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Integrated nutrient management enhances productivity, profitability and soil fertility of Chickpea (*Cicer arietinum* L.) under Vertisol conditions of Central India

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Abstract

A field experiment was conducted during the rabi season of 2024–25 in the Vertisol region of central India to evaluate the response of chickpea (*Cicer arietinum* L.) to integrated nutrient management (INM). Eight nutrient treatments, involving graded levels of recommended dose of fertilizers (RDF) in combination with farmyard manure (FYM) and biofertilizers, were tested in a randomized block design with three replications. Observations were recorded on growth parameters, yield attributes, yield, post-harvest soil fertility, and economic returns. Growth parameters showed a consistent improvement under integrated treatments, with 75% RDF + FYM @ 5 t ha⁻¹ + biofertilizers recording higher plant height (58.5 cm), branches per plant (7.9), nodules per plant (34.1), and dry matter accumulation (22.6 g plant⁻¹). Yield attributes followed a similar trend, with pods per plant (61.4) and 100-seed weight (22.9 g) increasing under integrated nutrient supply, while seeds per pod remained statistically non-significant. Grain yield reached a maximum of 1864 kg ha⁻¹ under 75% RDF + FYM + biofertilizers, followed by 1786 kg ha⁻¹ under 50% RDF + FYM + biofertilizers. Post-harvest soil analysis indicated an improvement in soil organic carbon (0.66%) and available nitrogen (318 kg ha⁻¹) and phosphorus (23.4 kg ha⁻¹) under integrated treatments, suggesting a combined influence of organic inputs and biological activity on nutrient availability. Economic evaluation showed higher net returns under integrated treatments; however, the highest benefit–cost ratio was obtained with 100% RDF, reflecting relatively lower input costs. The results indicate that integrated nutrient management contributes to improved productivity and soil fertility of *C. arietinum* under Vertisol conditions, though its economic advantage may vary with input availability and cost considerations.

Keywords: Chickpea, *Cicer arietinum* L., integrated nutrient management, Vertisol, soil fertility, yield, economics

Introduction

Chickpea (*Cicer arietinum* L.), a rabi-season legume belonging to the family Fabaceae, occupies a significant place in the pulse-based cropping systems of India, particularly in regions where cropping is sustained largely on residual soil moisture following the withdrawal of the monsoon. Its role within these systems extends beyond grain production. Through symbiotic association with *Rhizobium*, the crop contributes to biological nitrogen fixation, thereby influencing soil fertility and the performance of subsequent crops. Yet, despite this inherent advantage, the productivity of chickpea under field conditions often remains below its potential. The reasons for this are seldom singular; rather, they lie in the interaction between nutrient availability, soil physical environment, and the variability imposed by seasonal conditions. Vertisols, which occupy extensive areas of central India, present a soil environment that is both favourable and restrictive. Their high clay content, dominated by smectitic minerals such as montmorillonite, imparts a characteristic shrink–swell behaviour. This results in high moisture retention during the post-monsoon period, but also leads to poor aeration and mechanical impedance under certain moisture regimes. The consequence is a soil that, while chemically well supplied, does not always permit optimal root activity or nutrient uptake. In such conditions, the response of *C. arietinum* to applied nutrients is mediated as much by soil physical processes as by nutrient

concentration. The conventional approach to nutrient management in chickpea has often relied on the application of inorganic fertilizers, particularly phosphorus, given the crop's relatively modest external nitrogen requirement. While such inputs address immediate nutrient demand, they do not necessarily improve the soil environment within which nutrient uptake occurs. This has led to increasing interest in integrated nutrient management (INM), wherein inorganic fertilizers are supplemented with organic manures and biofertilizers. The inclusion of farmyard manure introduces organic carbon, which influences soil structure and microbial activity, while biofertilizers—particularly *Rhizobium* and phosphate-solubilizing bacteria—contribute to biological nitrogen fixation and enhanced phosphorus availability. However, the response to such integration is not always uniform. The benefits of organic and biological inputs tend to manifest gradually and are often moderated by soil moisture, temperature, and the inherent variability of field conditions. In Vertisols, where moisture dynamics fluctuate during the cropping season, the effectiveness of nutrient management practices may vary not only between treatments but also across micro-sites within the same field. This introduces a degree of uncertainty that is not easily resolved through controlled experimentation alone.

