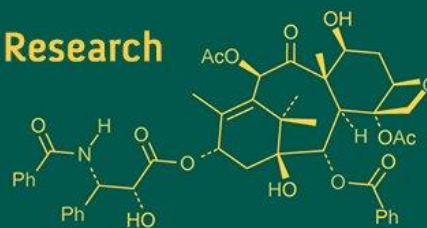
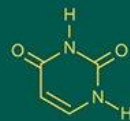


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Integrated nutrient management for enhancing growth and productivity of chickpea (*Cicer arietinum* L.)

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Abstract

The investigation was conducted during the *Rabi* season of the year 2017-18 at the Baba Farid Institutions Agricultural Farm at Suddhowala, Dehradun. High dependence on chemical fertilizers in intensive agriculture poses long-term risks to soil health and environmental sustainability. Integrating organic amendments and biofertilizers offers a viable strategy to enhance crop productivity while reducing chemical inputs. A field experiment was conducted to evaluate the impact of Integrated Nutrient Management (INM) on the growth and productivity of chickpea (*Cicer arietinum* L.). The study assessed fourteen treatments combining chemical fertilizers (RDF), vermicompost (VC), and *Rhizobium* culture (RC) and Phosphate Solubilizing Bacteria (PSB) in a randomized block design with three replications. The integrated application of 50% RDF + vermicompost @ 2 t ha⁻¹ + *Rhizobium* + PSB @ each 5 g kg⁻¹ seeds significantly improved vegetative, nodulation and yield parameters. At 60 Days After Sowing (DAS), achieved the maximum plant height (60.33 cm) and peak nodulation (28.00 nodules plant⁻¹), representing a 211.11% increase in nodules over the unfertilized control. Consequently, 50% RDF + VC + *Rhizobium* + PSB recorded the highest grain yield (20.66 q ha⁻¹) and straw yield (24.33 q ha⁻¹), outperforming the 100% RDF. Similarly, this treatment optimized the harvest index to 50.00%, reflecting highly efficient dry matter accumulation. The findings demonstrated that substituting 50% of the chemical fertilizer requirement with vermicompost and dual bio-inoculants (*Rhizobium* + PSB) sustains optimum chickpea productivity and promotes eco-friendly nutrient management.

Keywords: Chickpea, biofertilizers, fertility, nodulation, *Rhizobium*, sustainability, vermicompost, yield

Introduction

Pulses occupy a paramount position in global agriculture, playing a fundamental role in addressing food security and malnutrition. Globally, India stands out as a major pulse-growing country, accounting for a dominant share of the total world area under pulse cultivation and roughly one-fourth of global production. Within the domestic food basket, pulses serve as an indispensable dietary component, fulfilling more than 30% of the daily protein requirement of the population (John *et al.*, 2021) [5]. Among these food legumes, chickpea (*Cicer arietinum* L.), commonly referred to as gram, Bengal gram, chhola, or garbanzo bean is the most vital *Rabi* (winter) crop, valued widely for its high consumer acceptability and multi-purpose utilities. Nutritionally, chickpea seeds are an excellent source of plant-based protein (23-24%), carbohydrates (61.5%) and crude fat (4.5%), supplemented by essential minerals like calcium and phosphorus and dietary fiber (Jukanti *et al.*, 2012) [6]. The crop exhibits a favorable amino acid profile, supplying key constituents such as lysine (0.49%), methionine (0.11%) and tryptophan (0.04%) that complement cereal-based diets (Wallace *et al.*, 2016) [22]. Furthermore, a relatively low concentration of anti-nutritional factors such as trypsin inhibitors enhances its protein digestibility and biological value (Wood and Grusak, 2007) [23]. Consequently, chickpea serves as a highly nutritious, cost-effective protein source for human dietary supplementation and livestock feed formulations (Merga and Haji, 2019) [13].

