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Effect of Integrated Nutrient Management on Growth, Yield, and Economics of Cowpea (*Vigna unguiculata* L.) in Semi-Arid Conditions in Bundelkhand, India

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Abstract

Integrated nutrient management (INM) is a sustainable approach for improving crop productivity and soil health, particularly under nutrient-deficient semi-arid conditions. The present study was conducted to evaluate the effect of integrated nutrient management on growth, yield, and economics of cowpea (Vigna unguiculata) in the Bundelkhand region of Uttar Pradesh, India. A field experiment was carried out during the Kharif season of 2025–26 using a randomized block design (RBD) with nine treatments and three replications. The treatments comprised different combinations of inorganic fertilizers (NPK), biofertilizer (Rhizobium), and organic input (Jeevamrit). The results revealed that INM significantly influenced growth parameters, yield attributes, and economic returns. Among the treatments, the combined application of NPK + Rhizobium + Jeevamrit (T_9) proved to be the most effective. This treatment recorded the maximum plant height (109.52 cm), number of pods per plant (21.84), number of seeds per pod (15.36), and test weight (72.48 g). The improved growth and yield attributes under T_9 resulted in enhanced productivity and profitability. Economic analysis showed that the same treatment recorded the highest net return (Rs.69,060 ha^{-1}) along with a superior benefit–cost ratio of 6.09, indicating its strong economic viability. The enhanced performance under integrated nutrient application may be attributed to balanced nutrient supply, improved microbial activity, enhanced biological nitrogen fixation, and better nutrient uptake. Thus, integrated nutrient management involving NPK, Rhizobium, and Jeevamrit is an effective and economically viable strategy for improving cowpea productivity under Bundelkhand conditions.

Keywords: *Integrated Nutrient Management (INM); Cowpea (Vigna unguiculata); Rhizobium; Jeevamrit; Yield attributes.*

1. Introduction

Pulses play a vital role in global food and nutritional security, particularly in developing countries where they serve as an affordable and rich source of dietary protein. Among pulses, cowpea (*Vigna unguiculata* L.) is an important legume crop widely cultivated in tropical and subtropical regions. It is valued not only for its high protein content but also for its adaptability to harsh environmental conditions, especially drought-prone and low-fertility soils. Cowpea contributes significantly to sustainable agriculture due to its ability to fix atmospheric nitrogen through symbiotic association with *Rhizobium*, thereby improving soil fertility and reducing dependence on synthetic nitrogen fertilizers [1-2]. Its short duration, resilience to moisture stress, and multipurpose use as food, fodder, and green manure make it an ideal crop for semi-arid regions like Bundelkhand. Despite its potential, the productivity of cowpea remains relatively low in many parts of India, primarily due to declining soil fertility and imbalanced nutrient management. Continuous cropping without adequate nutrient replenishment has led to depletion of essential nutrients and deterioration of soil health.

Excessive reliance on chemical fertilizers, particularly macronutrients, without adequate incorporation of organic inputs has resulted in reduced soil organic carbon and poor nutrient use efficiency [3]. This imbalance not only limits crop productivity but also adversely affects soil biological activity and long-term sustainability. In semi-arid regions such as Bundelkhand, where soils are already low in organic matter and moisture availability is erratic, the problem of nutrient deficiency becomes more pronounced, further constraining crop yields. To address these challenges, the concept of Integrated Nutrient Management (INM) has gained prominence as a sustainable approach to maintain soil fertility and enhance crop productivity. INM involves the judicious use of chemical fertilizers in combination with organic manures and biofertilizers to achieve balanced nutrient supply and improve soil health. This approach ensures the efficient utilization of nutrients while minimizing environmental degradation. Recent studies have emphasized that INM not only enhances crop yield but also improves soil physical, chemical, and biological properties, making it a key strategy for sustainable agriculture [4-5]. The components of INM play distinct yet complementary roles in crop production.

