RESEARCH PAPER

# Integrated Nutrient Management Improves Productivity of Maize (*Zea mays* L.) and Its Residual Effect on Wheat (*Triticum aestivum* L.) in a Maize–Wheat Cropping System

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## ABSTRACT

A field experiment was conducted during 2023–24 and 2024–25 at Moradabad, India, to evaluate the effect of integrated nutrient management (INM) on maize (*Zea mays* L.) and its residual impact on wheat (*Triticum aestivum* L.). The experiment comprised 12 treatments combining the recommended dose of fertilizers (RDF) with organic sources such as farmyard manure, vermicompost, biogas slurry, and panchgavya in a randomized block design with three replications. The application of 125% RDF significantly improved growth and yield attributes of maize, including plant height, biomass accumulation, cob length, grains per cob, and grain yield, although it slightly delayed tasseling. The residual effect of this treatment also enhanced wheat performance in terms of plant population, tiller density, growth, and yield. Overall, integrated nutrient management improved productivity of both maize and the succeeding wheat crop, indicating its potential for sustaining soil fertility and crop performance in maize–wheat cropping systems.

**Keywords:** cropping system; integrated nutrient management; maize; residual effect; wheat.

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## Introduction

The maize–wheat (*Zea mays* L. – *Triticum aestivum* L.) cropping system is one of the most important production systems in irrigated regions of India and across the Indo-Gangetic Plains, contributing significantly to national food security and rural livelihoods (Jat *et al*. 2016; Hasanain *et al*. 2025). Maize, owing to its high yield potential and wide adaptability, and wheat, as a major staple crop, together provide a substantial share of dietary energy and nutrients to the global population (Chatzav *et al*. 2010; Shiferaw *et al*. 2011; Grigorieva *et al*. 2023).

However, continuous cultivation of cereal–cereal systems such as maize–wheat has resulted in considerable nutrient depletion and declining soil fertility (Usadadiya and Patel 2013; Singh and Singh 2025). Both crops are nutrient exhaustive, and their intensive cultivation without adequate replenishment has led to nutrient mining and stagnation in productivity, particularly in intensively farmed regions (Mukhametov *et al*. 2024; Ali *et al*. 2025). The excessive and imbalanced use of chemical fertilizers, especially nitrogen-centric applications, has further aggravated soil degradation, resulting in deficiencies of secondary and micronutrients and posing environmental concerns (Vasile *et al*. 2025).

Although inorganic fertilizers supply nutrients rapidly and support high crop productivity, their long-term exclusive use adversely affects soil health by reducing soil organic matter and biological activity. Moreover, nutrient use efficiency in such systems remains low due to losses through leaching, volatilization, and greenhouse gas emissions (Wang *et al*. 2023). These challenges highlight the need for sustainable nutrient management strategies that can maintain productivity while preserving soil health.

Organic nutrient sources improve soil physical properties, enhance microbial activity, and contribute to better nutrient cycling; however, their sole application is often insufficient to meet the nutrient demands of high-yielding crops. In this context, Integrated Nutrient Management (INM), which involves the combined use of organic and inorganic nutrient sources, is considered a sustainable and efficient approach for improving nutrient use efficiency and maintaining soil fertility (Yilmaz and Yilmaz 2025). INM has been reported to enhance crop productivity, improve soil health, and reduce environmental risks associated with excessive fertilizer use (Meena *et al*. 2025; Wang *et al*. 2023).

An important advantage of INM in cereal-based systems is the residual effect of organic inputs. Nutrients applied through organic sources are released gradually and remain available for subsequent crops. In maize–wheat systems, residual nutrients, particularly phosphorus, potassium, and micronutrients, can significantly improve the growth and productivity of the succeeding wheat crop and reduce dependence on chemical fertilizers (Rajani *et al*. 2025; Dhaliwal *et al*. 2025). This contributes to improved system productivity and long-term sustainability.

Despite the recognized benefits of INM, its effectiveness is highly location-specific and depends on soil type, climatic conditions, and management practices. In Western Uttar Pradesh, limited information is available on the response of maize–wheat cropping systems to integrated nutrient management practices under local conditions.

