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Influence of Integrated Nutrient Management on Nutrient Content and Nutrient Uptake in Rice (*Oryza sativa* L.)

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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

The present study was conducted during the *kharif* season of 2023 at the Instructional Farm, CSAUAT, Kanpur, to assess the effects of integrated nutrient management (INM) on nutrient content, nutrient uptake of rice (*Oryza sativa* L.). The experiment consisted of eight treatments involving different combinations of recommended doses of fertilizers (RDF), farmyard manure (FYM) and vermicompost (VC), arranged in a randomized block design (RCBD) with three replications. The results demonstrated that the integrated application of 75% RDF + FYM + VC (T_5) significantly improved nitrogen (1.33%), phosphorus (0.496%), and potassium (0.293%) content in rice grain as compared to the control treatment. Similarly, the maximum nutrient uptake was recorded under T5, with the values of 79.42 kg ha^{-1} nitrogen (N), 28.50 kg ha^{-1} for phosphorus (P), and 97.92 kg ha^{-1} for potassium (K), representing marked improvement over control and sole RDF treatments. The superior performance of T_5 may be attributed to the synergistic interaction between organic and inorganic nutrient sources, which enhanced nutrient availability, improved soil physical and biological properties and increased nutrient uptake efficiency. Overall, these findings underscore the effectiveness of INM in enhancing nutrient use efficiency and sustaining higher productivity of rice cultivation by reduced dependency on chemical fertilizers under alluvial soil conditions.

Keywords: INM; fertilizers; farmyard manure; vermicompost; rice cultivation; rice; global food security.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important staple food crops in the world, playing a major role in global food security. In India, rice occupies a central position in agriculture, covering about 43.7 million hectares with the production of 112.9 million tonnes, making the country the second-largest producer globally after China (Glauber & Mamun, 2025). It accounts for more than 40% of total food grain production and occupies nearly one-fourth of the total cropped area. Given the increasing population and food demand, enhancing rice productivity in a sustainable manner remains a national priority (Dhanda *et al.,* 2022, Shivangi et al., 2025).

However, intensive cultivation of high-yielding rice varieties has led to excessive dependence on chemical fertilizers, especially nitrogen (N), phosphorus (P), and potassium (K). While these inputs initially boosted yields, their imbalanced and continuous application has resulted in soil nutrient depletion, deterioration of soil physical and biological properties, and reduced nutrient use efficiency (Prasad *et al.,* 2017). Sole reliance on inorganic fertilizers has also contributed to micronutrient deficiencies and environmental degradation, further threatening the long-term sustainability of rice-based cropping systems.

Integrated Nutrient Management (INM), which combines the use of organic manures such as farmyard manure (FYM) and vermicompost (VC) with reduced levels of chemical fertilizers, has been widely advocated to restore soil fertility and sustain crop productivity. Organic amendments improve soil structure, water holding capacity, microbial activity, and nutrient cycling (Arancon *et al.,* 2005; Singh *et al*., 2016). Vermicompost has been recognized for its rich content of macro- and micronutrients and bioactive compounds that enhance nutrient availability and uptake by crops (Pilli *et al.,* 2019). Research indicates that INM not only enhances yield but also improves nutrient uptake and grain quality (Darjee *et al.,* 2023; Yadav *et al.,* 2019). Despite these documented benefits, existing studies are often site-specific and limited in scope, with little emphasis on the combined effects of integrated nutrient sources on nutrient content, nutrient uptake and yield under the alluvial soil conditions of the central Gangetic plains, particularly in Uttar Pradesh. Although several studies have assessed the agronomic benefits of INM, there remains a significant gap in quantifying how different combinations of reduced recommended fertilizer doses with FYM and vermicompost influence nutrient content, total nutrient uptake of rice cultivation under alluvial soils. Additionally, most research has focused on yield alone, with limited integrated evaluation of soil fertility, nutrient use efficiency and cost-effectiveness. Considering the dual challenge of maintaining soil health and increasing input-use efficiency, it is crucial to evaluate integrated nutrient strategies that are not only environmentally sustainable. Thus, the present investigation was carried out to study the effects of organic

manures and chemical fertilizers on nutrient content, nutrient uptake of rice cultivation.