Chemical fertilizers such as NPK provide readily available primary nutrients required for plant growth and development. Nitrogen is essential for vegetative growth and protein synthesis, phosphorus plays a crucial role in root development and energy transfer, and potassium regulates water balance and enzyme activation. However, sole reliance on chemical fertilizers may not sustain soil health in the long term. Biofertilizers, particularly *Rhizobium*, play a critical role in biological nitrogen fixation in leguminous crops like cowpea. The symbiotic association between *Rhizobium* bacteria and cowpea roots leads to the formation of root nodules, which fix atmospheric nitrogen and make it available to the plant. This not only reduces the need for synthetic nitrogen fertilizers but also enhances soil fertility for subsequent crops [6], organic inputs such as Jeevamrit, a traditional liquid organic formulation, have gained attention for their role in improving soil microbial activity and nutrient availability. Jeevamrit contains beneficial microorganisms that enhance decomposition of organic matter, increase nutrient mineralization, and improve soil structure. It also promotes plant growth by stimulating microbial-mediated processes in the rhizosphere [7-8]. The integration of these components under INM provides several agronomic and ecological benefits. It improves soil health by enhancing organic matter content and microbial diversity, increases nutrient use efficiency, and ensures a balanced supply of nutrients throughout the crop growth period. Moreover, INM reduces the cost of cultivation by minimizing the dependence on chemical fertilizers and promoting the use of locally available organic inputs. Studies have reported that integrated use of fertilizers and bio-organic inputs significantly improves growth parameters, yield attributes, and economic returns in legume crops [9-20]. However, the effectiveness of INM practices is highly location-specific and depends on soil type, climate, and cropping system. The Bundelkhand region, characterized by semi-arid climate, erratic rainfall, and degraded soils with low organic carbon, presents unique challenges for crop production. Despite the potential benefits of INM, there is a lack of region-specific studies evaluating the combined use of chemical fertilizers, biofertilizers, and organic inputs in cowpea cultivation under Bundelkhand conditions. Most of the existing studies focus on individual components rather than their integrated effects, leaving a significant research gap in developing sustainable nutrient management strategies for this region. Furthermore, with increasing emphasis on sustainable agriculture and climate-resilient farming systems, there is a growing need to adopt integrated approaches that enhance productivity while conserving natural resources. INM offers a promising solution by improving soil fertility, enhancing crop resilience, and ensuring long-term sustainability of agricultural systems. Therefore, the present study was conducted to evaluate the effect of integrated nutrient management on growth, yield, and economics of cowpea under Bundelkhand conditions.

2. Materials and Methods

2.1. Study Area

The field experiment was conducted during the Kharif season of 2025–26 at the Agricultural Research Farm, Nehru Mahavidyalaya, Lalitpur, Uttar Pradesh, India, located in the Bundelkhand region. The experimental site lies in a semi-arid agro-climatic zone, characterized by hot summers, moderate monsoon rainfall, and mild winters. The region receives an average annual rainfall of approximately 688 mm, most of which occurs during the southwest monsoon season (June–September). Geographically, the site is situated around 25.4° N latitude and 78.6° E longitude, with an elevation of approximately 373 m above mean sea level (Fig.1). The soil of the experimental field was sandy loam in texture, moderately fertile, and suitable for pulse cultivation.

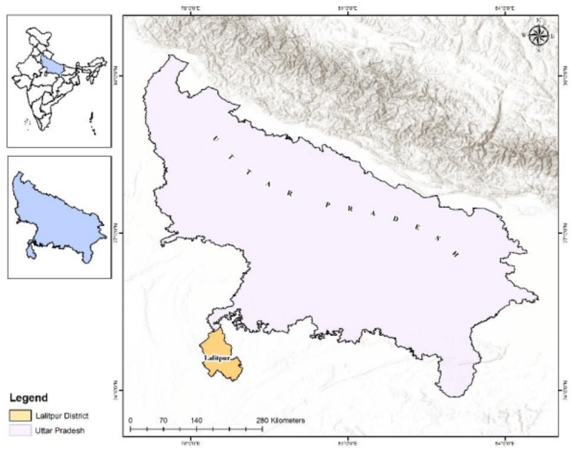

Fig 1: Location map of the experimental site at Nehru Mahavidyalaya, Lalitpur, Jhansi district, Uttar Pradesh, India

2.2. Experimental Design

The experiment was laid out in a Randomized Block Design (RBD) with nine treatments and three replications. Treatments were randomly allocated within each replication to minimize experimental error and ensure reliable statistical comparison.

2.3. Treatments

The details of integrated nutrient management treatments are presented in Table 1.

