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Ecological Evaluation of Intercropping and Organic–Inorganic Nutrient Integration for Sustainable Chickpea (*Cicer arietinum* L.) Production

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ABSTRACT

Chickpea (*Cicer arietinum* L.) is a dynamic legume crop for both food and nutritional security; nevertheless, its productivity in India persists low equated to global norms. Traditional practices, sole dependence on chemical fertilizers and deprived soil health limit yield improvements. Though intercropping and integrated nutrient management (INM) are standard as sustainable approaches, there is inadequate evidence on their collective effects on chickpea growth, yield and economic feasibility under semi-arid Trans-Gangetic Plains. This research experiment addressed the gap by assessing chickpea-based intercropping with diverse INM practices. A two-year field study (rabi 2023 and 2024) was carried out at G.D. Goenka University, Haryana, in a split-plot design with three replications. Treatments comprised of four intercropping systems [sole chickpea, chickpea + oats, chickpea + mustard, and chickpea + barley (3:2 row ratio)] and three INM practices [100% RDF, 50% RDF + 50% vermicompost, and equal mixture of FYM + compost + vermicompost]. Growth attributes (plant height, leaves, branches, nodules), yield attributes (grain, straw, harvest index) and monetary attributes (gross and net returns, B:C ratio) were assessed. Mustard-based intercropping pointedly enhanced growth attributes, with maximum plant height, leaf count, branching and nodulation when compared to oats and barley systems. Integrated nutrient management with 50% RDF + 50% vermicompost resulted in the maximum growth and yield responses, while sole dependence on chemical fertilizers was the least effective. Sole chickpea attained the maximum grain yield (21.46 q/ha), but mustard intercropping under INM produced analogous performance with sophisticated system stability. Straw yield and harvest index trailed similar trends. Economic analysis revealed that the mustard × INM produced the highest gross return (1,93,585.5/ha), net return (1,46,452.4/ha), and B:C ratio (3.51).Mustard-based intercropping cohesive with balanced nutrient management occurred as the most effective approach for refining chickpea growth, yield, viability and sustainability under semi-arid conditions.

Key words: *Organic manures, Intercropping systems, Oats, Mustard, INM, Growth, Yield, Sustainable Chickpea Production, Economics*

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Introduction

Chickpea (*Cicer arietinum* L.)is one of the most anciently domesticated legume crops, providing a rich source of protein and nutritional value, particularly in South Asian and African nations. It is under cultivation in more than 50 countries across the globe, with India contributing over 70% of global production. However, productivity in India (1,130 kg/ha) is less than in countries like Ethiopia and Canada due to traditional, outdated practices and resource constraints (FAO, 2023). Chickpea is key to contributing pointedly to food security, dietary and sustainable agriculture by elevating soil fertility via biological nitrogen fixation (Bana *et al.,* 2016; Meena *et al.,* 2023). However, chickpea cultivation is constrained by abiotic stresses, nutrient deficiencies and deteriorating soil health, challenges that were increased under rainfed conditions (Meena *et al.,* 2024). Addressing these problems necessitates sustainable crop management strategies, one of which is intercropping. Intercropping is the practice of cultivating two or more crops together, and it has shown potential in refining resource use efficiency, alleviating yields and increasing farm income. In chickpea-based intercropping systems, intercropping with mustard, barley or oats improves land use efficiency, diminishes pest as well as weed pressure and enhances pliability under climate erraticism (Singh *et al.,* 2019; Rakkammal *et al.,* 2023).

After intercropping, the nutrient management is correspondingly crucial. The chemical fertilizers have improved productivity, but their indiscriminate use has tarnished soil quality and led to environmental complications (Jakhar *et al.,* 2021). Integrated Nutrient Management (INM), which collectively uses chemical fertilizers along with organic amendments, bids a sustainable substitute by taming nutrient use efficiency, improving soil structure and auxiliary long-term productivity of various crops (Verma *et al.,* 2023). Consequently, chickpea-based intercropping systems cohesive with INM practices deliver a capable way for ameliorating crop productivity, nutrient dynamics, and farm profitability. The current study was conducted to assess the influence of INM and intercropping with mustard, barley and oats on growth, yield, and economic returns in chickpea.

