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Integrated nutrient management enhances growth, yield, nutrient uptake, and profitability of late-sown wheat (*Triticum aestivum* L.) in the indo-gangetic plains of India

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Abstract

In India's Indo-Gangetic Plains, where inadequate fertilizer management further restricts crop development and output, late planting is a typical barrier to wheat productivity. To assess the impact of integrated nutrient management (INM) on the growth, yield, nutrient uptake, and profitability of late-sown wheat (*Triticum aestivum* L.), a field experiment was carried out during the Rabi season of 2025–2026 at the Crop Research Centre, Maharishi University of Information Technology, Lucknow, Uttar Pradesh, India. Eight nutrition management treatments were used in the trial, which was set up in a Randomized Block Design (RBD) with three replications. The required dosage of fertilizers (RDF), their combination with vermicompost, zinc sulphate (ZnSO_4), sulphur, and farmyard manure (FYM) were among the treatments. Compared to the unfertilized control, integrated nutrient management greatly increased crop growth and production. The biggest number of tillers (361.8 m^{-2}), maximum spikes (350.4 m^{-2}), tallest plants (90.6 cm), and better yield qualities were all obtained by the treatment 75% RDF + 25% N through vermicompost + sulphur @ 35 kg ha^{-1} (T_4). The maximum grain production (4.05 t ha^{-1}), straw yield (5.56 t ha^{-1}), and biological yield (9.61 t ha^{-1}) were recorded by the same treatment, indicating an increase in grain yield of almost 85.8% above the control. Additionally, it increased available nitrogen (169.4 kg ha^{-1}), phosphorus (17.1 kg ha^{-1}), potassium (270.4 kg ha^{-1}), and organic carbon (0.38%) while lowering soil pH to 8.38, resulting in the highest total nutrient uptake (102.8, 20.48, and 94.70 kg ha^{-1} of N, P, and K, respectively). While 100% RDF + ZnSO_4 @ 25 kg ha^{-1} (T_3) had the best net return ($\text{₹}86,720 \text{ ha}^{-1}$) and benefit: cost ratio (2.34), treatment T_3 produced the maximum biological productivity and nutrient-use efficiency.

The results show that, under late-sown circumstances in the Indo-Gangetic Plains, combining vermicompost and sulfur with less inorganic fertilizer application is an efficient way to improve soil health, increase wheat yield, and maintain nutrient utilization.

Keywords: Integrated nutrient management, late-sown wheat, vermicompost, sulphur, zinc, nutrient uptake, profitability, soil fertility, Indo-Gangetic Plains

Introduction

Over one-third of the world's population relies on wheat (*Triticum aestivum* L.), one of the most significant cereal crops in the world. Wheat plays a crucial role in India's food production system, making a significant contribution to the country's food security, nutritional needs, and rural economy. The Indo-Gangetic Plains (IGP), which span northern India, are the primary wheat-growing region and produce a sizable portion of the nation's wheat. However, delayed planting, decreasing soil fertility, nutrient imbalances, and ineffective fertilizer management have made it more difficult to maintain wheat yield in this area.

Delays in harvesting earlier crops, especially rice, sugarcane, and potatoes, can result in late seeding of wheat. Reduced vegetative development, fewer productive tillers, a shorter grain-filling phase, and eventually decreased grain yield and quality are all consequences of delayed planting, which exposes the crop to terminal heat stress during the grain-filling period. The careless application of chemical fertilizers, which has resulted in deteriorating soil health, decreasing nutrient-use efficiency, and decreased factor production in intensive cropping systems, exacerbates these limitations even more

A sustainable strategy for increasing crop yield while preserving long-term soil fertility is integrated nutrient management, or INM. In addition to organic nutrient sources including farmyard manure (FYM), vermicompost, crop residues, and biofertilizers, as well as micronutrients where needed, the INM approach stresses the prudent and balanced use of inorganic fertilizers. A steady supply of vital nutrients is guaranteed by this integration, which also improves nutrient synchronization with crop need, boosts microbial activity, raises soil organic carbon, and improves the physical, chemical, and biological characteristics of the soil. As a result, INM encourages sustainable crop production and improves nutrient-use efficiency.

