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Effect of integrated nutrient management on growth, yield, nutrient uptake, quality and economics of wheat (*Triticum aestivum* L.) under indo-gangetic plains of Uttar Pradesh

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Abstract

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops and serves as a major source of food, energy and protein for a substantial proportion of the global population. However, the continuous and imbalanced use of chemical fertilizers has resulted in declining soil fertility, reduced nutrient-use efficiency, deterioration of soil health and stagnation in crop productivity. Integrated Nutrient Management (INM), involving the combined use of inorganic fertilizers, organic manures and beneficial microorganisms, has emerged as a sustainable strategy for enhancing crop productivity while maintaining soil health. Therefore, a field experiment was conducted during the Rabi season of 2025-26 at the Instructional Farm, Rama University, Kanpur, Uttar Pradesh, to evaluate the effect of different integrated nutrient management practices on growth, yield, nutrient uptake, grain quality and economics of wheat. The experiment was laid out in a Randomized Block Design (RBD) with nine treatments and three replications comprising different combinations of recommended dose of fertilizers (RDF), farmyard manure (FYM), vermicompost, poultry manure, neem cake, zinc sulphate, *Azotobacter* and phosphate-solubilizing bacteria (PSB). The experimental soil was sandy loam in texture, slightly alkaline in reaction (pH 7.8), low in organic carbon (0.42%), available nitrogen (218.5 kg ha⁻¹) and available phosphorus (18.6 kg ha⁻¹), and medium in available potassium (245.3 kg ha⁻¹). Growth parameters, yield attributes, yield, nutrient uptake, grain quality and economic returns were recorded and analyzed statistically. The results revealed that integrated nutrient management significantly enhanced crop growth and productivity compared with the control and sole chemical fertilization. Among the treatments, application of 50% RDF + 25% FYM + 25% Vermicompost + *Azotobacter* + PSB recorded the highest plant height (102.4 cm), leaf area index (4.82), dry matter accumulation (128.6 g plant⁻¹) and number of tillers (425 m⁻²) at harvest. The same treatment also produced superior yield attributes, including effective tillers (392 m⁻²), spike length (12.8 cm), grains spike⁻¹ (56.4) and test weight (45.8 g), resulting in the maximum grain yield (5.82 t ha⁻¹) and straw yield (7.46 t ha⁻¹). In comparison, the control treatment recorded a grain yield of only 3.21 t ha⁻¹. Nutrient uptake of nitrogen, phosphorus and potassium increased markedly under integrated nutrient management due to improved nutrient availability, enhanced microbial activity and better root development. The highest uptake of nitrogen (128.4 kg ha⁻¹), phosphorus (28.6 kg ha⁻¹) and potassium (112.7 kg ha⁻¹) was observed under the integrated application of 50% RDF + 25% FYM + 25% Vermicompost + *Azotobacter* + PSB. Grain quality in terms of protein content (13.4%) and crude protein yield (780 kg ha⁻¹) was also improved under integrated nutrient management treatments compared with the control (10.8% protein content). Economic analysis indicated that the integrated application of organic and inorganic nutrient sources generated higher gross returns (₹1,45,500 ha⁻¹), net returns (₹92,300 ha⁻¹) and benefit-cost ratio (2.74) than the control and sole RDF treatment. The control treatment recorded the lowest net return (₹38,600 ha⁻¹) and benefit-cost ratio (1.58). The findings suggest that integrated nutrient management not only improves wheat productivity and profitability but also contributes to long-term soil fertility and sustainability. Therefore, the integration of FYM, vermicompost and biofertilizers with reduced levels of chemical fertilizers may be recommended as an effective nutrient management strategy for sustainable wheat production under Indo-Gangetic conditions.

Keywords: Wheat, Integrated Nutrient Management, Vermicompost, Farmyard Manure, Biofertilizers, Nutrient Uptake, Grain Quality, Economics, Sustainable Agriculture, Soil Fertility

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops of the world and occupies a central position in global food and nutritional security. Belonging to the family Poaceae, wheat

is an allohexaploid species ($2n = 6x = 42$) possessing remarkable adaptability to diverse agro-climatic conditions. Owing to its high productivity, wide adaptability and nutritional value, wheat contributes nearly 20% of the total dietary calories and protein consumed worldwide (FAO, 2023). The crop serves as a staple food for more than one-third of the global population and forms the backbone of food security programmes in many developing countries, including India.

Globally, wheat is cultivated on approximately 220 million hectares with an annual production exceeding 790 million tonnes. China, India, Russia, the United States, France and Canada are among the leading wheat-producing nations. India occupies the second position in global wheat production with an area of about 31-32 million hectares and production exceeding 110 million tonnes, accounting for nearly 14% of the world's wheat output (Ministry of Agriculture and Farmers Welfare, 2024) ^[19]. The Indo-Gangetic Plains, particularly Uttar Pradesh, Punjab, Haryana and Bihar, contribute a major share of national wheat production due to favorable climatic conditions, fertile alluvial soils and extensive irrigation facilities (Singh *et al.*, 2020) ^[28].