Table 1: Treatment details of integrated nutrient management in cowpea

Treatment	Description
T_1	Control
T_2	50% RDF NPK
T_3	100% RDF NPK
T_4	Jeevamrit
T_5	FYM
T_6	50% RDF NPK + Jeevamrit
T_7	50% RDF NPK + FYM
T_8	FYM + Jeevamrit
T_9	100% RDF NPK + Rhizobium + Jeevamrit

2.4. Crop Details

Cowpea (*Vigna unguiculata* L.) was grown as the test crop during the Kharif season of 2025–26. The variety 'Ankur Gomti' was used for the experiment. The crop was sown following recommended agronomic practices, including appropriate spacing, seed rate, fertilization, irrigation, and plant protection measures, which were uniformly applied across all treatments.

2.5. Observations Recorded

Observations were recorded at different growth stages and categorized as follows:

1. Growth parameters: Plant height (cm), number of branches per plant, fresh weight (g), and dry weight (g).

2. Nodulation parameters: Number of root nodules per plant, reflecting biological nitrogen fixation efficiency.
3. Yield attributes: Number of pods per plant, number of seeds per pod, and test weight (g).
4. Yield: Seed yield (q ha^{-1}) and stover yield (q ha^{-1}).
5. Economic analysis: Cost of cultivation, gross returns, net returns, and benefit–cost (B:C) ratio.

2.6. Statistical Analysis

The experimental data were statistically analyzed using analysis of variance (ANOVA) appropriate for the Randomized Block Design, following the standard procedure described by Gomez and Gomez (1984). The significance of treatment effects was tested at the 5% level of probability (p = 0.05), and the critical difference (CD) was calculated for comparison of treatment means.

3. Results

3.1. Growth Parameters

Growth parameters of cowpea were significantly influenced by different integrated nutrient management (INM) treatments. The data revealed clear variation among treatments with respect to plant height, number of branches, fresh weight, and dry matter accumulation. Plant height increased progressively with crop growth across all treatments; however, the magnitude of increase was significantly higher under integrated nutrient application. The treatment T_9 (RDF + Rhizobium + Jeevamrit) recorded the maximum plant height (109.52 cm) at harvest, which was significantly superior to all other treatments, including RDF alone and control. This improvement in plant height may be attributed to enhanced nutrient availability and better physiological activity resulting from the combined effect of inorganic fertilizers, biofertilizers, and organic inputs. Similarly, the number of branches per plant was significantly higher under T_9, recording 15.92 branches per plant, indicating better vegetative growth and canopy development. Treatments involving partial integration (T_6, T_7, T_8) also showed improved branching compared to single-component treatments, but remained inferior to T_9.
Fresh weight and dry matter accumulation followed a similar trend. The highest fresh weight (148.63 g per plant) and dry weight (32.84 g per plant) were recorded under T_9, reflecting enhanced biomass production. The increase in dry matter accumulation indicates improved photosynthetic efficiency and nutrient assimilation under integrated nutrient management, the control treatment recorded the lowest values for all growth parameters, highlighting the importance of balanced nutrient supply. The results clearly indicate that INM practices significantly enhance vegetative growth of cowpea (Fig. 2, 3, and 4).

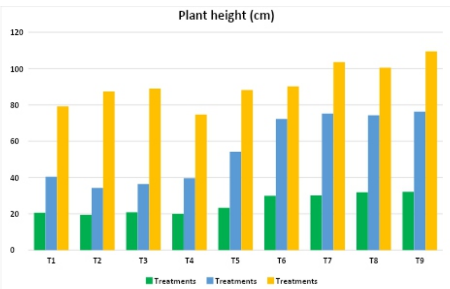

Fig. 2: Effect of integrated nutrient management treatments on plant height of cowpea at different growth stages (30, 60 and 90 DAS)

