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Integrated Nutrient Management Enhances Growth, Yield and Economic Returns of Maize (*Zea mays* L.) in Bundelkhand Region, India

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Abstract

Maize (Zea mays L.) productivity in the Bundelkhand region is often constrained by poor soil fertility and imbalanced nutrient use. The present study aimed to evaluate the effect of integrated nutrient management (INM) on growth, yield, and economics of maize cultivation. A field experiment was conducted during the kharif season of 2025 at Nehru Mahavidyalaya, Lalitpur (Uttar Pradesh), using a randomized block design with nine treatments and three replications. The treatments included combinations of recommended dose of fertilizers (RDF), biofertilizer (Rhizobium), and organic input (Jeevamrit). The results revealed that INM treatments significantly improved growth and yield attributes of maize. The treatment T_9 (100% RDF + Rhizobium + Jeevamrit) recorded the highest plant height (240.60 cm), number of leaves (15.6 plant^{-1}), fresh weight (420.60 g), and dry weight (68.90 g). Yield parameters such as number of cobs per plant (1.75), seeds per cob (360.80), and 100-seed weight (31.20 g) were also maximized under T_9. Consequently, the highest seed yield (6890 kg ha^{-1}) and stover yield (15060 kg ha^{-1}) were obtained. Economic analysis showed maximum net returns (₹77,950 ha^{-1}) under T_9, while the highest benefit–cost ratio (2.61) was recorded with T_8 (Rhizobium + Jeevamrit). The study concludes that integrated application of chemical fertilizers with biofertilizers and organic inputs enhances maize productivity and profitability, making INM a sustainable nutrient management strategy for the Bundelkhand region.

Keywords: *Integrated Nutrient Management; Maize (Zea mays L.); Biofertilizers; Jeevamrit; Yield attributes; Economic analysis.*

1. Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops globally, serving as a staple food, feed, and industrial raw material. Its versatility and high yield potential have positioned it as a key crop for food and nutritional security across diverse agro-ecological regions. In India, maize is placed in the third position among cereals after rice and wheat [1]. The crop has gained increasing importance due to its wider adaptability, higher productivity potential, and growing demand in feed, food, and industrial sectors [2]. It is widely cultivated under varied climatic conditions and contributes significantly to the agricultural economy, particularly in rainfed systems [3]. Despite this importance, the productivity of maize in India remains lower than the global average, mainly due to suboptimal management practices and environmental constraints [4]. One of the major factors limiting maize productivity is imbalanced and inefficient nutrient management. The continuous use of chemical fertilizers without adequate organic supplementation has resulted in soil degradation, nutrient imbalance, and reduced fertilizer-use efficiency [4]. Such practices adversely affect soil health by lowering organic carbon content, disturbing beneficial microbial activity, and deteriorating soil physical properties [5]. In regions like Bundelkhand, these issues are further intensified by poor soil fertility, erratic rainfall, and limited resource availability, which collectively constrain crop growth and yield [6]. To address these challenges, Integrated Nutrient Management (INM) has been recognized as a sustainable approach for maintaining soil fertility and enhancing crop productivity. INM involves the judicious combination of chemical fertilizers, organic manures, and biofertilizers to ensure balanced nutrient supply and improved soil health [7]. Organic sources such as farmyard manure, vermicompost, and compost improve soil structure, water-holding capacity, and microbial activity, thereby enhancing nutrient availability [8]. Biofertilizers like *Rhizobium* and phosphate-solubilizing bacteria contribute to biological nitrogen fixation and nutrient solubilization, further improving nutrient-use efficiency [9]. The integration of these components results in a synergistic effect that supports better plant growth and sustainable crop production [10].

Several studies have reported that integrated use of organic and inorganic nutrient sources significantly improves growth parameters, yield attributes, and overall productivity of maize.

For instance, combined application of recommended dose of fertilizers (RDF) with organic manures and biofertilizers enhances plant height, leaf area index, dry matter accumulation, and yield components [11]. Similarly, integration of nutrient sources has been shown to improve soil fertility status and increase nutrient uptake, resulting in higher grain yield and economic returns [12]. INM practices reduce dependency on chemical fertilizers and contribute to cost-effective and environmentally sustainable farming systems [13]. However, the effectiveness of INM practices is highly dependent on local soil and climatic conditions. The Bundelkhand region, characterized by degraded soils, low organic matter content, and frequent climatic stress, requires location-specific nutrient management strategies. Although the benefits of INM are well documented, there is limited research focusing on the combined use of chemical fertilizers, biofertilizers, and locally available organic inputs such as Jeevamrit under Bundelkhand conditions, comprehensive evaluation of economic returns under different INM treatments is still lacking, which is essential for promoting adoption among farmers. Therefore, the present study was undertaken to evaluate the effect of integrated nutrient management on the growth, yield, and cost of cultivation of maize in the Bundelkhand region. The specific objectives were: (i) to assess the impact of different INM treatments on growth and yield attributes of maize, (ii) to evaluate the role of biofertilizers and organic inputs in improving crop performance, and (iii) to identify the most effective and economically viable nutrient management practice for maize under the agro-climatic conditions of Bundelkhand.