The spectacular increase in wheat production during the Green Revolution era was largely attributed to the adoption of high-yielding varieties, assured irrigation and increased fertilizer consumption (Tilman *et al.*, 2002) ^[32]. Although these technological interventions substantially enhanced food grain production, long-term dependence on chemical fertilizers alone has created several challenges. Continuous cultivation and imbalanced nutrient application have resulted in nutrient mining, declining soil organic matter, reduced nutrient-use efficiency and deterioration of soil physical, chemical and biological properties (Manna *et al.*, 2005; Bhardwaj *et al.*, 2021) ^[4, 17]. Excessive use of nitrogenous fertilizers without adequate replenishment of phosphorus, potassium and micronutrients has further aggravated nutrient imbalances, adversely affecting crop productivity and soil sustainability (Singh *et al.*, 2021) ^[29].

Soil fertility degradation has emerged as one of the most critical constraints limiting wheat productivity under intensive cropping systems. The depletion of soil organic carbon due to continuous cultivation and insufficient organic matter recycling has reduced microbial activity and impaired nutrient transformation processes. Organic matter plays a vital role in maintaining soil structure, water-holding capacity, cation exchange capacity and nutrient availability. Therefore, restoration of soil organic matter has become an essential prerequisite for sustaining crop productivity and environmental quality (Blair *et al.*, 2006; Kundu *et al.*, 2007) ^[5, 16].

Integrated Nutrient Management (INM) has been recognized as a sustainable and environmentally sound approach for improving nutrient-use efficiency and maintaining soil health. INM refers to the judicious integration of chemical fertilizers, organic manures, crop residues and biofertilizers to achieve optimum crop productivity while preserving soil fertility for future generations. The concept emphasizes balanced nutrient supply through multiple nutrient sources that complement each other and ensure synchronization between nutrient release and crop demand (Fageria *et al.*, 2011) ^[8].

Organic nutrient sources such as farmyard manure (FYM), vermicompost, poultry manure and neem cake contribute significantly to soil fertility improvement. Farmyard manure improves soil aggregation, microbial activity and moisture retention while supplying essential macro- and micronutrients. Vermicompost enhances nutrient mineralization, enzyme activity and microbial proliferation in the rhizosphere. Poultry manure provides readily available nutrients, particularly nitrogen and

phosphorus, whereas neem cake acts as both a nutrient source and nitrification inhibitor, improving nutrient-use efficiency (Kumar and Sharma, 2021; Meena *et al.*, 2023) ^[14, 15, 18, 26, 27].

Biofertilizers have also gained considerable attention as components of integrated nutrient management systems. *Azotobacter* contributes to biological nitrogen fixation and synthesis of plant growth-promoting substances, whereas phosphate-solubilizing bacteria (PSB) improve phosphorus availability through the secretion of organic acids and phosphatase enzymes. Their combined use enhances nutrient uptake, root growth and overall crop performance (Prasad *et al.*, 2020; Sharma and Verma, 2021) ^[26, 27] 24v.

Several researchers have reported significant improvements in growth, yield and nutrient uptake of wheat under integrated nutrient management practices. Manna *et al.* (2005) ^[17] demonstrated that long-term application of organic and inorganic nutrient sources improved soil organic carbon and crop productivity. Singh *et al.* (2022) ^[30] observed significant enhancement in plant height, tillering, dry matter accumulation and grain yield when chemical fertilizers were integrated with vermicompost and biofertilizers. Similarly, Meena *et al.* (2023) ^[18] reported that integrated nutrient management increased nutrient uptake, grain yield and profitability of wheat under Indo-Gangetic conditions.

The significance of integrated nutrient management has become even more pronounced under changing climatic scenarios. Rising temperatures, erratic rainfall patterns and increasing frequency of abiotic stresses threaten wheat productivity across many production regions. Improved soil organic matter content under INM enhances water retention, nutrient buffering capacity and crop resilience against climatic stresses (Aggarwal, 2021) ^[1]. Furthermore, the integration of organic nutrient sources reduces dependence on costly chemical fertilizers and contributes to environmentally sustainable agriculture.

Economic viability is another important consideration in nutrient management research. Escalating fertilizer prices and increasing cultivation costs necessitate the development of nutrient management strategies that are both productive and profitable. Integrated nutrient management not only enhances crop yield but also improves nutrient-use efficiency and input productivity, thereby increasing net returns and benefit-cost ratio (Rashid *et al.*, 2022; Singh *et al.*, 2021) ^[25, 29]. Such strategies are particularly important for small and marginal farmers who constitute the majority of agricultural producers in India.