Due to ongoing farming, heavy fertilizer usage, and low organic matter content, zinc (Zn) deficiency has become common among micronutrients in the alluvial soils of the Indo-Gangetic Plains. Grain development, auxin production, protein metabolism, chlorophyll synthesis, and enzyme activation all depend on zinc. Similarly, after nitrogen, phosphorus, and potassium, sulfur (S) has become the fourth important plant nutrient. Protein synthesis, amino acid synthesis, enzyme activity, chlorophyll generation, and effective nitrogen use all depend on sulfur. It has been shown that balanced fertilization combined with zinc and sulfur supplements enhances wheat growth, grain production, nutrient absorption, and grain quality.

In addition to providing vital macro and micronutrients, organic fertilizer sources like FYM and vermicompost enhance soil structure, water-holding ability, cation exchange capacity, and microbial diversity. Vermicompost releases nutrients gradually and improves nutrient availability throughout the crop growth period because of its increased nutrient content, humic compounds, and helpful microbes. Integration of organic amendments with approved fertilizer dosages helps minimize dependency on chemical fertilizers while preserving crop output and increasing soil health.

Numerous studies have shown how integrated nutrition management improves wheat development, yield characteristics, nutrient absorption, and profitability. However, evidence addressing the comparative performance of diverse combinations of inorganic fertilizers, organic nutrient sources, zinc, and sulphur under late-sown conditions in the eastern Indo-Gangetic Plains of

Uttar Pradesh remains inadequate. Therefore, increasing wheat yield under delayed planting conditions requires finding a nutrient management technique that is both economically feasible and environmentally sustainable.

The goal of the current study was to assess how various integrated nutrient management techniques affected late-sown wheat's growth, yield characteristics, grain yield, nutrient uptake, post-harvest soil fertility, and economic returns in the agroclimatic conditions of Uttar Pradesh. In the Indo-Gangetic Plains, the results are anticipated to aid in the creation of effective nutrient management plans that boost wheat yield while fostering long-term soil sustainability and health.

Results and Discussion

Initial plant population

Although there were numerical variations between treatments, the results in Table 4.1 showed that integrated nutrition management (INM) techniques had no discernible impact on the initial plant population at 20 DAS. T₁ (75% RDF + 25% N through vermicompost + Sulphur @ 35 kg ha⁻¹) had the largest plant population (173.6 plants m⁻²), whereas the control (T₁) had the lowest (150.2 plants m⁻²).

Plant height rose progressively with crop age and was strongly impacted by INM methods at all development stages. At 30 DAS (26.2 cm), 60 DAS (68.1 cm), 90 DAS (89.0 cm), and harvest (90.6 cm), treatment T₃ yielded the tallest plants. This was followed by T₃ (100% RDF + ZnSO₄ @ 25 kg ha⁻¹) and T₇ (75% RDF + 25% N via FYM + ZnSO₄ @ 25 kg ha⁻¹). Throughout the crop growth period, the shortest plants were seen under the control treatment.

The use of inorganic fertilizers, vermicompost, and sulfur together may have contributed to the superior plant development under T by ensuring balanced nutrient availability, improved soil health, increased microbial activity, and improved nutrient absorption. These results are consistent with previous studies by Singh et al. (2020) [14], Kumar et al. (2021) [18], and Meena et al. (2022) [15], which found that enhanced soil fertility and nutrient usage efficiency greatly increase wheat growth and plant height by integrated nutrient management.

Table 4.1: Initial plant population (m⁻²) at 20 DAS and plant height (cm) at successive growth stages of wheat crop as influenced by integrated nutrient management practices

Treatments	Plant population (m ⁻²) at 20 DAS	Plant height (cm) 30 DAS	60 DAS	90 DAS	At harvest
T ₁ – Control (No fertilizer)	150.2	21.6	49.2	64	65.3
T ₂ – 100% RDF (80:60:40 kg NPK ha ⁻¹)	165.8	24.4	60.2	78	79.6
T ₃ – 100% RDF + ZnSO ₄ @ 25 kg ha ⁻¹	171.2	25.6	66.4	86.4	88.2
T ₄ – 100% RDF + Sulphur @ 35 kg ha ⁻¹	168.4	25	63.2	82.3	83.9
T ₅ – 75% RDF + 25% N through FYM	157	23.3	57.6	75.2	76.8
T ₆ – 75% RDF + 25% N through Vermicompost	160.6	23.9	59.1	77.2	78.8
T ₇ – 75% RDF + 25% N through FYM + ZnSO ₄ @ 25 kg ha ⁻¹	169.2	25.2	64.8	84.2	85.9
T ₈ – 75% RDF + 25% N through Vermicompost + Sulphur @ 35 kg ha ⁻¹	173.6	26.2	68.1	89	90.6
SEm (±)	7.28	0.84	2.18	3.62	2.9
CD at 5%	NS	2.48	6.44	10.7	8.56