Research methodology

A two-year field experiment was carried out during the rabi seasons of 2023 and 2024 at the Agronomy Research Farm, G.D. Goenka University, Sohna, Haryana. The site lies in the Trans-Gangetic Plains under a semi-arid climate, located at 28°152 N, 77°062 E; 211 m MSL. The experimental site soil was sandy loam in texture with mean chemical properties of two years. The pH was slightly alkaline in nature with 7.9, normal range of EC 0.14 dS/m, low in organic carbon 0.44%, low in available N (223 kg/ha), medium range in P (20.8 kg/ha) and high in K (411 kg/ha), indicating modest fertility. Five samples were randomly collected and mixed to prepare a composite sample that was analyzed using the standard procedures before sowing. The experiment was laid out in a split-plot design with three replications. The main plot comprised a factor intercropping system: sole chickpea, chickpea + oats, chickpea + mustard and chickpea + barley, each sown in a 3:2 row ratio. The subplot factor was nutrient management: 100% RDF through chemical fertilizers, 50% RDF + 50% vermicompost and (iii) 33% FYM + 33% compost + 33% vermicompost. The main and subplots are formulated to prepare a 12-treatmentcombinationpresented in the Table 1, with a total of 36 plots in the experiment. Each plot measured 4 × 3 m² with 0.5 m bunds and 1 m width irrigation channels. Chickpea (*cv.* Pusa 362) was used as the base crop, while mustard (PM 30), oats (HFO 114) and barley (PL 172) were used as intercrops.

Table 1. Experimental factors.

Treatments	Symbol
A. Intercropping (Main plot)	
Sole crop-Chick pea	IC 0
Chickpea+Oat (3row+2row)	IC 1
Chickpea+Mustard (3row+2row)	IC 2
Chickpea+Barley (3row+2row)	IC 3
B. Nutrient management (subplots)	
RDF through 100% Chemical fertilizers	NM 0
RDF 50%+Vermicompost 50%	NM 1
RDF through manure33% VC +33% CC+33% FYM	NM2

Land preparation comprised of ploughing, harrowing and levelling, followed by plot demarcation. N:P: K fertilizers were applied at 20:60:30 kg/ha for chickpea, 40:40:30 for mustard, and 80:40:30 for oats and barley, apportioned based on their area part in intercropping. Organic manures were incorporated into field 10 days before sowing. Crops were sown manually at a 5 cm depth, following row arrangements as per treatment combination. The field was sprayed with pre-emergence atrazine (1.0 kg/ha) and two hand weddings for effective weed control at 60 and 90 DAS. Four irrigations were scheduled at germination, vegetative, pre-flowering and pod filling stages. Pest control included two foliar sprays of Imidacloprid at 65 and 80 DAS. Growth observations included plant height (cm), leaf, branch and nodules count per plant, while yield attributes (grain yield (q/ha), straw yield (q/ha), and harvest index (%)) were recorded at harvest and economics parameters like cost of cultivation, gross return, net return (/ha) and benefit cost ratio were computed. Standard crop sampling procedures were followed to minimize variability. Data from both years were pooled to prepare mean data after testing for homogeneity of error variance. Statistical analysis was performed using analysis of variance (ANOVA) as per the split-plot design model described by Gomez and Gomez (1984). Main plot (intercropping) and subplot (nutrient management) effects, along with their interactions, were tested for significance at the 5% probability level using the F-test. Treatment means were compared using critical difference (CD) values at P = 0.05. Data analysis was performed using R statistical software.

Results

Growth attributes

The effect of intercropping and nutrient management on the growth attributes like plant height, no. of leaves, branches and nodules per plant was explained below and depicted in Figures 1-2.