Despite substantial research on integrated nutrient management, the response of wheat to different combinations of organic and inorganic nutrient sources varies considerably across soil types and agro-climatic conditions. Therefore, location-specific studies are essential for developing efficient nutrient management recommendations. Information regarding the combined influence of FYM, vermicompost, biofertilizers, poultry manure, neem cake and zinc on wheat productivity under the central plain zone of Uttar Pradesh remains limited.

Keeping these considerations in view, the present investigation entitled "Effect of Integrated Nutrient Management on Growth, Yield, Nutrient Uptake, Quality and Economics of Wheat (*Triticum aestivum* L.)" was undertaken to evaluate the influence of different nutrient management combinations on crop growth, productivity, nutrient dynamics, grain quality, soil fertility and economic returns under the agro-climatic conditions of Kanpur, Uttar Pradesh. The findings are expected to contribute towards the development of sustainable nutrient management strategies for achieving higher productivity and profitability in wheat-based cropping systems.

Materials and Methods

The present investigation entitled “Effect of Integrated Nutrient Management on Growth, Yield, Nutrient Uptake, Quality and Economics of Wheat (*Triticum aestivum* L.)” was conducted during the Rabi season of 2025-26 at the Instructional Farm, Faculty of Agricultural Sciences and Allied Industries, Rama University, Kanpur, Uttar Pradesh. The experimental site is situated in the Central Plain Zone of Uttar Pradesh under the Indo-Gangetic Plains and is characterized by a subtropical climate with hot summers, cool winters and moderate rainfall. During the crop growth period, the weather remained favorable for wheat cultivation, with comparatively lower temperatures during vegetative growth and moderate temperatures during grain filling and maturity. The soil of the experimental field was sandy loam in texture, slightly alkaline in reaction (pH 7.69), non-saline in nature and low in organic carbon, available nitrogen and phosphorus, while medium in available potassium. Such soil conditions provided an appropriate environment for evaluating the effectiveness of integrated nutrient management practices.

The experiment was laid out in a Randomized Block Design (RBD) with nine treatments and three replications. The wheat variety HD-2967 was sown during the second fortnight of November using a seed rate of 100 kg ha⁻¹ with row spacing of 22.5 cm. The recommended dose of fertilizer (RDF) for wheat was 120:60:40 kg N:P₂O₅:K₂O ha⁻¹ supplied through urea, diammonium phosphate and muriate of potash. Half of the nitrogen along with the full dose of phosphorus and potassium was applied as basal, while the remaining nitrogen was top-dressed in two equal splits at crown root initiation and first node stages. Organic manures were incorporated into the soil fifteen days before sowing, whereas biofertilizers (*Azotobacter* and phosphate-solubilizing bacteria) were applied as seed treatment before sowing. Standard agronomic practices and plant protection measures were adopted uniformly in all plots throughout the crop season.

Table 1: The treatment details were as follows

Treatment	Nutrient Management Practice
T ₀	Control
T ₁	100% RDF (120:60:40 N:P ₂ O ₅ :K ₂ O kg ha ⁻¹)
T ₂	75% RDF + 25% Vermicompost + <i>Azotobacter</i> + PSB
T ₃	50% RDF + 50% Vermicompost + ZnSO ₄ @ 20 kg ha ⁻¹
T ₄	75% RDF + 25% FYM + <i>Azotobacter</i> + PSB
T ₅	50% RDF + 50% FYM + ZnSO ₄ @ 20 kg ha ⁻¹
T ₆	50% RDF + 25% FYM + 25% Vermicompost + <i>Azotobacter</i> + PSB
T ₇	25% RDF + 25% Poultry Manure + 25% Neem Cake + 25% FYM
T ₈	T ₇ + ZnSO ₄ @ 20 kg ha ⁻¹

Observations on growth parameters such as germination percentage, plant height, leaf area index, dry matter accumulation, number of tillers, crop growth rate and relative growth rate were recorded at different crop growth stages. Yield attributes including effective tillers, spike length, grains spike⁻¹ and test weight were recorded at harvest. Grain yield, straw yield, biological yield and harvest index were computed following standard procedures. Nutrient content and uptake of nitrogen, phosphorus and potassium in grain and straw were determined using established analytical techniques. Grain quality was

assessed through protein content and crude protein yield. Post-harvest soil samples were analyzed for available nitrogen, phosphorus, potassium and organic carbon status to evaluate the residual effect of treatments on soil fertility.

Economic analysis was carried out by calculating cost of cultivation, gross returns, net returns and benefit-cost ratio based on prevailing input and output prices. The recorded data were statistically analyzed using the analysis of variance (ANOVA) technique appropriate for Randomized Block Design as described by Gomez and Gomez (1984) [10]. Treatment means were compared using the critical difference (CD) test at the 5% level of significance wherever the F-test indicated significant treatment effects.