2. Materials and Methods

2.1. Study location and experimental conditions

The field experiment was conducted during the kharif season of 2025 at the Agricultural Research Farm of Nehru Mahavidyalaya, Lalitpur, Uttar Pradesh, India.
The experimental site lies in the Bundelkhand region at approximately 25.45–25.47° N latitude and 78.60–78.62° E longitude with an elevation of about 222–285 m above mean sea level. The region is characterized by a semi-arid climate with erratic rainfall and moderate temperatures during the cropping season. The soil of the experimental field was sandy loam in texture with low to medium fertility status, typical of Bundelkhand soils [14].

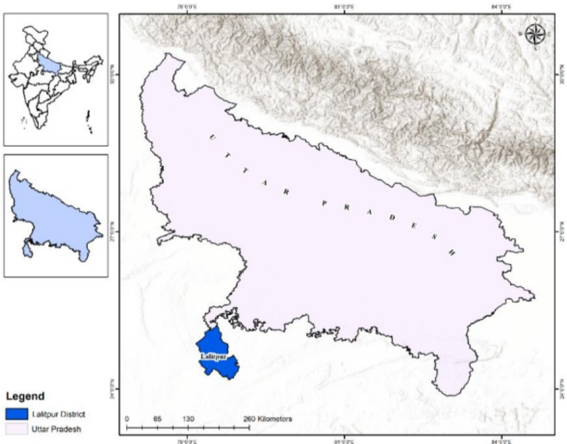


Fig 1: Location of the experimental site at Nehru Mahavidyalaya, Lalitpur, Uttar Pradesh, India

2.2. Experimental design and crop details

The experiment was laid out in a Randomized Block Design (RBD) with nine treatments and three replications. RBD is widely used in agronomic experiments to minimize the effect of field variability and improve the precision of treatment comparisons (Gomez and Gomez, 1984). Maize (*Zea mays* L.) was grown as the test crop using recommended agronomic practices for the region.

2.3. Treatment details

The treatments consisted of different combinations of chemical fertilizers (Recommended Dose of Fertilizers, RDF), biofertilizer (*Rhizobium*), and organic input (Jeevamrit), representing integrated nutrient management (INM) practices.

Table 1: Treatment combinations of integrated nutrient management applied to maize

Treatment Code	Treatment Details
T_1	Control
T_2	100% RDF
T_3	125% RDF
T_4	Rhizobium culture
T_5	Jeevamrit
T_6	100% RDF + Rhizobium culture
T_7	100% RDF + Jeevamrit
T_8	Rhizobium culture +Jeevamrit
T_9	100% RDF + Rhizobium + Jeevamrit

2.4. Observations recorded

Observations were recorded on growth, yield attributes, yield, and economic parameters. Growth parameters included plant height (cm), number of leaves per plant, fresh weight (g), dry weight (g), and root dry weight at different growth stages (30 DAS, 60 DAS, and harvest).
Yield attributes such as number of cobs per plant, number of seeds per cob, and 100-seed weight (g) were recorded at maturity. Final seed yield and stover yield (kg ha^{-1}) were calculated based on plot yield and converted to hectare basis. Economic analysis included calculation of cost of cultivation, gross returns, net returns, and benefit–cost ratio, following standard agricultural economic procedures [15].

2.5. Statistical analysis

The experimental data were analyzed using analysis of variance (ANOVA) appropriate for randomized block design to test the significance of treatment effects (Gomez and Gomez, 1984). The significance of differences among treatment means was evaluated using the F-test at 5% level of probability. Critical difference (CD) values were calculated to compare treatment means where the F-test was found significant.

3. Results

3.1 Growth parameters

The growth parameters of maize were significantly influenced by different integrated nutrient management (INM) treatments at all stages of observation (30 DAS, 60 DAS, and at harvest). The treatment T_9 (100% RDF + *Rhizobium* + Jeevamrit) consistently recorded the highest values for all growth attributes compared to other treatments, while the control (T_1) showed the lowest performance. Plant height increased progressively with crop growth under all treatments; however, significant differences were observed among treatments.