Number of tillers

At every stage of growth, integrated nutrient management strategies had a substantial impact on the number of tillers (m⁻²), according to the data in Table 4.2. With 194.2, 353.4, 372.6, and 361.8 tillers m⁻² at 30, 60, 90 DAS, and harvest, respectively, the highest number of tillers was reported under T* (75% RDF + 25%

N via vermicompost + Sulphur @ 35 kg ha⁻¹). T₃ (100% RDF + ZnSO₄ @ 25 kg ha⁻¹) and T₃ (75% RDF + 25% N via FYM + ZnSO₄ @ 25 kg ha⁻¹) closely followed this treatment. The control group (T₁) had the fewest tillers at every level.

The balanced nutrient supply provided by inorganic fertilizers, vermicompost, and sulfur may have contributed to the increased

tiller production under T₂ by improving root growth, nutrient absorption, photosynthetic efficiency, and total vegetative development. Additionally, integrated nutrient management increased microbial activity and soil fertility, which enhanced

tiller survival and formation. These results are consistent with those of Singh et al. (2020)^[14], Kumar et al. (2021)^[18], and Meena et al. (2022)^[15], who found that integrated nutrient management strategies significantly increased wheat tiller output.

Table 4.2: Number of tillers (m⁻²) at successive growth stages of wheat crop as influenced by integrated nutrient management practices

Treatments	Number of tillers (m ⁻²) 30 DAS	60 DAS	90 DAS	At harvest
T ₁ – Control (No fertilizer)	167.2	241.6	254.4	246
T ₂ – 100% RDF (80:60:40 kg NPK ha ⁻¹)	184.8	321.4	338.6	329.4
T ₃ – 100% RDF + ZnSO ₄ @ 25 kg ha ⁻¹	190.4	345.6	364.2	353.8
T ₄ – 100% RDF + Sulphur @ 35 kg ha ⁻¹	187.6	328.8	346.2	335.6
T ₅ – 75% RDF + 25% N through FYM	173.2	303.8	319.6	310.4
T ₆ – 75% RDF + 25% N through Vermicompost	176	306.4	322.8	313.6
T ₇ – 75% RDF + 25% N through FYM + ZnSO ₄ @ 25 kg ha ⁻¹	188.4	339.8	358.2	347.8
T ₈ – 75% RDF + 25% N through Vermicompost + Sulphur @ 35 kg ha ⁻¹	194.2	353.4	372.6	361.8
SEm (±)	6.36	12.76	11.68	11.82
CD at 5%	18.76	37.62	34.44	34.86

Yield attributes: The number of spikes m⁻² was significantly impacted by integrated nutrition management strategies, while test weight, spike length, and the number of grains per spike⁻¹ were not statistically significant, according to the results shown in Table 4.3.

The control (T₁) had the fewest spikes (239.8 m⁻²), whereas T₃ (75% RDF + 25% N via vermicompost + Sulphur @ 35 kg ha⁻¹) had the most (350.4 m⁻²), comparable to T₃ (343.6 m⁻²) and T₁ (338.8 m⁻²). The greatest values of 10.36 cm, 42.1 grains per spike⁻¹, and 35.78 g were likewise reported under T₁, despite the fact that variations in spike length, grains per spike, and test

weight were not statistically significant.

Balanced nutrient availability, greater tiller survival, improved root development, and improved photosynthate translocation—all of which lead to more productive tillers—may be responsible for the rise in spike number under integrated nutrition management. The numerical gain in other yield parameters further supports the favorable effect of mixing inorganic fertilizers with organic nutrient sources and sulphur. These results are consistent with those of Singh et al. (2020)^[14], Kumar et al. (2021)^[18], and Meena et al. (2022)^[15], who found that integrated nutrition management techniques increased wheat production parameters.