3.1 Results and Discussion: Growth Parameters

Growth parameters are important indicators of crop vigor, nutrient availability and physiological efficiency. Integrated nutrient management significantly influenced plant growth throughout the crop growth period. The combined application of inorganic fertilizers, organic manures and biofertilizers ensured a balanced nutrient supply, enhanced microbial activity and improved soil physical conditions, which collectively promoted better vegetative growth of wheat.

Table 2: Effect of integrated nutrient management on plant height (cm) of wheat at different growth stages

Treatment	30 DAS	60 DAS	90 DAS	At Harvest
T ₀ - Control	22.4	48.6	72.3	78.5
T ₁ - 100% RDF	25.8	56.2	85.4	91.6
T ₂ - 75% RDF + Vermicompost + Biofertilizers	27.6	60.8	92.3	98.7
T ₃ - 50% RDF + Vermicompost + ZnSO ₄	26.9	59.4	90.5	96.8
T ₄ - 75% RDF + FYM + Biofertilizers	27.1	60.1	91.2	97.5
T ₅ - 50% RDF + FYM + ZnSO ₄	26.4	58.7	89.3	95.2
T ₆ - 50% RDF + FYM + Vermicompost + Biofertilizers	28.3	62.5	94.6	101.2
T ₇ - Poultry Manure + Neem Cake + FYM	25.1	55.8	86.7	92.8
T ₈ - T ₇ + ZnSO ₄	26.0	57.6	88.9	94.5
SEm ±	0.72	1.12	1.46	1.68
CD (P=0.05)	2.15	3.34	4.35	5.02

Plant height increased progressively with crop age under all treatments. Significantly higher plant height was recorded under T₆ (50% RDF + 25% FYM + 25% Vermicompost + *Azotobacter* + PSB), which produced 101.2 cm height at harvest, representing 28.9% increase over control. The superiority of T₆ may be attributed to balanced nutrient availability, improved microbial activity and continuous nutrient release from organic sources. Similar observations were reported by Manna *et al.* (2005) [17], Singh *et al.* (2022) [30] and Meena *et al.* (2023) [18], who observed enhanced vegetative growth under integrated nutrient management practices.

The lowest plant height was recorded under control treatment due to poor nutrient availability and reduced soil biological activity. Treatments T₂ and T₄ remained statistically at par with T₆, indicating that partial substitution of chemical fertilizers with organic nutrient sources can effectively sustain crop growth while reducing dependence on inorganic fertilizers.

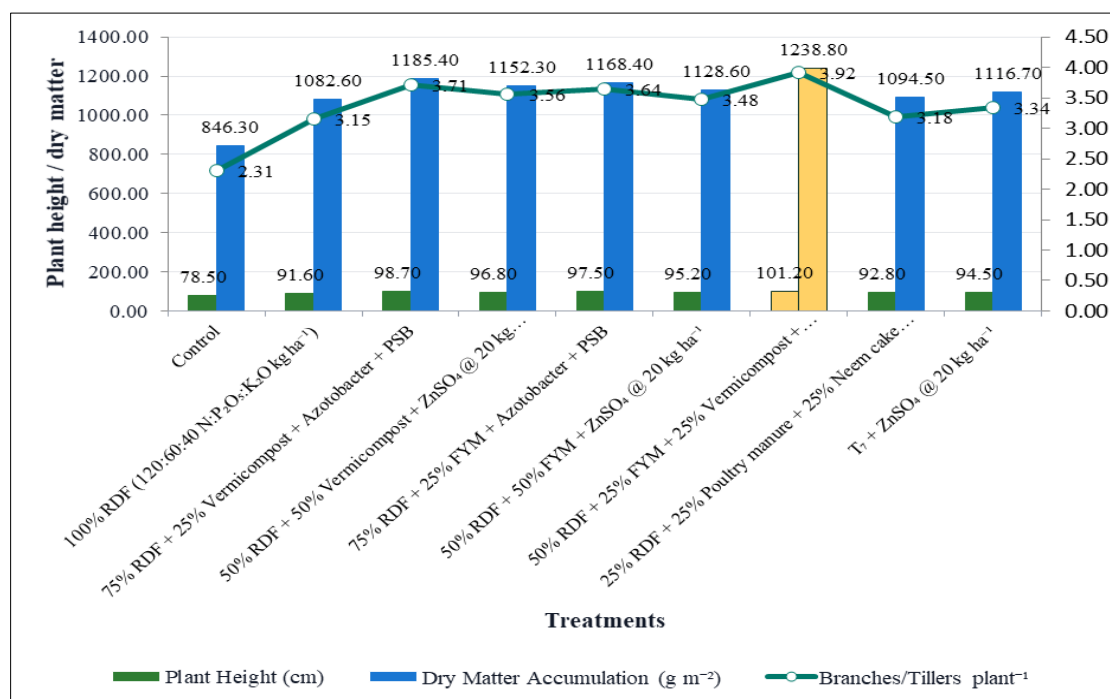


Fig 1: Integrated nutrient management significantly improved plant growth, dry matter, and tillering