The present investigation was undertaken within this context, with the objective of examining the response of chickpea to integrated nutrient management under Vertisol conditions of central India. Particular emphasis was placed on understanding the behaviour of growth parameters, yield components, soil fertility status, and economic returns, recognizing that these aspects, though analytically separable, are functionally interconnected in the field environment.

Materials and Methods

The field experiment was conducted during the rabi season of 2024–25 under Vertisol conditions of the Malwa plateau region of central India, a zone where chickpea (*Cicer arietinum* L.) is commonly cultivated on conserved soil moisture. The experimental field, though broadly uniform in appearance, exhibited the typical micro-variability associated with medium to deep black soils—differences in surface condition and moisture retention that tend to influence crop establishment and early growth.

The soil was clayey in texture with a slightly alkaline reaction ($\text{pH} \approx 7.8$) and moderate organic carbon status. Available nitrogen was in the lower range of adequacy, while available phosphorus was moderate and potassium relatively high, reflecting the general fertility pattern of Vertisols under continuous cultivation. Prior to sowing, composite soil samples were collected from the plough layer (0–15 cm) and analysed following standard procedures: organic carbon by Walkley and Black (1934)^[21], available nitrogen by the alkaline KMnO_4 method (Subbiah and Asija, 1956)^[20], available phosphorus by Olsen's method (Olsen *et al.*, 1954)^[14], and available potassium by flame photometry. These initial values served as a reference for interpreting treatment effects.

The experiment was laid out in a Randomized Block Design with eight treatments and three replications. The treatments comprised graded levels of recommended dose of fertilizers (RDF: 20:40:0 kg N:P₂O₅:K₂O ha⁻¹) applied alone or in combination with farmyard manure (FYM @ 5 t ha⁻¹) and biofertilizers (*Rhizobium* and phosphate-solubilizing bacteria). The treatment structure was intended to examine not only the

effect of nutrient quantity but also the manner in which nutrients were supplied within the soil–plant system.

The chickpea variety JG 16, commonly cultivated in the region, was sown at a seed rate of 80 kg ha⁻¹ under residual soil moisture conditions. Seeds were inoculated with *Rhizobium* and PSB cultures in the respective treatments prior to sowing. All agronomic practices, including land preparation, sowing, and intercultural operations, were carried out uniformly across treatments to reduce non-treatment variability. Observations on growth parameters were recorded from five randomly selected plants per plot at appropriate stages of crop growth. These included plant height, number of branches per plant, number of nodules per plant, and dry matter accumulation. Yield attributes—number of pods per plant, seeds per pod, and 100-seed weight—were recorded at maturity. Grain and straw yields were obtained from the net plot area and expressed on a hectare basis. Post-harvest soil samples were collected from each plot and analysed using the same procedures as those employed for initial soil analysis. Economic evaluation was carried out by computing cost of cultivation, gross return, net return, and benefit–cost ratio for each treatment, recognizing that such estimates are influenced not only by yield but also by input costs and prevailing price conditions. The experimental data were subjected to analysis of variance (ANOVA) appropriate for the Randomized Block Design, following the procedure described. Treatment effects were tested at the 5 per cent level of significance, and critical difference (CD) values were calculated for comparison of treatment means wherever the F-test indicated significant variation. While the design provides a structured basis for comparison, it may be acknowledged that field variability, particularly under Vertisol conditions, cannot be entirely eliminated. The results obtained are therefore to be interpreted within the context of this inherent variability, as expressions of treatment response under prevailing field conditions rather than as absolute measures independent of environment.