Therefore, the present study was conducted to evaluate the effect of integrated nutrient management on the growth and yield of maize and to assess its residual impact on the succeeding wheat crop under the maize–wheat cropping system.

## Materials and Methods

### Experimental site and soil

The field experiment was conducted during the *kharif* and *rabi* seasons of 2023–24 and 2024–25 at the Agronomical Research Farm, School of Agricultural Sciences and Engineering, IFTM University, Moradabad, Uttar Pradesh, India (28°21′ N latitude, 78°4′ E longitude; 193 m above mean sea level). The soil of the experimental field was sandy loam in texture, well-drained, and slightly alkaline in reaction (pH 7.7), with low available nitrogen and medium available phosphorus and potassium. The soil contained 0.44% organic carbon, with available N, P, and K levels of 234, 15.8, and 169 kg ha$^{-1}$, respectively.

### Experimental design and treatments

The experiment was laid out in a randomized block design with three replications, comprising twelve treatments: $T_1$ (control), $T_2$ (100% recommended dose of fertilizers (RDF)), $T_3$ (125% RDF), $T_4$ (75% RDF + 25% N through farmyard manure (FYM)), $T_5$ (75% RDF + 25% N through vermicompost), $T_6$ (75% RDF + 25% N through biogas slurry), $T_7$ (75% RDF + 25% N through panchgavya), $T_8$ (50% RDF + 50% N through FYM), $T_9$ (50% RDF + 50% N through vermicompost), $T_{10}$ (50% RDF + 50% N through biogas slurry), $T_{11}$ (50% RDF + 50% N through panchgavya), and $T_{12}$ (50% RDF + equal proportions of FYM, vermicompost, biogas slurry, and panchgavya).

The recommended dose of fertilizers for maize was 120:60:40 kg $N:P_2O_5:K_2O$ ha$^{-1}$. Organic manures were incorporated into the soil 20–25 days before sowing based on their nitrogen content to facilitate decomposition and nutrient release.

### Crop management and sampling

Maize hybrid ‘DKC 9144’ was grown during the *kharif* season, followed by wheat variety ‘DBW 187’ during the subsequent *rabi* season in each year. Wheat was cultivated on the same plots to assess the residual effect of treatments without further application of organic manures. Standard agronomic practices recommended for the region were followed throughout the crop growth period.

Composite soil samples (0–15 cm depth) were collected before sowing and after harvest of the wheat crop in each experimental year. Soil samples were analyzed for pH (Jackson 1967), electrical conductivity, organic carbon (Walkley and Black 1934), available nitrogen (Subbiah and Asija 1956), available phosphorus (Olsen *et al*. 1954), and available potassium (Jackson 1973) using standard procedures. Plant samples were collected at harvest, analyzed for nutrient concentration, and nutrient uptake was calculated based on dry matter yield and nutrient content.

**Statistical analysis**

The data were subjected to analysis of variance (ANOVA) appropriate for a randomized block design using the OPSTAT statistical software package. Treatment means were compared using the least significant difference (LSD) test at $P \leq 0.05$.

## 3. Results

### 3.1 Response of maize to integrated nutrient management

The application of different integrated nutrient management (INM) modules significantly influenced the growth, phenology, and yield attributes of maize during both years of the study (Table 1).

### 3.1.1 Growth dynamics and biomass accumulation

Initial plant stand and plant population at harvest were not significantly affected by nutrient treatments ($P > 0.05$), indicating that the application of organic and inorganic sources did not interfere with seedling establishment. However, vegetative growth parameters, including plant height, fresh weight, and dry matter accumulation, increased significantly ($P \leq 0.05$) with increasing nutrient levels.

The maximum plant height at 90 DAS (203.4 cm), fresh weight (360.4 g plant$^{-1}$), and dry matter accumulation (134.8 g plant$^{-1}$) were recorded under $T_3$ (125% RDF), which was statistically at par with $T_5$ (75% RDF + 25% N through vermicompost). The comparable performance of $T_5$ indicates the efficiency of integrated nutrient application in sustaining crop growth.

