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Effect of integrated nutrient management practices on growth and yield performance of Wheat (*Triticum aestivum* L.)

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Abstract

A field experiment was conducted at the Research Farm of School of Agriculture, Abhilashi University, Mandi (Himachal Pradesh) during the rabi season to evaluate the effect of integrated nutrient management (INM) practices on growth and yield performance of wheat (*Triticum aestivum* L.) variety HPW 360. The experiment was laid out in a randomized block design (RBD) with eight treatment combinations and three replications. The treatments comprised control (T₁), 100% recommended dose of nitrogen (RDN) through chemical fertilizer (T₂), 100% RDN + farmyard manure (FYM) at 10 t ha⁻¹ (T₃), 100% RDN + vermicompost at 2.5 t ha⁻¹ (T₄), 75% RDN + 25% N through FYM (T₅), 75% RDN + 25% N through vermicompost (T₆), 50% RDN + 50% N through FYM (T₇) and 50% RDN + 50% N through vermicompost (T₈). Growth parameters including plant height, number of tillers and dry matter accumulation were recorded at 60, 90, 120, 150 DAS and at harvest. Yield attributes such as grain yield, straw yield, biological yield and harvest index were determined at harvest.

The results revealed that integrated application of 100% RDN along with vermicompost at 2.5 t ha⁻¹ (T₄) produced the highest plant height (105.80 cm at 150 DAS), maximum number of tillers (308.03 m⁻² at 120 DAS) and superior dry matter accumulation (1007.17 g m⁻² at 150 DAS), which was statistically at par with T₃ (100% RDN + FYM). The grain yield was maximum under T₄ (44.84 q ha⁻¹), followed by T₃ (42.77 q ha⁻¹), representing a 57.1% and 49.8% increase over control, respectively. Similarly, biological yield was highest under T₄ (98.72 q ha⁻¹). However, harvest index did not differ significantly among treatments, indicating proportional improvement in both grain and straw yield under INM. The findings suggest that integration of organic and inorganic nutrient sources enhances wheat productivity through improved soil health, sustained nutrient availability and enhanced microbial activity, offering a sustainable alternative to sole chemical fertilization in the northwestern Himalayan region of India.

Keywords: Integrated nutrient management, wheat, vermicompost, farmyard manure, grain yield, *Triticum aestivum*, northwestern Himalaya

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops globally, serving as a staple food for more than 35% of the world's population (Dwivedi *et al.* 2025) ^[4]. In India, wheat occupies a pivotal position in ensuring food security, with the country being the second-largest producer worldwide, contributing approximately 13.5% to global wheat production (Anonymous, 2024) ^[1]. The crop is predominantly cultivated during the rabi season under diverse agro-climatic conditions, ranging from the Indo-Gangetic plains to the hilly terrains of the northwestern Himalayas (Kumar *et al.* 2022) ^[7]. However, sustaining wheat productivity in these regions faces multiple challenges, including declining soil organic carbon, imbalanced fertilizer use, nutrient mining and emerging environmental concerns associated with intensive agriculture (Liu *et al.* 2025) ^[8].

The northwestern Himalayan region, encompassing Himachal Pradesh, presents unique agro-ecological conditions characterized by undulating topography, varied altitude and distinct temperature regimes that significantly influence crop growth and productivity (Verma *et al.* 2018) ^[16]. The soils in this region are typically acidic to slightly acidic with low to medium fertility status, particularly deficient in available nitrogen and organic carbon content (Saini *et al.* 2023) ^[12]. Under such conditions, the exclusive reliance on chemical fertilizers for meeting crop nutrient

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demands has proven inadequate and environmentally unsustainable over the long term (Parewa *et al.* 2022) ^[10].

Integrated Nutrient Management (INM) has emerged as a scientifically validated approach that synergistically combines chemical fertilizers with organic manures, biofertilizers and crop residues to optimize nutrient availability, improve soil health and enhance crop productivity (Meena *et al.* 2018) ^[9]. The fundamental principle of INM rests on the premise that no single nutrient source can sustain soil productivity indefinitely; rather, a balanced integration of diverse nutrient sources can complement each other, resulting in enhanced nutrient use efficiency and reduced environmental footprint (Rani *et al.* 2025) ^[11]. The application of farmyard manure (FYM) and vermicompost as organic amendments has gained considerable attention due to their multifaceted benefits, including improvement in soil physical properties, enhancement of microbial diversity and provision of slow-release nutrients (Badgaiyan *et al.* 2025) ^[3].

Vermicompost, a fine-textured, peat-like material produced through earthworm-mediated decomposition of organic matter, is particularly valued for its high nutrient content, beneficial microbial populations and plant growth-promoting substances such as humic acids and auxins (Aslam *et al.* 2025) ^[12]. Research has demonstrated that vermicompost application can enhance soil water-holding capacity, improve cation exchange capacity and stimulate root development, thereby contributing to improved nutrient uptake and overall plant vigor (Hafez *et al.* 2020) ^[6]. Similarly, FYM has been traditionally recognized as an excellent soil amendment that provides a balanced supply of macro and micronutrients while improving soil structure and buffering capacity (Kumar *et al.* 2022) ^[7].