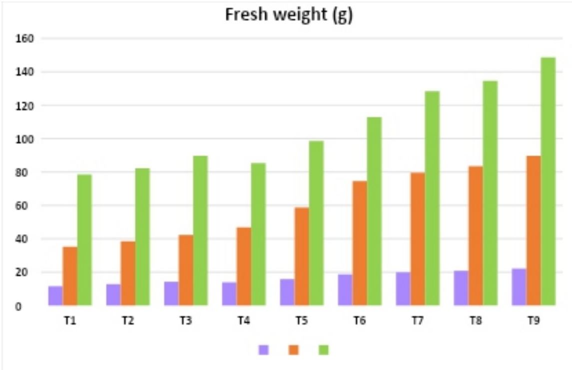

Fig. 3: Effect of integrated nutrient management treatments on fresh weight of cowpea at different growth stages (30, 60 and 90 DDAS)

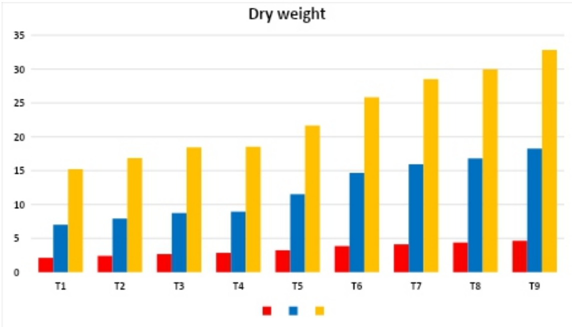

Fig. 4: Effect of integrated nutrient management treatments on dry weight of cowpea at different growth stages (30, 60 and 90 DAS)

3.2 Nodulation and Biomass Accumulation

Nodulation is a critical parameter in leguminous crops as it directly influences biological nitrogen fixation. The results showed that integrated nutrient management treatments significantly affected nodulation characteristics and biomass accumulation. The number of root nodules per plant was markedly higher under treatments involving *Rhizobium* inoculation, particularly T_9. The enhanced nodulation under T_9 indicates effective symbiotic association between *Rhizobium* and cowpea roots, leading to increased nitrogen fixation. This improvement can be attributed to the favorable soil environment created by the combined application of organic and inorganic inputs, which supports microbial activity and root development. Treatments without *Rhizobium* inoculation recorded comparatively lower nodulation, highlighting the essential role of biofertilizers in legume production. The presence of Jeevamrit further enhanced microbial activity in the rhizosphere, contributing to improved nodulation and nutrient availability. Biomass accumulation was also significantly higher under integrated treatments. The highest biomass production observed under T_9 is consistent with its superior growth performance, indicating efficient utilization of nutrients and improved physiological activity. The combined effect of enhanced nodulation and nutrient availability resulted in increased biomass production. These findings demonstrate that INM practices not only improve plant growth but also enhance biological nitrogen fixation and soil microbial activity (Fig. 5 and 6).

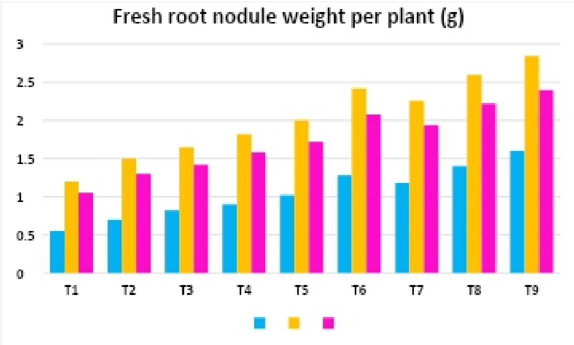

Fig. 5: Fresh root nodule weight per plant (g)

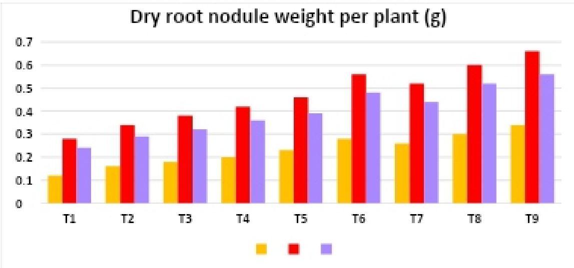

Fig. 6: Dry root nodule weight per plant (g)