Results and Discussion

The response of chickpea (*Cicer arietinum* L.) to nutrient management, when examined across growth, yield, and soil parameters, presents a pattern that is progressive yet not strictly proportional. Growth attributes—plant height, branching, nodulation, and dry matter accumulation—showed a consistent increase with increasing levels of nutrient application, although the rate of increase tended to narrow at higher levels of integration (Table 1). The integrated treatments, particularly those combining inorganic fertilizers with farmyard manure (FYM) and biofertilizers, recorded comparatively higher values. The response, however, appears to extend beyond the direct addition of nutrients. The inclusion of organic and biological inputs likely influenced the soil environment—improving aggregation, moderating moisture fluctuations, and supporting microbial activity—thereby enabling a more sustained pattern of nutrient uptake.

It is equally apparent that the differences between higher integrated treatments were relatively modest. Under Vertisol conditions, where soil aeration and moisture availability fluctuate during the season, the response of the crop may increasingly depend on these physical constraints rather than nutrient supply alone. Thus, the observed pattern reflects an interaction between nutrient input and soil behaviour rather than a simple input–output relationship.

Table 1: Effect of INM on Growth Parameters of Chickpea

Treatment	Plant height (cm)	Branches plant ⁻¹	Nodules plant ⁻¹	Dry matter (g plant ⁻¹)
T ₁	41.2	4.8	18.5	12.6
T ₂	44.3	5.3	20.2	14.2
T ₃	48.6	6.1	22.8	16.8
T ₄	52.1	6.8	24.6	18.5
T ₅	54.4	7.2	25.3	19.7
T ₆	50.8	6.5	30.4	17.9
T ₇	56.2	7.6	32.8	21.3
T ₈	58.5	7.9	34.1	22.6
SEm (±)	1.35	0.21	1.08	0.74
CD (P=0.05)	3.92	0.61	3.14	2.14

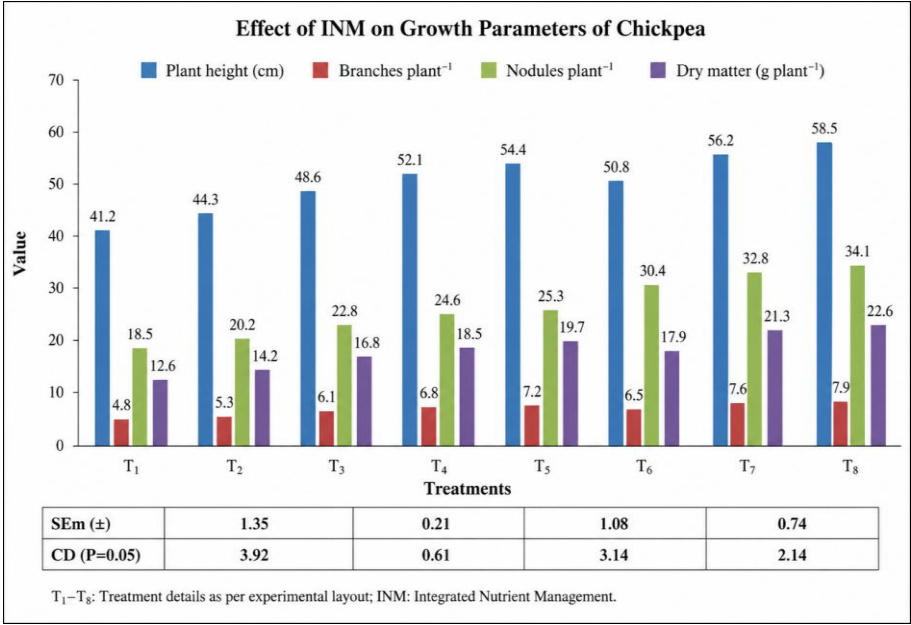


Fig 1: Effect of Integrated Nutrient Management on Growth Parameters of Chickpea (*Cicer arietinum* L.)