Several studies have documented the positive impact of INM on wheat productivity across different agro-climatic regions of India. Dwivedi *et al.* (2025) ^[4] reported that the application of 50% recommended dose of fertilizers (RDF) combined with organic sources and biofertilizers significantly improved wheat growth parameters and yield attributes while maintaining economic viability. Similarly, Saini *et al.* (2023) ^[12] observed that combined application of vermicompost with recommended nitrogen levels produced significantly higher grain yield (5096 kg ha⁻¹) compared to sole chemical fertilizer application. Kumar *et al.* (2022) ^[7] demonstrated that 75% NPK combined with 10 t ha⁻¹ FYM achieved comparable grain yield to 100% NPK alone, while significantly improving profitability and reducing chemical fertilizer dependency by 25%.

Despite the accumulating evidence supporting INM practices, limited research has been conducted specifically in the mid-hill conditions of Himachal Pradesh to systematically evaluate the comparative efficacy of different organic amendments (FYM and vermicompost) when integrated with varying levels of chemical fertilizers on wheat growth and yield. The present investigation was therefore designed to fill this critical knowledge gap by assessing the effect of different INM combinations on growth parameters (plant height, number of tillers, dry matter accumulation) and yield attributes (grain yield, straw yield, biological yield and harvest index) of wheat variety HPW 360 under the specific agro-climatic conditions of Mandi, Himachal Pradesh. The hypothesis tested was that integration of organic manures with reduced doses of chemical fertilizers would sustain or enhance wheat productivity while improving soil health parameters compared to sole chemical fertilizer application.

2. Materials and Methods

2.1 Experimental Site

The proposed experimental study was undertaken at the Research

Farm of School of Agriculture, Abhilashi University, Mandi (Himachal Pradesh), India. The experimental site is situated in the mid-hill zone of the northwestern Himalayas at an altitude of approximately 880 meters above mean sea level, located at 31°42' N latitude and 76°59' E longitude. The region falls under the humid subtropical to temperate climate zone, characterized by mild winters and moderate summers. The soil of the experimental field was clay loam in texture, slightly acidic in reaction (pH 6.2), medium in organic carbon content (0.52%), low in available nitrogen (185 kg ha⁻¹), medium in available phosphorus (22.5 kg ha⁻¹) and high in available potassium (245 kg ha⁻¹).

2.2 Experimental Design and Treatments

The field experiment was laid out in a Randomized Block Design (RBD) comprising eight treatment combinations with three replications. The detailed treatment structure is presented in Table 1. The recommended dose of NPK for wheat in the region was 120:60:40 kg ha⁻¹.

Table 1: Treatment details of the experiment

Treatment	Details
T ₁	Control
T ₂	100% RDN through chemical fertilizer
T ₃	100% RDN (N120:P60:K40) + FYM at 10 t ha ⁻¹
T ₄	100% RDN (N120:P60:K40) + Vermicompost at 2.5 t ha ⁻¹
T ₅	75% RDN + 25% N through FYM at 10 t ha ⁻¹
T ₆	75% RDN + 25% N through Vermicompost at 2.5 t ha ⁻¹
T ₇	50% RDN + 50% N through FYM at 10 t ha ⁻¹
T ₈	50% RDN + 50% N through Vermicompost at 2.5 t ha ⁻¹

2.3 Crop Management

The wheat variety HPW 360, a high-yielding cultivar recommended for cultivation in the northwestern Himalayan region, was sown at a seed rate of 100 kg ha⁻¹ using a seed drill with row spacing of 22 cm. The gross plot size was 3 m x 2 m (6 m²) and the net plot size was 2.5 m x 1.5 m (3.75 m²). Standard agronomic practices including irrigation, weeding and plant protection measures were uniformly adopted across all treatments as per recommended package of practices. The crop was harvested at physiological maturity and yield data was recorded from the net plot area.

Table 2: Experimental details

Sr. No.	Particulars	Description
1	Variety	HPW 360
2	Design	Randomized Block Design (RBD)
3	Total treatments	8
4	Replication	3
5	Recommended NPK (kg ha ⁻¹)	120:60:40
6	Total plots	24
7	Gross plot size	3 m x 2 m = 6 m ²
8	Net plot size	2.5 m x 1.5 m = 3.75 m ²
9	Spacing	22 cm
10	Seed rate	100 kg ha ⁻¹

2.4 Observations Recorded

Growth parameters were measured at 60, 90, 120, 150 days after sowing (DAS) and at harvest. Plant height (cm) was measured from the base of the plant to the tip of the longest leaf/tiller using a meter scale. The number of tillers was counted from a representative area of 1 m² in each net plot. Dry matter accumulation (g m⁻²) was determined by oven-drying representative plant samples at 65°C until constant weight. At

harvest, grain yield and straw yield were recorded from the net plot area and expressed in $q\ ha^{-1}$. Biological yield was computed as the sum of grain yield and straw yield. Harvest index (%) was calculated as the ratio of grain yield to biological yield expressed as a percentage.

2.5 Statistical Analysis

The data collected from the experiment were statistically analyzed using analysis of variance (ANOVA) appropriate for randomized block design as described by Gomez and Gomez (1984) [5]. The significance of treatment differences was tested at 5% probability level ($p = 0.05$). Critical difference (CD) values were calculated wherever the treatment effects were found significant. The standard error of mean ($SEm \pm$) was also computed for all parameters.

