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Research Article

Effect of Bio Fertilizer on Growth, Yield Attribute and Yield of Groundnut (*Arachis Hypogaea* L.) Varieties at Lowland Areas of South Omo Zone, South Ethiopia

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Abstract

Groundnut (*Arachis hypogaea* L.) is an important oilseed and protein crop, yet its productivity in Ethiopia is constrained by poor soil fertility and limited access to improved varieties. Bio-fertilizers, particularly Rhizobium inoculants, offer an environmentally friendly option to enhance nitrogen fixation and crop yields. This study evaluated the effect of Rhizobium inoculation on the growth, yield attributes, and yield of five groundnut varieties (Shilmith, Bulki, Babile-4, Werer 961, and Roba) under lowland conditions of South Omo Zone during the 2024 main cropping season. Treatments consisted of two inoculants (GND Moderate-2 and GNA 10) and a non-inoculated control, arranged in a 5 × 3 factorial within a randomized complete block design (RCBD) with three replications. Results revealed significant ($p < 0.05$) effects of variety, inoculation, and their interaction on phenology, growth, and yield traits. Inoculated plants generally outperformed the control, with Shilmith inoculated with GND Moderate-2 achieving the highest grain yield (16.72 q ha^{-1}), followed by Bulki with the same inoculant (16.33 q ha^{-1}). Partial budget analysis indicated that Shilmith × GND Moderate-2 generated the highest net benefit ($188,148 \text{ ETB ha}^{-1}$), confirming both agronomic and economic advantages. Overall, the study demonstrates that adopting the Shilmith variety with GND Moderate-2 inoculation could substantially enhance groundnut productivity and profitability in the lowland agro-ecologies of South Omo Zone.

Keywords: Groundnut, Bio-fertilizer, Rhizobium inoculation, Yield components, Economic return.

Introduction

Groundnut or peanut (*Arachis hypogaea* L.) is a critical legume crop that belongs to the Fabaceae family. Groundnut is an allotetraploid ($2n = 4x = 40$) and primarily self-pollinating legume with its highest uses being for high-quality edible oil (45-55%), digestible protein (25-28%), and for its high energy value [1,2]. Groundnut, which is originally native to South America, has been a major crop in subtropical and tropical countries worldwide and is produced by India, China, Nigeria, and Sudan as the world's top producers [3,4]. Apart from being a cash crop, groundnut is an important component of food security programs that provide essential calories and

nutrients to millions of people, primarily smallholder farmers in Sub-Saharan Africa where it is a central component of dietary consumption and household income [5,6]. In Ethiopia, groundnut production is primarily located in the mid-altitude and lowland areas, which are normally associated with irregular rains and droughts [7, 8]. To smallholder producers in these regions, groundnut is a dual-purpose crop: a primary source of domestic dietary protein and oil, and a valuable commodity that can be sold to generate revenue, hence enhancing livelihood resilience [9,10]. Despite its huge potential and increasing importance, the Ethiopian national av-

erage groundnut yield remains far less than its genetic potential and international levels. This yield gap mainly exists because of a vast array of constraints, including the frequency of drought stress, disease, and pest attack, and above all else, the widespread soil fertility issue of low and decreasing soil fertility [11,7]. Soil nitrogen deficiency and soil fertility depletion are significant limitations to legume productivity in the majority of Ethiopian soils. Traditional measures for controlling soil nutrient deficiencies have largely relied on the application of inorganic nitrogen fertilizers. However, this practice is very costly to resource-poor farmers due to the very high and notoriously fluctuating price of these inputs, which renders them economically inaccessible [12]. Besides, the constant and imbalanced use of chemical fertilizers can lead to undesirable environmental effects like soil acidification, microbial community disruption, and water body pollution [13-15]. Therefore, it is crucial to promote more sustainable and cost-effective soil fertility management practices appropriate for smallholder farming systems. In this context, bio-fertilizers can seem to be an effective green answer to enhanced crop yields and soil fertility. Bio-fertilizers consist of microorganisms that facilitate plant nutrient uptake. For groundnut and other legumes, Rhizobium inoculants are particularly critical. These soil bacteria form a symbiotic relationship with the plant roots and lead to the development of nodules where biological nitrogen fixation (BNF) occurs. This process converts nitrogen in the air (N_2) into ammonia, a state that can be readily taken up by the plant [16,17]. Successful and effective legume inoculation with suitable and effective Rhizobium strains has the potential to significantly reduce synthetic N fertilizer use, save on production costs, improve soil fertility for subsequent crops, and ultimately towards more sustainable agricultural systems [18,19]. The effectiveness of this symbiosis is not always general but highly specific and dependent on the compatibility between the Rhizobium strain and host plant genotype [20]. A highly effective strain for one variety will prove to be inefficient for another, and hence the selection of the correct variety-inoculant combinations is a critical area of research.