2. Materials and Methods

The study was conducted during the *kharif* season (June - November 2023) at the Student Instructional Farm of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh (26.58°N, 80.34°E, 124 m altitude). The experimental site featured a subtropical climate with 850 mm average annual rainfall, predominantly during the monsoon season. Initial soil analysis (0–15 cm depth) revealed clay loam texture (32.5% sand, 47.75% silt, 19.75% clay) with pH 7.6, organic carbon content of 4.5 g kg^{-1}, and available N, P, and K levels of 247, 10.8, and 60 kg ha^{-1}, respectively. The experiment employed a Randomized Complete Block Design (RCBD) with three replications and eight treatments: T_1 (control, no inputs), T_2 (100% recommended dose of fertilizers [RDF]: 120-60-60 kg N-P_2O_5-K_2O ha^{-1}), T_3 (75% RDF + 10 t ha^{-1} farmyard manure [FYM]), T_4 (75% RDF + 5 t ha^{-1} vermicompost), T_5 (75% RDF + FYM + vermicompost), T_6 (50% RDF + FYM), T_7 (50% RDF + vermicompost), and T_8 (50% RDF + FYM + vermicompost). The rice variety CSR-36 was used as the test crop, with seeds treated with Thiram 75% WP (2.5 g kg^{-1} seed) before sowing in a nursery. Twenty-five-day-old seedlings were transplanted at 20 × 10 cm spacing in main field. Nutrient management followed a split application approach for nitrogen (50% basal, 25% at tillering [25 days after transplanting, DAT], and 25% at panicle initiation [45 DAT]), while phosphorus and potassium were applied entirely as basal doses. Organic amendments (FYM containing 0.5% N, 0.25% P_2O_5, and 0.5% K; vermicompost with 1.94% N, 0.47% P_2O_5, and 0.7% K) were incorporated 7–15 days before transplanting. The chemical analysis of plant sample were done at harvest, composite samples of grain and straw were collected from each treatment to analyze the concentration (%) and uptake (kg ha^{-1}) of nitrogen (N), phosphorus (P), and potassium (K). The samples were oven-dried at 70 ± 5°C for 72 hours, ground separately, and used for chemical analysis. Nitrogen content was estimated using the micro-Kjeldahl method (Jackson, 1973), while phosphorus was determined through wet digestion followed by the vanado-molybdate yellow colour method (Jackson, 1973). Potassium concentration was measured using a flame photometer. Nutrient uptake for each element was calculated by multiplying the respective nutrient concentration with the dry matter yield of grain and straw. All data were subjected to analysis of variance (ANOVA) using RStudio (v4.3.1), with treatment means compared using Critical Difference (CD) at $p \leq 0.05$.

3. Results and Discussion

3.1 Effects of Treatments on Nutrient Content in Grain and Straw

The nutrient content of rice grain and straw, particularly nitrogen (N), phosphorus (P) and potassium (K), was significantly influenced by the integrated application of inorganic fertilizers and organic manures. The treatments comprising different combinations of recommended doses of fertilizers (RDF) with farmyard manure (FYM) and vermicompost (VC) demonstrated a consistent improvement in nutrient concentration compared to the control (T1), which received no fertilizer input (Table 1).

Table 1. Effect of inorganic fertilizers and organic manures on NPK content by rice grain and straw

Treatments	Nitrogen content (%)		Phosphorus content (%)		Potassium content (%)	
	Grain	straw		straw	Grain	straw
T_1: CONTROL	1.13	0.17	0.334	0.033	0.232	1.03
T_2: 100% RDF	1.26	0.31	0.485	0.059	0.287	1.27
T_3: 75% RDF + FYM	1.28	0.29	0.483	0.057	0.286	1.26
T_4: 75% RDF + VC	1.29	0.32	0.489	0.061	0.289	1.28
T_5: 75% RDF + FYM + VC	1.33	0.35	0.496	0.067	0.293	1.31
T_6: 50% RDF + FYM	1.20	0.24	0.453	0.048	0.272	1.22
T_7: 50% RDF + VC	1.21	0.26	0.461	0.052	0.274	1.24
T_8: 50% RDF + FYM + VC	1.23	0.27	0.465	0.056	0.277	1.25
CD ($p \leq 0.05$)	0.055	0.014	0.029	0.009	0.014	0.066