Yield attributes exhibited a more selective sensitivity to nutrient management (Table 2). The number of pods per plant increased progressively with nutrient integration, while 100-seed weight showed a moderate but consistent rise. In contrast, seeds per pod remained statistically non-significant across treatments, indicating a degree of stability that aligns with its genetic control. This differentiation suggests that yield formation in *C. arietinum* is governed by both responsive components—such as pod number and seed size—and relatively conservative traits that are less influenced by external inputs.

Table 2: Effect of INM on Yield Attributes

Treatment	Pods plant ⁻¹	Seeds pod ⁻¹	100-seed weight (g)
T ₁	38.2	1.24	19.8
T ₂	42.5	1.28	20.4
T ₃	48.6	1.32	21.1
T ₄	52.3	1.36	21.6
T ₅	55.7	1.38	22.0
T ₆	50.2	1.35	21.4
T ₇	58.9	1.40	22.5
T ₈	61.4	1.42	22.9
SEm (±)	1.52	0.03	0.42
CD (P=0.05)	4.41	NS	1.21

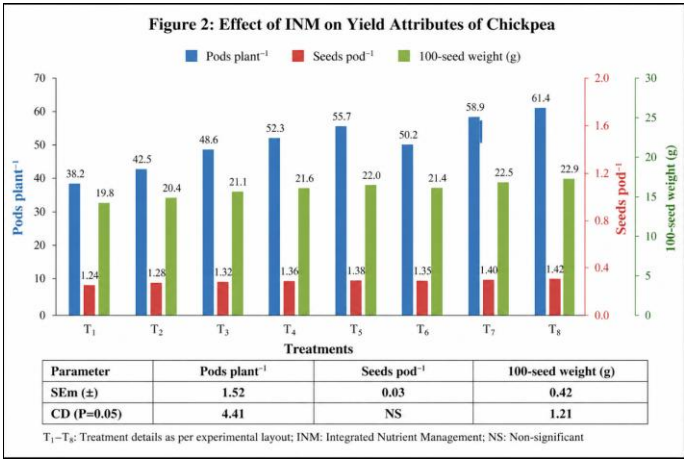
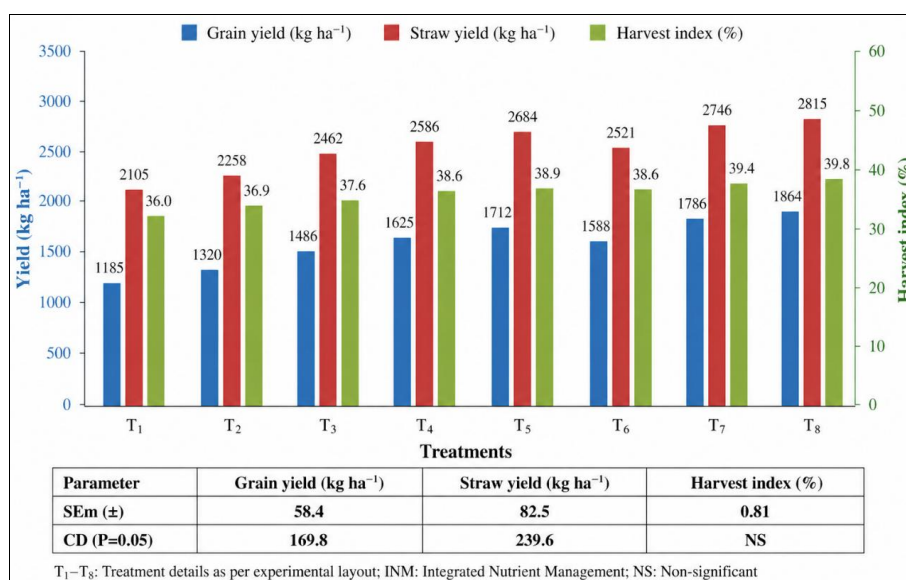


Fig 2: Effect of Integrated Nutrient Management on Yield Attributes of Chickpea (*Cicer arietinum* L.)