Chickpea belonging to the sub-family Papilionaceae of the family Fabaceae, is historically recognized as one of the earliest grain legumes domesticated by humans in the Old World (Maesen, 1972) [11]. Its origin is closely linked to Western Asia, from where it

gradually spread across the Indian subcontinent and other parts of the world (Zhang *et al.*, 2024) ^[24]. In India major production landscapes are concentrated in states like Madhya Pradesh, Maharashtra, Rajasthan, Andhra Pradesh, Uttar Pradesh and Karnataka (Kumari and Malik, 2024) ^[9]. However, despite holding the status of the world's largest producer, India's aggregate supply frequently struggles to fulfill its surging internal market demands.

A primary challenge preventing the crop from achieving its full genetic yield potential is inadequate and skewed crop nutrition. While macronutrients like nitrogen (N), phosphorus (P) and potassium (K) are critical for robust metabolic activity, photosynthetic capacity and enzymatic operations (Hernandez *et al.*, 2024) ^[4], the intensive and indiscriminate utilization of chemical fertilizers over the decades has precipitated severe land degradation, environmental pollution and widening multi-nutrient deficiencies. Although chemical nitrogen application provides a vital initial starter boost (*e.g.*, 20 kg N ha⁻¹) that triggers early root development and nodule formation before biological nitrogen fixation kicks in, sole reliance on synthetic NPK inputs threatens long-term production stability.

To bridge this productivity gap while restoring ecological integrity, the adoption of Integrated Nutrient Management (INM) has become a modern agricultural imperative. The core philosophy of INM revolves around adjusting soil fertility and plant nutrient reserves to an optimum level, sustaining high yields via the combined exploitation of mineral fertilizers, organic amendments, and microbial inoculants (Krishna *et al.*, 2025) ^[8]. Mixing graded doses of Recommended Dose of Fertilizers (RDF) with organic matrices like vermicompost and microbial formulations provided superior yield stability (Upadhyaya and Chapai, 2024, Meena and Suman, 2025) ^[21]. Organic additions improve soil physical properties and offer balanced nutrition, while biofertilizers like *Rhizobium* actively fix

atmospheric nitrogen. Concurrently, Phosphate Solubilizing Bacteria (PSB) synthesize organic molecules (*e.g.*, citric, succinic and malic acids) that unlock fixed, insoluble soil fractions into plant-available orthophosphates (Laxmi *et al.*, 2002; Tarafdar, 2008) ^[10, 19]. Keeping these factors in view, the present field investigation was structured to systematically evaluate the synergistic effects of chemical fertilizers alongside organic manures and microbial inoculants for maximized chickpea output and sustained soil vitality.

Materials and Methods

The field experiment was conducted during the *Rabi* season of 2017-2018 at the instructional farm of the BFIT Group of Institutions, Department of Agronomy, Suddhowala, Dehradun (Uttarakhand), India. The site is located in the transitional Bhabar and Tarai Zone at 29°58' N to 31°02' N latitude, 77°34' E to 78°18' E longitude and an elevation of 648 meters above mean sea level.

Pre-sowing mechanical and chemical analysis of the initial 0-15 cm soil layer revealed a sandy loam texture (50.58% sand, 28.50% silt and 11.12% clay) with a neutral pH of 6.67, normal electrical conductivity (0.38 dS m⁻¹) and 0.91% organic carbon. The baseline soil fertility was low in available nitrogen (228.60 kg ha⁻¹), high in available phosphorus (36.34 kg ha⁻¹) and low in available potassium (267.73 kg ha⁻¹).

The experiment was laid out in a Randomized Block Design (RBD) with 14 treatments replicated three times (Table 1). Chickpea variety Pant G-114 was sown at a seed rate of 60-70 kg ha⁻¹ with a crop geometry of 30 cm row-to-row and 8-10 cm plant-to-plant spacing. Biometric growth parameters and yield attributes recorded were processed through analysis of variance (ANOVA) for RBD as outlined by Panse and Sukhatme (1957) ^[15], using a critical difference (CD) at a 5% level of significance (*P* = 0.05).

