International Journal of Plant & Soil Science

Volume 38, Issue 7, Page 104-115, 2026; Article no.IJPSS.158588
ISSN: 2320-7035

Integrated Nutrient Management through Biofertiliser and Organic Manure Enhances Growth and Yield of Chickpea (*Cicer arietinum L.*)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i76146

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/158588

Original Research Article

Received: 05/04/2026
Published: 20/06/2026

Abstract

The chickpea crop in Rajasthan is commonly grown under rainfed or limited-irrigation conditions in arid and semi-arid environments. A field experiment was conducted to evaluate the effects of integrated nutrient management involving inorganic fertilisers, organic manures and *Rhizobium* inoculation on the growth and yield of chickpea (*Cicer arietinum L.*). The experiment was laid out in a Randomised Block Design with twelve treatments and three replications during the rabi season of 2025-26 at the Agricultural Research Farm, School of Agricultural Sciences, Career Point University, Kota, Rajasthan, located in the Humid South-

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Cite as: *Zuber, M., Yadav, S., Singh, S., Nagar, R., Malav, M., Khan, K., & Khandelwal, D. (2026). Integrated Nutrient Management through Biofertiliser and Organic Manure Enhances Growth and Yield of Chickpea (Cicer arietinum L.). International Journal of Plant & Soil Science, 38(7), 104–115. https://doi.org/10.9734/ijpss/2026/v38i76146*

Eastern Plain Zone. Treatments comprised combinations of the recommended dose of fertilisers (RDF: 15 kg N and 40 kg P_2O_5 ha^{-1}), farmyard manure (FYM), vermicompost and *Rhizobium* inoculation. The experimental soil was clay loam in texture and alkaline in reaction, with a pH of 8.2. It was low in organic carbon and available nitrogen, medium in available phosphorus and high in available potassium. Integrated nutrient management significantly influenced the growth parameters, yield attributes and yield of chickpea. Among the treatments, 75% RDF + vermicompost @ 2.5 t ha^{-1} + *Rhizobium* (T7) recorded the highest plant height (90.1 cm), dry matter accumulation (35.6 g plant-1) and leaf area index (5.42 at 90 DAS), and was statistically at par with 100% RDF + vermicompost and 100% RDF + FYM. Yield attributes, including branches per plant (7.6), pods per plant (55.8), seeds per pod (2.2) and test weight (14.9 g), were also highest under T7. Accordingly, T7 produced the highest grain yield (2610 kg ha^{-1}), straw yield (3520 kg ha^{-1}) and biological yield (6130 kg ha^{-1}), while harvest index remained non-significant across treatments. The findings indicate that 75% RDF combined with vermicompost @ 2.5 t ha^{-1} and *Rhizobium* inoculation improved chickpea growth and yield under the tested conditions.

Keywords: Chickpea (Cicer arietinum L.); integrated nutrient management; Rhizobium; vermicompost; farmyard manure; growth parameters; yield attributes.

1. Introduction

The chickpea (*Cicer arietinum L.*), also known as gram or chana, is a premier rabi pulse crop widely cultivated mainly in semi-arid and warm temperate regions of the world for its protein-rich grains and its role in improving dietary quality and farming-system sustainability (ICAR-IIPR, 2024; Singh et al., 2025). It is diploid, with chromosome number 2n=16 (Meena et al., 2025). Chickpea is also suitable for novel product development, supporting the increasing production of plant-based foods and the rising demand for vegan and vegetarian products (Silva et al., 2025). In India, chickpea is a strategic pulse crop, and national estimates for 2021-22 reported production of 13.75 million tonnes from 10.91 million ha, with a mean productivity of 12.6 q ha^{-1}, reflecting its large footprint and food-security importance (ICAR-IIPR, 2024; Directorate of Pulses Development, 2023). Rajasthan is among the major chickpea-producing states of India, contributing a substantial share of national production; therefore, improving chickpea productivity in the state is agronomically and economically important (ICAR-IIPR, 2024). However, productivity levels in parts of Rajasthan remain comparatively low; for example, a Rajasthan-focused study reported chickpea cultivation over 12.35 lakh ha, production of 7.50 lakh tonnes and productivity of 607 kg ha^{-1}, indicating considerable scope for yield improvement (Yadav et al., 2024).

Chickpea in Rajasthan is frequently grown under rainfed or limited-irrigation conditions across arid and semi-arid environments where rainfall is uncertain and drought risk is recurrent (Singh et al., 2018). In arid regions of Rajasthan, low and unstable crop productivity has been associated not only with harsh climatic conditions but also with the adoption of traditional practices and technology gaps at the farm level (Singh et al., 2018). Such environments often have sandy to sandy-loam soils that are commonly low in nitrogen, with variable phosphorus and potash status, which can directly constrain chickpea growth, nodulation and yield formation. Nutrient constraints are particularly important for chickpea because yield depends on both adequate soil nutrient supply and efficient biological functioning of the root-rhizosphere system (Nabati et al., 2025). Chickpea can obtain a substantial proportion of its nitrogen requirement through symbiotic nitrogen fixation when effective nodulation occurs, but this process is highly sensitive to the presence of compatible rhizobia, soil moisture status and balanced nutrition, especially adequate phosphorus availability (Nabati et al., 2025). When nodulation is weak or soil biological activity is reduced, nitrogen fixation declines, leading to poor canopy development, reduced biomass accumulation and ultimately lower grain yield (Nabati et al., 2025; Sun et al., 2026).