Grain yield, which integrates the cumulative effect of growth and yield attributes, showed a marked increase under integrated nutrient management (Table 3). The highest yield was recorded under 75% RDF combined with FYM and biofertilizers (T_8), followed closely by T_7 . This pattern suggests that partial substitution of inorganic fertilizers with organic and biological inputs may improve nutrient use efficiency. Straw yield followed a similar trend, indicating increased biomass production under improved nutrient conditions. The harvest index, however, remained statistically non-significant, implying that while total biomass increased, its partitioning between grain and straw remained relatively stable.

Table 3: Effect of INM on Yield Parameters

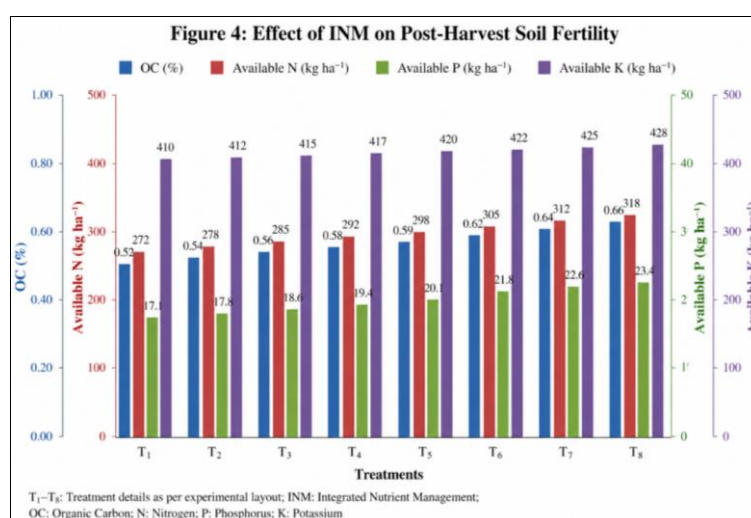
Treatment	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Harvest index (%)
T_1	1185	2105	36.0
T_2	1320	2258	36.9
T_3	1486	2462	37.6
T_4	1625	2586	38.6
T_5	1712	2684	38.9
T_6	1588	2521	38.6
T_7	1786	2746	39.4
T_8	1864	2815	39.8
SEm ($\pm$)	58.4	82.5	0.81
CD (P=0.05)	169.8	239.6	NS

**Fig 3:** Effect of Integrated Nutrient Management on Yield Parameters of Chickpea (*Cicer arietinum* L.)

Post-harvest soil fertility parameters showed a gradual improvement under integrated treatments (Table 4). Organic carbon content increased with the addition of FYM, while available nitrogen and phosphorus also exhibited upward trends. These changes may be associated with enhanced microbial activity, including biological nitrogen fixation and phosphorus solubilization. However, the magnitude of change within a single season remained moderate, reflecting the inherently gradual nature of soil fertility build-up. Potassium levels showed only marginal variation, consistent with the already sufficient status of this nutrient in Vertisols.

Table 4: Effect of INM on Post-Harvest Soil Fertility

Treatment	OC (%)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)
T_1	0.52	272	17.1	410
T_2	0.54	278	17.8	412
T_3	0.56	285	18.6	415
T_4	0.58	292	19.4	417
T_5	0.59	298	20.1	420
T_6	0.62	305	21.8	422
T_7	0.64	312	22.6	425
T_8	0.66	318	23.4	428

**Fig 4:** Effect of Integrated Nutrient Management on Post-Harvest Soil Fertility of Chickpea (*Cicer arietinum* L.)

The economic analysis introduces a further dimension to the interpretation (Table 5). Integrated treatments recorded higher net returns, reflecting their superior yield performance. However, the highest benefit–cost ratio was observed under 100% RDF (T₅), indicating that treatments with lower input cost may exhibit higher relative economic efficiency. This divergence suggests that productivity and profitability, though related, do not always coincide. The practical choice of nutrient management strategy, therefore, may depend not only on yield potential but also on the availability and cost of inputs at the farm level.

