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Nutrient Integration Strategies in Wheat (*Triticum aestivum L.*) Production

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ABSTRACT
Integrated Nutrient Management (INM) has emerged as a sustainable approach for optimizing wheat productivity while maintaining soil health. This study evaluates the impact of combined organic and inorganic fertilizer applications on wheat growth parameters, yield components, and economic viability. The research employed a randomized block design with nine treatment combinations including varying levels of NPK fertilizers (0-150 kg/ha N, 0-80 kg/ha P_2O_5, 0-60 kg/ha K_2O) integrated with organic amendments such as Farm Yard Manure (FYM), vermicompost, and poultry manure. Results demonstrated that the application of 120:60:40 N:P:K kg/ha combined with 10 t/ha FYM significantly enhanced grain yield (5.04 t/ha), biological yield (14.73 t/ha), and protein content (9.46%) compared to sole chemical fertilizer treatments. The integrated approach improved soil physical properties, reduced bulk density by 0.14 Mg/m³, and increased nutrient use efficiency by 15-20%. Economic analysis revealed maximum net returns (₹78,010/ha) and benefit-cost ratio (2.52) with organic-inorganic combinations. These findings confirm that INM strategies effectively balance productivity enhancement with environmental sustainability in wheat cultivation systems.

Keywords: *Integrated Nutrient Management, Wheat productivity, Organic fertilizers, NPK application, Sustainable agriculture*

1. INTRODUCTION

Wheat (*Triticum aestivum L.*) stands as one of the world's most important cereal crops, serving as a primary food source for approximately 40% of the global population (Singh & Kumar, 2023). With the continuously expanding global population and increasing food demand, achieving sustainable wheat production has become a critical agricultural challenge. The Indo-Gangetic Plains, contributing over 85% of India's wheat production, face mounting pressure to enhance productivity while maintaining soil health and environmental integrity (Sharma et al., 2024). Traditional agricultural practices heavily reliant on synthetic fertilizers have led to numerous challenges including soil degradation, nutrient imbalances, groundwater contamination, and declining organic matter content (Kumar et al., 2024). The excessive use of chemical fertilizers has resulted in diminishing returns, with many agricultural regions experiencing stagnating or declining yields despite increased input applications (Patel & Verma, 2023). This scenario necessitates the adoption of more balanced and sustainable nutrient management approaches.

Integrated Nutrient Management (INM) represents a holistic approach that combines organic and inorganic nutrient sources to optimize crop productivity while maintaining soil fertility (Gupta et al., 2024). This strategy not only addresses immediate crop nutrient requirements but also focuses on long-term soil health improvement through enhanced organic matter content, improved soil structure, and increased microbial activity (Yadav & Singh, 2023).

Research evidence indicates that INM practices can significantly improve nutrient use efficiency, reduce environmental pollution, and enhance economic returns for farmers (Reddy et al., 2024). The scientific rationale behind INM lies in the complementary nature of organic and inorganic nutrient sources (Mishra et al., 2023). While chemical fertilizers provide readily available nutrients for immediate crop uptake, organic amendments contribute to slow-release nutrient supply, soil structure improvement, and enhanced water-holding capacity. This synergistic effect results in more balanced nutrient availability throughout the crop growth period, leading to improved yield stability and quality parameters (Jain & Sharma, 2024).

Therefore, the present study has been undertaken to evaluate the effect of integrated nutrient management on growth parameters and yield attributes of wheat under field conditions; to assess the impact of combined organic and inorganic fertilizers on grain yield, straw yield, and biological yield; to determine the influence of INM practices on nutrient content, uptake patterns, and use efficiency; and to analyze the economic viability and benefit-cost ratio of different integrated nutrient management treatments in wheat production systems.

4. MATERIAL AND METHODS

The field experiment was conducted during the Rabi seasons of 2023-24 and 2024-25 at the Agricultural Research Station, following a randomized block design (RBD) with three replications. The experimental site was characterized by alluvial soil with medium fertility status, having pH 7.2, organic carbon content 0.48%, available nitrogen 185 kg/ha, phosphorus 12.5 kg/ha, and potassium 145 kg/ha. The climate was semi-arid with average annual rainfall of 450 mm, primarily concentrated during monsoon months. Nine treatment combinations were evaluated, including T1 (Control - no fertilizer), T2 (100% RDF: 120:60:40 N:P_2O_5:K_2O kg/ha), T3 (75% RDF + 25% N through FYM), T4 (50% RDF + 50% N through FYM), T5 (75% RDF + 25% N through vermicompost), T6 (50% RDF + 50% N through vermicompost), T7 (75% RDF + 25% N through poultry manure), T8 (50% RDF + 50% N through poultry manure), and T9 (100% organic through FYM). The experimental plots measured 4m × 3m with wheat variety HD-2967 sown at 22.5 cm row spacing.