### 3.1.2 Yield attributes and productivity

Yield attributes were significantly influenced by nutrient management practices. The highest cob length (17.47 cm), number of grains per cob (381.03), and grain yield (63.50 q ha$^{-1}$) were recorded under $T_3$. However, $T_5$ (63.38 q ha$^{-1}$) and $T_6$ (75% RDF + 25% N through biogas slurry; 61.16 q ha$^{-1}$) were statistically at par with $T_3$.

The lowest values of yield parameters were consistently observed under the control ($T_1$) and reduced nutrient treatments ($T_8$–$T_{11}$), indicating the importance of adequate nutrient supply for optimum productivity.

### 3.1.3 Phenological observations

Nutrient levels significantly influenced the time taken to reach 50% tasseling. The maximum duration (53.1 days) was recorded under $T_3$, indicating a delay in flowering with higher nutrient application. In general, increased nutrient availability resulted in a prolonged vegetative phase before the transition to reproductive growth.

### 3.2 Residual effect of integrated nutrient management on succeeding wheat

The nutrient management practices applied to the preceding maize crop significantly influenced the growth, yield attributes, and productivity of the succeeding wheat crop (Table 2).

### 3.2.1 Growth parameters

The initial plant population of wheat was significantly affected by residual treatments (CD = 7.51). The highest population was recorded under $T_3$ (256.2 m$^{-2}$), which was statistically at par with $T_2$ (255.6 m$^{-2}$) and $T_5$ (254.5 m$^{-2}$).

Plant height showed non-significant variation at 30 DAS but differed significantly at later stages. At 90 DAS, the maximum plant height was recorded under $T_3$ (88.66 cm), followed by $T_2$ (86.93 cm) and $T_5$ (85.98 cm). A similar trend was observed in tiller density, where $T_3$ produced the highest number of tillers (319 m$^{-2}$), remaining statistically at par with $T_2$, $T_4$, $T_5$, $T_6$, and $T_7$.

Dry matter accumulation did not differ significantly at 30 DAS; however, at 90 DAS, the highest dry matter was recorded under $T_3$ (972.77 g), which was statistically comparable with $T_5$ (959.11 g), $T_2$ (948.03 g), and $T_4$ (940.30 g). The lowest values for all growth parameters were consistently recorded under the control ($T_1$).

