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Optimizing Integrated Nutrient Management (INM) for Enhanced Growth and Yield of Chickpea (*Cicer arietinum* L.) Under Irrigated Conditions

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Authors' contributions

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

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ABSTRACT

A field experiment was conducted during the *Rabi* season of 2021-22 at the Agronomy Research Farm, CCS Haryana Agricultural University, Hisar, Haryana. The experiment followed a randomized complete block design with three replications. This study attempts to examine how

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Integrated Nutrient Management (INM) affects chickpea growth, yield and productivity. Integrated Nutrient Management (INM) is a sustainable farming method that improves soil fertility, crop output, and quality by combining biofertilizers, organic and inorganic fertilisers, and other nutrient sources. In addition to providing the necessary plant nutrients, the use of vermicompost as an organic source and biofertilizers such as *Rhizobium* and PSB (Phosphate Solubilising Bacteria) as living sources in conjunction with inorganic fertilisers has improved the physical, chemical, and biological characteristics of the soil and contributed to environmental and soil sustainability. The treatments were as follows: T_1: control, T_2: 100% RDF (18:48:0 kg ha^{-1}), T_3: 100% vermicompost (3.00 t ha^{-1}), T_4: 75% RDF + 25% vermicompost (0.75 t ha^{-1}), T_5: 50% RDF + 50% vermicompost (1.5 t ha^{-1}), T_6: 25% RDF + 75% vermicompost (2.25 t ha^{-1}), T_7: 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB), T_8: 50% RDF + 50% vermicompost (1.5 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB), and T_9: 25% RDF + 75% vermicompost (2.25 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB). The results indicated that the application of 75% RDF + 25% vermicompost (0.75 t ha^{-1}) combined with biofertilizers (*Rhizobium* + PSB) yielded the highest growth attributes, such as plant height (37.5 cm and 77.5 cm at 60 and 120 DAS, respectively) and dry matter accumulation (2.6 g/plant and 21.7 g/plant at 60 and 120 DAS, respectively). This treatment also showed the highest yield attributes, including the number of branches per plant (7.4), number of pods per branch (53.8), number of seeds per pod (2.0), and test weight (14.8 g). The highest grain yield, biological yield, straw yield, gross return and B:C ratio were recorded under the 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB) treatment, followed by the 75% RDF + 25% vermicompost (0.75 t ha^{-1}) and 100% RDF (18:48:0 kg ha^{-1}) treatments. The control treatment produced the lowest grain yield (1395 kg ha^{-1}). The maximum harvest index (45%) was observed in the treatment with 100% vermicompost (3.00 t ha^{-1}). The study highlights that the treatment of 75% RDF + 25% vermicompost (0.75 t ha^{-1}) combined with biofertilizers significantly improved growth attributes and yield components of chickpea. This finding underscores the role of INM in sustainable intensification of chickpea production. (*RDF; Recommended Dose of Fertilizer, *PSB; Phosphate Solubilizing Bacteria.).

Keywords: Integrated nutrients management; vermicompost; bio-fertilizers; chickpea; economics.

1. INTRODUCTION

Traditionally, pulses have been regarded as a vital component of Indian agriculture. The primary pulses grown and consumed in India include lentils, white peas, kidney beans, cowpeas, chickpeas, green grams, and pigeon peas. Even today, pulses are primarily cultivated under rainfed conditions on marginal and sub-marginal lands. Pulses play an essential role in the diets of the poor and vegetarians across India, providing high-quality carbohydrates, minerals, fats, essential amino acids, protein, and fiber (Verma et al., 2021; Bairwa et al., 2020). Recognizing their nutritional value, the United Nations declared 2016 as the "International Year of Pulses" to raise public awareness of the benefits of pulses as part of sustainable food production for food security and nutrition (Anonymous, 2016).