Table 1: Experiment treatment details

Treatment No.	Treatments
T ₁	Vermicompost (VC) @ 2 t ha ⁻¹
T ₂	Seed treatment with 5g <i>Rhizobium</i> (RC) culture kg ⁻¹ seeds
T ₃	Seed treatment with <i>Phosphorus solubilizing bacteria</i> (PSB) @ 5g kg ⁻¹ seeds
T ₄	Seed treatment with <i>Rhizobium</i> and PSB culture @ each 5 g kg ⁻¹ seeds
T ₅	100% Recommended dose fertilizers (RDF) @ 25: 50: 20 kg ha ⁻¹
T ₆	Seed treatment with 5g <i>Rhizobium</i> (RC) culture kg ⁻¹ seeds + Vermicompost (VC) @ 2 t ha ⁻¹
T ₇	Seed treatment with <i>Phosphorus solubilizing bacteria</i> (PSB) @ 5g kg ⁻¹ seeds + Vermicompost (VC) @ 2 t ha ⁻¹
T ₈	Seed treatment with <i>Rhizobium</i> and PSB culture @ each 5 g kg ⁻¹ seeds + Vermicompost (VC) @ 2 t ha ⁻¹
T ₉	50% RDF + <i>Rhizobium</i> and PSB culture @ each 5 g kg ⁻¹ seeds + Vermicompost (VC) @ 2 t ha ⁻¹
T ₁₀	50% RDF + seed treatment with <i>Rhizobium</i> culture @ 5 g kg ⁻¹ seeds
T ₁₁	50% RDF + seed treatment with PSB @ 5 g kg ⁻¹
T ₁₂	50% RDF + seed treatment with <i>Rhizobium</i> and PSB @ each 5 g kg ⁻¹ seeds
T ₁₃	50% RDF + Vermicompost (VC) @ 2 t ha ⁻¹
T ₁₄	Control (C)

Results and Discussion

Growth parameters

Plant height

The statistical analysis revealed that the variation in plant height was non-significant (NS) at the early vegetative steps of 30 DAS and 45 DAS, as well as at the terminal harvest stage (Table 2). However, a significant treatment response was recorded at 60 DAS, aligning with the peak vegetative expansion phase of the legume. At 60 DAS, the maximum plant height of 60.33 cm was observed under T₉ (50% RDF

+ RC + PSB + VC), displaying an increase of 7.92% over the absolute control (T₁₄ 55.90 cm). Treatment T₉ was statistically at par with T₅ (100% RDF: 59.78 cm), T₈ (RC + PSB + VC: 59.00 cm), T₁₂ (50% RDF + RC + PSB: 59.00 cm) and T₁₃ (50% RDF + VC: 59.00 cm).

The significant expansion in plant height at 60 DAS under T₉ is due to the sustained, balanced synchrony of synthetic nitrogen, phosphorus and potassium combined with organic carbon from vermicompost. Vermicompost acts as a steady-release matrix of macr and micronutrients, while dual bio-

inoculation with *Rhizobium* and PSB facilitates early nitrogen fixation and phosphorus solubilization. This combined approach drives enhanced cell division and

internodal elongation during peak growth phases, a finding supported by the work of Doğan and Çiğ (2023) ^[12].

Table 2: Effect of integrated nutrient management on plant height (cm) of chickpea

Tr. No.	Treatments	30 DAS	45 DAS	60 DAS	Harvest
T ₁	Vermicompost (VC) @ 2 t ha ⁻¹	28.00	41.66	58.33	58.33
T ₂	<i>Rhizobium</i> Culture (RC) @ 5 g kg ⁻¹	30.66	42.33	57.33	57.33
T ₃	PSB Culture @ 5 g kg ⁻¹	30.33	40.66	56.00	56.00
T ₄	RC + PSB @ each 5 g kg ⁻¹	30.00	42.00	58.12	58.12
T ₅	100% RDF	29.66	43.33	59.78	59.78
T ₆	RC + VC	30.00	43.00	57.00	57.00
T ₇	PSB + VC	29.00	41.66	57.66	57.66
T ₈	RC + PSB + VC	27.66	42.66	59.00	59.00
T ₉	50% RDF + RC + PSB + VC	31.66	44.65	60.33	60.33
T ₁₀	50% RDF + RC	28.00	43.66	56.00	56.00
T ₁₁	50% RDF + PSB	30.30	41.60	57.33	57.33
T ₁₂	50% RDF + RC + PSB	28.33	44.00	59.00	59.00
T ₁₃	50% RDF + VC	27.68	41.66	59.00	59.00
T ₁₄	Control	27.00	43.56	55.90	55.90
	SE(m) ±	0.99	0.80	0.32	0.81
	CD (P = 0.05)	NS	NS	1.09	NS