Table 3: Effect of integrated nutrient management on Leaf Area Index (LAI)

Treatment	60 DAS	90 DAS
T ₀	2.42	3.08
T ₁	3.28	4.02
T ₂	3.74	4.58
T ₃	3.61	4.42
T ₄	3.68	4.49
T ₅	3.55	4.31
T ₆	3.92	4.82
T ₇	3.31	4.05
T ₈	3.47	4.18
SEm ±	0.08	0.11
CD (P=0.05)	0.24	0.33

Leaf area index showed significant variation among nutrient management treatments. The highest LAI was recorded under T₆, which exceeded control by 56.5% at 90 DAS. Increased leaf area under integrated nutrient management was mainly due to enhanced nitrogen availability, improved root growth and

increased photosynthetic surface area. Organic manures improve nutrient retention and microbial activity, resulting in better canopy development. Similar findings were reported by Kundu *et al.* (2007) ^[16], Ali *et al.* (2023) ^[2] and Sharma and Verma (2021) ^[26, 27].

Table 4: Effect of integrated nutrient management on dry matter accumulation (g m⁻²)

Treatment	30 DAS	60 DAS	90 DAS	At Harvest
T ₀	62.5	285.4	612.8	846.3
T ₁	75.8	378.6	842.5	1082.6
T ₂	81.6	426.5	964.8	1185.4
T ₃	79.8	412.8	931.6	1152.3
T ₄	80.4	419.3	946.2	1168.4
T ₅	78.6	401.5	912.4	1128.6
T ₆	84.5	445.8	1012.4	1238.8
T ₇	74.2	368.7	854.3	1094.5
T ₈	76.4	387.6	886.8	1116.7
SEm ±	2.34	8.65	18.45	22.15
CD (P=0.05)	6.98	25.81	55.05	66.08

Dry matter accumulation increased significantly under integrated nutrient management treatments. Treatment T₆ recorded the maximum biomass accumulation (1238.8 g m⁻²), which was 46.4% higher than control. Enhanced dry matter production under integrated nutrient management may be attributed to improved

nutrient availability, increased chlorophyll synthesis, better photosynthetic efficiency and enhanced root development. Similar observations were reported by Rashid *et al.* (2022) ^[25], Fageria *et al.* (2011) ^[8] and Singh *et al.* (2022) ^[30].

Table 4: Effect of integrated nutrient management on number of tillers (m^{-2})

Treatment	60 DAS	At Harvest
T ₀	258	231
T ₁	342	315
T ₂	398	371
T ₃	384	356
T ₄	392	364
T ₅	375	348
T ₆	425	392
T ₇	346	318
T ₈	362	334
SEm $\pm$	8.42	7.65
CD (P=0.05)	25.12	22.84

Discussion

The number of tillers was significantly influenced by nutrient management practices. The highest tiller population was observed under T₆, which produced 69.7% more effective tillers than control. Improved tillering under integrated nutrient management resulted from balanced nutrient availability and enhanced root proliferation. The beneficial role of FYM, vermicompost and biofertilizers in stimulating rhizosphere activity and nutrient uptake has been widely documented by Kumar and Sharma (2021) [14, 15, 26, 27], Singh *et al.* (2022) [30] and Meena *et al.* (2023)

[18].

3.2 Results and Discussion: Yield Attributes and Yield

Yield is the cumulative expression of growth, nutrient utilization efficiency and assimilate translocation during crop development. Integrated nutrient management significantly influenced yield-contributing characters and final productivity of wheat. The combined application of organic and inorganic nutrient sources ensured balanced nutrient availability throughout the crop growth period, resulting in improved reproductive growth and grain development.

Table 5: Effect of integrated nutrient management on yield attributes of wheat

Treatment	Effective Tillers (m^{-2})	Spike Length (cm)	Grains Spike ⁻¹	Test Weight (g)
T ₀ - Control	231	8.6	34.2	34.8
T ₁ - 100% RDF	315	10.8	45.4	40.6
T ₂ - 75% RDF + Vermicompost + Biofertilizers	371	12.1	53.2	44.3
T ₃ - 50% RDF + Vermicompost + ZnSO ₄	356	11.8	51.1	43.4
T ₄ - 75% RDF + FYM + Biofertilizers	364	12.0	52.4	43.9
T ₅ - 50% RDF + FYM + ZnSO ₄	348	11.5	49.8	42.7
T ₆ - 50% RDF + FYM + Vermicompost + Biofertilizers	392	12.8	56.4	45.8
T ₇ - Poultry Manure + Neem Cake + FYM	318	10.9	46.8	41.2
T ₈ - T ₇ + ZnSO ₄	334	11.2	48.5	42.0
SEm $\pm$	7.65	0.24	1.18	0.82
CD (P=0.05)	22.84	0.71	3.52	2.44