Plant height (cm)

Plant height is a crucial attribute that defines growth visually. Analysis of variance (ANOVA) indicated that intercropping systems significantly influenced chickpea plant height at harvest ($p < 0.05$). The maximum plant height was recorded under IC02 (65.88 cm), while the minimum was recorded under IC01 (62.98 cm). INM treatments also exhibited a significant outcome, with maximum plant height recorded under NM01 (64.65 cm) and minimum under NM00 (63.99 cm). The interaction between intercropping and INM was statistically non-significant ($p > 0.05$) at harvest.

Number of leaves per plant

The number of leaves was significantly impacted ($p < 0.05$) by intercropping and INM treatments. IC02 had the maximum leaf count (151.83), and IC01 had the minimum (144.38). Amongst INM treatments, NM01 (148.95) was superior to the lowest NM00 (146.58). The interaction effect of both factors was statistically significant ($p < 0.05$) at harvest; with NM01 × IC02 yielding the maximum leaves (153.83) and NM00 × IC01 the minimum (143.66). Treatments NM00 × IC02 and NM01 × IC03 were statistically at par with NM01 × IC02.

Number of branches per plant

Intercropping and INM significantly influenced the branch number per plant ($p < 0.05$). IC02 produced the maximum number of branches (38.65) and IC01 the minimum (34.06). Among INMs, NM02 (36.49) had more branches, followed by NM01 (35.96) and NM00 (35.70). The interaction effect of both factors

Table 2. Treatment combinations of the experiment

S.N.	T. N.		Treatment combination
1	T_1	IC0 + NM 0	Sole crop-Chick pea + RDF through 100% Chemical fertilizers
2	T_2	IC0 + NM 1	Sole crop-Chick pea + RDF 50%+Vermicompost 50%
3	T_3	IC0 + NM 2	Sole crop-Chick pea + RDF through manure 33% VC +33% CC +33%FYM
4	T_4	IC1 + NM0	Chickpea+Oat (3row+2row) + RDF through 100%Chemical fertilizers
5	T_5	IC1 + NM1	Chickpea+Oa t (3row+2row) + RDF 50%+Vermicompost 50%
6	T_6	IC1 + NM2	Chickpea+Oat (3row+2row) + RDF through manure 33% VC +33% CC +33%FYM
7	T_7	IC2 + NM0	Chickpea+Mustard (3row+2row) + RDF through 100% Chemical fertilizers
8	T_8	IC2 + NM1	Chickpea+Mustard (3row+2row) + RDF 50%+Vermicompost 50%
9	T_9	IC2 + NM2	Chickpea+Mustard (3row+2row) + RDF through manure 33% VC +33% CC + 33% FYM
10	T_{10}	IC3 + NM0	Chickpea+Barley (3row+2row) + RDF through 100% Chemical fertilizers
11	T_{11}	IC3 + NM1	Chickpea+Barley (3row+2row) + RDF 50%+Vermicompost 50%
12	T_{12}	IC3 + NM2	Chickpea+Barley (3row+2row) + RDF through manure 33% VC +33% CC + 33% FYM