Number of branches plant⁻¹

Branching determines the final canopy structure and the number of operational fruiting nodes in grain legumes. The number of branches plant⁻¹ varied significantly across all observation intervals (Table 3). At 30 DAS, the highest number of branches was recorded in T₅ (100% RDF: 11.00), which was statistically at par with 50% RDF + RC + PSB (10.66) and 50% RDF + PSB (10.33). By 60 DAS and final harvest, the maximum values were achieved under 50% RDF + RC + PSB + VC (13.00 and 15.00 branches, respectively) and 50% RDF + VC (13.00 and 15.00 branches, respectively). This lateral development indicates that the organic matter in vermicompost, coupled with synthetic NPK, improves soil physical architecture and moisture retention. This improvement facilitates the continuous lateral translocation of nutrients like potassium, which regulates the cellular turgor required for auxiliary bud development (Sohu *et al.*, 2015) ^[17].

Table 3: Effect of Integrated Nutrient Management on the Number of Branches Plant-

Tr. No.	Treatments	30 DAS	60 DAS	Harvest
T ₁	Vermicompost (VC) @ 2 t ha ⁻¹	6.66	11.65	11.66
T ₂	<i>Rhizobium</i> Culture (RC) @ 5 g kg ⁻¹	5.67	9.00	11.33
T ₃	PSB Culture @ 5 g kg ⁻¹	5.56	9.33	11.30
T ₄	RC + PSB @ each 5 g kg ⁻¹	7.00	11.00	12.66
T ₅	100% RDF	11.00	9.00	14.00
T ₆	RC + VC	8.00	9.66	11.33
T ₇	PSB + VC	7.23	10.66	11.30
T ₈	RC + PSB + VC	9.00	10.59	12.33
T ₉	50% RDF + RC + PSB + VC	10.00	13.00	15.00
T ₁₀	50% RDF + RC	8.68	12.00	13.00
T ₁₁	50% RDF + PSB	10.33	11.50	12.30
T ₁₂	50% RDF + RC + PSB	10.66	11.56	13.00
T ₁₃	50% RDF + VC	10.00	13.00	15.00
T ₁₄	Control	4.00	7.00	12.94
	SE(m) ±	0.35	0.27	0.24
	CD (\$P = 0.05\$)	1.02	0.89	0.69

Number of nodules plant⁻¹

Root nodulation represents the biological machinery responsible for atmospheric nitrogen fixation in chickpeas. The data track a clear curve reflecting nodule initiation, peak activity and natural senescence, as documented in

Table 4. Nodulation dynamics showed strong treatment responses across all intervals. At 30 DAS, the application of chemical nutrients in 100% RDF stimulated early nodule counts (21.00 plant⁻¹), followed closely by 50% RDF + VC (19.89) and 50% RDF + RC + PSB + VC (19.00). However, at 45 and 60 DAS, treatment 50% RDF + RC + PSB + VC produced the highest nodule counts, reaching 26.66 and 28.00 nodules plant⁻¹, respectively. This represents a 211.11% increase in nodulation at 60 DAS compared to the absolute control (9.00 plant⁻¹).