Phosphorus is widely recognised as a key limiting nutrient for pulses because much of the soil P becomes chemically fixed in less available forms, especially where soil reactions restrict P solubility and diffusion to roots (Nabati et al., 2025). It plays a vital role in important physiological and biochemical processes in plants, including photosynthesis, energy transfer, nutrient mobilisation, carbohydrate translocation and metabolism, and it also constitutes an essential component of nucleic acids (Kumar et al., 2024). In chickpea, low P availability can limit root development and energy transfer processes, and it can indirectly depress nitrogen fixation by restricting nodule development and functioning (Pushpalata et al., 2024). Therefore, technologies that increase plant-available phosphorus and improve the soil biological processes responsible for nutrient cycling are central to sustainable chickpea production in Rajasthan's stress-prone agro-ecosystems (Delfim et al., 2024).

Biofertilisers, which are microbial inoculants containing beneficial organisms such as *Rhizobium* for nitrogen fixation and phosphate-solubilising bacteria (PSB), have emerged as environmentally compatible inputs to improve nutrient availability, nutrient uptake and crop performance in legumes (Pan & Cai, 2023). Recent chickpea field research in an arid environment reported that biofertiliser combinations increased soil bacterial populations, improved plant physiological traits such as chlorophyll content, enhanced nodulation and increased grain yield compared with a non-inoculated control (Sun et al., 2026). The same study documented improvements in N, P and K contents in plant and grain tissues in inoculated treatments, suggesting that microbial interventions can convert soil nutrients into plant-available forms and strengthen plant nutrient acquisition pathways (Nabati et al., 2025). For Rajasthan conditions, applied research also indicates the benefits of inoculating chickpea with *Rhizobium* and PSB, particularly when integrated with phosphorus fertilisation (Seleiman & Abdelaal, 2018). A field experiment conducted at Kota, Rajasthan, during rabi 2024-25 reported that seed inoculation with *Rhizobium* + PSB produced synergistic effects on growth and yield attributes relative to single inoculation and the control (Seleiman & Abdelaal, 2018). The same study reported the highest net returns under *Rhizobium* + PSB inoculation with its tested nutrient combinations, emphasising that biofertiliser-based options can be economically attractive when responses are consistent (Seleiman & Abdelaal, 2018).

Organic manures, such as farmyard manure (FYM), compost and vermicompost, contribute to chickpea productivity by supplying nutrients in slow-release forms while also improving soil structure, moisture retention and microbial habitat quality (Patel et al., 2025; Kayesh et al., 2023). Decomposition of organic manures in soil helps to prevent various disease-causing pathogens through different types of biological reactions (Narender et al., 2023). These soil improvements are especially relevant for Rajasthan's coarse-textured soils in many areas, where low organic carbon and limited water-holding capacity restrict nutrient availability during key phenological stages (Yadav et al., 2024; Patel et al., 2025). By adding organic carbon substrates, organic manures can stimulate microbial activity and nutrient mineralisation, which can support better root growth and nutrient uptake under low-input conditions. However, relying on a single nutrient source, whether organic or inorganic, can be suboptimal because nutrient release from organics may not always synchronise with crop demand, while mineral fertilisers alone may not address underlying soil biological constraints and may face reduced efficiency in stress-prone environments (Seleiman & Abdelaal, 2018; Patel et al., 2025).

These limitations provide a strong rationale for integrated nutrient management (INM), which strategically combines organic manures, biofertilisers and judicious mineral fertilisation to achieve balanced nutrition, improve nutrient-use efficiency and sustain soil fertility. Long-standing experimental evidence also supports that combining microbial inoculants with balanced nutrients and organic amendments can significantly increase chickpea yield and profitability while improving soil fertility indicators (Tiwari et al., 2018). In a Vertisol study, treatments integrating recommended fertilisation with *Rhizobium* + PSB inoculation and associated nutrient packages produced higher seed yield and a higher benefit: cost ratio than the control and farmer practice, illustrating the potential of integrated approaches to improve both productivity and farm economics (Tiwari et al., 2018). The same study reported that INM treatments including FYM improved soil organic carbon and available N, P, K and micronutrients after harvest compared with other treatments, indicating soil fertility improvement alongside yield gains (Tiwari et al., 2018).

The economic dimension is particularly important for chickpea farmers in Rajasthan because adoption depends on net returns, benefit: cost ratio and risk reduction under rainfall uncertainty (Yadav et al., 2024). Research from arid Rajasthan has shown that improved production technologies increased chickpea grain yield by about 28.63-38.07% over farmer practice and increased net returns by up to about 50.11%, demonstrating that technology packages can translate into tangible economic benefits. Consequently, evaluating biofertiliser- and organic manure-mediated improvement in the growth and yield of chickpea is justified for Rajasthan because it integrates biological efficiency, soil health and profitability, three pillars required for sustainable adoption (Singh et al., 2018; Nabati et al., 2025).