Chickpea (*Cicer arietinum* L.) is the third most cultivated food legume globally and ranks second in South Asia after field pea (*Pisum sativum* L.) and common bean (*Phaseolus vulgaris* L.). India is the largest producer of chickpeas, accounting for 64% of global production (Gaur et al., 2010). In 2021-22, India produced 13.75 million tonnes of chickpeas from an area of 10.91 million hectares, with a productivity of 12.6 q/ha (DES, 2023). By 2050, India's pulse requirement is projected to reach 39 million tonnes, necessitating an annual growth rate of 2.14% to achieve self-sufficiency (Anonymous, 2015). In Haryana, the area under pulse cultivation is 0.356 lakh hectares, with a production of 0.35 lakh tonnes and a productivity of 1,005 kg/ha (Anonymous, 2020-21).

Chickpeas are well known for their nitrogen-fixing ability through a symbiotic mechanism, estimated to fix approximately 140 kg of nitrogen per hectare during a growing season (Singh et al., 2018). Major chickpea-producing countries include India, Australia, Pakistan, Myanmar, Ethiopia, Turkey, Iran, Mexico, the USA, Canada, and Tanzania. Approximately 90% of global chickpea cultivation occurs under rainfed conditions, with drought being a major constraint. India contributes more than 75% of the world's chickpea production, with the states of Madhya Pradesh, Rajasthan, Maharashtra, Andhra Pradesh, Karnataka, Uttar Pradesh, Gujarat, and Chhattisgarh accounting for over 95% of the national output. The *kabuli* type is predominantly grown in northern India, while the *desi* type is grown in other parts of the country.

The yield of chickpea is influenced by various factors, including agronomic, genetic, and environmental conditions. Unbalanced fertilizer application remains a key limiting factor in chickpea yield. While inorganic fertilizers provide essential nutrients but they do not supply all the required micronutrients. Continuous use of inorganic fertilizers can deteriorate the biological, chemical and physical properties of the soil. Excessive application of inorganic fertilizers leads to leaching, runoff, erosion, volatilization and other environmental issues. There is considerable interest in investigating the potential for nutrient alternatives that are both economical and environmentally benign to replace chemical fertilisers. (Paramesh et al., 2023).

Biofertilizers, containing effective microorganisms derived from root nodules or rhizospheric soil, offer a cost-effective and eco-friendly alternative. They can reduce the need for chemical fertilizers, enhancing environmental safety. Long-term use of biofertilizers has been shown to be more economical, environmentally sustainable, productive, and accessible for marginal and small farmers compared to chemical fertilizers. Biofertilizers may colonise the rhizosphere and increase crop development by supplying more nutrients and/or stimulating growth. Microorganisms known as nitrogen fixers and phosphate solubilising agents are crucial for providing plants with additional nitrogen and phosphorus, enabling the long-term usage of fertilisers containing these elements. (Singh et al*.,* 2018). Biofertilizers supply significant amounts of nitrogen and phosphorus at lower input costs when combined with chemical fertilizers and organic manure to maintain soil health and provide essential nutrients.

Integrated Nutrient Management (INM) the combined use of organic and inorganic nutrient sources helps maintain soil nutrient reserves and improves nutrient use efficiency, which is essential for sustainable crop production. Organic matter acts as both a source and a sink for plant nutrients and provides energy substrates for soil microorganisms. This enhances soil microflora and fauna activity, improves soil properties, increases nutrient capital, boosts water-holding capacity, and strengthens soil structure, making it less prone to leaching and erosion. INM practices are thus vital for improving soil quality and sustaining agro-ecosystems (Carter et al., 2002). Organic manures like FYM, vermicompost, poultry manure, and oilcakes enhance soil aeration and structure and increase water storage capacity. They also stimulate microbial activity, making macro- and micronutrients more accessible through enhanced biological processes and optimal pH maintenance (Alabadan et al., 2009). Organic compost serves as an effective nutrient source for plants without environmental harm (Haruna et al., 2011).