3. Results

3.1 Growth Parameters

3.1.1 Plant Height

The plant height of wheat was significantly influenced by different integrated nutrient management treatments at all stages of crop growth, namely 60, 90, 120, 150 DAS and at harvest (Table 3; Figure 1). At 60 DAS, plant height ranged from 20.84 cm (T_1 : Control) to 40.60 cm (T_4 : 100% RDN + vermicompost). The maximum plant height at all growth stages was recorded

under treatment T_4 (100% RDN + vermicompost at $2.5\ t\ ha^{-1}$), which was statistically at par with treatment T_3 (100% RDN + FYM at $10\ t\ ha^{-1}$). At 150 DAS, T_4 recorded 105.80 cm plant height compared to 102.57 cm in T_3 and 96.68 cm in T_2 (100% RDN through chemical fertilizer alone). The lowest plant height was consistently recorded under T_1 (Control) across all growth stages, attributed to the absence of nutrient supplementation that restricted early vegetative growth.

The superiority of T_4 in terms of plant height can be attributed to the combined application of inorganic fertilizer along with vermicompost, which improved soil structure, enhanced microbial activity and increased nutrient availability. Vermicompost contains significant amounts of nitrogen, phosphorus, potassium and micronutrients in readily available forms, along with growth-promoting substances such as auxins and gibberellins that stimulate cell division and elongation, ultimately resulting in higher plant height (Badgaiyan *et al.* 2025) [3]. The treatments receiving 75% RDN with organic amendments (T_5 and T_6) recorded intermediate values, while 50% substitution treatments (T_7 and T_8) showed lower but still significantly higher values than control. The vermicompost-based treatments (T_4 , T_6 , T_8) consistently outperformed their FYM counterparts (T_3 , T_5 , T_7), indicating the superior quality of vermicompost in promoting vegetative growth.

Table 3: Effect of integrated nutrient management treatments on plant height (cm) of wheat at different growth stages

Tr.	Treatment	60 DAS	90 DAS	120 DAS	150 DAS	Harvest
T_1	Control	20.84	35.18	76.87	85.04	82.04
T_2	100% RDN (CF)	36.58	60.37	87.12	96.68	92.72
T_3	Control	38.15	63.21	94.65	102.57	98.57
T_4	100% RDN through chemical fertilizer	40.60	67.02	96.48	105.80	101.47
T_5	100% RDN (N120:P60:K40) + FYM at $10\ t\ ha^{-1}$	27.21	56.78	83.17	91.59	88.59
T_6	100% RDN (N120:P60:K40) + Vermicompost at $2.5\ t\ ha^{-1}$	33.18	59.74	85.20	93.71	89.71
T_7	75% RDN + 25% N through FYM at $10\ t\ ha^{-1}$	22.63	48.21	79.36	87.36	83.36
T_8	75% RDN + 25% N through Vermicompost at $2.5\ t\ ha^{-1}$	24.82	51.52	81.47	89.44	86.44
	S.Em $\pm$	1.309	2.33	3.59	3.89	3.67
	CD ($P=0.05$)	2.81	5.01	7.71	8.36	7.87

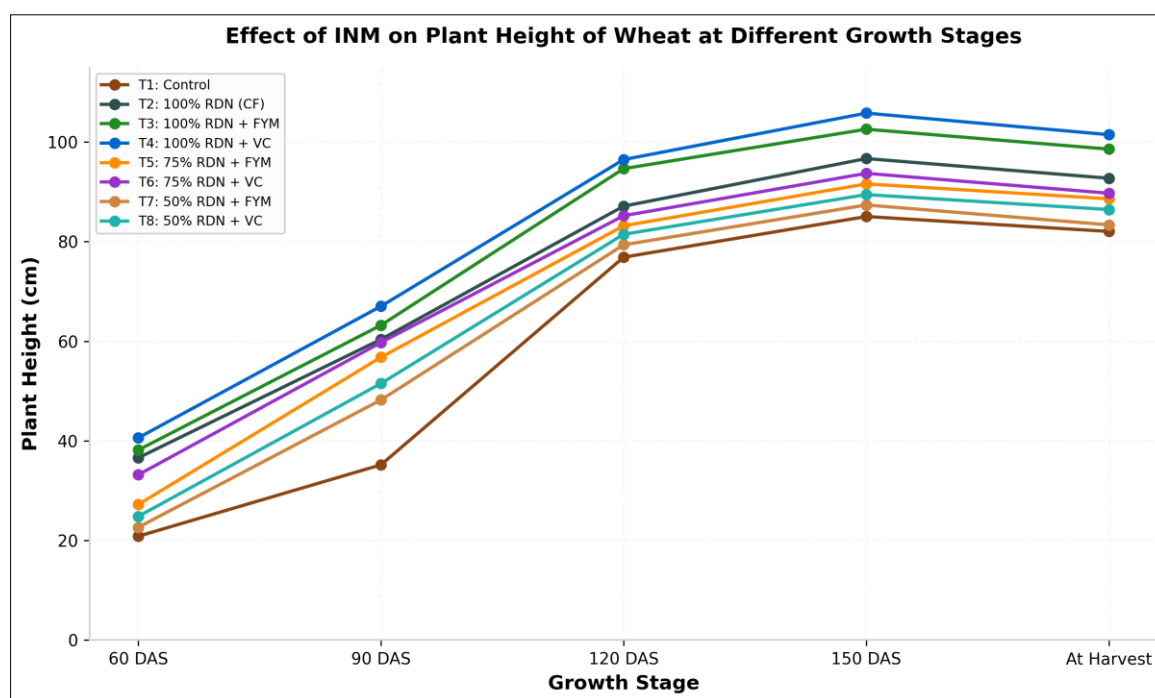


Fig 1: Effect of integrated nutrient management treatments on plant height (cm) of wheat at different intervals