Although previous studies have demonstrated the usefulness of organic manures, mineral fertilisers and microbial inoculation in chickpea, location-specific information on the comparative response of chickpea to reduced RDF integrated with vermicompost or FYM and *Rhizobium* under the Humid South-Eastern Plain Zone of Rajasthan remains limited. Therefore, the present investigation was undertaken to evaluate the effect of integrated nutrient management through biofertiliser and organic manure on the growth and yield of chickpea under the agro-climatic conditions of Kota, Rajasthan.

2. Materials and Methods

The field experiment was conducted at the Agricultural Farm of Career Point University, Alaniya, Kota, during the rabi season of 2025-26. The site is geographically located at 25° 11' N latitude and 75° 54' E longitude, with an elevation of 273 metres above mean sea level within the Humid South-Eastern Plain Zone (Zone V) of Rajasthan.

The soil of the experimental field was clay loam in texture and alkaline in reaction, with pH 8.2, EC 0.27 ds m^{-1}, low organic carbon (0.43%), low available N (175 kg ha^{-1}), medium available P (14.8 kg ha^{-1}) and high available K (319 kg ha^{-1}).

The twelve treatments (T1 to T12), involving various combinations of the recommended dose of fertilisers (RDF), FYM, vermicompost and *Rhizobium*, were tested in a Randomised Block Design (RBD) with three replications.

The recommended doses of nitrogen and phosphorus (15 kg N ha^{-1} and 40 kg P_2O_5 ha^{-1}), as per the treatments, were supplied through urea and single super phosphate (SSP), respectively, and applied in furrows at a depth of 8 to 10 cm at sowing. Well-decomposed FYM and vermicompost were applied according to the treatments and mixed thoroughly into the soil at the time of sowing. For biofertiliser application, the required quantity of seed was treated with *Rhizobium* culture using a jaggery solution and allowed to dry in the shade before sowing.

The chickpea variety GNG 1581 (Gangor) was sown in rows spaced 30 cm apart, with a plant-to-plant spacing of 8 cm, using a seed rate of 40 kg ha-1 in November (11-11-2025). Sowing was carried out by placing one seed at a depth of 8-10 cm using the hand-ploughing method. The crop was harvested at full maturity on April 14, 2026.

2.1 Growth and Development Studies

Five plants were selected randomly from each plot, and their height was measured (in cm) using a metre scale from the ground surface to the top of a mature leaf at maturity; the values were then averaged. The same method of selecting five random plants was used to record the number of primary branches per plant, pods per plant and seeds per pod, and the values were averaged. Clean seeds from each plot were collected, and 100 seeds from each sample were counted and weighed to record the seed index. In addition, dry matter accumulation per plant and leaf area index (LAI) were recorded.

2.2 Yield Studies

Seed yield from the net plot was recorded after threshing the sun-dried harvested produce from each plot, weighing it with a balance and converting it into seed yield (kg ha^{-1}). Straw yield was computed by deducting seed yield from biological yield (crop biomass) and was also converted into kg ha^{-1}.

2.3 Statistical Analysis

The data generated from the study were subjected to analysis of variance using SPSS to determine the statistical significance of treatment effects. The 'F' test was used for this purpose. Interpretation of the results was based on the statistical significance of the derived 'F' value at the 5% probability level. Critical difference (CD) values were determined to examine significant differences among treatments, as described by Gomez and Gomez (1984).

3. Results and Discussion

3.1 Growth Studies

3.1.1 Plant Height (cm)

Data on plant height were collected at 30, 60, 90 and 120 DAS and at maturity, analysed statistically and presented in Table 1. Plant height at all growth stages was significantly affected by the integrated nutrient management treatments. Plant height at 30, 60, 90 and 120 DAS and at maturity ranged from 12.8-17.9 cm, 26.5-37.2 cm, 42.9-56.8 cm, 64.2-77.1 cm and 75.8-90.1 cm, respectively. Plant height increased progressively with crop age and reached its maximum at maturity across all treatments. The highest plant heights at 30, 60, 90 and 120 DAS and at maturity were 17.9 cm, 37.2 cm, 56.8 cm, 77.1 cm and 90.1 cm, respectively, under 75% RDF + vermicompost @ 2.5 t ha^{-1} + *Rhizobium* (T7). This treatment was statistically at par with 100% RDF + vermicompost @ 2.5 t ha^{-1} (T4) and 100% RDF + FYM @ 5 t ha^{-1} (T3) at all successive stages. The lowest plant height was recorded in the control plot (T1), where no fertilisers were applied.