**Table – 1 Effect of Integrated Nutrient Management Practices on Growth and Yield Parameters of Maize**

| **Treatments** | **Plant Population** | | **Plant Height (cm.)** | | | **Fresh Weight (g/Plant)** | | | **Dry Weight(g/plant)** | | | **Days taken to 50% tasseling** | **Cob length (cm)** | **No. of grains/cob** | **Grain Yield (q/ha)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Initial stage (15DAS)** | **At harvesting time** | **30DAS** | **60DAS** | **90 DAS** | **30DAS** | **60DAS** | **90 DAS** | **30DAS** | **60DAS** | **90 DAS** | | | | |
| $T_1$ | 8.14 | 7.52 | 85.0 | 141.5 | 175.4 | 42.1 | 105.2 | 210.1 | 9.8 | 27.4 | 82.7 | 50.5 | 12.78 | 253.57 | 31.18 |
| $T_2$ | 8.26 | 7.66 | 105.5 | 160.5 | 192.4 | 74.2 | 168.1 | 345.2 | 16.5 | 49.4 | 133.9 | 52.4 | 14.62 | 314.34 | 51.82 |
| $T_3$ | 8.35 | 7.90 | 113.5 | 168.6 | 203.4 | 76.2 | 172.0 | 360.4 | 16.8 | 50.5 | 134.8 | 53.1 | 17.47 | 381.03 | 63.50 |
| $T_4$ | 8.30 | 7.82 | 110.1 | 163.6 | 198.5 | 70.4 | 162.3 | 335.3 | 15.8 | 47.2 | 127.2 | 52.5 | 16.14 | 349.00 | 57.69 |
| $T_5$ | 8.33 | 7.90 | 113.4 | 165.8 | 200.6 | 73.3 | 165.2 | 355.7 | 16.3 | 48.2 | 130.3 | 52.9 | 17.45 | 376.86 | 63.38 |
| $T_6$ | 8.32 | 7.90 | 110.7 | 165.5 | 200.4 | 69.2 | 160.2 | 330.3 | 15.6 | 46.8 | 125.6 | 52.5 | 16.89 | 362.20 | 61.16 |
| $T_7$ | 8.31 | 7.88 | 110.5 | 165.1 | 199.7 | 68.3 | 158.1 | 340.4 | 15.0 | 45.9 | 128.6 | 52.8 | 16.79 | 360.34 | 59.81 |
| $T_8$ | 8.18 | 7.56 | 91.9 | 145.6 | 178.9 | 55.1 | 132.2 | 270.4 | 12.5 | 37.6 | 105.3 | 51.0 | 13.44 | 269.23 | 37.43 |
| $T_9$ | 8.28 | 7.80 | 108.6 | 163.3 | 198.2 | 61.3 | 145.2 | 300.5 | 13.9 | 41.2 | 114.5 | 51.9 | 15.94 | 342.76 | 57.18 |
| $T_{10}$ | 8.23 | 7.65 | 103.7 | 157.6 | 191.5 | 58.2 | 138.3 | 290.2 | 13.4 | 39.8 | 110.2 | 51.1 | 13.72 | 304.77 | 48.70 |
| $T_{11}$ | 8.27 | 7.73 | 106.2 | 161.2 | 193.9 | 62.1 | 145.3 | 310.6 | 14.2 | 42.6 | 118.4 | 51.4 | 15.36 | 324.19 | 53.53 |
| $T_{12}$ | 8.27 | 7.76 | 107.1 | 162.6 | 197.0 | 56.2 | 136.2 | 280.3 | 13.1 | 38.5 | 109.0 | 53.0 | 15.52 | 337.60 | 53.58 |
| SEm± | 0.73 | 0.49 | ***1.03*** | ***2.06*** | ***3.18*** | ***2.14*** | ***4.82*** | ***9.86*** | ***0.52*** | ***1.36*** | ***3.42*** | ***0.46*** | ***0.36*** | ***7.95*** | ***0.74*** |
| CD(p=0.05) | NS | NS | ***3.03*** | ***6.04*** | ***9.38*** | ***6.35*** | ***14.3*** | ***28.7*** | ***1.54*** | ***4.01*** | ***10.1*** | ***1.34*** | ***1.04*** | ***23.31*** | ***2.18*** |

$T_1$-Control, $T_2$-100% RDF (120:60:40), $T_3$-125% RDF, $T_4$-75% RDF+25% through FYM, $T_5$-75% RDF+25% through Vermicompost, $T_6$-75% RDF + 25% through Biogas slurry, $T_7$-75% RDF + 25% through Panchgavya, $T_8$-50% RDF+50% through FYM, $T_9$-50% RDF+50% throughVermicompost, $T_{10}$-50% RDF + 50% through Biogas slurry, $T_{11}$-50% RDF + 50% through Panchgavya, $T_{12}$- 50% RDF+12.5% through FYM + 12.5% through Vermicompost + 12.5% through Biogas slurry + 12.5% through Panchgavya