Discussion

Integrated nutrient management significantly improved all yield-attributing characters. Treatment T₆ recorded the maximum number of effective tillers (392 m^{-2}), spike length (12.8 cm), grains spike⁻¹ (56.4) and test weight (45.8 g). Compared with the control, T₆ increased effective tillers by 69.7%, spike length by 48.8%, grains spike⁻¹ by 64.9% and test weight by 31.6%. The improvement in yield attributes may be attributed to

sustained nutrient release from FYM and vermicompost, enhanced nutrient availability through biofertilizers and improved physiological activity resulting in better assimilate production and translocation towards reproductive organs. Similar findings have been reported by Singh *et al.* (2022) [30], Meena *et al.* (2023) [18], Panwar *et al.* (2012) [23] and Fageria *et al.* (2011) [8], who observed significant enhancement in spike characteristics and grain development under integrated nutrient management.

Table 6: Effect of integrated nutrient management on grain yield, straw yield, biological yield and harvest index

Treatment	Grain Yield (t ha^{-1})	Straw Yield (t ha^{-1})	Biological Yield (t ha^{-1})	Harvest Index (%)
T ₀ - Control	3.21	4.92	8.13	39.48
T ₁ - 100% RDF	4.58	6.58	11.16	41.04
T ₂ - 75% RDF + Vermicompost + Biofertilizers	5.52	7.28	12.80	43.13
T ₃ - 50% RDF + Vermicompost + ZnSO ₄	5.31	7.02	12.33	43.07
T ₄ - 75% RDF + FYM + Biofertilizers	5.44	7.15	12.59	43.21
T ₅ - 50% RDF + FYM + ZnSO ₄	5.12	6.86	11.98	42.74
T ₆ - 50% RDF + FYM + Vermicompost + Biofertilizers	5.82	7.46	13.28	43.82
T ₇ - Poultry Manure + Neem Cake + FYM	4.71	6.64	11.35	41.50
T ₈ - T ₇ + ZnSO ₄	4.94	6.79	11.73	42.11
SEm $\pm$	0.15	0.18	0.24	0.62
CD (P=0.05)	0.44	0.54	0.72	NS

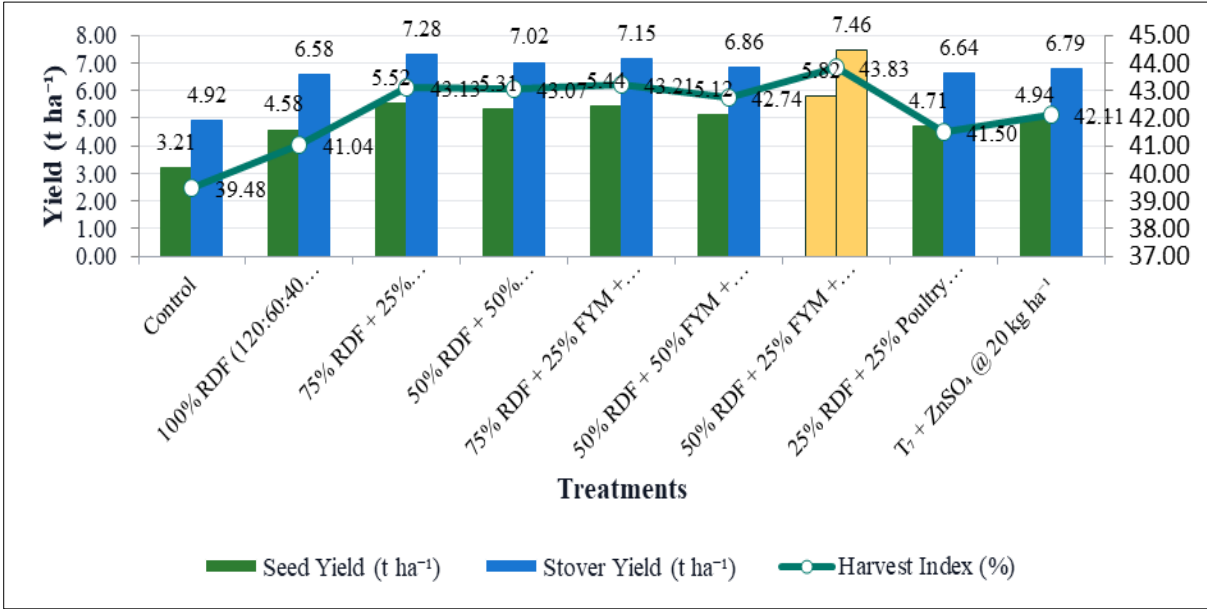


Fig 2: Integrated nutrient management significantly enhanced seed yield, stover yield, and harvest index

Grain yield differed significantly among nutrient management treatments. The highest grain yield (5.82 t ha⁻¹) was obtained with T₆, followed by T₂ (5.52 t ha⁻¹) and T₄ (5.44 t ha⁻¹). Treatment T₆ produced 81.3% higher grain yield than the control and 27.1% higher yield than the sole RDF treatment.