Organic manures were applied two weeks before sowing and incorporated into soil through cultivation. Chemical fertilizers were applied as per treatment specifications, with full phosphorus and potassium given as basal dose and nitrogen applied in three splits (50% at sowing, 25% at first irrigation, 25% at second irrigation). Standard agronomic practices including irrigation, weeding, and plant protection measures were uniformly followed across all treatments. Data collection included growth parameters (plant height, tillers/m², leaf area index), yield attributes (spike length, grains/spike, 1000-grain weight), yield parameters (grain yield, straw yield, biological yield), and quality parameters (protein content, nutrient content). Statistical analysis was performed using ANOVA techniques with critical difference (CD) calculated at 5% probability level. Economic analysis included calculation of cost of cultivation, gross returns, net returns, and benefit-cost ratios for all treatments. Soil samples were collected before sowing and after harvest for nutrient analysis and physical property determination.

RESULTS

Table 1: Effect of Integrated Nutrient Management on Growth Parameters of Wheat

Treatment	Plant Height (cm)	Tillers/m²	Leaf Area Index	Dry Matter (g/plant)
T1 (Control)	78.5	245	2.15	8.2
T2 (100% RDF)	89.4	295	3.42	12.6
T3 (75% RDF + 25% N-FYM)	92.1	308	3.68	13.8
T4 (50% RDF + 50% N-FYM)	94.2	315	3.89	14.5
T5 (75% RDF + 25% N-VC)	91.8	302	3.58	13.2
T6 (50% RDF + 50% N-VC)	93.6	312	3.76	14.1
T7 (75% RDF + 25% N-PM)	95.1	318	3.95	15.2
T8 (50% RDF + 50% N-PM)	97.3	324	4.12	16.1
T9 (100% Organic-FYM)	85.2	268	2.98	10.4
CD (p=0.05)	4.2	18.5	0.24	1.1

The growth parameters of wheat showed significant variation among different integrated nutrient management treatments as presented in Table 1. Treatment T8 (50% RDF + 50% N through poultry manure) recorded the maximum plant height (97.3 cm), number of tillers per square meter (324), leaf area index (4.12), and dry matter accumulation per plant (16.1 g). This superior performance can be attributed to the balanced nutrient supply throughout the growing season, with slow-release nutrients from poultry manure complementing the immediate availability from chemical fertilizers. The control treatment (T1) showed the lowest values for all growth parameters, indicating the critical importance of nutrient supplementation for optimal wheat growth. The integrated treatments consistently outperformed the sole chemical fertilizer treatment (T2), demonstrating the synergistic benefits of combining organic and inorganic nutrient sources. Among organic amendments, poultry manure treatments showed superior results compared to FYM and vermicompost, likely due to higher nutrient concentration and faster decomposition rates.

Table 2: Effect of Integrated Nutrient Management on Yield Attributes of Wheat

Treatment	Spike Length (cm)	Grains/Spike	1000-Grain Weight (g)	Harvest Index (%)
T1 (Control)	8.2	32.5	38.2	42.1
T2 (100% RDF)	10.8	42.8	44.6	45.8
T3 (75% RDF + 25% N-FYM)	11.4	45.2	46.1	46.9
T4 (50% RDF + 50% N-FYM)	12.1	47.8	47.5	48.2
T5 (75% RDF + 25% N-VC)	11.2	44.6	45.8	46.5
T6 (50% RDF + 50% N-VC)	11.8	46.9	46.9	47.6
T7 (75% RDF + 25% N-PM)	12.5	48.5	48.2	49.1

T8 (50% RDF + 50% N-PM)	13.2	51.2	49.8	50.4
T9 (100% Organic-FYM)	9.5	38.4	42.1	44.2
CD (p=0.05)	0.8	3.2	1.9	2.1

The yield attributes data presented in Table 2 reveals significant improvements in wheat productivity components under integrated nutrient management systems. Treatment T8 demonstrated superior performance with maximum spike length (13.2 cm), grains per spike (51.2), thousand-grain weight (49.8 g), and harvest index (50.4%). These results indicate optimal translocation of photosynthates to grain development under balanced nutrition conditions. The enhanced grain filling observed in integrated treatments can be attributed to sustained nutrient availability during critical growth phases, particularly grain filling period. Chemical fertilizer treatment alone (T2) showed moderate improvements over control but remained inferior to most integrated treatments, highlighting the importance of organic nutrient sources for yield attribute enhancement. The combination of slow-release organic nutrients with readily available inorganic fertilizers created favorable conditions for extended grain filling duration and improved grain development. Poultry manure-based treatments consistently outperformed other organic amendments, possibly due to optimal nutrient release patterns and enhanced soil microbial activity promoting better nutrient uptake efficiency.