Table 5: Effect of INM on Economics of Chickpea

Treatment	Cost (₹ ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B:C ratio
T ₁	25000	71000	46000	2.84
T ₂	27000	79200	52200	2.93
T ₃	29000	89160	60160	3.07
T ₄	31000	97500	66500	3.14
T ₅	33000	102720	69720	3.11
T ₆	34000	95280	61280	2.80
T ₇	36000	107160	71160	2.98
T ₈	38000	111840	73840	2.94

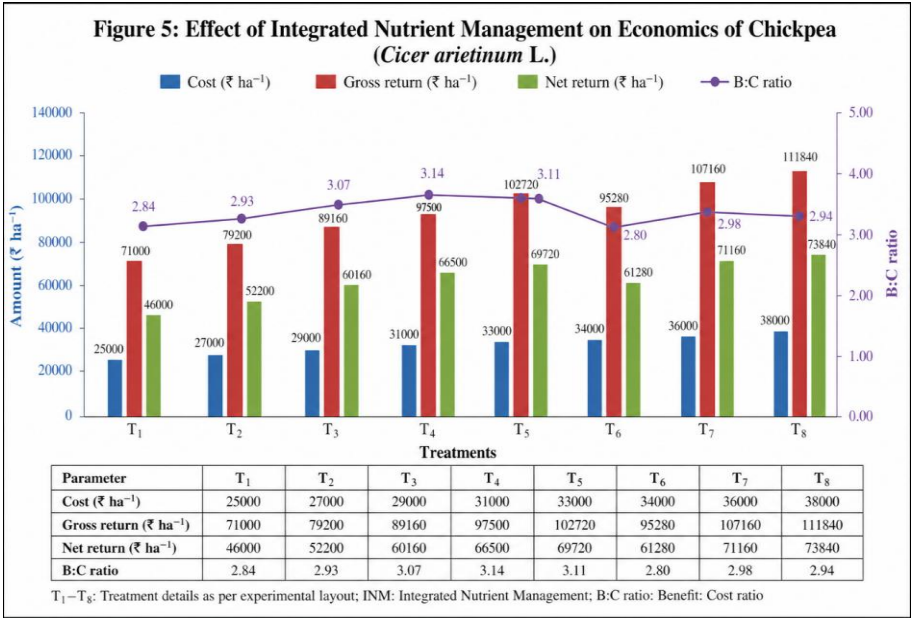


Fig 5: Effect of Integrated Nutrient Management on Economics of Chickpea (*Cicer arietinum* L.)

The pattern that emerges from these observations does not lend itself to a strictly linear interpretation. Rather, it suggests that integrated nutrient management influences crop performance through a set of interacting processes—nutrient availability, soil physical condition, and biological activity—while economic outcomes remain conditioned by input cost and resource availability.

Discussion

The response of chickpea (*Cicer arietinum* L.) to integrated nutrient management, when viewed in relation to both growth behaviour and yield formation, reflects a pattern that is shaped not merely by nutrient supply but by the interaction between soil environment and crop physiology. The increase observed in growth parameters under integrated treatments suggests that the availability of nutrients in a more regulated form may have supported sustained vegetative development. The role of farmyard manure in this context may extend beyond its direct nutrient contribution. Its incorporation into Vertisols is likely to influence soil aggregation and moisture retention, conditions that are particularly relevant in post-monsoon cropping where moisture becomes progressively limiting. Similarly, the enhanced nodulation observed under treatments involving biofertilizers indicates that biological nitrogen fixation may have contributed to improved nitrogen availability during early growth stages. Comparable responses have been noted in pulse crops where integrated nutrient management supports both microbial activity and plant growth (Ahlawat & Gangaiah, 2017) [1].

