen fixation and seed quality, which likely contributed to the superior performance of TGX1885-10E. In contrast, BUK's nitrogen-deficient but phosphorus-rich soils favored TGX1447-2E, whose adaptability to low-nitrogen environments made inoculation particularly effective. These outcomes reflect broader soil-inoculation dynamics. Slightly acidic pH at both sites supports soybean growth, though inoculation benefits were more evident at BUK due to its lower native nitrogen, a condition known to amplify *Rhizobium* effectiveness (Jemo *et al.*, 2023). Conversely, to fully realize inoculation benefits at Gaya, phosphorus supplementation may be necessary due to its lower P content, despite otherwise favorable fertility conditions. Although the interaction between variety and inoculation was not statistically significant, both factors independently contributed to performance. Their combined benefits were most evident when varieties were well-suited to local soil conditions. These findings align with Wang *et al.* (2022), who noted that soil pH and nutrient availability critically influence *Rhizobium* inoculation effectiveness and varietal responses. Similarly, Nakei *et al.* (2023) emphasized that appropriate matching of varieties to specific soil environments enhances yield potential in savanna agro-ecologies.

CONCLUSION AND RECOMMENDATION

This study clearly demonstrated the significant positive effects of *Rhizobium* inoculation on the growth, nodulation, and yield performance of soybean under the Sudan savanna conditions of Nigeria. The response to inoculation varied by location due to differences in soil fertility status particularly nitrogen and organic matter content, highlighting the importance of site-specific soil characteristics in determining the effectiveness of biological nitrogen fixation. While TGX1885-10E performed best at the more fertile Gaya site, TGX1447-2E was better suited to the low-nitrogen, high-phosphorus soils at BUK. The lack of interaction between variety and inoculation suggests that both factors contribute independently to yield, but their benefits can be maximized when variety selection aligns with local soil conditions. To enhance soybean productivity and soil health across the Sudan savanna, farmers should routinely adopt *Rhizobium* inoculation especially in nitrogen-deficient soils like BUK, while selecting varieties based on local soil fertility (e.g., TGX1885-10E for organic-rich soils like Gaya, and TGX1447-2E for phosphorus-rich, nitrogen-poor soils like BUK). This should be integrated with balanced fertilization and organic matter management to ensure sustainable and site-specific soil fertility improvement.

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