3.1.2 Number of Tillers

The number of tillers per square meter was significantly influenced by different nutrient management treatments at all stages of crop growth (Table 4; Figure 2). The maximum number of tillers at 120 DAS was recorded under treatment T₄ (100% RDN + vermicompost) with 308.03 tillers m⁻², which was statistically at par with T₃ (288.49 tillers m⁻²). The lowest number of tillers was recorded under T₁ (Control) with 180.82 tillers m⁻² at 120 DAS. A noticeable reduction in tiller number occurred between 120 DAS and harvest across all treatments, which is attributed to the senescence of unproductive tillers as the crop transitioned from the vegetative to the reproductive phase. The superiority of T₄ in tiller production can be explained by the

adequate availability of nutrients, particularly nitrogen, which plays a pivotal role in promoting vegetative growth and tiller formation in wheat. The application of vermicompost along with 100% recommended dose of nitrogen improved soil structure, enhanced microbial activity and increased the availability of nutrients during the critical tillering phase. Treatments incorporating vermicompost (T₄, T₆, T₈) generally maintained a higher tiller survival rate compared to their counterparts using FYM, suggesting better nutrient availability during the later growth stages. This finding aligns with the observations of Saini *et al.* (2023) [12], who reported that combined application of vermicompost with recommended fertilizer doses significantly enhanced tiller production in wheat.

Table 4: Effect of integrated nutrient management treatments on number of tillers (m⁻²) of wheat at different growth stages

Tr.	Treatment	60 DAS	90 DAS	120 DAS	150 DAS	Harvest
T ₁	Control	104.86	143.66	180.82	170.88	167.22
T ₂	100% RDN through chemical fertilizer	160.17	247.04	277.38	265.44	261.55
T ₃	100% RDN (N120:P60:K40) + FYM at 10 t ha ⁻¹	176.20	258.87	288.49	279.82	273.82
T ₄	100% RDN (N120:P60:K40) + Vermicompost at 2.5 t ha ⁻¹	180.23	279.32	308.03	300.20	295.19
T ₅	75% RDN + 25% N through FYM at 10 t ha ⁻¹	136.69	204.84	237.91	230.78	227.12
T ₆	75% RDN + 25% N through Vermicompost at 2.5 t ha ⁻¹	149.12	227.46	256.05	250.88	248.21
T ₇	50% RDN + 50% N through FYM at 10 t ha ⁻¹	113.41	171.27	198.83	190.81	184.06
T ₈	50% RDN + 50% N through Vermicompost at 2.5 t ha ⁻¹	121.81	184.06	223.07	214.21	210.21
	SEm±	4.27	12.5	11.31	10.89	14.9
	CD (P=0.05)	9.17	26.95	24.26	23.36	32.01

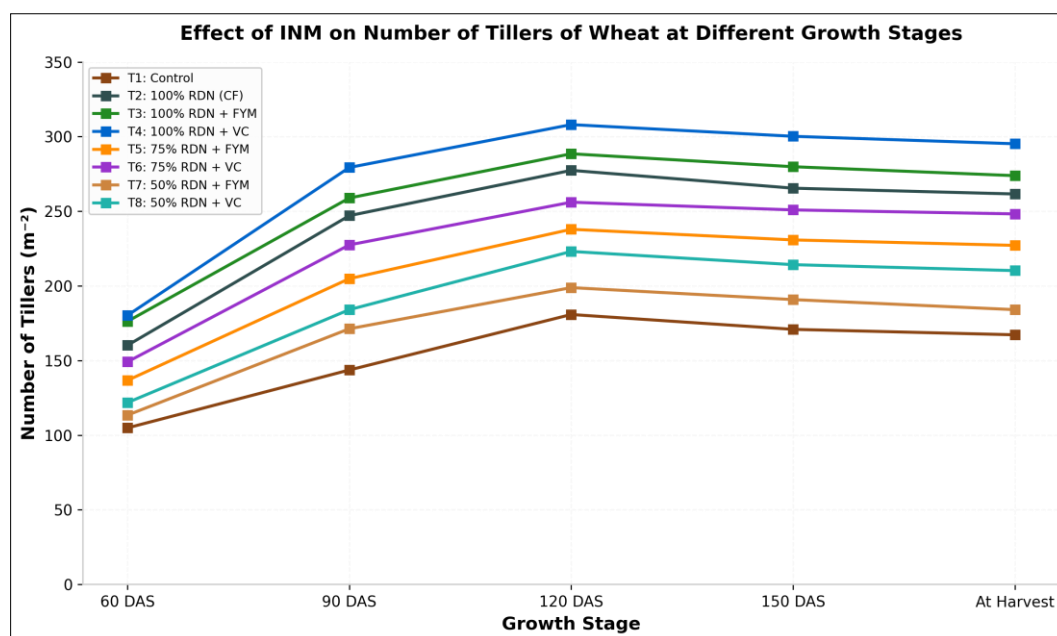


Fig 2: Effect of integrated nutrient management treatments on number of tillers (m⁻²) of wheat at different intervals