Vermicomposting, a biochemical and mesophilic (10-32°C) process, provides essential crop nutrients and is integral to INM strategies in agriculture (Bejbaruha et al., 2009). It can be useful to combine organic manures and biofertilizers to maintain crop output and address issues with soil health. The ability of base crops to withstand drought was also found to be improved by intercropping with pulse and oilseed crops (Rajanna et al., 2023). Biofertilizers such as *Rhizobium* and Phosphate Solubilizing Bacteria (PSB) have also been shown to enhance chickpea productivity. These microorganisms aid in solubilizing inorganic soil phosphates, making them available to plants (Barroso et al., 2006). *Rhizobium* and PSB play critical roles in nitrogen fixation and phosphorus solubilization. Therefore, judicious use of organic manures and biofertilizers, in addition to chemical fertilizers, may help maintain crop yields and soil health (Jaipal et al., 2011). Keeping this in view, the experiment was undertaken to study the **"**Effect of integrated nutrient management (INM) on growth and yield of chickpea (*Cicer arietinum* L.) under irrigated condition**".**

2. MATERIALS AND METHODS

The field experiment was conducted at Agronomy Research Farm, CCS Haryana Agricultural University, Hisar (Haryana) (29°8'56.62"N latitude and 75°41'4.24"E longitude) with an elevation of 215.2 m above mean sea level in winter season 2021-22 in the Haryana state of India to assess the "Effect of integrated nutrient management (INM) on growth and yield of chickpea (*Cicer arietinum* L.) under irrigated condition**".**

The experiment was performed at Research Area of Agronomy Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar, during the *rabi* season of 2021-22. Hisar is situated in the sub-tropical region of north-western India at latitude 29º10'N, longitude 75º46'E and altitude of 215.2 m above mean sea level in the Indian state of Haryana. Hisar has a typical semi-arid climate, with extremely hot summers (temperatures can reach 45 °C or higher) and very cold winters (temperatures can drop to 1-2 °C or less) throughout the summer and winter seasons, the mean monthly temperature shows a broad range of variations in minimum and maximum temperatures. In Hisar, the average annual rainfall is 450 mm, with large variations in distribution throughout the region. During the crop season 2021-22, the range of maximum and minimum temperature varied between 14.0 to 39.3 ºC and 3.3 to 14.2°C, respectively. The weekly mean relative humidity during the crop growing season varied from 73 to 99 % in morning hours and 17 to 79 % in evening hours. The total rainfall received during the crop growing period was 71 mm and the highest amount of rainfall received was 23.5 mm. The soil of the experimental site was sandy loam in texture, slightly alkaline in reaction (pH 7.8) and normal electrical conductivity (0.23 dS m^{-1}). Soil organic carbon (0.43%) and nitrogen (115.67 kg ha^{-1}) were found to be low, while phosphorus (10.09 kg ha^{-1}) and potassium content (270.45 kg ha^{-1}) were reported to be medium. The gram variety HC 7 was sown in a regularly tilled seed bed with a seed rate of 40 kg seed ha^{-1} and spacing of 45×10 cm. The experiment was conducted in randomized block design with three replications. Different treatments were: T_1: control, T_2: 100% Recommended dose of fertilizer (RDF) i.e. 18:48:0 kg ha^{-1}, T_3: 100% vermicompost @ 3.00 t ha^{-1}, T_4: 75% RDF + 25% vermicompost @ 0.75 t ha^{-1} , T_5: 50% RDF + 50% vermicompost @1.5 t ha^{-1}, T_6: 25% RDF + 75% vermicompost @ 2.25 t ha^{-1}, T_7: 75% RDF + 25% vermicompost @ 0.75 t ha^{-1} + biofertilizers (*Rhizobium* + PSB), T_8: 50% RDF + 50% vermicompost @ 1.5 t ha^{-1} + biofertilizers (*Rhizobium* + PSB), T_9: 25% RDF + 75% vermicompost @ 2.25 t ha^{-1} + biofertilizers (*Rhizobium* + PSB).

2.1 Statistical Analysis of Data

All the experimental data for various parameters was statistically analysed by online computer programme OPSTAT (Sheoran et al., 1998).