The superiority of T₆ may be attributed to improved vegetative growth, higher dry matter production, enhanced tillering and superior yield attributes. The integration of FYM and vermicompost improved soil physical conditions and nutrient retention, while *Azotobacter* and PSB enhanced nutrient availability and uptake. Consequently, greater photosynthate production and efficient partitioning towards grains resulted in higher productivity.

Straw yield and biological yield followed a trend similar to grain yield. The highest straw yield (7.46 t ha⁻¹) and biological yield (13.28 t ha⁻¹) were recorded under T₆. Biological yield under T₆ was approximately 63.3% higher than control, indicating the substantial influence of integrated nutrient management on biomass production.

Although harvest index varied numerically among treatments, differences remained statistically non-significant. This indicates that integrated nutrient management improved both grain and

straw production proportionately. Similar observations have been reported by Manna *et al.* (2005) [17], Rashid *et al.* (2022) [25], Kumar *et al.* (2021) [14, 15] and Ali *et al.* (2023) [2].

Relationship between Growth and Yield

The increase in grain yield under integrated nutrient management was strongly associated with enhanced growth parameters. Treatments producing higher plant height, leaf area index, dry matter accumulation and tiller population also recorded superior yield attributes and final grain yield. The positive relationship demonstrates that balanced nutrient supply improved photosynthetic efficiency, nutrient absorption and assimilate translocation, thereby enhancing crop productivity.

3.4 Economics, Correlation and Regression Analysis

Economic profitability is one of the most important criteria for evaluating the feasibility of nutrient management practices. Integrated nutrient management significantly influenced gross returns, net returns and benefit-cost ratio through its positive effect on crop productivity. Correlation and regression analyses were performed to understand the relationship between growth parameters, nutrient uptake and grain yield.

Table 7: Effect of integrated nutrient management on economics of wheat cultivation

Treatment	Cost of Cultivation (₹ ha ⁻¹)	Gross Returns (₹ ha ⁻¹)	Net Returns (₹ ha ⁻¹)	B:C Ratio
T ₀ - Control	42,600	81,200	38,600	1.58
T ₁ - 100% RDF	47,800	116,500	68,700	2.44
T ₂ - 75% RDF + Vermicompost + Biofertilizers	52,300	138,000	85,700	2.64
T ₃ - 50% RDF + Vermicompost + ZnSO ₄	53,800	133,600	79,800	2.48
T ₄ - 75% RDF + FYM + Biofertilizers	51,600	136,100	84,500	2.64
T ₅ - 50% RDF + FYM + ZnSO ₄	52,900	128,400	75,500	2.43
T ₆ - 50% RDF + FYM + Vermicompost + Azotobacter + PSB	53,200	145,500	92,300	2.74
T ₇ - Poultry Manure + Neem Cake + FYM	50,600	119,400	68,800	2.36
T ₈ - T ₇ + ZnSO ₄	51,800	125,800	74,000	2.43
SEM ±	612	2,485	2,162	0.08
CD (P=0.05)	NS	7,420	6,455	0.24