Lowlands area of the South Omo Zone in Ethiopia's southern region are a representative agro-ecology with groundnut being an important crop but productivity constrained by soil fertility factors. Adoption of Rhizobium inoculation technology in the region would have to be evidence-based on locally derived information because variety and bacterial strain performance could be significantly influenced by specific soil and climatic conditions. While experiments have been conducted on other legume species with respect to Rhizobium inoculation in Ethiopia, there is a scarcity of knowledge regarding its influence on the growth and yield of groundnut varieties that have been developed specifically for the lowland agro-ecologies of the South Omo Zone. This study was therefore conducted to evaluate the effects of different Rhizobium inoculants on the growth, yield components, and

grain yield of selected groundnut varieties.

Materials And Methods

Description of the Study Area

The research was conducted during the 2024 main cropping season (March to July) at the Farmers' Training Centre (FTC) located in the Bena-Tsema District of the South Omo Zone, Ethiopia. The geographic location of the site are approximately 5.1°N latitude and 36.1°E longitude, with an elevation ranging between 540 and 3,350 meters above sea level. The climate of the area is characterized by an average annual temperature of 22–27°C and receives annual precipitation ranging from 1,190 to 1,450 mm.

Experimental Materials

The plant material consisted of five groundnut (*Arachis hypogaea* L.) varieties: Shilmith, Bulki, Werer 961, Babile-4, and Roba. The microbial inoculants included two strains of Rhizobium—(GND Moderate-2, GNA 10) and control (non-inoculated) treatment (Table 1). The inoculants were obtained from Holleta research center.

Experimental Design and Treatment Structure

The experiment was established using a 5 × 3 factorial treatment arrangement, incorporating five groundnut varieties and three inoculation treatments (two inoculant strains plus a control), deployed in a Randomized Complete Block Design (RCBD) with three replications. Each plot consisted 2 m in length and 2.4 width. spaced between row 0.6 m apart, with intra-row plant spacing of 0.1 m. A distance of 1 m separated adjacent blocks. Data were collected from the two central rows of each plot to minimize border effects. All plots received uniform agronomic management, including, weeding, and pest control.

Data Collection Procedures

Soil Sampling and Analysis

Prior to trial establishment, composite soil samples were collected from the experimental site at a depth of 0–30 cm using fourteen randomly distributed points. The samples were thoroughly mixed, air-dried, and passed through a 2 mm sieve before laboratory analysis. Soil texture was determined using the hydrometer method [21]. Organic matter content was analysed using the Walkley-Black method [22], while soil pH was measured potentiometrically with a glass electrode pH meter [23]. Total nitrogen was assessed by the Kjeldahl method [24]; available phosphorus by the Olsen extraction method [25]; available boron by hot-water extraction followed by azomethine-H spectrophotometry [26]; and available sulfur by turbidimetric measurement after potassium phosphate extraction [27]. The physico-chemical properties of the experimental site soils are presented in Table 1.