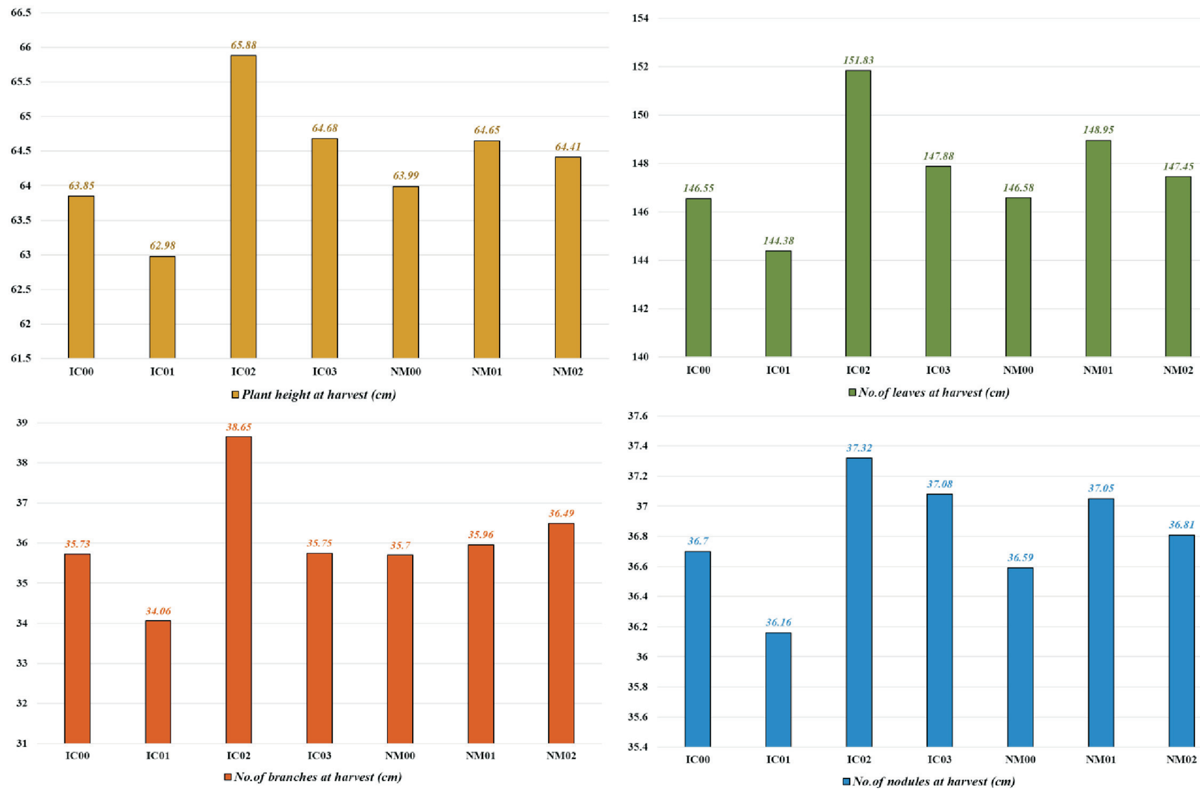

Fig. 1. Effect of intercropping and INM on chickpea growth attributes.

was significant ($p < 0.05$), with NM01 × IC02 recording the most branches (39.63) and NM00 × IC01 the lowest (34.18). Treatments NM00 × IC02 and NM02 × IC02 were statistically at par with NM01 × IC02.

Number of nodules per plant

Nodule count was significantly impacted ($p < 0.05$) by intercropping and INM treatments. IC02 recorded the highest number of nodules (37.32), whereas IC01 had the lowest (36.16). NM01 (37.05) recorded the maximum nodules, while the lowest was under NM00 (36.59). The interaction effect of both the factors was statistically significant at harvest ($p < 0.05$), the treatment NM01 × IC02 showed

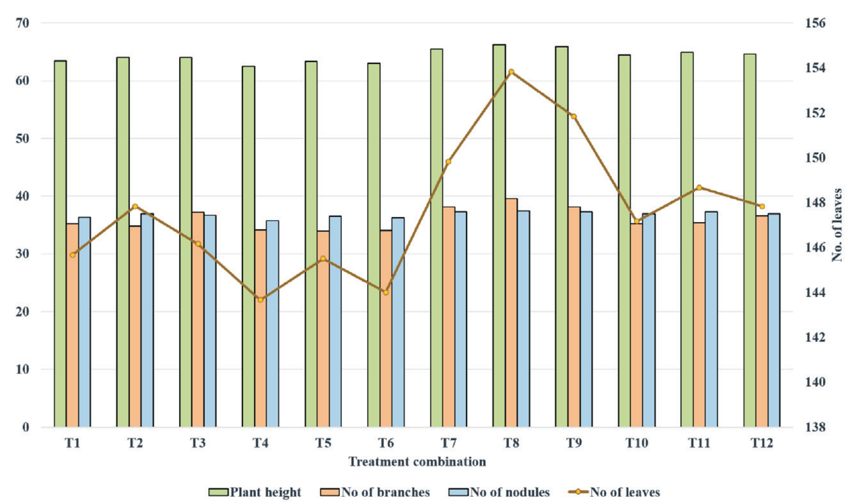

Fig. 2. Interaction impact of intercropping and INM on chickpea growth attributes.