3. RESULTS AND DISCUSSION

3.1 Effect on Plant Height (cm)

The pertaining data of plant height is presented in Table 1. Plant height at 60 and 120 DAS was significantly affected by various fertilizers treatments. The data conveyed plant height at 60 and 120 DAS through various fertilizers application ranged from 27.7-37.5 cm and 66.0-77.7 cm, respectively. At 60 and 120 DAS, the highest plant height was recorded under the application of 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB) (37.5 and 77.7 cm respectively), which was statistically at par with 75% RDF + 25% vermicompost (0.75 t ha^{-1}) (35.4 and 74.4 cm respectively), 100% RDF (18:48:0 kg ha^{-1}) (35.3 and 74.4 cm respectively), and 50% RDF + 50% vermicompost (1.5 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB) (35.0 and 73.6 cm respectively). The reason for the better development and growth in the above treatments could be due to the greater availability of nutrients in the soil as a result of increasing fertilizer application with vermicompost and biofertilizers. The P associated in photosynthesis, which is directly related to the formation of plant root biomass and produced robust development of plants and an extensive root system leading the considerable growth parameters, may be responsible for the increase in plant height. Similar results were also reported by Meena et al. (2015).

3.2 Effect on Dry Matter Accumulation (g plant^{-1})

The data regarding the dry matter accumulation is presented in Table 1. Various fertilizer application significantly affected the dry matter accumulation per plant and highest dry matter accumulation was recorded under the application of 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB), which is significantly higher than the rest of treatments at 60 DAS and at par with the treatment of 75% RDF + 25% vermicompost (0.75 t ha^{-1}) and 100% RDF (18:48:0 kg ha^{-1}) at 120 DAS. The lowest dry matter accumulation was recorded under control during 60 and 120 DAS. These fertilizers may have enhanced meristematic activity, increasing the availability of major nutrients to plants from deeper layers of soil, ultimately leading to increased plant growth in terms of plant height. These results are in close conformity with the findings of Kumar et al.

(2018), Ahmed et al. (2017) and Singh et al. (2017).

3.3 Effect on Yield Attributing Characters

The data pertaining to yield attributing character Table 1 and the graphical representation in Fig. 1 revealed that various fertilizer treatments significantly influenced the yield attributing character of chickpea at maturity and highest number of branches per plant, number of pods per plant, number of seed per pod and 100 seed weight (g) were recorded with the fertilizer treatment 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB). Among the treatments, 75% RDF + 25% vermicompost + biofertilizers (*Rhizobium* + PSB) resulted in better yield due to adequate supply of nutrients which in turn helped in vigorous vegetative growth of plants and subsequently increased the number of branches through cell elongation, cell expansion, cell division, photosynthesis and turbidity of plant cell. These findings are comparable with the finding of Pramanik and Bera (2012) and Prasad et al. (2008).

Table 1. Effect of integrated nutrient management on Plant height (cm), Dry matter accumulation (g plant^{-1}) and Yield attributes of chickpea (*Cicer arietinum* L.) under irrigated condition

Treatments	Plant height (cm)		Dry matter accumulation (g plant^{-1})		Yield attributes			
	60 DAS	120 DAS	60 DAS	120 DAS	No. of branches per plant	No. of pods per plant	No. of seeds per pod	100 seed weight (g)
T_1	27.7	66.0	0.9	11.8	4.0	31.6	0.5	14.0
T_2	35.3	74.4	2.4	19.8	6.5	50.4	1.8	14.3
T_3	29.9	68.2	1.0	12.8	4.0	36.0	0.8	14.0
T_4	35.4	74.4	2.4	20.3	6.7	51.1	1.8	14.4
T_5	32.5	72.0	1.8	17.7	5.8	44.4	1.3	14.2
T_6	31.1	69.7	1.2	15.1	4.7	38.7	1.0	14.1
T_7	37.5	77.7	2.6	21.7	7.4	53.8	2.0	14.8
T_8	35.0	73.6	2.2	19.1	6.4	50.3	1.5	14.7
T_9	31.8	71.1	1.7	17.0	5.2	43.3	1.2	14.1
SEm ±	1.00	1.5	0.06	0.65	0.32	1.35	0.06	0.19
C.D. (p=0.05)	3.03	4.56	0.19	1.97	0.97	4.10	0.20	NS