NO	Groundnut varieties	Rhizobium inoculants	Treatment combination
1	Shilmith	Control	Shilmith control(SC)
2	Shilmith	GN.D. Moderate-2	Shilmith GND. Moderate-2 (SM)
3	Shilmith	GN A.10	Shilmith GN.A.10 (SA)
4	Roba	Control	Roba Control (RC)
5	Roba	GN.D. Moderate-2	Roba GND.Moderate-2 (RM)
6	Roba	GN A.10	Roba GN.A.10 (RA)
7	Were 961	Control	Were 961 Control (WC)
8	Were 961	GN.D. Moderate-2	Were 961 GN.D.Moderate 2(WM)
9	Were 961	GN A.10	Were 961 GN.A.10 (WA)
10	Bulki	Control	Bulki Control (BUC)
11	Bulki	GN.D. Moderate-2	Bulki GN D. Moderate 2 (BUM)
12	Bulki	GN A.10	Bulki GN.A 10 (BUA)
13	Babile-4	Control	Babile-4 Control (BAC)
14	Babile-4	GN.D. Moderate-2	Babile-4 GN.D.Moderate 2 (BAM)
15	Babile-4	GN A.10	Babile-4 GN.A.10 (BAA)

Table1. Experimental Treatment Combinations of Groundnut Varieties and Rhizobium Inoculants

Crop Growth and Yield Measurements

The following agronomic parameters were recorded:

Number of branches per plant: - calculate the average from five randomly selected number of branches per plant for the plot.

Number of seeds per pod: - was determined from five randomly selected mature pods per plant across five sampled plants per plot.

Hundred-seed weight (g):- was estimated by randomly selecting 100 pods per treatment, shelling them, mixing the seeds, and weighing a subsample of 100 seeds.

Grain yield: - was measured from the two central harvestable area of each plot. Pods were air-dried, threshed, and cleaned before weighing. Yield was converted to quintals per hectare (q ha⁻¹) at 10% moisture content.

Yield components: - including pods per plant, seeds per pod, and hundred-seed weight, were evaluated from five representative plants sampled at physiological maturity. Samples were oven-dried at 65°C to constant weight before measurement.

Biological yield: - was determined as the total above-ground dry biomass per plot, and the

Harvest index was calculated as the ratio of grain yield to biological yield.

Data Quality Assurance

Strict protocols were followed during data collection to minimize errors. The use of replication and randomization ensured robustness and statistical validity. All data were rigorously checked for consistency and completeness before analysis.

Economic Analysis

A partial budget analysis was conducted according to the framework described by [28]. Variable costs included the prices of groundnut seed and bio-fertilizer. The market price of groundnut grain at the time of harvest (April 2024) in Keyafer town was 135 ETB kg⁻¹, and the cost of Rhizobium inoculant was 40 ETB kg⁻¹. All economic values were calculated on a per-hectare basis. The gross benefit was estimated by multiplying the grain yield (adjusted downward by 10% to account for potential post-harvest losses) by the prevailing market price.

Statistical Analysis

Data were subjected to Analysis of Variance (ANOVA) using the General Linear Model (GLM) procedure in [28]. Mean separation was performed using the Least Significant Difference (LSD) test at a 5% probability level, as described by [29].

Data Quality and Handling

All measurements were recorded carefully to minimize errors. Replication and randomization within the experimental design ensured reliability and statistical validity. Data were checked for consistency and completeness before statistical analysis.

Results and Discussion

Physic chemical soil property

The soil at the experimental site was classified as clay loam, with 35% sand, 21% silt, and 38% clay (Table 2). It had a

nearly neutral pH (6.9), low organic matter (2.15%), and medium total nitrogen (0.14%). The cation exchange capacity (22.9 cmolc kg⁻¹) was rated as moderate, while available potassium (84.5 ppm) was moderate and exchangeable potassium (0.53 cmolc kg⁻¹) was high. These characteristics

suggest that the soil has a reasonable nutrient-holding capacity but limited organic matter, which may restrict groundnut productivity unless improved through fertilizer or organic amendments.