the highest nodules (37.43) and NM00 × IC01 the lowest nodules count per plant (35.73). Treatments NM00 × IC02, NM01 × IC03, and NM02 × IC02 were statistically at par with NM01 × IC02.

Yield attributes

The effect of intercropping and nutrient management on the yield attributes like grain yield, straw yield (q/ha)and harvest index (%) was explained below and depicted in Figures 3-4.

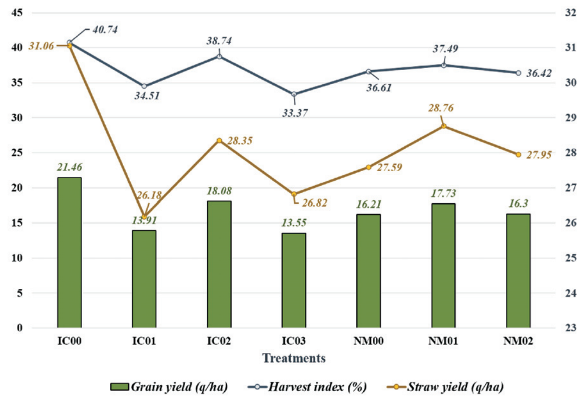

Fig. 3. Effect of intercropping and INM on yield attributes of chickpea.

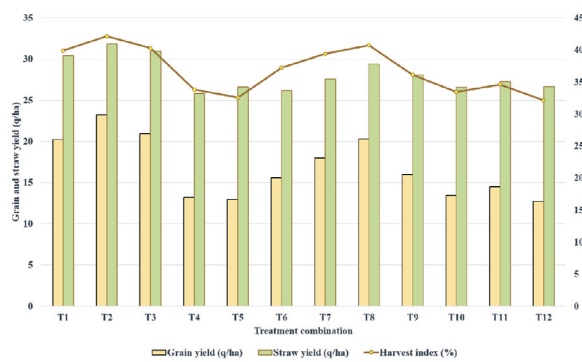

Fig. 4. Interaction effect of intercropping and INM on yield attributes of chickpea.

Grain yield (q/ha)

Analysis of variance revealed that intercropping significantly impacted chickpea grain yield ($p < 0.05$). The highest grain yield was recorded under sole chickpea (IC00) with 21.46 q/ha, followed by IC02 and IC03, whereas the lowest grain yield (13.91 q/ha) was recorded under IC01 (chickpea + oats). Among integrated nutrient management (INM) treatments, NM01 obtained the highest grain yield (17.73 q/ha), followed by NM02 (16.30 q/ha) and NM00 (16.21 q/ha). The interaction effect between the intercropping and INM was statistically significant ($p < 0.05$). The combination NM01 × IC00 resulted in the maximum grain yield (23.21 q/ha), while NM02 × IC04 recorded the minimum (12.73 q/ha). Treatments NM00 × IC00 (22.85 q/ha), NM01 × IC02 (22.76 q/ha), and NM02 × IC00 (22.63 q/ha) were statistically at par with NM01 × IC00.

Straw yield (q/ha)

Intercropping significantly influenced straw yield ($p < 0.05$), with IC00 resulted in the highest straw yield of 31.06 q/ha, followed by IC02 and IC03. The lowest straw yield of 26.18 q/ha resulted under IC01. Among INM treatments, NM01 resulted in the maximum straw yield (28.76 q/ha), followed by NM02 (27.95 q/ha) and NM00 (27.59 q/ha). The interaction effect of both factors was found to be statistically significant ($p < 0.05$). The combination NM01 × IC00 resulted in the maximum straw yield (31.81 q/ha), whereas NM00 × IC01 resulted in the minimum (25.80 q/ha). The treatments NM00 × IC00 (31.62 q/ha) and NM01 × IC02 (31.54 q/ha) were statistically at par with NM01 × IC00.