High concentrations of initial synthetic nitrogen (as in 100% RDF) can inhibit leghemoglobin synthesis and nodule formation at later growth stages via feedback inhibition (Nishida *et al.*, 2018) ^[14]. Conversely, the integrated approach supplies a minimal starter dose of chemical nitrogen alongside a steady release of organic carbon, fostering an optimal rhizosphere environment for *Rhizobium* colonization. Furthermore, the inclusion of PSB solubilizes fixed soil phosphorus via organic acid production, providing the high ATP energy required by the nitrogenase enzyme complex for biological nitrogen fixation (Tarafdar, 2008; Tagore *et al.*, 2013) ^[19, 18].

Table 4: Effect of integrated nutrient management on nodule count of chickpea

Tr. No.	Treatments	30 DAS	45 DAS	60 DAS
T ₁	Vermicompost (VC) @ 2 t ha ⁻¹	17.33	18.00	12.00
T ₂	<i>Rhizobium</i> Culture (RC) @ 5 g kg ⁻¹	13.00	19.27	11.00
T ₃	PSB Culture @ 5 g kg ⁻¹	12.68	17.66	12.00
T ₄	RC + PSB @ each 5 g kg ⁻¹	14.66	16.00	14.00
T ₅	100% RDF	21.00	25.00	23.01
T ₆	RC + VC	16.00	16.90	14.66
T ₇	PSB + VC	17.33	17.80	16.76
T ₈	RC + PSB + VC	17.66	20.00	19.00
T ₉	50% RDF + RC + PSB + VC	19.00	26.66	28.00
T ₁₀	50% RDF + RC	18.00	21.49	19.33
T ₁₁	50% RDF + PSB	16.56	21.00	18.38
T ₁₂	50% RDF + RC + PSB	18.23	20.00	16.00
T ₁₃	50% RDF + VC	19.89	24.47	23.00
T ₁₄	Control	9.66	12.58	9.00
	SE(m) ±	0.25	0.78	0.21
	CD (\$P = 0.05\$)	0.68	0.97	0.63

Yield attributing characters

The integrated nutrient management regimes significantly improved all yield-attributing components. The maximum number of pods plant⁻¹ (63.33) was achieved under 50% RDF + RC + PSB + VC, which was statistically at par with 100% RDF (63.00) and significantly superior to all other remaining setups. This reflects a 104.29% increase in pod production over the control. In case if grains per pod, Treatment 50% RDF + RC + PSB yielded the highest grain count of 1.66 grains pod⁻¹, which was statistically at par with 50% RDF + RC + PSB + VC (1.60) and 100% RDF (1.59). Whereas the maximum 100-seed weight of 18.00 g was produced under both 50% RDF + RC + PSB + VC and 50% RDF + PSB, outperforming the control value of 13.00 g. These structural increases indicate that combining mineral inputs with bio-organic matrices expands source-to-sink efficiency. Available phosphorus drives primordial flower initiation and pod setting, while potassium optimizes carbohydrates and amino acid translocation into developing seeds, resulting in higher seed indices (Kemal *et al.*, 2018) [7]. Similar effect of INM practices on yield attributes of chickpea was observed by Tiwari *et al.* (2022) [20], Sodavadiya *et al.* (2023) [16]

Table 5: Effect of integrated nutrient management on chickpea yield attributes

Tr. No.	Treatments	Pods plant ⁻¹	Grains pod ⁻¹	Seed index (g)
T ₁	Vermicompost (VC) @ 2 t ha ⁻¹	31.40	1.33	14.66
T ₂	<i>Rhizobium</i> Culture (RC) @ 5 g kg ⁻¹	38.33	1.00	13.65
T ₃	PSB Culture @ 5 g kg ⁻¹	36.63	1.20	13.00
T ₄	RC + PSB @ each 5 g kg ⁻¹	47.76	1.00	16.00
T ₅	100% RDF	63.00	1.59	17.40
T ₆	RC + VC	45.00	1.10	16.90
T ₇	PSB + VC	46.00	1.00	17.00
T ₈	RC + PSB + VC	49.14	1.21	17.80
T ₉	50% RDF + RC + PSB + VC	63.33	1.60	18.00
T ₁₀	50% RDF + RC	51.00	1.37	17.33
T ₁₁	50% RDF + PSB	51.53	1.44	18.00
T ₁₂	50% RDF + RC + PSB	59.21	1.66	17.32
T ₁₃	50% RDF + VC	58.46	1.28	17.30
T ₁₄	Control	31.00	1.00	13.00
	SE(m) ±	0.23	0.02	0.20
	CD (\$P = 0.05\$)	0.70	0.04	0.42