The better development and growth observed in the above treatments may be attributed to greater nutrient availability in the soil as a result of integrating inorganic fertilisers with organic manure (vermicompost) and biofertiliser (*Rhizobium*). These nutrient sources may have enhanced meristematic activity and increased the availability of major nutrients to plants from deeper soil layers. The rapid release of nitrogen produced by root rhizobia during vegetative growth may have contributed to increased plant height. Furthermore, photosynthate production may have increased because nitrogen and phosphorus improve photosynthetic efficiency. Phosphorus (P) is also directly related to the formation of plant root biomass and robust plant development, leading to considerable improvement in growth parameters. These findings are in agreement with earlier reports (Reddy et al., 2022; Meena et al., 2020; Singh et al., 2017).

3.1.2 Dry Matter Accumulation (g) Per Plant

Dry matter accumulation per plant, recorded at 30, 60, 90 and 120 DAS and at maturity, was significantly influenced by the treatments. Dry matter accumulation per plant ranged from 0.36-0.68 g, 0.82-2.8 g, 4.8-8.9 g, 11.2-22.4 g and 22.5-35.6 g at the respective stages. The highest dry matter accumulation per plant at maturity (35.6 g) was recorded with 75% RDF + vermicompost @ 2.5 t ha^{-1} + *Rhizobium* (T7), which was statistically at par with T4 and T3. The lowest dry matter accumulation (22.5 g at maturity) was recorded in the control plot (T1).

The significant increase in dry matter accumulation with 75% RDF + vermicompost @ 2.5 t ha^{-1} + *Rhizobium* may be attributed to a balanced nutrient supply during the first three to four weeks of growth, from germination to nodulation. Starter doses of N, P and K help seedlings maintain vigour and develop a robust root system. A limited nutrient supply impedes root development, making weak seedlings more susceptible to diseases and reducing their ability to compete with weeds or tolerate herbicide stress. Adequate nutrient supply through integrated sources supported vigorous vegetative growth. These results are in close conformity with earlier findings (Meena et al., 2020; Singh et al., 2017).

3.1.3 Leaf Area Index

Leaf area index at 30, 60 and 90 DAS was significantly affected by the integrated nutrient management treatments. Leaf area index at 30, 60 and 90 DAS ranged from 0.60-1.15, 2.10-3.65 and 3.15-5.42, respectively, and reached its maximum at 90 DAS across all treatments. The highest leaf area index values at 30, 60 and 90 DAS were 1.15, 3.65 and 5.42, respectively, under 75% RDF + vermicompost @ 2.5 t ha^{-1} + *Rhizobium* (T7). This treatment was statistically at par with T4 and T3 at all successive stages. The lowest leaf area index was recorded in the control plot (T1). The increase in leaf area index may be linked to an adequate supply of integrated nutrients, which promotes cell elongation, cell expansion, cell division and vigorous vegetative growth. These results are in close conformity with earlier findings (Reddy et al., 2022; Singh et al., 2017).

3.2 Yield Studies

3.2.1 Grain Yield (kg ha^{-1})

An examination of the data revealed that the integrated nutrient management treatments significantly affected grain yield. Grain yield ranged from 1350-2610 kg ha^{-1}. The maximum grain yield (2610 kg ha^{-1}) was recorded in treatment T7 (75% RDF + vermicompost @ 2.5 t ha^{-1} + *Rhizobium*), which was statistically at par with treatments T4 and T3. The minimum grain yield (1350 kg ha^{-1}) was recorded in the control (T1), which differed significantly from the remaining treatments.

The enhancement in grain yield may be attributed to the cumulative effect of yield-attributing characteristics, such as the number of flowers, pods per plant (55.8), seeds per pod (2.2) and 100-seed weight (14.9 g). This increase may be due to the optimum availability and supply of macronutrients, which positively affected flowering, seed production and greater mobilisation of photosynthates to the developing seeds. By increasing the movement of photosynthates from source (leaf and stem) to sink (pods), the development of more reproductive organs may have increased sink size and seed yield. Similar findings were reported by Tomar and Singh (2025) and Tiwari et al. (2018).

Table 1. Effect of different treatments on plant height (cm) of chickpea (*Cicer arietinum L.*)

Treatments	**Plant Height**				
	30 DAS	**60 DAS**	**90 DAS**	**120 DAS**	**At maturity**
T_1- Control	12.8	26.5	42.9	64.2	75.8
T2- 100% RDF (Recommended Dose of Fertilisers)	16.4	34.8	53.1	73.1	84.5
T_3- 100% RDF + FYM @ 5 t ha^{-1}	17.2	36.1	55.4	75.8	88.2
T_4- 100% RDF + Vermicompost @ 2.5 t ha^{-1}	17.5	36.7	56.2	76.5	89.4
T_5- 75% RDF + Vermicompost @ 2.5 t ha^{-1}	16.1	33.9	52.5	72.8	83.9
T_6- 75% RDF + FYM @ 5 t ha^{-1}	15.7	32.4	50.8	71.2	82.1
T7- 75% RDF + Vermicompost @ 2.5 t ha-1 + *Rhizobium*	17.9	37.2	56.8	77.1	90.1
T8- 75% RDF + FYM @ 5 t ha-1 + *Rhizobium*	17.0	35.8	54.9	74.9	87.3
T_9- 50% RDF + Vermicompost @ 2.5 t ha^{-1}	14.8	31.2	48.5	68.9	79.5
T_{10}- 50% RDF + FYM @ 5 t ha^{-1}	14.2	30.1	47.2	67.5	78.2
T11- 50% RDF + Vermicompost @ 2.5 t ha^{-1} + *Rhizobium*	15.6	32.8	51.4	71.8	82.7
T12- 50% RDF + FYM @ 5 t ha^{-1} + *Rhizobium*	15.2	31.9	50.1	70.4	81.3
SE(m)±	0.52	0.94	1.12	1.42	1.78
CD at 5%	1.58	2.85	3.39	4.31	5.39