At harvest, the maximum plant height (240.60 cm) was recorded under T_9, followed by T_6 (100% RDF + *Rhizobium*) and T_8 (*Rhizobium* + Jeevamrit), whereas the minimum plant height was observed under the control treatment. Similarly, the number of leaves per plant was significantly higher under integrated treatments, with T_9 recording the maximum value (15.6 leaves plant^{-1}), which was statistically superior to most other treatments. Fresh weight and dry weight of plants were also significantly affected by INM practices. The highest fresh weight (420.60 g plant^{-1}) and dry weight (68.90 g plant^{-1}) were observed under T_9, followed by treatments receiving combined nutrient sources. Root dry weight showed a similar trend, with T_9 recording the highest value (18.90 g plant^{-1}), indicating better root development under integrated nutrient supply. Thus, treatments involving the combined application of chemical fertilizers, biofertilizers, and organic inputs (T_9, T_6, and T_8) performed significantly better than sole applications or control across all growth parameters.

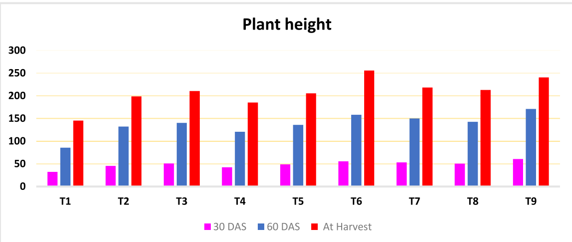


Fig 2: Effect of integrated nutrient management treatments on plant height of maize at different growth stages (30 DAS, 60 DAS, and at harvest)

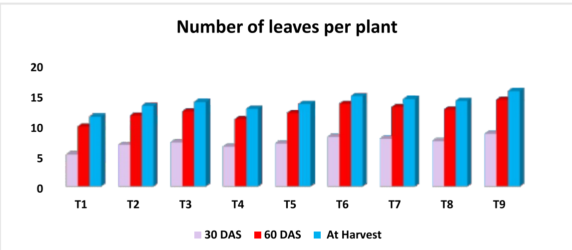


Fig 3: Effect of integrated nutrient management treatments on number of leaves per plant of maize at different growth stages (30 DAS, 60 DAS, and at harvest)

3.2 Yield attributes

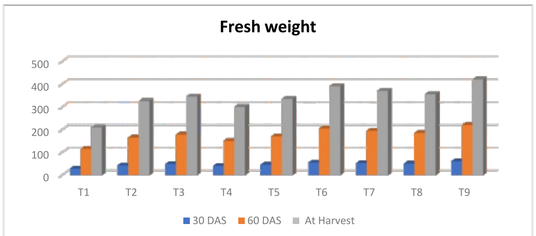
Yield attributes of maize were significantly influenced by different INM treatments. The number of cobs per plant, number of seeds per cob, and 100-seed weight showed considerable variation among treatments. The highest number of cobs per plant (1.75) was recorded under T_9, which was significantly higher than most other treatments, while the lowest was observed under the control. Similarly, the number of seeds per cob was maximum under T_9 (360.80), followed by T_6 and T_8, indicating better reproductive performance under integrated nutrient management. The 100-seed weight also varied significantly among treatments, with T_9 recording the highest value (31.20 g), which was statistically at par or superior to other integrated treatments but significantly higher than the control. Treatments involving combinations of biofertilizers and organic inputs along with RDF generally performed better than individual applications.

Thus, integrated treatments, particularly T_9, exhibited superior performance in all yield attributes compared to sole nutrient applications and control.

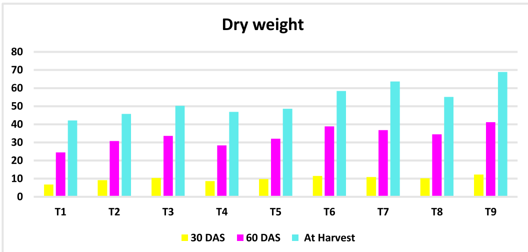
3.3 Yield

Grain yield and stover yield of maize were significantly influenced by different INM treatments. The highest seed yield (6890 kg ha^{-1}) was recorded under T_9 (100% RDF + *Rhizobium* + Jeevamrit), which was significantly superior to all other treatments. This was followed by T_6 and T_8, which also recorded comparatively higher yields than other treatments. The lowest seed yield was observed under the control treatment, indicating the importance of nutrient application for achieving higher productivity.

A similar trend was observed in stover yield, where T_9 recorded the highest stover yield (15060 kg ha^{-1}), followed by integrated treatments involving RDF and biofertilizers. The results clearly indicate that integrated nutrient management practices significantly enhanced both grain and biomass production compared to sole or no nutrient application.