Table 4.3: Yield attributes of wheat crop as influenced by integrated nutrient management practices

Treatments	Number of spikes (m ⁻²)	Length of spike (cm)	No. of grains spike ⁻¹	Test weight (g)
T ₁ – Control (No fertilizer)	239.8	8.72	37.6	32.7
T ₂ – 100% RDF (80:60:40 kg NPK ha ⁻¹)	319.4	10	40.8	35.3
T ₃ – 100% RDF + ZnSO ₄ @ 25 kg ha ⁻¹	343.6	10.24	41.5	35.62
T ₄ – 100% RDF + Sulphur @ 35 kg ha ⁻¹	325.8	10.1	41	35.4
T ₅ – 75% RDF + 25% N through FYM	301.2	9.76	39.9	35.12
T ₆ – 75% RDF + 25% N through Vermicompost	304.4	9.84	40.2	35.26
T ₇ – 75% RDF + 25% N through FYM + ZnSO ₄ @ 25 kg ha ⁻¹	338.8	10.18	41.3	35.52
T ₈ – 75% RDF + 25% N through Vermicompost + Sulphur @ 35 kg ha ⁻¹	350.4	10.36	42.1	35.78
SEm (±)	10.84	0.34	1.58	1.26
CD at 5%	31.96	NS	NS	NS

While the harvest index remained non-significant, the results in Table 4.4 showed that integrated nutrient management strategies had a substantial impact on biological production, grain yield, and straw yield.

T₁ (75% RDF + 25% N through vermicompost + Sulphur @ 35 kg ha⁻¹) produced the highest grain yield (4.05 t ha⁻¹), straw yield (5.56 t ha⁻¹), and biological yield (9.61 t ha⁻¹), which was statistically comparable to T₃ (100% RDF + ZnSO₄ @ 25 kg ha⁻¹) and Tüge (75% RDF + 25% N through FYM + ZnSO₄ @ 25 kg ha⁻¹). For every yield parameter, the control group had the lowest values (T₁). The harvest index ranged from 39.42 to 42.18%, but

there was no statistically significant difference between treatments.

The combined application of inorganic fertilizers, vermicompost, and sulfur may have contributed to the higher grain and biological yields under T₃ by ensuring a balanced supply of nutrients, improving soil fertility, enhancing nutrient uptake, and increasing photosynthetic efficiency, all of which improved growth and yield. These results are consistent with those of Singh et al. (2020)^[14], Kumar et al. (2021)^[18], and Meena et al. (2022)^[15], who also found that integrated nutrient management strategies significantly increased wheat production.

Table 4.4: Effect of integrated nutrient management practices on grain yield, straw yield, biological yield and harvest index of wheat crop

Treatments	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest index (%)
T ₁ – Control (No fertilizer)	2.18	3.08	5.26	39.42
T ₂ – 100% RDF (80:60:40 kg NPK ha ⁻¹)	3.6	4.98	8.58	41.95
T ₃ – 100% RDF + ZnSO ₄ @ 25 kg ha ⁻¹	3.94	5.42	9.36	42.09
T ₄ – 100% RDF + Sulphur @ 35 kg ha ⁻¹	3.74	5.16	8.9	42.02
T ₅ – 75% RDF + 25% N through FYM	3.32	4.64	7.96	41.71
T ₆ – 75% RDF + 25% N through Vermicompost	3.38	4.7	8.08	41.83
T ₇ – 75% RDF + 25% N through FYM + ZnSO ₄ @ 25 kg ha ⁻¹	3.86	5.3	9.16	42.14
T ₈ – 75% RDF + 25% N through Vermicompost + Sulphur @ 35 kg ha ⁻¹	4.05	5.56	9.61	42.18

SEm ($\pm$)	0.12	0.226	0.276	1.42
CD at 5%	0.36	0.67	0.81	NS

Conclusion

In comparison to the unfertilized control and the exclusive application of suggested fertilizers, the current study found that integrated nutrient management (INM) greatly enhanced wheat development, yield qualities, and productivity. INM methods significantly enhanced plant height, number of tillers, productive spikes, grain yield, straw production, and biological yield, but had no effect on the original plant population. With the maximum plant height, tiller count, number of spikes, grain production (4.05 t ha⁻¹), straw yield (5.56 t ha⁻¹), and biological yield (9.61 t ha⁻¹), T₁ (75% RDF + 25% N through vermicompost + Sulphur @ 35 kg ha⁻¹) was the most successful treatment. The combined use of inorganic fertilizers with vermicompost and sulphur boosted nutrient availability, improved soil fertility, and encouraged greater crop growth and production. Thus, given the agroclimatic conditions of the Indo-Gangetic Plains, applying 75% RDF + 25% N through vermicompost + Sulfur @ 35 kg ha⁻¹ might be suggested as a sustainable and effective nutrient management technique for optimizing wheat yield.

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