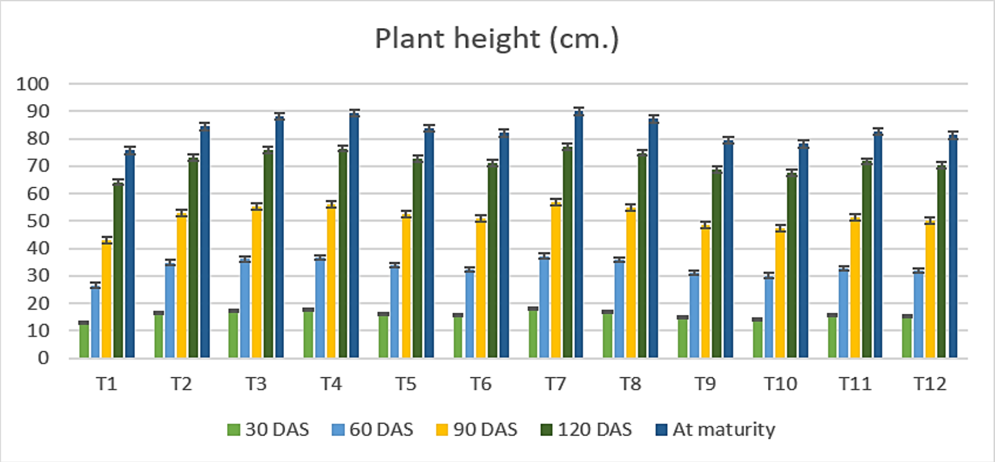

Fig. 1. Graph showing the effect of different treatments on plant height (cm) of chickpea (*Cicer arietinum L.*)

Table 2. Effect of different treatments on dry matter accumulation (g plant^{-1}) of chickpea (*Cicer arietinum L.*)

Treatments	Dry Matter Accumulation				
	30 DAS	60 DAS	90 DAS	120 DAS	At maturity
T_1- Control	0.36	0.82	4.8	11.2	22.5
T2- 100% RDF (Recommended Dose of Fertilisers)	0.54	2.2	7.6	18.9	30.2
T_3- 100% RDF + FYM @ 5 t ha^{-1}	0.61	2.5	8.2	20.8	32.7
T_4- 100% RDF + Vermicompost @ 2.5 t ha^{-1}	0.64	2.7	8.6	21.5	34.1
T_5- 75% RDF + Vermicompost @ 2.5 t ha^{-1}	0.56	2.3	7.8	19.6	31.0
T_6- 75% RDF + FYM @ 5 t ha^{-1}	0.52	2.1	7.2	18.2	29.4
T7- 75% RDF + Vermicompost @ 2.5 t ha^{-1} + *Rhizobium*	0.68	2.8	8.9	22.4	35.6
T8- 75% RDF + FYM @ 5 t ha^{-1} + *Rhizobium*	0.62	2.6	8.4	21.1	33.5
T_9- 50% RDF + Vermicompost @ 2.5 t ha^{-1}	0.48	1.6	6.8	16.5	28.1
T_{10}- 50% RDF + FYM @ 5 t ha^{-1}	0.44	1.4	6.4	15.8	26.8
T11- 50% RDF + Vermicompost @ 2.5 t ha^{-1} + *Rhizobium*	0.53	1.9	7.4	17.8	29.7
T12- 50% RDF + FYM @ 5 t ha^{-1} + *Rhizobium*	0.50	1.7	7.1	17.2	28.9
SE(m)±	0.02	0.05	0.18	0.58	0.72
CD at 5%	0.05	0.16	0.55	1.76	2.18