Harvest index (%)

Intercropping significantly impacted the harvest index ($p < 0.05$), with IC00 resulted in the maximum harvest index of 40.74% and IC01 the minimum (33.37%). INM alone had a non-significant effect, with NM01 (37.49%), NM00 (36.61%), and NM02 (36.42%). The interaction between intercropping and INM was significant ($p < 0.05$). The combination NM01 × IC00 exhibited the highest harvest index (42.12%), while NM00 × IC01 recorded the lowest (32.09%). The treatments NM00 × IC00 (41.85%), NM01 × IC02 (41.79%), NM00 × IC02 (41.72%), and NM02 × IC00 (41.65%) were found to be statistically at par with maximum, i.e., NM01 × IC00.

Economic attributes

The effect of intercropping and nutrient management on the economic attributes is depicted in Figure 5. The mean data over two years showed that the cost of cultivation was maximum in treatment T_8 (Rs. 48,032.84/ha) and minimum in T_7 (Rs. 38,676.12/ha). Among the treatments, T_8 also resulted in the maximum gross return (Rs. 1,93,585.5/ha) and net return (Rs. 1,46,452.4/ha), while T_{12}resulted in the minimum gross (Rs. 1,14,117.3/ha)

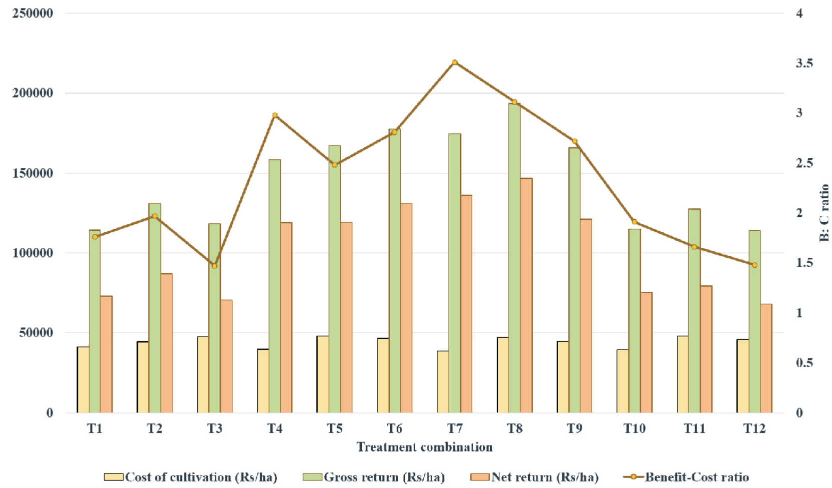

Fig. 5. Effect of intercropping and INM on monetary attributes of chickpea.

and net return (Rs. 68,124.03/ha). The benefit-cost ratio (B:C) was highest in T_8 (3.51) and lowest in T_3 (1.47). These results indicate that, despite higher investment, T_8 was the most profitable and economically efficient treatment, whereas treatments with lower costs, such as T_{12} and T_3, resulted in lower returns and efficiency.