RDF: Recommended dose of fertilizers, FYM: Farm yard manure, VC: Vermicompost

Table 2. Effect of inorganic fertilizers and organic manures on uptake of NPK (kg/ha) by rice grain and straw

Treatments	Nitrogen content uptake (kg/ha)			Phosphorus uptake (kg/ha)			Potassium uptake (kg/ha)		
	Grain	straw	Total		straw	Total	Grain	straw	Total
T_1: CONTROL	30.75	4.91	35.66	9.17	0.74	9.91	6.63	36.17	42.80
T_2: 100% RDF	55.86	15.57	71.43	22.13	3.12	25.25	13.78	69.25	83.03
T_3: 75% RDF + FYM	53.93	13.89	67.82	21.04	2.89	23.93	12.36	64.12	76.48
T_4: 75% RDF + VC	57.67	16.42	74.09	23.26	3.75	27.01	14.42	78.15	92.57
T_5: 75% RDF + FYM + VC	61.15	18.27	79.42	24.37	4.13	28.50	15.82	82.10	97.92
T_6: 50% RDF + FYM	43.82	10.22	54.04	18.42	2.18	20.60	11.27	57.25	68.52
T_7: 50% RDF + VC	45.25	12.35	57.60	19.74	2.67	22.41	12.73	61.27	74.00
T_8: 50% RDF + FYM + VC	48.12	13.67	61.79	21.14	3.10	24.24	13.25	72.43	85.68
CD ($p \leq 0.05$)	2.571	0.675		0.996	0.141		3.156	2.614	

RDF: Recommended dose of fertilizers, FYM: Farm yard manure, VC: Vermicompost

Nitrogen content in both grain and straw of rice showed marked increases under integrated nutrient management. Among the treatments, the combination of 75% RDF with FYM and VC (T_5) recorded the highest nitrogen content in grain at 1.33%, compared to 1.13% in the control, reflecting a 17.70 % increment over control. Similarly, nitrogen content in straw was 0.35% under T5, compared to 0.17% in the control. This enhancement can be attributed to the synergistic effect of organic and inorganic nutrient sources that improve nitrogen availability and assimilation. The gradual mineralization of organic nitrogen from farm yard manures and vermicompost ensures a sustained supply throughout the crop growth period, thereby enriching plant tissues with higher nitrogen concentration (Sankati *et al.,* 2024). The comparative nitrogen content in other integrated treatments further supports this trend. For instance, T4 (75% RDF + VC) and T3 (75% RDF + FYM) recorded nitrogen content in grain of 1.29% and 1.28%, respectively, also higher than the control and sole RDF treatment. The increased nitrogen content observed in both grain and straw under vermicompost application can be ascribed to its low carbon-to-nitrogen ratio, which promotes rapid mineralization. Additionally, the composting process enhances the activity of nitrogen-fixing microorganisms, thereby improving nitrogen availability (Daniel and Anderson, 1992). These findings are consistent with the results reported by Singh *et al.* (2013) and Wolie and Admassu (2016).

Phosphorus content in both grain and straw exhibited significant improvement with the integrated application of fertilizers and organic manures. The highest grain phosphorus content was observed under T_5, registering 0.496%, which is substantially higher than the 0.334% recorded in the control, representing a 31.69% increase. The enhanced phosphorus levels in grain and straw can be ascribed to improved solubilization and mobility of phosphorus in the presence of organic acids and microbial metabolites produced during decomposition of FYM and VC. These organic amendments also enhance root proliferation and rhizosphere activity, facilitating greater phosphorus uptake and translocation. Treatments T_4 and T_3 also showed elevated phosphorus content in grain (0.489% and 0.483%, respectively) and straw (0.061% and 0.057%, respectively), underscoring the effectiveness of both FYM and VC in phosphorus enrichment. The increase in phosphorus content in the crop could be linked to the role of organic anions in improving phosphorus solubility and availability to plants. Similar outcomes were reported by Singh, A.K. (2017) and Wolie and Admassu (2016).