3.3. Yield Attributes and Yield

Yield attributes and productivity of cowpea were significantly influenced by integrated nutrient management treatments. The superiority of combined nutrient application was clearly reflected in improved yield components. The treatment T_9 recorded the highest number of pods per plant (21.84), which was significantly higher than all other treatments. Similarly, the number of seeds per pod was maximum under T_9 (15.36 seeds per pod), indicating improved reproductive efficiency. Test weight, an important indicator of seed quality and grain filling, was also significantly higher under T_9, with a value of 72.48 g. This suggests that integrated nutrient application ensured better assimilate translocation and grain development. Seed yield was significantly enhanced under INM treatments, with T_9 recording the highest yield. The increase in seed yield can be attributed to improved growth parameters, enhanced nodulation, and better reproductive development. Stover yield also followed a similar trend, indicating overall improvement in biomass production. The control treatment recorded the lowest yield and yield attributes due to nutrient deficiency and poor growth performance. The results clearly demonstrate that integrated nutrient management significantly enhances both yield attributes and productivity of cowpea (Fig. 7).

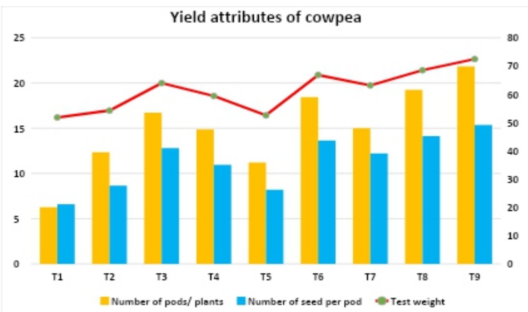

Fig. 7: Yield attributes of cowpea under different integrated nutrient management treatments

3.4. Economic Analysis

Economic evaluation of integrated nutrient management practices revealed significant variation among treatments in terms of profitability. The treatment T_9 recorded the highest net return of Rs.69,060 ha^{-1}, indicating its economic superiority over all other treatments. This treatment also achieved the highest benefit–cost (B:C) ratio of 6.09, which is considerably high and highlights its strong economic viability. The higher profitability of T_9 can be attributed to increased yield and efficient utilization of inputs without a proportionate increase in cost. Treatments involving partial integration also showed improved economic returns compared to control and RDF alone, but were inferior to T_9. The control treatment recorded the lowest economic returns due to poor yield performance. These findings clearly indicate that integrated nutrient management is not only agronomically beneficial but also economically rewarding for farmers (Fig. 8).

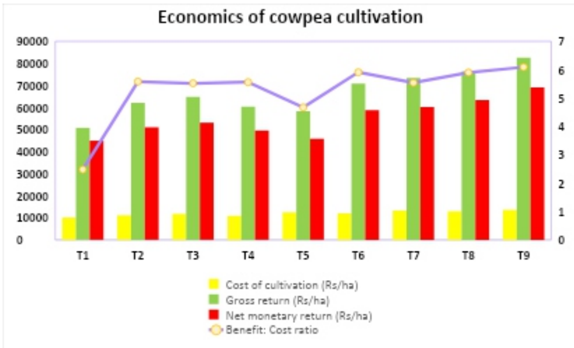

Fig. 8: Economics of cowpea cultivation under different integrated nutrient management treatments.

4. Discussion

The results of the present study clearly demonstrate that integrated nutrient management (INM), particularly the combined application of RDF + Rhizobium + Jeevamrit (T_9), significantly enhanced growth, nodulation, yield attributes, productivity, and economic returns of cowpea under Bundelkhand conditions . The superiority of T_9 can be explained through the complementary and synergistic effects of its individual components, which collectively improved nutrient availability, soil biological activity, and plant physiological processes.

The enhanced growth observed under T_9, including higher plant height, number of branches, and biomass accumulation, can primarily be attributed to the balanced and continuous supply of nutrients. The application of NPK fertilizers ensured the availability of essential macronutrients required for plant growth and development. Nitrogen promoted vegetative growth and protein synthesis, phosphorus enhanced root development and energy transfer, and potassium regulated physiological functions such as enzyme activation and water balance. However, the effectiveness of these nutrients was significantly improved when combined with biological and organic inputs.

The role of *Rhizobium* inoculation was particularly evident in the significant increase in nodulation observed under T_9. The symbiotic association between *Rhizobium* and cowpea roots led to enhanced biological nitrogen fixation, which supplemented the nitrogen requirement of the crop.