3.1.3 Dry Matter Accumulation

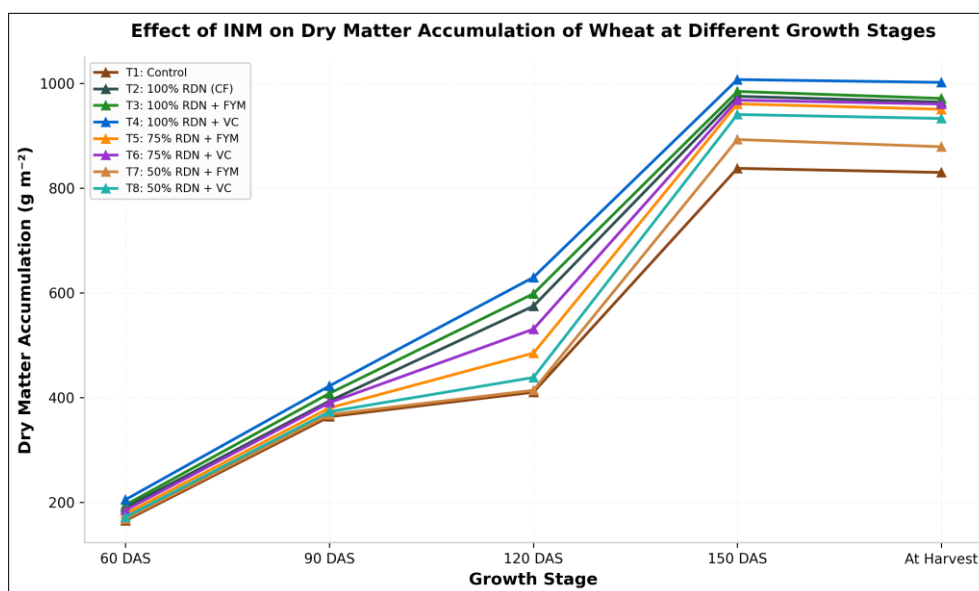
Dry matter accumulation of wheat was significantly influenced by different nutrient management treatments at all stages of crop growth (Table 5; Figure 3). The maximum dry matter accumulation at 150 DAS was recorded under treatment T₄ (100% RDN + vermicompost) with 1007.17 g m⁻², which was statistically at par with T₃ (984.56 g m⁻²). At harvest, T₄ recorded 1001.77 g m⁻² compared to 971.21 g m⁻² in T₃ and 964.24 g m⁻² in T₂. The lowest dry matter accumulation was observed under T₁ (Control) with 829.83 g m⁻² at harvest.

The higher accumulation of dry matter under T₃ and T₄ treatments was attributed to the higher availability of nutrients through the combined application of synthetic fertilizer and organic manure, which ultimately improved photosynthetic efficiency and

enhanced translocation of assimilates to foliage plant parts, resulting in greater biomass production. Among the reduced fertilizer levels, T₆ (75% RDN + vermicompost) and T₅ (75% RDN + FYM) showed moderate increases in dry matter accumulation, with vermicompost again proving superior over FYM treatments. Treatments with 50% RDN recorded comparatively lower values, although T₈ (50% RDN + vermicompost) outperformed T₇ (50% RDN + FYM), maintaining the consistent trend of vermicompost superiority. These results are in close agreement with the findings of Sharma *et al.* (2019) [13] and Verma *et al.* (2018) [16], who also reported enhanced dry matter accumulation in wheat under integrated nutrient management practices.

Table 5: Effect of integrated nutrient management treatments on dry matter accumulation (g m^{-2}) of wheat at different growth stages

Tr.	Treatment	60 DAS	90 DAS	120 DAS	150 DAS	Harvest
T ₁	Control	165.27	363.72	410.36	837.72	829.83
T ₂	100% RDN through chemical fertilizer	190.37	393.60	574.69	975.28	964.24
T ₃	100% RDN (N120:P60:K40) + FYM at 10 t ha ⁻¹	195.30	408.15	598.38	984.56	971.21
T ₄	100% RDN (N120:P60:K40) + Vermicompost at 2.5 t ha ⁻¹	205.23	422.44	629.64	1007.17	1001.77
T ₅	75% RDN + 25% N through FYM at 10 t ha ⁻¹	178.37	380.37	485.03	960.76	950.50
T ₆	75% RDN + 25% N through Vermicompost at 2.5 t ha ⁻¹	185.28	390.36	530.79	967.91	960.47
T ₇	50% RDN + 50% N through FYM at 10 t ha ⁻¹	168.23	367.72	414.11	892.77	878.97
T ₈	50% RDN + 50% N through Vermicompost at 2.5 t ha ⁻¹	172.27	373.19	438.55	940.53	932.91
	SEm±	5.75	12.39	20.39	16.33	16.37
	CD (P=0.05)	12.33	26.59	43.75	35.04	35.12