Discussion

Growth and yield parameters of chickpea were markedly influenced by intercropping patterns and integrated nutrient management practices. Plant height consistently improved under mustard-based intercropping when combined with integrated nutrient supply. This trend can be attributed to light-mediated elongation responses and improved nutrient mobilization in the rhizosphere, which created favourable conditions for stem elongation (Meena *et al.,* 2024). Vermicompost-based nutrient integration supported steady nutrient availability and hormonal stimulation; further enhancing height compared with sole chemical fertilizers that provided only short-term benefits (Heidari *et al.,* 2020; Devi *et al.,* 2024). The number of leaves followed a similar pattern, with mustard intercropping coupled with integrated nutrient management recording the highest leaf counts. This was due to improved light quality and synchronized nutrient release that supported leaf initiation and expansion (Narendra *et al.,* 2023; Devi *et al.,* 2024). By contrast, oats-based intercropping reduced leaf development owing to intense belowground competition for nitrogen and moisture (Meena *et al.,* 2022). Residual effects of organics across years also improved vegetative performance, reflecting cumulative soil fertility gains (Ajeet Singh *et al.,* 2018). Enhanced branching was observed in mustard intercrops, where partial shade and reduced intra-specific competition promoted axillary bud initiation (Gupta *et al.,* 2019; Devi *et al.,* 2024). Vermicompost further improved cytokinin activity and microbial mineralization, encouraging better shoot proliferation compared to sole fertilizers or slower nutrient-releasing organic mixtures. The mustard × INM combination thus created synergistic conditions for maximum branch retention and pod-bearing potential (Suhasini *et al.,* 2018). Nodule formation was most responsive to integrated nutrient management with 50% RDF + vermicompost, which enhanced microbial activity and root–rhizobia interactions (Bahadur *et al.,* 2016; Devi *et al.,* 2024).

Mustard intercropping also favoured nodulation by creating a complementary root environment, while oats exerted suppressive effects due to stronger resource competition. The positive synergy of mustard × INM confirmed the ecological facilitation necessary for sustained biological nitrogen fixation (Jadhav and Kulkarni, 2016).

Among yield traits, grain yield increased substantially under integrated nutrient management, reflecting improved source–sink balance and assimilate partitioning toward reproductive organs (Vipul Singh *et al.,* 2019; Maitra *et al.,* 2021). Mustard-based intercropping contributed positively by minimizing competition and maintaining reproductive efficiency. Similarly, straw yield benefitted from greater biomass accumulation under favourable combinations of balanced nutrient supply and reduced competition, reinforcing the role of integrated practices in supporting vegetative vigour (Raza *et al.,* 2023). The harvest index was maximized under sole chickpea and compatible intercrops, where efficient assimilate partitioning to seed was supported by optimal nutrient availability and minimal competition (Vasava *et al.,* 2024). Competitive systems such as chickpea + oats reduced HI by diverting assimilates to vegetative parts rather than grain. Treatments integrating organics and inorganics thus achieved superior reproductive efficiency and yield stability. Economic analysis revealed that intercropping and nutrient management practices significantly influenced profitability. Integrated nutrient management (50% RDF + 50% vermicompost) with mustard intercropping consistently achieved the highest gross and net returns by enhancing grain and straw yields. Although input costs were higher than sole chemical fertilization, improved productivity and soil fertility offset these expenses, leading to superior B:C ratios (Meena *et al.,* 2024; Vasava *et al.,* 2024). Oats-based intercropping proved less profitable due to intense competition, whereas mustard created synergistic effects. Thus, mustard × INM emerged as the most economically viable and sustainable option (Devi *et al.,* 2024).

Conclusion

The current study confirmed that both intercropping and integrated nutrient management exerted substantial outcome on the growth, yield, and economics of chickpea under semi-arid conditions of the Trans-Gangetic Plains. Mustard-based intercropping constantly outperformed oats and barley by improving plant height, leaf production, branching, and nodulation, thus refining yield consistency. Integrated nutrient management with 50% RDF + 50% vermicompost showed the most effective, sustaining soil fertility while safeguarding balanced nutrient availability. While sole chickpea achieved the maximum grain yield, mustard intercropping under INM attained analogous productivity with greater economic returns, echoedin the maximum net profit and benefit–cost ratio. In disparity, oats intercropping enduredthe least advantage due to intense struggle for resources. Generally, the mustard × INM combination appeared as the most feasible and sustainable method to augment chickpea efficiency, viability, and resource-use efficacy.

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Conflict of Interest

The authors declare that there is no conflict of interest among the authors regarding the publication of this research work.

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