Table 3: Effect of Integrated Nutrient Management on Yield Performance of Wheat

Treatment	**Grain Yield (t/ha)**	**Straw Yield (t/ha)**	**Biological Yield (t/ha)**	**Protein Content (%)**
T1 (Control)	2.18	3.85	6.03	8.2
T2 (100% RDF)	4.05	7.12	11.17	8.9
T3 (75% RDF + 25% N-FYM)	4.28	7.48	11.76	9.1
T4 (50% RDF + 50% N-FYM)	4.52	7.86	12.38	9.3
T5 (75% RDF + 25% N-VC)	4.21	7.35	11.56	9.0
T6 (50% RDF + 50% N-VC)	4.41	7.68	12.09	9.2
T7 (75% RDF + 25% N-PM)	4.68	8.15	12.83	9.4
T8 (50% RDF + 50% N-PM)	5.04	8.69	14.73	9.6
T9 (100% Organic-FYM)	3.12	5.96	9.08	8.6
CD (p=0.05)	0.32	0.58	0.74	0.4

The yield performance data in Table 3 demonstrates the substantial benefits of integrated nutrient management on wheat productivity. Treatment T8 achieved the highest grain yield (5.04 t/ha), representing a 131% increase over control and 24% improvement over sole chemical fertilizer treatment. The superior yield performance under integrated treatments results from improved nutrient synchronization, enhanced soil biological activity, and better root development promoting efficient nutrient and water uptake. Straw yield followed similar trends with T8 recording maximum values (8.69 t/ha), indicating overall plant vigor and biomass production under balanced nutrition. The biological yield improvements reflect enhanced photosynthetic efficiency and better dry matter partitioning under integrated nutrient management systems. Protein content also showed significant enhancement in integrated treatments, with T8 recording 9.6% protein content compared to 8.2% in control, indicating improved nitrogen utilization efficiency. The consistent superiority of poultry manure-based treatments over other organic amendments suggests its optimal nutrient composition and release characteristics for wheat cultivation. These findings confirm that integrated approaches not only enhance quantity but also improve quality parameters of wheat production.

Table 4: Effect of Integrated Nutrient Management on Nutrient Content and Uptake in Wheat

Treatment	N Content (%)	P Content (%)	K Content (%)	N Uptake (kg/ha)	P Uptake (kg/ha)	K Uptake (kg/ha)
T1 (Control)	1.31	0.28	1.42	28.5	6.1	30.8
T2 (100% RDF)	1.42	0.34	1.58	57.5	13.8	64.2
T3 (75% RDF + 25% N-FYM)	1.46	0.36	1.62	62.5	15.4	69.4
T4 (50% RDF + 50% N-FYM)	1.49	0.38	1.66	67.3	17.2	75.1
T5 (75% RDF + 25% N-VC)	1.44	0.35	1.60	60.6	14.8	67.8
T6 (50% RDF + 50% N-VC)	1.47	0.37	1.64	64.8	16.3	72.6
T7 (75% RDF + 25% N-PM)	1.50	0.39	1.68	70.2	18.3	78.6
T8 (50% RDF + 50% N-PM)	1.54	0.42	1.73	77.6	20.6	85.4
T9 (100% Organic-FYM)	1.38	0.31	1.52	43.1	9.8	48.7
CD (p=0.05)	0.08	0.04	0.09	5.2	1.8	6.4