The behaviour of yield attributes provides a more differentiated view of crop response. While the number of pods per plant and test weight increased under integrated treatments, the number of seeds per pod remained statistically unchanged. This suggests that reproductive response in chickpea is partly governed by factors that are sensitive to external inputs and partly by traits that remain relatively stable. Similar observations have been reported by Ali and Kumar (2018) [2], who indicated that seeds per pod in chickpea tends to show limited response to nutrient management. Grain yield, as an integrated outcome of these components, showed a clear advantage under treatments combining inorganic fertilizers with organic and biological inputs. The higher yield recorded under 75% RDF with FYM and biofertilizers suggests that complete reliance on inorganic fertilizers may not always provide optimal results under Vertisol conditions. The improvement in yield under integrated treatments may be associated with better synchronization between nutrient release and crop demand, along with a more favourable root environment. At the same time, the relatively small difference between the higher integrated treatments suggests that the response tends to plateau beyond a certain level. Under field conditions, particularly in Vertisols, factors such as soil aeration and moisture availability may begin to limit further response. This introduces a degree of variability that is not easily captured through nutrient management alone. The improvement observed in post-harvest soil fertility parameters, particularly organic carbon and available nitrogen

and phosphorus, indicates that integrated nutrient management may contribute to maintaining or enhancing soil fertility. However, the magnitude of change within a single season remains modest, reflecting the gradual nature of soil organic matter dynamics. Long-term studies have similarly indicated that the benefits of integrated nutrient management become more apparent over successive cropping cycles (Bhattacharyya *et al.*, 2015) [3].

The economic analysis introduces an additional dimension to the interpretation. While integrated treatments recorded higher net returns, the highest benefit–cost ratio was observed under 100% RDF. This suggests that economic efficiency is influenced not only by yield but also by input cost. In practical terms, the adoption of integrated nutrient management may depend on the availability of organic inputs such as FYM, which may not be uniformly accessible across farms.

Taken together, the findings indicate that integrated nutrient management offers advantages in terms of crop performance and soil fertility, though its effectiveness is conditioned by soil characteristics, environmental factors, and resource availability. The response of chickpea under Vertisol conditions, therefore, cannot be attributed to a single factor, but emerges from the interaction of multiple processes operating within the soil–plant system.

Conclusion

The response of chickpea (*Cicer arietinum* L.) to integrated nutrient management under Vertisol conditions, as observed in the present investigation, suggests that crop performance is shaped by a combination of nutrient availability, soil physical environment, and biological activity rather than by fertilizer input alone.

Growth parameters, including plant height, branching, nodulation, and dry matter accumulation, showed improvement with increasing levels of nutrient application, with comparatively higher values recorded under treatments integrating inorganic fertilizers with FYM and biofertilizers. The response, however, did not increase proportionately at higher levels, indicating that beyond a certain threshold, other factors—particularly soil moisture regime and aeration—begin to influence crop growth.

Yield attributes exhibited a differentiated behaviour. The number of pods per plant and 100-seed weight responded positively to integrated nutrient management, whereas seeds per pod remained statistically unchanged, reflecting its relatively stable nature. Grain yield, as an outcome of these components, recorded higher values under integrated treatments, with 75% RDF combined with FYM and biofertilizers producing the maximum yield, followed closely by 50% RDF with similar integration. This suggests that partial substitution of inorganic fertilizers with organic and biological inputs may enhance nutrient use efficiency under Vertisol conditions.

Post-harvest soil fertility showed improvement in terms of organic carbon and available nitrogen and phosphorus under integrated treatments. Although the magnitude of change within a single season remained moderate, the trend indicates a tendency towards improved soil fertility with the inclusion of organic and biological inputs.

The economic analysis revealed that while integrated treatments resulted in higher net returns, the highest benefit–cost ratio was observed under 100% RDF. This indicates that economic efficiency does not necessarily coincide with maximum productivity and may vary with input cost and availability.

The findings, when viewed collectively, indicate that integrated

nutrient management contributes to improved crop performance and soil fertility in chickpea under Vertisol conditions, though the extent of response remains influenced by soil characteristics, seasonal variability, and resource availability at the farm level.

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