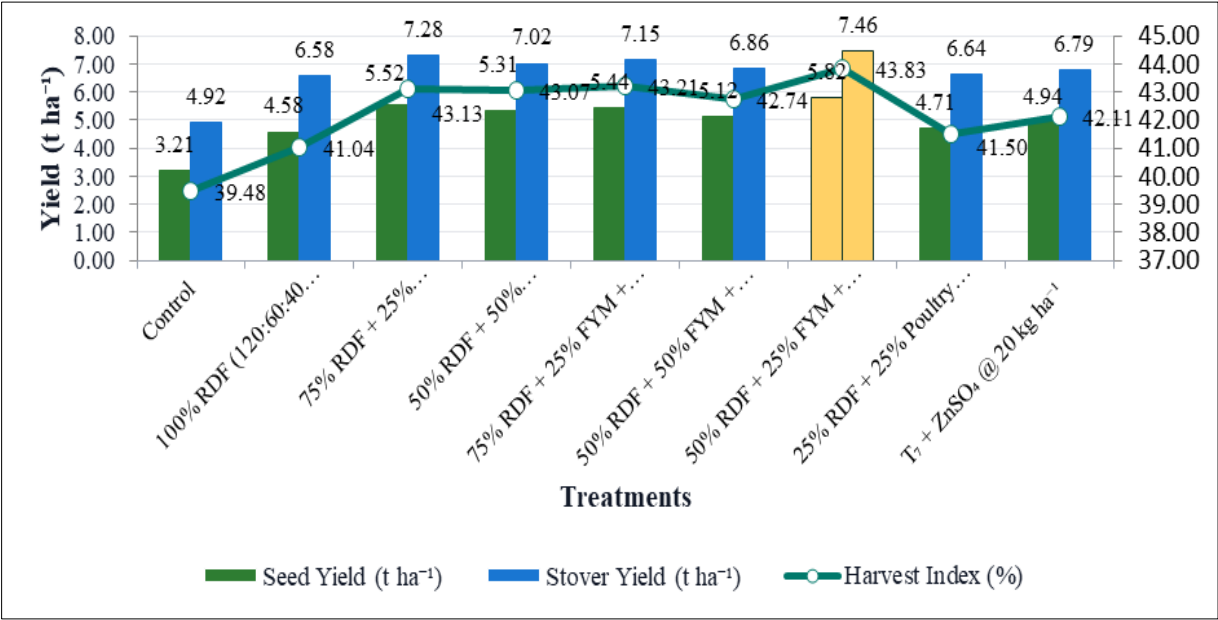


Fig 3: Integrated nutrient management enhanced seed yield, stover yield, and harvest index

Economic analysis clearly revealed that integrated nutrient management practices substantially improved profitability of wheat cultivation. Treatment T₆ recorded the highest gross return (₹145,500 ha⁻¹), net return (₹92,300 ha⁻¹) and benefit-cost ratio (2.74). Compared with control, net returns increased by approximately 139.1%. Although the cost of cultivation under integrated nutrient management treatments was slightly higher because of organic manure and biofertilizer application, the additional expenditure

was compensated by significantly higher grain and straw yields. Treatments T₂ and T₄ also produced comparable economic returns and remained statistically at par with T₆. These findings agree with those reported by Kumar *et al.* (2021)^[14, 15], Rashid *et al.* (2022)^[25], Singh *et al.* (2021) and Meena *et al.* (2023)^[18], who observed higher profitability under integrated nutrient management compared with sole fertilizer application.

Correlation Analysis

Table 8: Correlation coefficients among important parameters

Parameter	Grain Yield
Plant Height	0.948**
Leaf Area Index	0.963**
Dry Matter Accumulation	0.978**
Effective Tillers	0.986**
Nitrogen Uptake	0.971**
Phosphorus Uptake	0.958**
Potassium Uptake	0.944**
Protein Content	0.916**

Significant at P = 0.01

Discussion

Correlation analysis revealed strong positive associations between grain yield and major growth parameters. Effective tillers (r = 0.986) exhibited the strongest correlation with grain yield, followed by dry matter accumulation (r = 0.978) and nitrogen uptake (r = 0.971). These results indicate that enhanced vegetative growth and nutrient acquisition directly contributed to increased grain production.

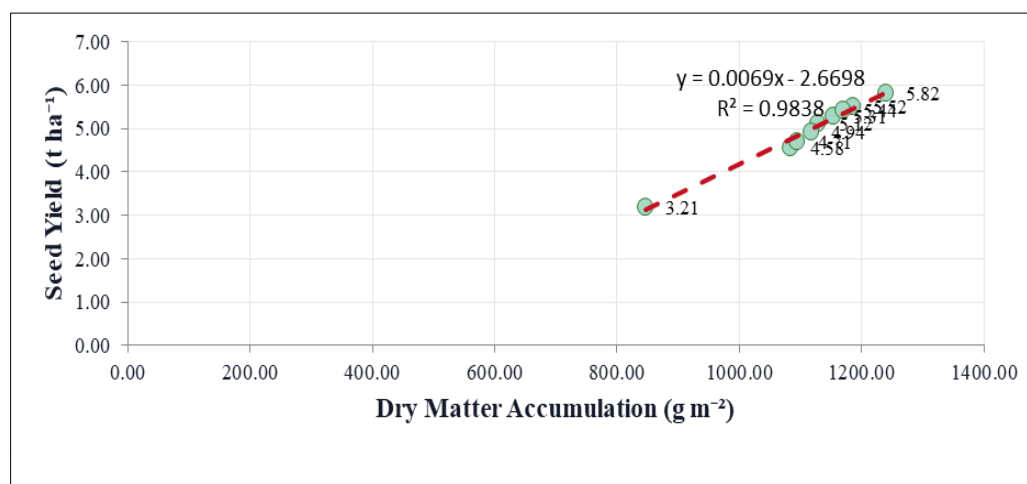
The positive relationship between nutrient uptake and grain yield confirms that balanced nutrient availability improved crop physiological efficiency and assimilate production. Similar relationships have been reported by Fageria *et al.* (2011)^[8], Panwar *et al.* (2012)^[23] and Singh *et al.* (2022).

Regression Analysis

Table 9: Regression relationship between nitrogen uptake and grain yield

Variable	Regression Equation	R ²
Grain Yield vs Nitrogen Uptake	Y = 0.042X + 0.41	0.943
Grain Yield vs Effective Tillers	Y = 0.013X + 0.68	0.972
Grain Yield vs Dry Matter Accumulation	Y = 0.004X + 0.79	0.956

Where:
Y = Grain yield (t ha⁻¹)
X = Independent variable



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