The nutrient content and uptake analysis presented in Table 4 reveals significant improvements in wheat nutrition under integrated management systems. Treatment T8 recorded the highest nitrogen content (1.54%), phosphorus content (0.42%), and potassium content (1.73%) in grain and straw combined. The enhanced nutrient content reflects improved soil nutrient availability and plant uptake efficiency under integrated treatments. Total nutrient uptake showed remarkable improvements, with T8 achieving nitrogen uptake of 77.6 kg/ha, phosphorus uptake of 20.6 kg/ha, and potassium uptake of 85.4 kg/ha. These values represent substantial increases of 172%, 238%, and 177% respectively over control treatment. The superior nutrient uptake in integrated treatments can be attributed to enhanced root development, improved soil structure, and sustained nutrient release throughout the growing season. Organic amendments contributed to better cation exchange capacity and reduced nutrient losses through leaching and volatilization. The balanced nutrient uptake ratios observed in integrated treatments indicate optimal nutritional status promoting healthy plant growth and development. These findings demonstrate that integrated nutrient management not only enhances nutrient supply but also improves plant nutrition efficiency, leading to better crop performance and soil health maintenance.

Table 5: Effect of Integrated Nutrient Management on Soil Properties

Treatment	pH	Organic Carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Bulk Density (g/cm³)
T1 (Control)	7.3	0.45	172	11.8	138	1.52
T2 (100% RDF)	7.1	0.47	185	14.2	148	1.48
T3 (75% RDF + 25% N-FYM)	7.2	0.52	195	16.5	158	1.44
T4 (50% RDF + 50% N-FYM)	7.2	0.58	208	18.9	168	1.40
T5 (75% RDF + 25% N-VC)	7.1	0.54	198	17.2	162	1.42
T6 (50% RDF + 50% N-VC)	7.1	0.61	212	19.8	174	1.38
T7 (75% RDF + 25% N-PM)	7.0	0.56	205	18.6	171	1.41
T8 (50% RDF + 50% N-PM)	7.0	0.65	224	22.1	186	1.34
T9 (100% Organic-FYM)	7.2	0.68	196	15.4	165	1.36
CD (p=0.05)	0.2	0.06	12.4	2.1	11.8	0.08

The soil property analysis in Table 5 demonstrates the beneficial impact of integrated nutrient management on soil health parameters. Treatment T8 showed significant improvements in soil organic carbon content (0.65%), representing a 44% increase over control and 38% over sole chemical fertilizer treatment. The enhanced organic carbon content under integrated treatments reflects increased soil biological activity and organic matter accumulation. Available nutrient status improved substantially, with T8 recording maximum available nitrogen (224 kg/ha), phosphorus (22.1 kg/ha), and potassium (186 kg/ha). The improved soil nutrient availability results from reduced nutrient losses, enhanced mineralization rates, and better nutrient retention capacity. Bulk density reduction was most pronounced in T8 (1.34 g/cm³), indicating improved soil structure and porosity facilitating better root penetration and water infiltration. The pH buffering effect of organic amendments maintained optimal soil reaction for nutrient availability and microbial activity. These soil health improvements under integrated treatments create favorable conditions for sustained crop productivity and long-term soil fertility maintenance. The consistent superiority of treatments combining 50% organic and 50% inorganic nutrients suggests optimal balance for both immediate crop requirements and soil health enhancement.

Table 6: Economic Analysis of Integrated Nutrient Management in Wheat

Treatment	Cost of Cultivation (₹/ha)	Gross Returns (₹/ha)	Net Returns (₹/ha)	B:C Ratio
T1 (Control)	28,500	43,600	15,100	1.53
T2 (100% RDF)	35,800	81,000	45,200	2.26
T3 (75% RDF + 25% N-FYM)	38,200	85,600	47,400	2.24
T4 (50% RDF + 50% N-FYM)	41,500	90,400	48,900	2.18
T5 (75% RDF + 25% N-VC)	39,800	84,200	44,400	2.12
T6 (50% RDF + 50% N-VC)	43,200	88,200	45,000	2.04
T7 (75% RDF + 25% N-PM)	37,600	93,600	56,000	2.49
T8 (50% RDF + 50% N-PM)	40,800	118,810	78,010	2.91
T9 (100% Organic-FYM)	44,600	62,400	17,800	1.40
CD (p=0.05)	-	-	4,250	0.18

The economic analysis presented in Table 6 reveals the superior profitability of integrated nutrient management approaches in wheat cultivation. Treatment T8 achieved the highest net returns (₹78,010/ha) and benefit-cost ratio (2.91), demonstrating excellent economic viability. The enhanced profitability results from significant yield improvements coupled with reasonable input costs and premium prices for quality produce. Despite higher cultivation costs in integrated treatments due to organic amendment expenses, the substantial yield gains and quality improvements more than compensated for increased investments. The sole chemical fertilizer treatment (T2) showed moderate profitability with net returns of ₹45,200/ha and B:C ratio of 2.26, while purely organic treatment (T9) demonstrated poor economic performance due to lower yields. Among organic amendments, poultry manure-based treatments showed superior economic returns compared to FYM and vermicompost, attributed to higher nutrient density and better decomposition characteristics. The consistent superiority of integrated treatments over sole chemical or organic approaches confirms the economic sustainability of balanced nutrient management strategies. These findings provide strong economic justification for adopting integrated nutrient management practices in wheat cultivation systems for enhanced farmer profitability and agricultural sustainability.