The potassium content in grain and straw followed a similar upward trend in response to integrated nutrient management. T_5 once again led with the highest potassium content in grain at 0.293%, compared to 0.232% in the control. In straw, the potassium content rose to 1.31% under T_5 and minimum was recorded under the

control (1.03%). The increase in potassium content under integrated treatments can be attributed to the role of FYM and VC in enhancing the cation exchange capacity of soil and facilitating the release of native and applied potassium. The organic matter also buffers potassium fixation, making more K+ ions available in the root zone for plant uptake. Other treatments such as T_4 and T_3 also recorded increased potassium levels in grain (0.289% and 0.286%, respectively) and in straw (1.28% and 1.26%, respectively), again confirming the contribution of organic inputs in nutrient enrichment. Similarly, Thakur *et al.,* 2020, recorded maximum and micronutrient content in grains of rice under the treatment integrated nutrient management with conventional practices. The observed increase in potassium content in both grain and straw under integrated nutrient management (INM), particularly in treatment T_5 (75% RDF + FYM + VC), can be primarily attributed to the beneficial impact of organic manures on soil chemical and biological properties. Farmyard manure (FYM) and vermicompost (VC) significantly contribute to improving the soil's cation exchange capacity (CEC), which enhances the soil's ability to retain and exchange essential cations like potassium (K^+). This improved CEC reduces leaching losses and increases the availability of potassium in the soil solution for plant uptake. Additionally, the gradual decomposition of farm yard manures and vermicompost releases organic acids and humic substances that help mobilize both native and applied forms of potassium. These organic acids chelate and solubilize potassium-bound minerals, thereby increasing the pool of plant-available potassium. The increased biological activity stimulated by organic inputs further promotes the mineralization of nutrients and improves root growth and nutrient absorption. These findings align with previous research by Thakur et al. (2020), who also reported enhanced macronutrient and micronutrient content in rice grains under integrated nutrient management practices combined with conventional fertilization methods. Similar findings were also reported by (Sekhar *et al*., 2014; Wolie and Admassu ,2016; Chandra *et al*., 2021 and Kumar *et al.,* 2022). In another study, the maximum nutrient contents (N = 1.39%, P = 0.51%, and K = 0.30%) were recorded under the treatment containing 75% RDF + vermicompost in rice.

Across all treatments, a clear trend emerged indicating that the integration of 75% RDF with organic manures, particularly when farm yard manure and vermicompost were applied together (T_5), resulted in the highest nutrient content in both grain and straw for all three major nutrients-nitrogen, phosphorus and potassium. The lowest values were consistently recorded in the control (T_1), highlighting the essential role of nutrient supplementation in enhancing the nutritive quality of the crop.

3.2 Nutrient Uptake in Grain and Straw

Nutrient uptake by crops is a critical parameter reflecting not only the plant's nutrient absorption efficiency but also the effectiveness of the applied nutrient sources. In this study, the uptake of nitrogen (N), phosphorus (P) and potassium (K) by rice plants were recorded separately for grain and straw, it was significantly influenced by the different integrated nutrient management (INM) treatments (Table 2).

Nitrogen uptake in grain, straw and total plant biomass showed a marked and statistically significant improvement under integrated treatments. The maximum total nitrogen uptake was observed in treatment T_5 (75% RDF + FYM + VC) (61.15 kg ha^{-1} in grain, 18.27 kg ha^{-1} in straw and a combined uptake of 79.42 kg ha^{-1}). This represents a 49.71% increase in grain N uptake, 73.12% increase in straw N uptake and 55.09% increase in total N uptake when compared to the control (T1), which had only 30.75 kg ha^{-1} in grain, 4.91 kg ha^{-1} in straw, and a total of 35.66 kg ha^{-1}. The enhanced nitrogen uptake in T_5 can be attributed to the continuous mineralization of organic N from FYM and VC, which complements the immediate availability of nitrogen from inorganic sources (Biswakarma *et al.,* 2025).