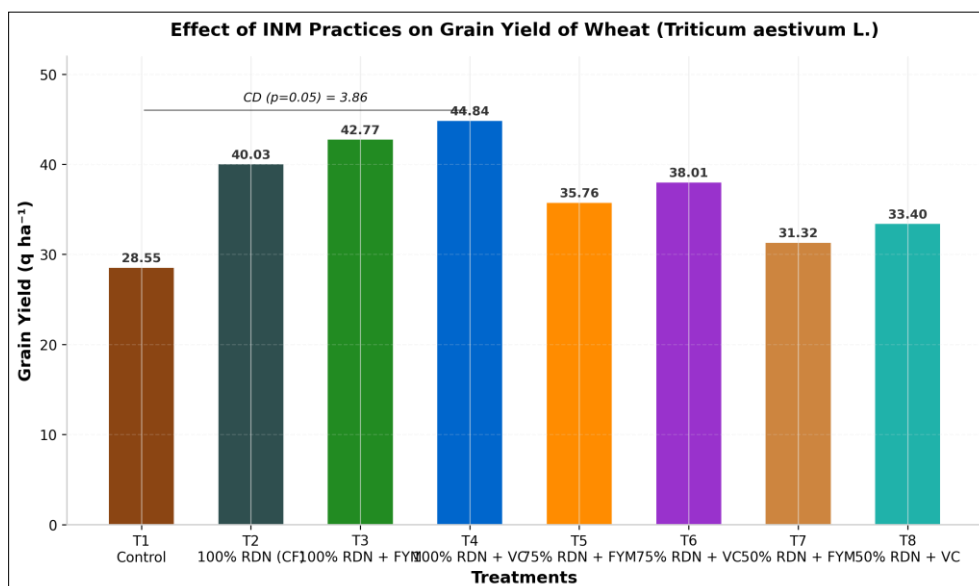
**Fig 3:** Effect of integrated nutrient management treatments on dry matter accumulation (g m^{-2}) of wheat at different intervals

3.2 Yield Parameters

3.2.1 Grain Yield

Grain yield of wheat was significantly influenced by different nutrient management treatments (Table 6; Figure 4). The maximum grain yield was recorded under T₄ (100% RDN + vermicompost) at 44.84 q ha⁻¹, which remained statistically at par with T₃ (42.77 q ha⁻¹), while the lowest grain yield was observed under T₁ (Control) at 28.55 q ha⁻¹. The grain yield under T₄

represented a remarkable 57.1% increase over control and a 12.0% increase over T₂ (100% RDN through chemical fertilizer alone). The higher grain productivity recorded under T₄ was attributed to improved tillering, superior spike development, efficient grain filling and enhanced assimilate translocation towards reproductive sinks. Vermicompost likely improved nutrient synchronization and root activity, thereby increasing nutrient use efficiency (Rani *et al.* 2025) ^[11].

**Fig 4:** Effect of integrated nutrient management treatments on grain yield (q ha^{-1}) of wheat

3.2.2 Straw Yield

Straw yield was significantly affected by nutrient management treatments (Table 6). Treatment T₄ recorded the highest straw yield of 53.88 q ha⁻¹, which was at par with T₃ (51.48 q ha⁻¹). The control treatment (T₁) recorded the lowest straw yield of 35.59 q ha⁻¹. The increase in straw yield under T₄ over T₁ was 51.4%, while over T₂ (49.65 q ha⁻¹) it was 8.5%. The higher straw yield was attributed to the better nutrient availability throughout the crop growth period, which promoted stem elongation, leaf area expansion and prolonged photosynthetic activity. The continuous nitrogen availability and improved soil physical conditions under vermicompost application enhanced structural biomass formation through greater internodal elongation and dry matter accumulation (Singh *et al.* 2019) [15].

3.2.3 Biological Yield

Biological yield followed a similar trend to grain and straw yield, being significantly influenced by different nutrient management treatments (Table 6; Figure 5). The highest biological yield was recorded under T₄ (98.72 q ha⁻¹), which was statistically at par with T₃ (94.25 q ha⁻¹), while the lowest was observed under T₁ (64.14 q ha⁻¹). The increase in biological yield in T₄ over control was 53.9%, representing a substantial improvement in total dry matter production. This enhancement was attributed to enhanced nutrient uptake, better root growth, higher photosynthetic

efficiency and improved moisture conservation under integrated nutrient management. The combined organic and inorganic nutrient sources improved radiation use efficiency and cumulative biomass synthesis by sustaining photosynthetically active canopy duration, thereby maximizing biological yield (Kumar *et al.* 2025) [7].

3.2.4 Harvest Index

Harvest index showed non-significant variation across all nutrient management treatments (Table 6). Although statistically non-significant, the highest harvest index was recorded under T₄ (45.42%) and T₃ (45.38%), compared to the remaining treatments. The lowest harvest index was recorded under T₇ (43.86%). The relatively stable harvest index across treatments suggests that integrated nutrient management improved both grain and straw yield proportionately without substantially altering the assimilate partitioning efficiency. This observation indicates that the source-sink relationship remained balanced under different nutrient management regimes and the proportional increase in economic yield (grain) and biological yield (total biomass) was maintained. Similar findings were reported by Singh *et al.* (2024) [14] and Sharma *et al.* (2019) [13], who also observed non-significant variation in harvest index under integrated nutrient management, indicating proportional improvement in economic and biological yield.