**Table -2 Residual effects of Integrated Nutrient Management Practices on Growth and Yield Parameter of Wheat**

| **Treatments** | **Plant Population** | **Plant Height (cm.)** | | | **Number of tillers($m^{-2}$)** | | | **Dry Weight(g/plant)** | | | **Spike Length (cm)** | **Number of grains spike-$^{1}$** | **Grains Yield(q ha$^{-1}$)** | **Straw Yield(q ha$^{-1}$)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Initial stage** | **30DAS** | **60DAS** | **90 DAS** | **30DAS** | **60DAS** | **90 DAS** | **30DAS** | **60DAS** | **90 DAS** | | | | |
| $T_1$ | 226.1 | 18.16 | 48.14 | 77.23 | 94 | 196 | 212 | 37.88 | 204.77 | 539.18 | 8.76 | 41 | 27.10 | 47.36 |
| $T_2$ | 255.6 | 22.36 | 57.46 | 86.93 | 122 | 238 | 318 | 47.43 | 349.49 | 948.03 | 11.98 | 44 | 50.28 | 64.72 |
| $T_3$ | 256.2 | 22.49 | 58.90 | 88.66 | 126 | 248 | 319 | 48.21 | 355.81 | 972.77 | 12.26 | 46 | 51.44 | 65.40 |
| $T_4$ | 251.5 | 22.19 | 55.22 | 84.49 | 115 | 227 | 313 | 45.89 | 315.91 | 940.30 | 10.78 | 43 | 49.86 | 64.23 |
| $T_5$ | 254.5 | 22.25 | 56.03 | 85.98 | 118 | 233 | 316 | 45.96 | 331.49 | 959.11 | 11.87 | 44 | 49.71 | 64.37 |
| $T_6$ | 251.8 | 22.16 | 55.18 | 85.78 | 114 | 219 | 312 | 45.43 | 298.07 | 935.08 | 10.63 | 43 | 48.58 | 64.20 |
| $T_7$ | 251.6 | 22.02 | 52.71 | 85.03 | 111 | 215 | 310 | 44.54 | 286.82 | 920.63 | 10.19 | 44 | 48.27 | 63.42 |
| $T_8$ | 245.2 | 18.28 | 48.60 | 79.23 | 95 | 197 | 220 | 38.78 | 212.23 | 546.78 | 9.02 | 41 | 28.41 | 53.67 |
| $T_9$ | 249.5 | 18.43 | 53.14 | 81.77 | 103 | 210 | 233 | 42.85 | 234.07 | 633.19 | 9.38 | 41 | 29.33 | 60.52 |
| $T_{10}$ | 249.2 | 18.35 | 51.06 | 81.05 | 98 | 206 | 232 | 41.72 | 229.90 | 598.15 | 9.29 | 42 | 28.88 | 58.36 |
| $T_{11}$ | 249.7 | 21.93 | 53.68 | 83.74 | 107 | 213 | 309 | 44.43 | 275.28 | 912.38 | 9.69 | 42 | 47.29 | 62.48 |
| $T_{12}$ | 247.7 | 18.30 | 49.78 | 80.07 | 96 | 203 | 229 | 39.75 | 218.62 | 571.78 | 9.17 | 41 | 28.52 | 56.85 |
| SEm± | ***2.50*** | ***1.49*** | ***0.93*** | ***0.80*** | ***3.95*** | ***8.95*** | ***8.33*** | ***6.05*** | ***6.69*** | ***15.36*** | ***0.28*** | ***1.26*** | ***0.48*** | ***0.59*** |
| CD(p=0.05) | ***7.51*** | ***NS*** | ***2.77*** | ***2.38*** | ***11.56*** | ***26.17*** | ***24.36*** | ***NS*** | ***19.76*** | ***45.33*** | ***0.82*** | ***3.69*** | ***1.42*** | ***1.75*** |

$T_1$-Control, $T_2$-100% RDF (120:60:40), $T_3$-125% RDF, $T_4$-75% RDF+25% through FYM, $T_5$-75% RDF+25% through Vermicompost, $T_6$-75% RDF + 25% through Biogas slurry, $T_7$-75% RDF + 25% through Panchgavya, $T_8$-50% RDF+50% through FYM, $T_9$-50% RDF+50%throughVermicompost, $T_{10}$-50% RDF + 50% through Biogas slurry, $T_{11}$-50% RDF + 50% through Panchgavya, $T_{12}$- 50% RDF+12.5% through FYM + 12.5% through Vermicompost + 12.5% through Biogas slurry + 12.5% through Panchgavya

### 3.2.2 Yield attributes and productivity

Yield attributes of wheat were significantly influenced by residual nutrient availability. The maximum spike length (12.26 cm) and number of grains per spike (46) were recorded under $T_3$, followed by $T_2$ and $T_5$, which also performed significantly better than the control and lower nutrient treatments ($T_8$–$T_{12}$).