Effect of Different Treatments on the Fresh Weight Dynamics of Zea mays at Successive Growth Stages



Influence of Different Treatment Regimes on Dry Weight Partitioning at Successive Growth Intervals

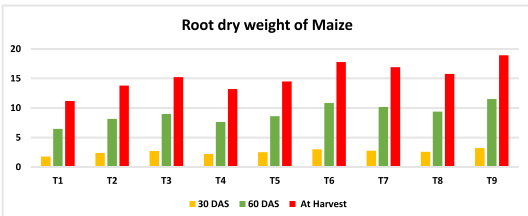


Fig. 4.1.5: Root dry weight of Maize (Zea mays)

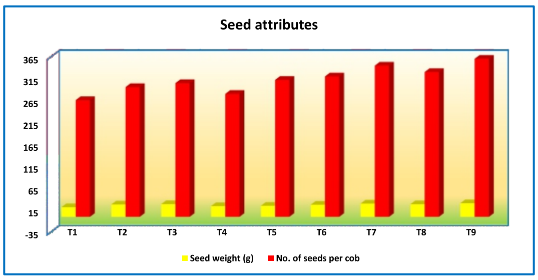


Fig. 4.2.1: No. of seeds per cob and seed weight

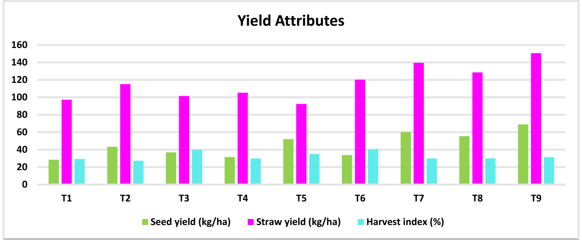


Fig. 4.2.2 Yield attributes of maize

3.4 Economics

Economic analysis revealed significant variation among treatments in terms of cost of cultivation, gross returns, net returns, and benefit–cost (B:C) ratio. The treatment T_9 recorded the highest gross returns (₹1,37,800 ha^{-1}) and net returns (₹77,950 ha^{-1}), indicating its superiority in terms of profitability.

However, the highest benefit–cost ratio (2.61) was recorded under T_8 (*Rhizobium* + Jeevamrit), followed by T_6 (100% RDF + *Rhizobium*), suggesting that treatments with lower input cost and reasonable yield provided better economic efficiency. The control treatment recorded the lowest economic returns and B:C ratio. Thus, integrated nutrient management treatments not only improved yield but also enhanced economic returns compared to sole or no nutrient application.

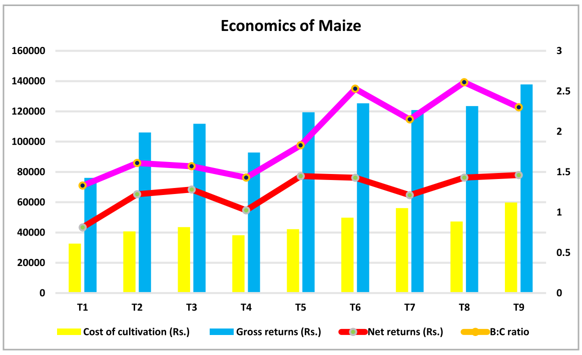


Fig. 4.3.1: Economics of Maize cultivation

4. Discussion

The present investigation clearly demonstrated that integrated nutrient management (INM) significantly improved growth, yield attributes, yield, and economic returns of maize. Among the treatments, T_9 (100% RDF + *Rhizobium* + Jeevamrit) consistently recorded superior performance across all parameters. The enhanced performance under this treatment can be attributed to the synergistic interaction between chemical fertilizers, biofertilizers, and organic inputs, which ensured balanced nutrient availability and improved soil health.

4.1. Effect on growth parameters

The significant improvement in growth parameters such as plant height, number of leaves, fresh weight, dry weight, and root development under T_9 indicates better vegetative growth due to integrated nutrient supply. The combined application of RDF with *Rhizobium* and Jeevamrit likely enhanced nutrient availability throughout the crop growth period, resulting in increased cell division, elongation, and biomass accumulation. Similar findings have been reported by [16], who observed improved plant height and dry matter accumulation with integrated use of fertilizers and organic amendments.

The role of biofertilizers, particularly *Rhizobium*, in enhancing biological nitrogen fixation and improving nutrient uptake may have contributed to better plant growth. [17] reported that seed treatment with biofertilizers significantly increased growth parameters in maize. In addition, Jeevamrit, being a rich source of beneficial microorganisms and enzymes, likely enhanced microbial activity and nutrient mineralization in soil, thereby improving nutrient uptake efficiency [18].The improved root dry weight under T_9 further supports the hypothesis that INM enhances root proliferation and nutrient absorption capacity [19].