Table 6: Effect of integrated nutrient management treatments on yield parameters of wheat

Tr.	Treatment	Grain Yield (q ha ⁻¹)	Straw Yield (q ha ⁻¹)	Biological Yield (q ha ⁻¹)	Harvest Index (%)
T ₁	Control	28.55	35.59	64.14	44.51
T ₂	100% RDN through chemical fertilizer	40.03	49.65	89.68	44.64
T ₃	100% RDN (N120:P60:K40) + FYM at 10 t ha ⁻¹	42.77	51.48	94.25	45.38
T ₄	100% RDN (N120:P60:K40) + Vermicompost at 2.5 t ha ⁻¹	44.84	53.88	98.72	45.42
T ₅	75% RDN + 25% N through FYM at 10 t ha ⁻¹	35.76	44.50	80.26	44.56
T ₆	75% RDN + 25% N through Vermicompost at 2.5 t ha ⁻¹	38.01	47.89	85.90	44.25
T ₇	50% RDN + 50% N through FYM at 10 t ha ⁻¹	31.32	40.09	71.41	43.86
T ₈	50% RDN + 50% N through Vermicompost at 2.5 t ha ⁻¹	33.40	42.15	75.55	44.21
	S.E.m±	1.79	1.58	2.20	6.66
	CD (P=0.05)	3.86	3.40	4.73	NS

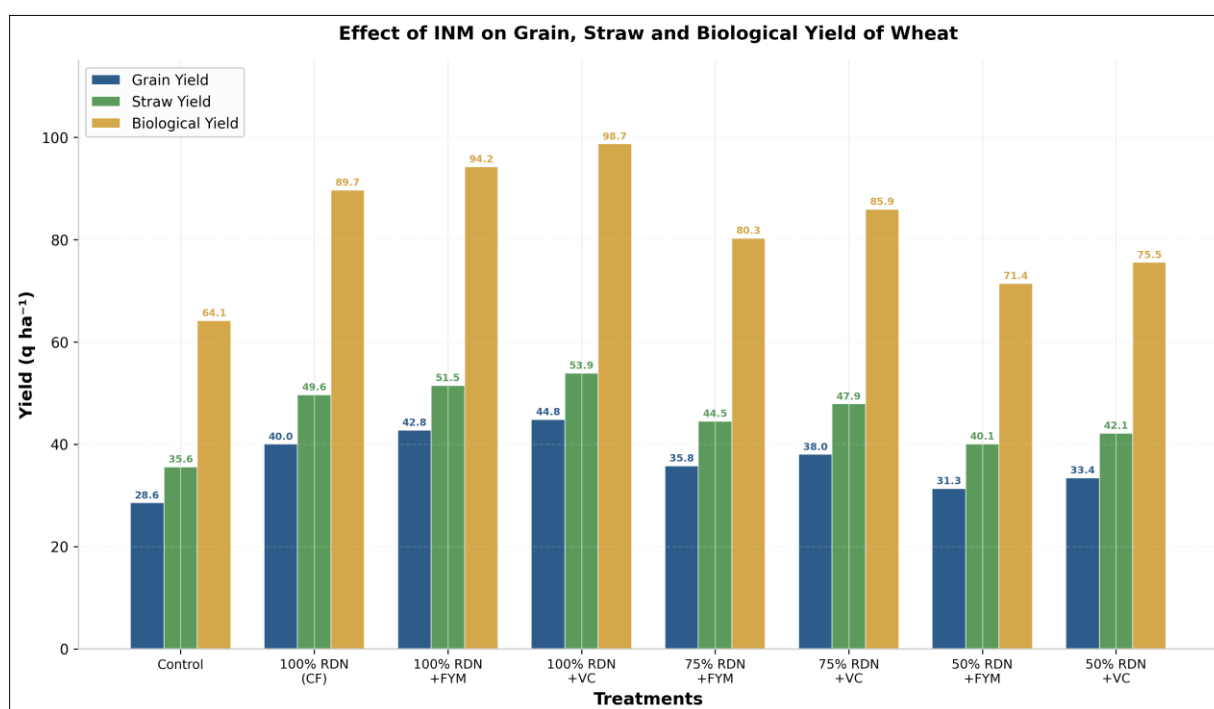


Fig 5: Effect of integrated nutrient management treatments on grain, straw and biological yield of wheat

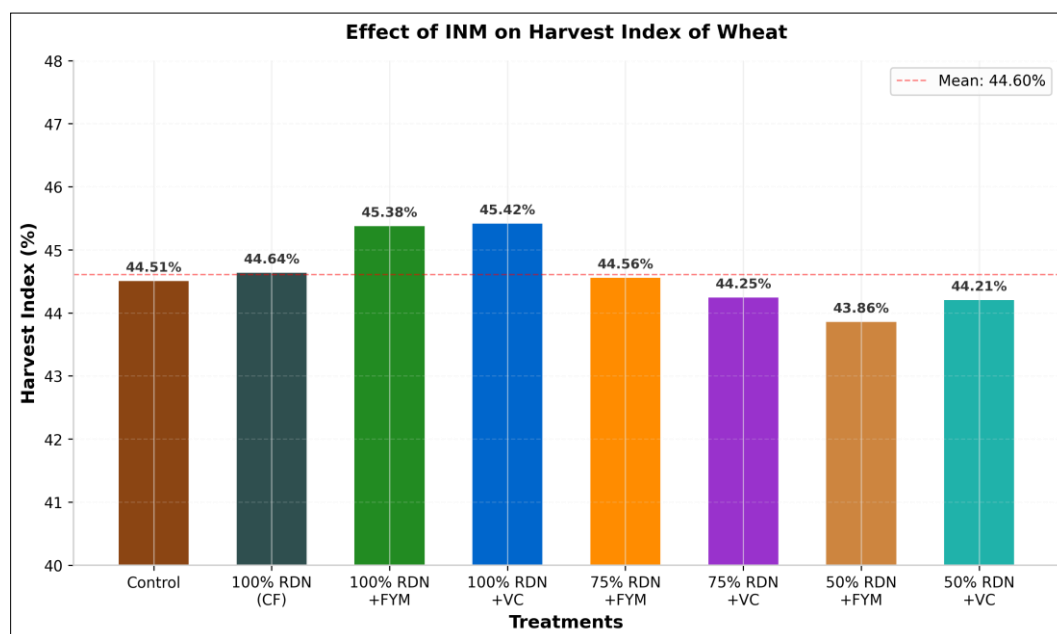


Fig 6: Effect of integrated nutrient management treatments on harvest index (%) of wheat