Grain yield was significantly affected by treatments (CD = 1.42). The highest grain yield was recorded under $T_3$ (51.44 q $ha^{-1}$), which was statistically at par with $T_2$ (50.28 q $ha^{-1}$), $T_5$ (49.71 q $ha^{-1}$), and $T_4$ (49.86 q $ha^{-1}$). Straw yield followed a similar trend, with maximum values under $T_3$ (65.40 q $ha^{-1}$) and $T_5$ (64.37 q $ha^{-1}$). Significantly lower yields were recorded under $T_8$–$T_{12}$, with grain yield ranging between 27 and 29 q $ha^{-1}$.

## Discussion

### 4.1 Impact of nutrient integration on maize growth and yield

The non-significant variation in plant population suggests that organic amendments were well decomposed and did not exert any adverse effect on germination or early plant establishment. The superior growth observed under $T_3$ and $T_5$ can be attributed to improved availability of essential nutrients during the active growth phase.

The comparable performance of $T_5$ with $T_3$ highlights the effectiveness of integrating organic sources such as vermicompost with inorganic fertilizers. Vermicompost improves nutrient availability, enhances microbial activity, and promotes better root development, leading to improved nutrient uptake (Wang *et al*. 2023; Oyege *et al*. 2023).

Similarly, the comparable grain yield observed under $T_5$ and $T_6$ with $T_3$ indicates that partial substitution of mineral fertilizers with organic sources can sustain productivity. The combined use of organic and inorganic sources ensures a continuous nutrient supply, reduces nutrient losses, and improves nutrient use efficiency during critical growth stages (Sande *et al*. 2024; Meena *et al*. 2025).

The delay in 50% tasseling under higher nutrient levels may be attributed to increased nitrogen availability, which promotes vegetative growth and delays reproductive development. Although flowering is slightly delayed, improved vegetative growth enhances biomass accumulation and ultimately contributes to higher yield. In contrast, nutrient deficiency in the control treatment resulted in restricted growth and reduced yield.

### 4.2 Mechanism of residual nutrient impact on wheat

The improved growth and yield of wheat under $T_3$, $T_5$, and $T_2$ highlight the importance of residual nutrient effects in cereal-based cropping systems. The superiority of $T_3$ (125% RDF) may be attributed to higher residual availability of nutrients, particularly phosphorus and potassium, from the preceding maize crop.

The comparable performance of $T_5$ (75% RDF + vermicompost) and $T_4$ (75% RDF + FYM) with $T_3$ indicates that organic amendments contribute to sustained nutrient release beyond the cropping season. Organic sources decompose gradually, providing a continuous supply of nutrients and improving soil physical properties such as aggregation and moisture retention, which are crucial for wheat establishment (Dhaliwal *et al*. 2023; Marahatta *et al*. 2025).

Enhanced tiller density and dry matter accumulation under integrated treatments may also be attributed to improved soil biological activity. Residual organic matter supports microbial populations that enhance nutrient mineralization and availability, thereby improving crop growth (Meena *et al*. 2025; Bhattacharya *et al*. 2025).

Higher grain yield under $T_3$ and $T_5$ was associated with improved yield attributes, indicating efficient utilization of residual nutrients during critical growth stages. In contrast, lower yields under reduced fertilizer treatments ($T_8$–$T_{12}$) suggest that organic sources alone cannot fully compensate for inadequate mineral fertilization. These findings emphasize that a balanced combination of organic and inorganic nutrient sources is essential for sustaining productivity in maize–wheat cropping systems.

## Conclusion

This two-year study highlights integrated nutrient management (INM) as an effective approach for sustainable maize–wheat production. While 125% RDF ($T_3$) yielded the highest grain output, treatment $T_5$ (75% RDF + 25% nitrogen via vermicompost) achieved comparable maize yields and provided significant residual benefits for wheat. The superior performance of INM reflects the synergy of immediate nutrient supply from fertilizers and gradual nutrient release from organic amendments, coupled with improvements in soil physical and biological properties. INM strategies using vermicompost and biogas slurry can replace up to 25% of mineral nitrogen without compromising yield, enhancing wheat growth and overall system productivity. Reduced fertilizer application (50% RDF) significantly lowered yields, underscoring the need for minimum mineral inputs. For sandy loam soils of Western Uttar Pradesh, 75% RDF combined with 25% nitrogen from organic sources offers a sustainable, efficient, and practical nutrient management strategy for maize–wheat systems.

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