**NS; Non-significant*

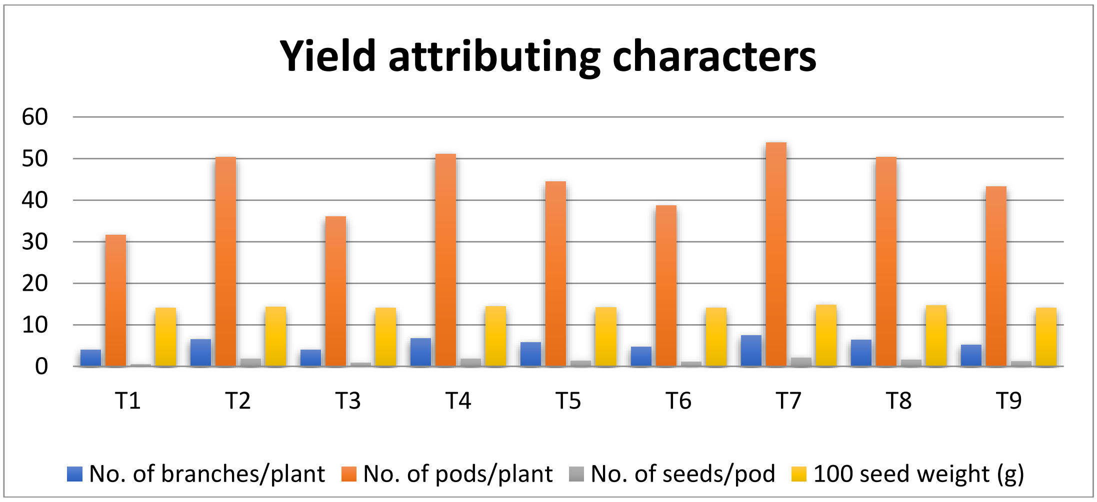

Fig. 1. Effect of integrated nutrient management on yield attributing characters of chickpea (*Cicer arietinum* L.) under irrigated condition

3.4 Effect on Grain Yield (kg ha^{-1})

A detailed examination at the data in Table 2 and the graphical representation in Fig. 2 showed that different fertilisers treatments had a major impact on grain yield. According to the data the grain yield in various fertilisers treatments ranged from 1395-2515 kg ha^{-1}. Maximum grain yield (2515 kg ha^{-1}) was recorded under 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB), which was statistically at par with treatments 75% RDF + 25% vermicompost (0.75 t ha^{-1}) and 100% RDF (18:48:0 kg ha^{-1}). Minimum grain yield (1395 kg ha^{-1}) was recorded in control, where no any application of fertilizers was applied. This increase in yield was attributed to increase in yield components of the crop in fertilized plots. These results are corroborated with the results of Sodavadiya et al. (2023), Singh et al. (2017), Pawar et al. (1997) and Konde and Deshmukh (1996).

3.5 Effect on Straw Yield (kg ha^{-1})

A look into the information shown in Table 2 and the figure's graphical representation 2 indicated that various fertiliser treatments had an enormous effect on chickpea straw yield. The data culminated straw yield through various fertilizer treatments ranged from 1822-3413 kg ha^{-1}. Among the various fertilizer treatments, 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB) recorded significantly higher straw yield (3413 kg ha^{-1}) and which was statistically at par with treatments 75% RDF + 25% vermicompost (0.75 t ha^{-1}) and 100% RDF (18:48:0 kg ha^{-1}). Lowest straw yield (1822 kg ha^{-1}) was observed in control, which was significantly lower than rest of all treatments. Similar finding was done by Mustafa et al*.* (2008).

3.6 Effect on Biological Yield (kg ha^{-1})

The data in Table 2 and the graphical representation in Fig. 2 make it clear that the biological yield was greatly impacted by the various fertiliser treatments. The data concluded that biological yield recorded in different fertilizers treatment ranged from 3218-5927 kg ha^{-1}. Maximum biological yield (5927 kg ha^{-1}) was recorded in 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB), which was statistically at par with 75% RDF + 25% vermicompost (0.75 t ha^{-1}) and 100% RDF (18:48:0 kg ha^{-1}). Among the different fertilizers treatments, control, where no any fertilizers application was given, recorded significantly minimum biological yield (3218 kg ha^{-1}). Better plant growth, higher yield and yield components are the possible reasons for higher biological yield in fertilized plot. Similar results were reported by Singh et al. (2023) and Roy et al. (1995).