4.2. Effect on yield attributes

The superior yield attributes under T_9, including higher number of cobs per plant, seeds per cob, and test weight, can be linked to improved nutrient availability during reproductive stages. Balanced nutrition plays a critical role in flowering, pollination, and grain filling, ultimately influencing yield components. The integrated supply of nutrients from chemical, organic, and biological sources ensures a continuous and adequate nutrient supply, which is essential for reproductive development [20]. Similar results have been reported by [21] who observed higher grains per cob and grain weight with combined application of RDF and organic manures. Likewise, [22] reported improved yield attributes with integrated nutrient management involving vermicompost and chemical fertilizers. The improved performance under INM treatments may also be attributed to enhanced photosynthetic activity and assimilate partitioning, resulting in better grain development [23].

4.3. Effect on yield

The significantly higher seed yield and stover yield recorded under T_9 indicate the effectiveness of integrated nutrient management in enhancing overall crop productivity. The increased yield can be attributed to cumulative improvements in growth parameters and yield attributes under integrated treatments. The balanced nutrient supply ensured by RDF, along with the biological nitrogen fixation by *Rhizobium* and nutrient mineralization by Jeevamrit, resulted in improved nutrient-use efficiency and higher biomass production.

These findings are in agreement with [24] who reported that integrated application of organic and inorganic fertilizers significantly increased grain and stover yield of maize. Similarly, [25] observed that application of RDF along with organic manures produced higher yields compared to sole fertilizer application. The results also corroborate the findings of [26] who reported increased maize yield with combined use of biofertilizers and inorganic fertilizers, integrated nutrient management improves soil physico-chemical properties and microbial activity, which enhances nutrient availability and uptake, ultimately leading to higher crop productivity [17]. The improved yield under T_9 can therefore be attributed to both direct nutrient supply and indirect improvement in soil health.

4.4. Economic analysis

The economic analysis revealed that T_9 resulted in maximum gross and net returns, indicating that higher yield translated into greater profitability.

However, the highest benefit–cost ratio observed under T_8 (*Rhizobium* + Jeevamrit) suggests that treatments with lower input cost and moderate yield can sometimes be more economically efficient. This highlights the importance of considering both yield and input cost while recommending nutrient management practices. The higher profitability under integrated treatments is consistent with the findings of [12] who reported maximum net returns and B:C ratio under integrated nutrient management involving organic and inorganic sources. Similarly, [12] emphasized that INM practices not only enhance productivity but also reduce production costs and improve economic returns. The use of locally available organic inputs such as Jeevamrit further reduces dependency on costly chemical fertilizers, making INM practices more accessible and economically viable for farmers in resource-limited regions like Bundelkhand.

4.5. Role of nutrient synergy

The superior performance of T_9 can be primarily attributed to nutrient synergy, where the combined application of chemical fertilizers, biofertilizers, and organic inputs creates a balanced and efficient nutrient supply system. Chemical fertilizers provide readily available nutrients for immediate crop uptake, while organic inputs ensure slow and sustained nutrient release and improve soil structure. Biofertilizers enhance nutrient availability through biological processes such as nitrogen fixation and phosphorus solubilization [21]. This synergistic interaction not only improves nutrient-use efficiency but also enhances soil biological activity and long-term soil fertility [19]. The integrated approach ensures that nutrient losses through leaching and volatilization are minimized, leading to better utilization of applied nutrients [9;27]. Thus, the results of the present study strongly support the concept that integrated nutrient management is a sustainable and efficient approach for improving maize productivity and profitability under Bundelkhand conditions.

5. Conclusion

The present study demonstrates that integrated nutrient management significantly enhances the growth, yield, and profitability of maize under Bundelkhand conditions. Among the treatments, T_9 (100% RDF + *Rhizobium* + Jeevamrit) proved to be the most effective, recording the highest growth parameters, yield attributes, and grain yield. This treatment also resulted in maximum net returns, indicating its superiority in terms of overall productivity and profitability. However, T_8 (*Rhizobium* + Jeevamrit) showed the highest benefit–cost ratio, suggesting better economic efficiency with lower input cost. The findings highlight that the combined use of chemical fertilizers, biofertilizers, and organic inputs is a practical and sustainable nutrient management strategy for maize cultivation. Therefore, the application of integrated nutrient management, particularly T_9, is recommended for improving maize productivity and farm income in the Bundelkhand region. Further research may focus on long-term soil health and multi-location validation of these practices.

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