Phosphorus uptake followed a similar pattern. The total phosphorus uptake under T_5 was the highest at 28.50 kg ha^{-1}, with 24.37 kg ha^{-1} absorbed by grain and 4.13 kg ha^{-1} by straw. This marked a significant increase of 62.37% in grain P uptake, 82.08% in straw P uptake and 65.22% in total P uptake when compared to the control treatment (T1), which recorded 9.17 kg ha^{-1} in grain, 0.74 kg ha^{-1} in straw, and 9.91 kg ha^{-1} in total. The increased phosphorus uptake under integrated treatments is due to the organic acids and microbial exudates produced during the decomposition of farm yard manures and vermicompost, which enhance phosphorus solubilization and mobility in the soil. Treatment T_4 (75% RDF + VC) recorded a total P uptake of

27.01 kg ha^{-1}, while T_3 (75% RDF + FYM) recorded 23.93 kg ha^{-1}. Interestingly, T_2 (100% RDF) also recorded a slightly lower value (25.25 kg ha^{-1}) than T_5, again confirming the superior performance of integrated applications over sole chemical fertilizer use. The data also showed that lower-dose RDF treatments (T_6, T_7, T_8) had significantly lower uptake values than their 75% RDF counterparts, highlighting the necessity of maintaining a sufficient base of chemical fertilizer for optimal phosphorus availability.

The uptake of potassium in rice grain and straw was significantly improved by integrated nutrient management practices. The treatment T_5 exhibited the highest potassium uptake, with 15.82 kg ha^{-1} in grain and 82.10 kg ha^{-1} in straw, resulting in a total uptake of 97.92 kg ha^{-1}. This corresponded to a 58.09% increase in grain K uptake, 55.94% increase in straw uptake, and 56.29% higher total K uptake relative to the control (T1), which recorded 6.63 kg ha^{-1} in grain, 36.17 kg ha^{-1} in straw, and 42.80 kg ha^{-1} in total. The combined use of FYM and VC contributed to a more favourable soil structure and cation exchange capacity, facilitating the release and movement of potassium to the plant roots. The results of present experiment get supported by findings of (Vishwanathan and Singaravel, 2016; Mohan Rao *et al.*, 2017: Kumar *et al*., 2018; Ganguly *et al.* (2019); Shultana *et al*., 2019 and; Ram *et al.,* 2020), they recorded that combination of 75% recommended dose of fertilizers (RDF) with organic manures, specifically farmyard manure (FYM) and vermicompost (VC), proved to be the most effective treatment in enhancing nitrogen, phosphorus, and potassium concentrations in both grain and straw. The superior performance of this treatment underscores the importance of combining fast-acting inorganic nutrients with slow-releasing, soil-enriching organic sources. The enhanced uptake observed in T5 reflects not just the improved availability of nutrients but also better root development, microbial activity, and nutrient mobility in the rhizosphere. The results clearly indicate that integrated nutrient management promotes higher and more efficient nutrient uptake, supporting optimal plant growth and contributing to improved yield and quality. Moreover, these findings provide a strong rationale for promoting INM practices among rice growers aiming for sustainable intensification, especially under the resource-constrained and nutrient-deficient conditions typical of many rice-growing regions.

4. Conclusion

The present study clearly demonstrated that integrated nutrient management, particularly the application of 75% RDF combined with FYM and vermicompost (T_5), significantly improved nutrient content and uptake of nitrogen, phosphorus and potassium in rice grain and straw. The synergistic effects of organic and inorganic sources contributed to better nutrient availability and uptake efficiency. Thus, adopting INM practices can ensure higher productivity, improved soil health, and long-term sustainability in rice cultivation, especially in nutrient-depleted alluvial soils of the Indo-Gangetic plains.

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 writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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