3.7 Effect on Harvest Index (%)

A review of the information shown in Table 2 and the figure's graphical representation. 2 demonstrated that the harvest index was not substantially impacted by the various fertiliser treatments. The data conveyed harvest index in different fertilizers treatments ranged from 42-45% (Table 2). Maximum harvest index was recorded in treatment with 100% vermicompost (3.00 t ha^{-1}). The results are in conformity with the findings of Singh and Khare (2024), Sahu et al. (2010) and Thenua et al. (2010).

Table 2. Effect of integrated nutrient management on yield of chickpea (*Cicer arietinum* L.) under irrigated condition

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	HI (%)
T_1	1395	1822	3218	43
T_2	2385	3141	5525	43
T_3	1685	2039	3725	45
T_4	2337	3234	5570	42
T_5	2177	2824	5001	44
T_6	1788	2377	4164	43
T_7	2515	3413	5927	42
T_8	2265	3154	5419	42
T_9	1979	2592	4570	43
SEm ±	79.04	107.49	117.71	1.44
C.D. (p=0.05)	239.01	325.03	355.95	NS

**NS; Non-significant, HI; Harvest index*

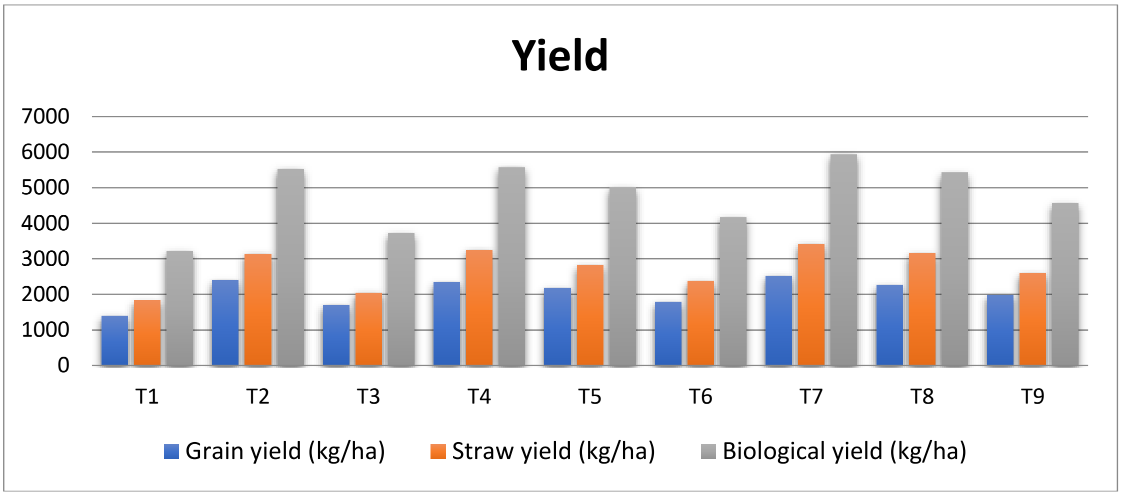

Fig. 2. Effect of integrated nutrient management on yield of chickpea (*Cicer arietinum* L.) under irrigated condition

Table 3. Effect of integrated nutrient management on economics of chickpea (*Cicer arietinum* L.) under irrigated condition

Treatments	Cost of cultivation (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	B:C ratio
T_1: Control	42255	80736	38481	1.9
T_2: 100% RDF (18:48:0 kg ha^{-1})	45765	125994	80229	2.8
T_3: 100% vermicompost (3.00 t ha^{-1})	57927	96659	38732	1.7
T_4: 75% RDF + 25% vermicompost (0.75 t ha^{-1})	49281	136734	87453	2.8
T_5: 50% RDF + 50% vermicompost (1.5 t ha^{-1})	52163	120079	67916	2.3
T_6: 25% RDF + 75% vermicompost (2.25 t ha^{-1})	55046	103656	48610	1.9
T_7: 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB)	49341	146600	97259	3.0
T_8: 50% RDF + 50% vermicompost (1.5 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB)	52223	139120	86897	2.7
T_9: 25% RDF + 75% vermicompost (2.25 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB)	55106	114512	59406	2.1