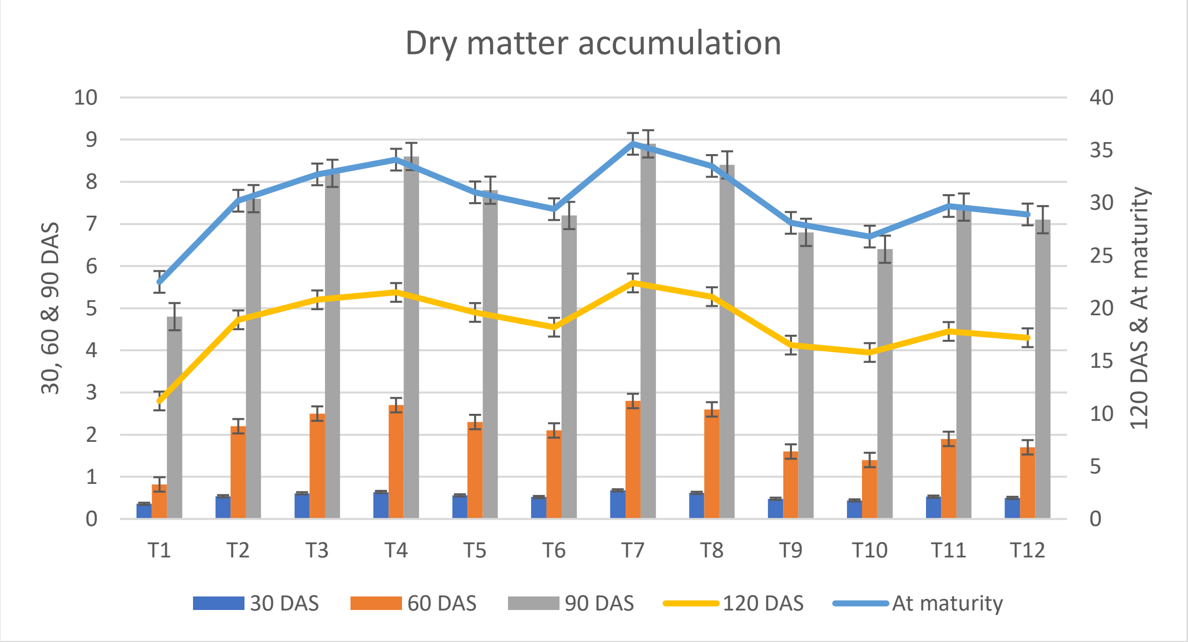

Fig. 2. Graph showing the effect of different treatments on dry matter accumulation (g plant-1) of chickpea (*Cicer arietinum L.*)

3.2.2 Straw Yield (kg ha^{-1})

An examination of the data showed that the fertiliser treatments significantly influenced straw yield. Straw yield ranged from 1780-3520 kg ha^{-1}. Among the treatments, T7 (75% RDF + vermicompost @ 2.5 t ha^{-1} + *Rhizobium*) recorded the maximum straw yield (3520 kg ha^{-1}), which was statistically at par with T4 and T3. The lowest straw yield (1780 kg ha^{-1}) was observed in the control (T1).

Table 3. Effect of different treatments on leaf area index of chickpea (*Cicer arietinum L.*)

Treatments	**Leaf area index**		
	30 DAS	**60 DAS**	**90 DAS**
T_1- Control	0.60	2.10	3.15
T2- 100% RDF (Recommended Dose of Fertilisers)	0.95	3.15	4.75
T_3- 100% RDF + FYM @ 5 t ha^{-1}	1.05	3.42	5.08
T_4- 100% RDF + Vermicompost @ 2.5 t ha^{-1}	1.10	3.55	5.25
T_5- 75% RDF + Vermicompost @ 2.5 t ha^{-1}	0.92	3.05	4.62
T_6- 75% RDF + FYM @ 5 t ha^{-1}	0.85	2.85	4.28
T7- 75% RDF + Vermicompost @ 2.5 t ha^{-1} + *Rhizobium*	1.15	3.65	5.42
T8- 75% RDF + FYM @ 5 t ha^{-1} + *Rhizobium*	1.02	3.35	4.95
T_9- 50% RDF + Vermicompost @ 2.5 t ha^{-1}	0.78	2.65	3.95
T_{10}- 50% RDF + FYM @ 5 t ha^{-1}	0.75	2.55	3.82
T_{11}- 50% RDF + Vermicompost @ 2.5 t ha^{-1} + *Rhizobium*	0.88	2.95	4.45
T_{12}- 50% RDF + FYM @ 5 t ha^{-1} + *Rhizobium*	0.82	2.78	4.15
SE(m)±	0.04	0.12	0.15
CD at 5%	0.12	0.35	0.45