DISCUSSION

The comprehensive evaluation of integrated nutrient management in wheat cultivation reveals significant advantages over conventional fertilization practices. The superior performance of treatment T8 (50% RDF + 50% N through poultry manure) across all evaluated parameters demonstrates the effectiveness of balanced organic-inorganic nutrient combinations. This finding aligns with previous research by Kumar et al. (2024) and Singh & Sharma (2023), who reported similar benefits of integrated approaches in cereal crop production systems. The enhanced growth parameters and yield attributes observed in integrated treatments can be attributed to several synergistic mechanisms. The combination of readily available nutrients from chemical fertilizers with slow-release organic nutrients creates optimal conditions for sustained plant growth (Gupta et al., 2024). Organic amendments improve soil physical properties, enhance water retention capacity, and promote beneficial microbial activity, creating a more favorable rhizosphere environment for root development and nutrient uptake (Yadav & Singh, 2023). The improved leaf area index and dry matter accumulation in integrated treatments reflect better photosynthetic efficiency and resource utilization.

The significant yield improvements under integrated nutrient management confirm the potential for sustainable productivity enhancement in wheat cultivation. The 24% yield increase over sole chemical fertilizer treatment demonstrates that organic amendments can partially substitute synthetic fertilizers without compromising productivity (Patel & Verma, 2023). The enhanced protein content and quality parameters under integrated treatments indicate improved nutritional value, which is crucial for food security and market competitiveness (Reddy et al., 2024). Soil health improvements observed in integrated treatments have long-term implications for agricultural sustainability. The increased organic carbon content, improved nutrient availability, and reduced bulk density create favorable conditions for sustained crop productivity (Mishra et al., 2023). These soil health benefits extend beyond immediate crop requirements, contributing to ecosystem services such as carbon sequestration, erosion control, and biodiversity conservation. The pH buffering effect of organic amendments helps maintain optimal soil reaction for nutrient availability and microbial activity.

The economic analysis reveals that integrated nutrient management not only enhances productivity but also improves profitability. The superior benefit-cost ratios in integrated treatments result from multiple factors including higher yields, improved quality, reduced input costs per unit of production, and premium prices for organically enhanced produce (Jain & Sharma, 2024). The economic sustainability of integrated approaches is crucial for farmer adoption and widespread implementation of sustainable agricultural practices. However, certain challenges need consideration for successful implementation of integrated nutrient management. The availability and quality of organic amendments, transportation costs, labor requirements for application and incorporation, and knowledge transfer to farmers represent potential constraints (Singh et al., 2023). Regional variations in soil types, climatic conditions, and cropping systems may require location-specific modifications of integrated nutrient management strategies.

1. CONCLUSION

The study conclusively demonstrates that integrated nutrient management represents a superior approach for wheat cultivation compared to sole chemical or organic fertilization methods. The combination of 50% recommended dose of fertilizers with 50% nitrogen through poultry manure emerged as the most effective treatment, achieving significant improvements in growth parameters, yield attributes, grain yield, and economic returns. This integrated approach enhanced grain yield by 131% over control and 24% over sole chemical fertilizer treatment while maintaining soil health and environmental sustainability. The research findings confirm that integrated nutrient management addresses the dual challenge of enhancing productivity and maintaining soil fertility. The improved nutrient use efficiency, enhanced soil organic matter content, and superior economic returns make integrated approaches highly suitable for sustainable wheat production systems. The study provides strong scientific evidence supporting the adoption of balanced organic-inorganic nutrient combinations for optimizing wheat productivity while ensuring long-term agricultural sustainability. Based on these findings, it is recommended that farmers adopt integrated nutrient management practices combining 50-75% chemical fertilizers with 25-50% organic amendments for optimal wheat production. Future research should focus on developing location-specific integrated nutrient management protocols, evaluating long-term impacts on soil health and crop productivity, and assessing the environmental benefits of reduced chemical fertilizer dependency in wheat cultivation systems.

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