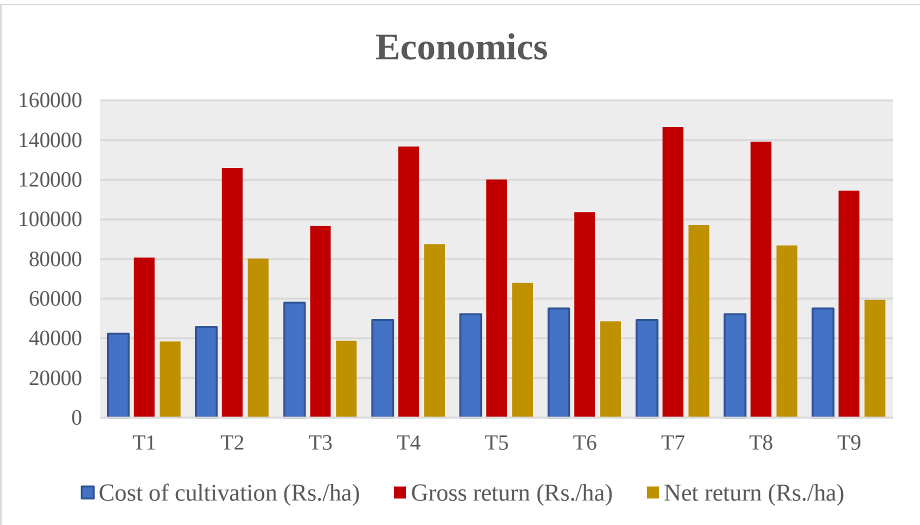

Fig. 3. Effect of integrated nutrient management on economics of chickpea (*Cicer arietinum* L.) under irrigated condition

3.8 Effect on Economics

3.8.1 Cost of cultivation

According to a detailed analysis from Table 3 and graphical representation in Fig. 3, the cost of cultivation varied between 42255 and 57927 Rs. ha^{-1} across the various treatments. The treatment with 100% vermicompost (3.0 t ha^{-1}) has the highest cultivation cost (57927 Rs. ha^{-1}). The lowest cultivation cost (42255 Rs. ha^{-1}) was noted in the control group, which received no treatments, and this was substantially different from the other treatments.

3.8.2 Gross return (Rs. ha^{-1})

The final gross return, calculated using different fertiliser treatments, varied between 80736 and 146600 Rs. ha^{-1}. The control group, which received no treatment, had the lowest gross return (80736 Rs. ha^{-1}). With 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB), the highest gross yield (146600 Rs. ha^{-1}) was seen. Fig. 3 graphical representation and Table 3 data analysis revealed that the different fertiliser treatments had a considerable impact on gross returns.

3.8.3 Net return (Rs. ha^{-1})

According to the data, net returns for various fertiliser treatments varied between 38481 and 97259 Rs. ha^{-1}. When integrated nutrient management was implemented using 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB), the highest net return (97259 Rs. ha^{-1}) was recorded. The control, which received no treatments, had the lowest net return (38481 Rs. ha^{-1}), which was substantially different from the other treatments. A closer look of the data represents in Table 3 and the graphical representation in Fig. 3.

3.8.4 Benefit: Cost ratio

Fig. 3 graphical representation and Table 3 data probe revealed that the benefit-cost ratio was strongly impacted by the varied fertiliser treatments. The final benefit-cost ratio derived from the various fertiliser treatments ranged from 1.7 to 3.0. 100% vermicompost (3.00 t ha^{-1}) had the lowest benefit-cost ratio (1.7). Biofertilizers (*Rhizobium* + PSB) combined with 75% RDF + 25% vermicompost (0.75 t ha^{-1}) had the highest benefit cost ratio (3.0).

4. CONCLUSION

Amongst all the treatments, highest grain yield was recorded with the application of 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB), followed by 75% RDF + 25% vermicompost (0.75 t ha^{-1}) and 100% RDF (18:48:0 kg ha^{-1}). The improved grain yield can be attributed to several factors: higher plant height, higher dry matter accumulation, higher yield attributing character and economics. Specifically, the grain yield was increased by 80.28% in treatment 75% RDF + 25% vermicompost (0.75 t ha^{-1}) + biofertilizers (*Rhizobium* + PSB) compared to control conditions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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