Parameter	Value	Rating	Reference
Particle size distribution (%)			FAO 2006
Sand	35		
Silt	21		
Clay	38		
Textural class	Clay loam		
Ph	6.9	Neutral	Tekalign, 1991
Organic matter (%)	2.15	Low	Tekalign, 1991
Total N (%)	0.14	Medium	Tekalign, 1991
CEC (cmol/kg)	22.9	moderate	Hazelton & Murphy, 2002
Available K (ppm)	84.50	moderate	Haylin et al., 1999
Exchangeable K (cmol/kg)	0.53	High	FAO 2006

PH = Soil reaction; OC=Organic carbon; N=Nitrogen; Av. P=Available phosphorus; Na= Sodium, K=Potassium, Ca=Calcium, Mg=Magnesium, SO₄=Sulphate, ppm=Parts per million; CEC= Cation exchange capacity; cmol kg⁻¹=centimole per kg of soil; mg kg⁻¹=milligram

Table 2. Selected physico-chemical properties of the experimental soil before planting

Phonological Parameters

Both the main effects (variety and Rhizobium inoculation) and their interaction significantly ($P < 0.05$) influenced the phonological parameters of days to 50% flowering and days to 90% physiological maturity (Table 3). The combination of the variety Roba with GNA 10 inoculation recorded the longest duration for both 50% flowering (63 days) and physiological maturity (153.3 days). Conversely, the shortest time

to flowering (52.33 days) was observed in the un-inoculated Shilmith control, while the un-inoculated Werer 961 control reached maturity in the shortest time (139.3 days). The extended phonological periods in some treatments may be attributed to the inherent genetic characteristics of the variety combined with enhanced nutrient availability from Rhizobium inoculation, which can promote prolonged vegetative growth and delay the transition to reproductive development.

Varieties	RI	Days to 50% Flowering	Days to 90% Physiological Maturity
Shilmith	Control	52.33ghi	142.3f*
	GN.D. Moderate-2	55.00efg	145.0ef
	GNA.10	59.00bcd	149.0cd
Roba	Control	61.00ab	150.7abc
	GN.D. Moderate-2	60.00bc	151.0abc
	GNA.10	63.00a	153.3a
Werer 961	Control	51.00i	139.3g
	GN.D. Moderate-2	55.67ef	146.0de
	GNA.10	57.67cde	145.3e
Bulki	Control	54.33fgh	152.3ab
	GN.D. Moderate-2	56.33def	143.7ef
Babile-4	GNA.10	57.67cde	150.0bc
	Control	55.33ef	145.0ef
	GN.D. Moderate-2	56.33def	148.3cd
	GNA.10	61.00ab	151.0abc

	LSD (5%)	2.8	2.984
	CV (%)	3.0	1.2

*means within a column followed by the same letter(s) are not significantly different at the 5% probability level according to the LSD test.
Table 3. Days to 50% Flowering and 90% Physiological Maturity of Groundnut Varieties as Affected by Rhizobium Inoculation (RI)

Growth Traits

The main effects of variety and Rhizobium inoculation (RI), as well as their interaction, significantly ($P < 0.05$) influenced all measured growth parameters, including plant height and the number of branches per plant. Inoculated plants consistently demonstrated superior growth, exhibiting greater height and more branches compared to the un-inoculated control plants. The highest values for these traits were recorded in the Shilmith and Bulki varieties when inoculated with GND Moderate-2 (Table 4). This enhancement in vegetative growth is likely a result of improved nutrition and en-

hanced nitrogen fixation facilitated by the Rhizobium. Plant height, branch number, and related growth parameters were significantly affected by variety and Rhizobium inoculation's main and interaction effects ($P < 0.05$). The tallest plants with highest branching were obtained in Shilmith and Bulki varieties when they were inoculated with GND Moderate-2. Inoculated treatments resulted in the promotion of vegetative growth over control, as previously indicated by [19] and Shikha et al. (2023), that Rhizobium maximizes nitrogen fixation and nutrient availability.