Grain yield, straw yield and harvest Index

The highest grain yield (20.66 q ha⁻¹) and straw yield (24.33 q ha⁻¹) were recorded under 50% RDF + *Rhizobium* + PSB + Vermicompost which was statistically at par with 100% RDF (20.00 q ha⁻¹ of grain and 23.80 q ha⁻¹ of straw yield). This integrated approach resulted in a 98.08% increase in grain yield and an 87.15% increase in straw yield over the absolute control, which recorded the lowest overall yields (10.43 q ha⁻¹ grain and 13.00 q ha⁻¹ straw yield). Similarly, the highest harvest index of 50.00% was achieved under T₉, outperforming the control value of 40.00% (Tale 5). The superior grain and straw yield observed under T₉ confirms that substituting 50% of synthetic mineral fertilizers with vermicompost and microbial inoculants delivers balanced crop nutrition. Vermicompost slowly releases secondary and micronutrients while improving soil structure, which extends root architecture. Concurrently, *Rhizobium* and PSB maximize nutrient availability in the root zone. This combined effect maintains high chlorophyll levels and photosynthetic rates, promoting dry matter accumulation and efficient translocation into the final grain

sink (Boreddy *et al.*, 2019; Dotaniya *et al.*, 2022) [1, 3]. These findings confirm that INM strategies can reduce reliance on chemical fertilizers by 50% while improving agronomic yield.

Table 6: Effect of integrated nutrient management on chickpea yield

Tr. No.	Treatments	Grain yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)	Harvest index (%)
T ₁	Vermicompost (VC) @ 2 t ha ⁻¹	13.00	15.00	47.00
T ₂	<i>Rhizobium</i> Culture (RC) @ 5 g kg ⁻¹	12.00	14.00	40.87
T ₃	PSB Culture @ 5 g kg ⁻¹	11.00	14.53	39.00
T ₄	RC + PSB @ each 5 g kg ⁻¹	14.00	15.00	48.33
T ₅	100% RDF	20.00	23.80	48.00
T ₆	RC + VC	15.00	16.66	48.00
T ₇	PSB + VC	15.33	17.33	44.00
T ₈	RC + PSB + VC	14.00	20.00	41.33
T ₉	50% RDF + RC + PSB + VC	20.66	24.33	50.00
T ₁₀	50% RDF + RC	17.00	21.00	44.23
T ₁₁	50% RDF + PSB	15.66	22.23	43.66
T ₁₂	50% RDF + RC + PSB	17.67	23.22	41.00
T ₁₃	50% RDF + VC	19.00	21.30	45.00
T ₁₄	Control	10.43	13.00	40.00
	SE(m) ±	0.14	0.49	0.79
	CD (\$P = 0.05\$)	0.38	1.00	1.70

Conclusion

The field experiment demonstrates that an integrated nutrient management strategy effectively secures high agronomic productivity in chickpea (*Cicer arietinum* L.) while simultaneously preserving chemical inputs. The combined application of 50% Recommended Dose of Fertilizers (10 kg N + 30 kg P₂O₅ + 10 kg K₂O ha⁻¹) paired with vermicompost 2 t ha⁻¹ and dual biofertilizer seed inoculation with *Rhizobium* culture and Phosphate Solubilizing Bacteria, each @ 5 g kg⁻¹ seed) optimized plant vegetative architecture, enhanced biological root nodulation by 211.11% at 60 days after sowing and achieved a remarkable 98.08% increase in grain yield and 87.15% increase in straw yield over the unfertilized absolute control. Replacing 50% of the mineral fertilizer requirement with organic amendments and targeted microbial inoculants provides an excellent, highly productive method for maintaining crop yields, optimizing resource utilization and fostering sustainable soil fertility.

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