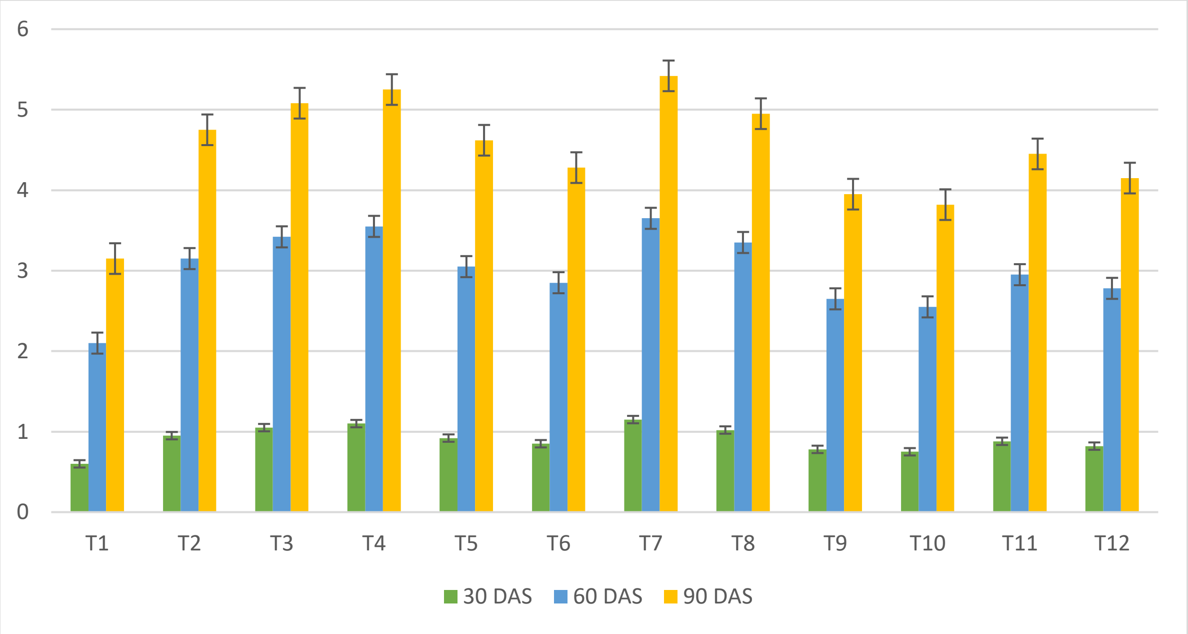

Fig. 3. Graph showing the effect of different treatments on leaf area index of chickpea (*Cicer arietinum L.*)

Table 4. Effect of different treatments on yield of chickpea (*Cicer arietinum L.*)

Treatments	**Grain yield (kg ha^{-1})**	**Straw yield (kg ha^{-1})**	**Biological yield (kg ha^{-1})**	**HI (%)**
T_1- Control	1350	1780	3130	43
T2- 100% RDF (Recommended Dose of Fertilisers)	2320	3105	5425	43
T_3- 100% RDF + FYM @ 5 t ha^{-1}	2480	3310	5790	43
T_4- 100% RDF + Vermicompost @ 2.5 t ha^{-1}	2540	3385	5925	43
T_5- 75% RDF + Vermicompost @ 2.5 t ha^{-1}	2315	3210	5525	42
T_6- 75% RDF + FYM @ 5 t ha^{-1}	2240	3120	5360	42
T7- 75% RDF + Vermicompost @	2610	3520	6130	43

Treatments	**Grain yield (kg ha^{-1})**	**Straw yield (kg ha^{-1})**	**Biological yield (kg ha^{-1})**	**HI (%)**
2.5 t ha^{-1} + *Rhizobium*				
T8- 75% RDF + FYM @ 5 t ha^{-1} + *Rhizobium*	2505	3415	5920	42
T$_9$- 50% RDF + Vermicompost @ 2.5 t ha^{-1}	2150	2805	4955	43
T$_{10}$- 50% RDF + FYM @ 5 t ha^{-1}	2080	2715	4795	43
T11- 50% RDF + Vermicompost @ 2.5 t ha^{-1} + *Rhizobium*	2255	3010	5265	43
T12- 50% RDF + FYM @ 5 t ha^{-1} + *Rhizobium*	2190	2940	5130	43
SE(m)±	75.12	102.45	112.30	1.38
CD at 5%	226.50	308.20	338.40	NS