Increased nodulation directly contributed to improved nitrogen availability, thereby supporting vegetative growth and biomass production. The relationship between nodulation and nitrogen supply observed in the present study confirms that higher nodulation leads to increased nitrogen fixation, which in turn enhances plant growth and yield. Similar findings have been reported by [11-12] who observed significant improvement in nodulation and growth parameters of legumes under integrated nutrient management practices.

The inclusion of Jeevamrit further strengthened the effectiveness of INM by enhancing soil microbial activity. Jeevamrit, being a rich source of beneficial microorganisms, improved the biological environment of the soil, leading to increased nutrient mineralization and availability. It also facilitated better root growth and nutrient uptake by promoting microbial-mediated processes in the rhizosphere. The synergistic interaction between Jeevamrit and *Rhizobium* likely created a favorable environment for microbial proliferation and activity, resulting in improved nodulation and nutrient utilization. [13] have also highlighted that organic formulations such as Jeevamrit significantly enhance microbial activity, soil fertility, and crop productivity under sustainable farming systems. The combined effect of these components resulted in significantly higher biomass accumulation, which played a crucial role in enhancing yield attributes and productivity. Increased dry matter production indicates improved photosynthetic efficiency and resource utilization, which ultimately leads to greater availability of assimilates for reproductive development. The present study clearly shows that higher biomass production is directly associated with improved yield performance, as reflected in the increased number of pods per plant, seeds per pod, and test weight under T_9.

The improvement in yield attributes under T_9 can be attributed to better nutrient availability during critical growth stages, particularly flowering and pod development. Adequate nitrogen supply from biological fixation, combined with improved nutrient uptake facilitated by Jeevamrit, ensured efficient translocation of assimilates from source to sink. This resulted in better pod formation, seed development, and grain filling. Similar results have been reported by [4-5], who observed significant improvement in yield attributes of cowpea under integrated nutrient management. Likewise, [14] reported that combined application of chemical fertilizers, organic manures, and biofertilizers significantly increased seed yield and yield components in legume crops.

The findings of the present study are also consistent with recent research, which emphasizes the importance of integrated nutrient management in enhancing crop productivity and sustainability. Recent studies have reported that INM practices improve nutrient use efficiency, enhance soil biological activity, and increase crop yield under different agro-climatic conditions [10-11]. The improved performance under T_9 in the present study aligns with these findings, highlighting the effectiveness of integrating chemical, biological, and organic nutrient sources. Economic analysis further validated the superiority of T_9, which recorded the highest net returns and benefit–cost ratio.

The enhanced profitability can be attributed to increased yield and efficient utilization of inputs, resulting in higher returns without a proportionate increase in cost. The integration of locally available organic inputs such as Jeevamrit also reduces dependency on expensive chemical fertilizers, making the system more cost-effective and sustainable, the results indicate that the combined application of NPK, *Rhizobium*, and Jeevamrit creates a synergistic effect that enhances nutrient availability, improves soil biological activity, and promotes efficient resource utilization. This integrated approach not only improves growth and yield but also ensures sustainability and economic viability of cowpea cultivation under semi-arid conditions.

5. Conclusion

The present study clearly demonstrates that integrated nutrient management (INM) is superior to single nutrient approaches in enhancing the growth, productivity, and profitability of cowpea under semi-arid conditions. Among the treatments, the combined application of RDF + Rhizobium + Jeevamrit (T_9) proved to be the most effective, resulting in significantly higher growth parameters, nodulation, yield attributes, and seed yield. The improved performance was associated with enhanced biomass accumulation and efficient nutrient utilization. This treatment also recorded the highest economic returns, confirming its practical feasibility. Therefore, the integrated use of chemical fertilizers, biofertilizers, and organic inputs can be recommended as a sustainable and economically viable nutrient management strategy for cowpea cultivation in the Bundelkhand region.

6. Recommendations

Based on the findings of the present study, the adoption of integrated nutrient management (INM) involving NPK, *Rhizobium*, and Jeevamrit is recommended for improving cowpea productivity under Bundelkhand conditions. This approach ensures balanced nutrient supply, enhances soil biological activity, and promotes sustainable crop production. It is particularly suitable for low-input farming systems, as the inclusion of organic inputs like Jeevamrit reduces dependence on costly chemical fertilizers. Therefore, this practice can be effectively adopted by small and marginal farmers to achieve higher yield and profitability while maintaining soil health.

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