varieties	RI	Plant Height (cm)	Number of Branches
Shilmith	Control	32.33d*	12.67cd
	GN.D. Moderate-2	35.33c	13.90bc
	GNA.10	41.33a	15.90a
Roba	Control	28.67f	11.77de
	GN.D. Moderate-2	36.33c	14.90ab
	GNA.10	32.33d	12.90cd
Werer 961	Control	27.00g	10.23e
	GN.D. Moderate-2	31.33de	15.23ab
	GNA.10	28.67f	13.23cd
Bulki	Control	30.67e	12.90cd
	GN.D. Moderate-2	36.33c	16.23a
	GNA.10	38.67b	16.23a
Babile-4	Control	27.67fg	10.90e
	GN.D. Moderate-2	30.33e	14.90ab
	GNA.10	32.33d	14.90ab
	LSD (5%)	1.616	2.726
	CV (%)	3.0	6.7

*means within a column followed by the same letter(s) are not significantly different at the 5% probability level according to the LSD test.
Table 4. Plant Height and Number of Branches of Groundnut Varieties as Affected by Rhizobium Inoculation (RI)

Yield and Yield Components

The interaction between variety and Rhizobium inoculation had a significant ($P < 0.05$) impact on key yield components and the final grain yield. The results for the number of pods per plant, hundred-seed weight (HSW), and grain yield are consolidated (Table 5).

The Shilmith variety, particularly when inoculated with GND Moderate-2, consistently demonstrated superior performance across most metrics, achieving the highest grain yield. This

combination also resulted in a high number of pods per plant. The *Babile-4* variety with GNA.10 inoculation produced the highest number of pods, while Roba recorded the heaviest seeds on average. These improvements are attributed to effective symbiotic nitrogen fixation, which enhances nutrient uptake, supports reproductive growth, and improves assimilate partitioning towards pod and seed development, as previously reported by [18].

Variety	Rhizobium Inoculant	Pods per Plant	Hundred Seed Weight (g)	Grain Yield (q ha ⁻¹)
Shilmith	(No Inoculation)	18.83 ^g	51.44 ^b	14.50 ^c
	GN.D. Moderate-2	21.83 ^{defg}	53.50 ^{ab}	16.72 ^a
	GNA.10	25.17 ^{abcd}	52.00 ^b	15.80 ^b
Roba	Control	23.83 ^{abcde}	55.22 ^a	13.20 ^d
	GN.D. Moderate-2	23.17 ^{bcde}	54.50 ^a	15.22 ^c
	GNA.10	22.50 ^{cdef}	56.00 ^a	14.50 ^c
Werer 961	“non-inoculated Control	20.50 ^{efg}	52.89 ^b	14.00 ^{cd}
	GN.D. Moderate-2	24.00 ^{abcd}	53.50 ^{ab}	16.29 ^{ab}
	GNA.10	22.00 ^{cdef}	52.50 ^b	15.50 ^{bc}
Bulki	Control “non-inoculated	19.50 ^{fg}	52.89 ^b	14.80 ^{bc}
	GN.D. Moderate-2	26.00 ^a	54.00 ^{ab}	16.33 ^{ab}
	GNA.10	24.50 ^{abc}	53.00 ^{ab}	15.90 ^b
	“non-inoculated Control	19.50 ^{fg}	52.89 ^b	14.80 ^{bc}
Babile-4	“non-inoculated Control	18.00 ^h	45.11 ^c	13.50 ^d
	GN.D. Moderate-2	23.50 ^{bcde}	46.50 ^c	15.10 ^c
	GNA.10	26.50 ^a	47.00 ^c	15.78 ^{bc}
	LSD (5%)	2.5	1.6	0.87
	CV (%)	6.5	3.2	5.6

*means within a column followed by the same letter(s) are not significantly different at the 5% probability level according to the LSD test.

Table 5. Yield and Yield Components of Groundnut Varieties as Affected by Rhizobium Inoculation (RI)

Partial budget analysis of response of ground nut variety

The economic viability of the treatments was assessed using partial budget analysis (Table 6) analysis considered the variable costs of seeds and bio-fertilizers against the gross income generated from the grain yield. The market price for groundnut grain was set at 135 ETB kg⁻¹, and the cost of Rhizobium inoculant was 40 ETB kg⁻¹. Grain yield was adjusted downward by 10% to account for potential post-harvest losses before calculating the gross benefit. The combination of Shilmith variety with GND Moderate-2 inoculation yielded the highest grain output (16.72 q ha⁻¹). After economic analysis, this same treatment combination also generated the highest net benefit of 188,148 ETB ha⁻¹, demonstrating its superior profitability. Among the inoculation treatments, the GND Moderate-2 strain provided the highest net benefit (195,578 ETB ha⁻¹) and an attractive marginal rate of return, indicating that the additional cost of this inoculant was justified by a significant increase in income. The non-inoculated control,

while having no additional variable cost for inoculant, resulted in a lower net benefit due to its substantially lower yield.