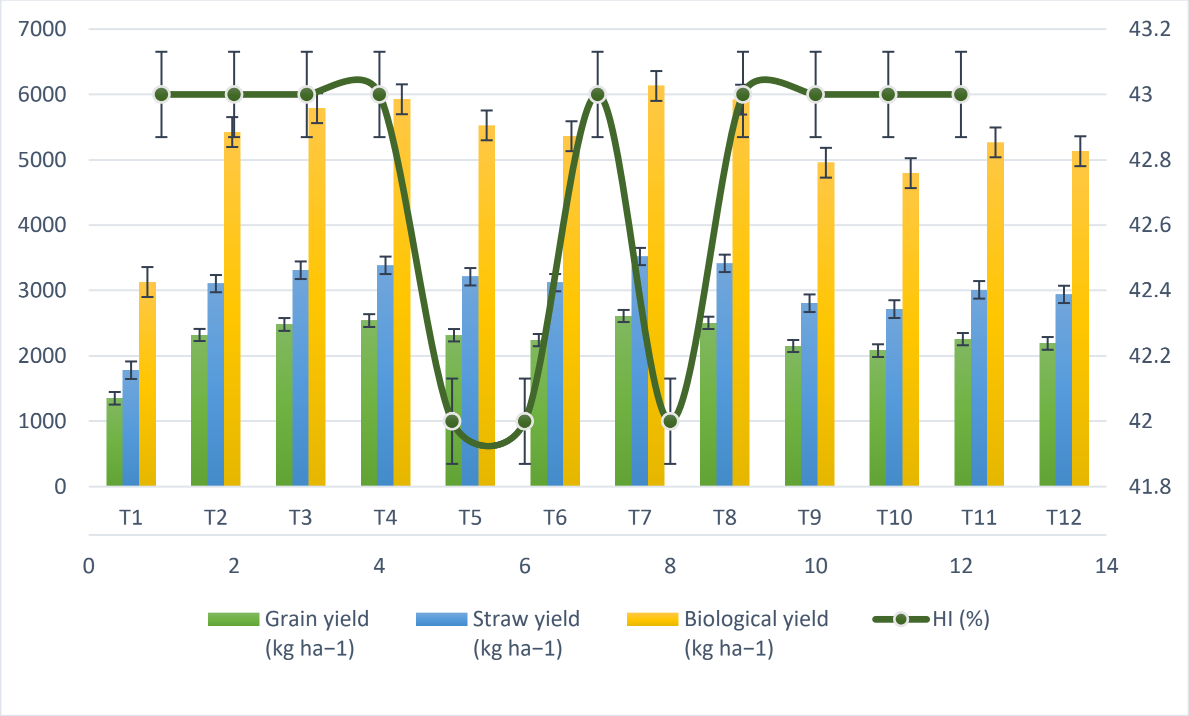

Fig. 4. Graph showing the effect of different treatments on yield of chickpea (*Cicer arietinum L.*)

The significant response observed with the application of integrated inorganic and organic fertilisers may be due to an adequate nutrient supply, which supported vigorous vegetative growth of the plants. This growth subsequently increased the number of branches through cell elongation, cell expansion, cell division, photosynthesis and turgidity of plant cells, ultimately resulting in higher straw biomass. Similar findings were reported by Tomar and Singh (2025) and Tiwari et al. (2018).

3.2.3 Biological yield (kg ha^{-1})

The data indicate that fertiliser treatments significantly affected biological yield, which ranged from 3130-6130 kg ha^{-1}. The maximum biological yield (6130 kg ha^{-1}) was recorded in treatment T7, which was statistically at par with T4 and T3. The control recorded the minimum biological yield (3130 kg ha^{-1}). This substantial increase in biological yield under T7 may be due to greater dry matter accumulation during the early stages of growth, which contributed to higher overall biomass production. Similar results were obtained by Choudhury et al. (2025) and Seleiman and Abdelaal (2018).

3.2.4 Harvest Index (%)

An examination of the data showed that the fertiliser treatments did not significantly influence the harvest index (NS). The harvest index ranged narrowly from 42-43% across treatments. The maximum harvest index (43%) was recorded in several treatments, including T7, T4, T2 and T1, while the minimum value (42%) was recorded in treatments such as T5, T6 and T8.

4. Conclusions

The field experiment conducted during the rabi season of 2025-26 at Career Point University, Kota, showed that integrated nutrient management significantly influenced the growth, yield attributes and yield of chickpea. Among the tested treatments, 75% RDF + vermicompost @ 2.5 t ha^{-1} + *Rhizobium* (T7) produced the highest plant height, dry matter accumulation and leaf area index. It also recorded the highest number of branches (7.6), pods per plant (55.8), seeds per pod (2.2) and 100-seed weight (14.9 g), resulting in the maximum grain yield (2610 kg ha^{-1}), straw yield (3520 kg ha^{-1}) and biological yield (6130 kg ha^{-1}). These responses were significantly higher than those observed in the control and statistically comparable with 100% RDF + vermicompost @ 2.5 t ha^{-1} and 100% RDF + FYM @ 5 t ha^{-1}. The harvest index was not significantly affected and remained within a narrow range of 42-43%. Based on these findings, applying 75% RDF with vermicompost @ 2.5 t ha^{-1} and *Rhizobium* inoculation may be considered a suitable nutrient management option for improving chickpea performance under the tested agro-climatic conditions of Rajasthan while allowing a reduction in mineral fertiliser use. This treatment therefore offers a balanced option within the tested treatment structure.

5. Limitations of the Study

The present study was conducted during a single rabi season at one experimental site in Kota, Rajasthan, using the chickpea variety GNG 1581 (Gangor). Therefore, the findings should be interpreted within the soil and agro-climatic conditions described for the experimental field. Treatment responses may vary under different soil textures, rainfall patterns, irrigation regimes, varieties or management systems. The study focused mainly on growth parameters, yield attributes and yield, while detailed post-harvest soil biological properties, nutrient-use efficiency, long-term soil fertility changes and economic analysis were not evaluated. The performance of organic manures and *Rhizobium* inoculation may also depend on manure quality, microbial viability and local soil moisture conditions, which were not compared independently. Multi-location and multi-year trials involving different chickpea varieties, post-harvest soil assessment and economic evaluation would be useful to confirm the consistency and practical suitability of the identified nutrient management approach for wider adoption by farmers and researchers alike.

Acknowledgement

The researchers express their gratitude to the Department of Agronomy, School of Agricultural Sciences, Career Point University, Kota, Rajasthan, India, for providing the required facilities.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/158588