Conclusion

This study demonstrated that Rhizobium inoculation significantly improved the growth, yield components, and grain yield of groundnut, with responses varying among varieties. The Shilmith variety inoculated with GND Moderate-2 consistently produced the highest grain yield and economic return, making it the most promising combination for the lowland conditions of South Omo Zone. These findings confirm the potential of bio-fertilizer use as a sustainable alternative to costly chemical fertilizers, while also improving soil fertility. Farmers in similar agro-ecologies are strongly encouraged to adopt Shilmith with GND Moderate-2. Further multi-season and multi-location evaluations are recommended to validate these results and support large-scale adoption.

Treatment	Grain Yield (q ha ⁻¹)	Adj. Yield* (q ha ⁻¹)	Gross Benefit (ETB ha ⁻¹)	Total Variable Cost (ETB ha ⁻¹)	Net Benefit (ETB ha ⁻¹)	Marginal Rate of Return (%)
By Variety						
Shilmith	16.72	15.05	203,148	15,000	188,148	-

Bulki	16.33	14.70	198,410	15,300	183,110	-
Werer 961	16.29	14.66	197,924	15,000	182,924	-
Babile-4	15.78	14.20	191,727	15,100	176,627	-
Roba	15.22	13.70	184,923	15,270	169,653	-
By Inoculation (RI)						
GND Moderate-2	16.92	15.23	205,578	10,000	195,578	118.7
non-inoculated Control	15.12	13.61	183,708	0	183,708	-
GNA.10	16.17	14.55	196,466	12,000	184,466	6.3

Table 6: Partial budget analysis for the response of groundnut varieties to Rhizobium inoculation.

Recommendation

The study revealed that both variety and Rhizobium inoculation significantly influenced phenological, growth, and yield traits of groundnut under lowland conditions of South Omo Zone. Inoculated plants flowered and matured later than the control, suggesting that enhanced nitrogen availability supported prolonged vegetative growth before reproductive development. Similar findings were reported by [20], who emphasized that the compatibility between host genotype and Rhizobium strain affects phenology and overall crop performance. Growth traits such as plant height and number of branches were consistently higher in inoculated treatments compared to the control. Shilmith and Bulki inoculated with GND Moderate-2 recorded the best vegetative growth, reflecting improved nitrogen fixation and nutrient uptake. This agrees with earlier reports by [19] and Shikha et al. (2023), who noted that effective Rhizobium strains enhance vegetative vigor in legumes.

Yield and yield components were also significantly improved by inoculation. Shilmith with GND Moderate-2 produced the highest grain yield, followed closely by Bulki with the same inoculant. Enhanced pod number, seed size, and final yield in inoculated treatments align with the findings of [18], who demonstrated that bio-fertilizers improve assimilate partitioning and reproductive efficiency. The variation among varieties highlights the importance of selecting compatible genotype-strain combinations, as previously emphasized by [20]. Economic analysis further showed that Shilmith × GND Moderate-2 provided the highest net benefit, indicating that bio-fertilizer use is not only ergonomically effective but also economically viable for resource-limited farmers. This confirms earlier conclusions by [9,10], who identified groundnut as both a nutritional and income-generating crop when supported by improved soil fertility practices. Overall, the study reinforces the role of bio-fertilizers as sustainable alternatives to chemical fertilizers, offering both productivity and profitability gains for smallholder farmers in Ethiopia's lowland agro-ecologies.

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Conflict of interest

The authors confirm that there are no competing interests or conflicts of interest to disclose

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