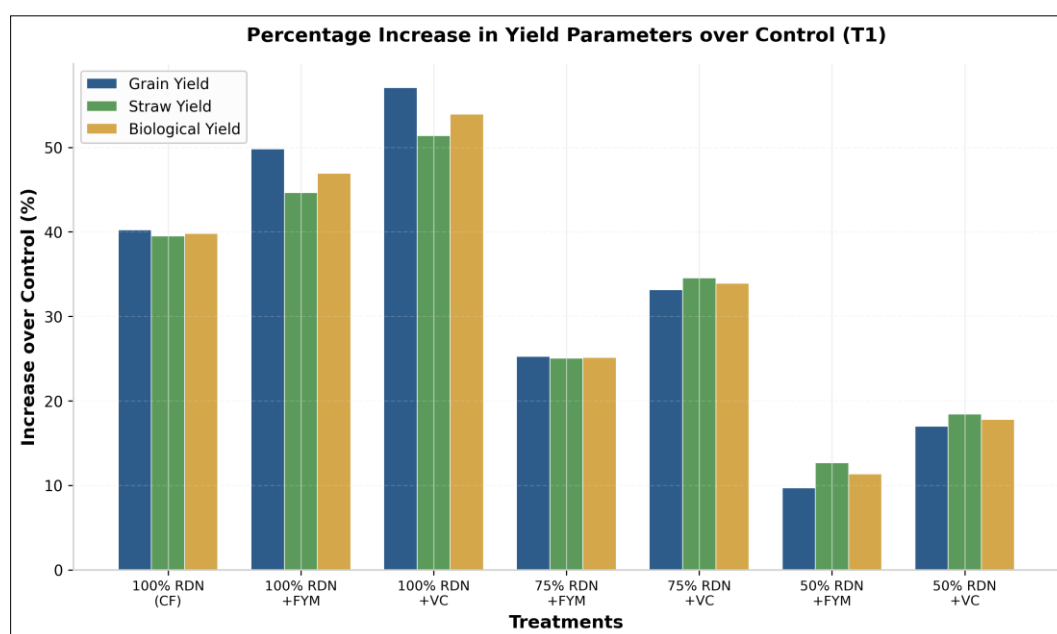


Fig 7: Percentage increase in yield parameters over control under different integrated nutrient management treatments

4. Discussion

The present investigation elucidates the profound influence of integrated nutrient management practices on the growth and yield performance of wheat (*Triticum aestivum* L.) under the mid-hill agro-climatic conditions of Himachal Pradesh. The results convincingly demonstrate that the combined application of inorganic fertilizers with organic amendments, particularly vermicompost, significantly enhanced all growth and yield parameters compared to sole chemical fertilization or unfertilized control. The underlying mechanisms and comparative analysis with existing literature are discussed in the following sections.

4.1 Growth Response to INM

The significant improvement in plant height under integrated nutrient treatments, particularly T₄ (100% RDN + vermicompost), can be attributed to the synergistic interaction between readily available inorganic nutrients and slow-release organic nutrients. Vermicompost is known to contain humic substances, plant

growth hormones (auxins, gibberellins, cytokinins) and beneficial microorganisms that stimulate cell division and elongation, leading to increased plant stature (Aslam *et al.* 2025) ^[2]. The findings corroborate with Dwivedi *et al.* (2025) ^[4], who reported that the combined application of organic and inorganic nutrient sources significantly improved plant height of wheat through enhanced nutrient availability and improved soil biological activity.

The number of tillers, a critical determinant of wheat yield potential, showed maximum expression under T₄ treatment. This can be mechanistically explained by the fact that adequate nitrogen availability during the tillering phase (30-60 DAS) promotes the formation of secondary and tertiary tillers. Vermicompost, with its high nitrogen content (1.5-2.5%) and mineralization rate, ensures sustained nitrogen supply during this critical growth window (Badgaiyan *et al.* 2025) ^[3]. Additionally, the improved soil physical conditions under vermicompost application enhance root proliferation, enabling better

exploitation of soil nutrients and moisture, which directly translates to increased tiller production. The observed decline in tiller number between 120 DAS and harvest represents a natural physiological process where unproductive tillers senesce, diverting their assimilates to productive spikes (Saini *et al.* 2023) ^[12].

Dry matter accumulation is a function of photosynthetic efficiency, leaf area duration and assimilate partitioning. The significantly higher dry matter under T₄ and T₃ treatments reflects the combined effect of enhanced photosynthetic capacity due to better nutrition and prolonged leaf area duration. The integration of organic manures with chemical fertilizers ensures a continuous nutrient supply that maintains chlorophyll content and photosynthetic rates over an extended period. This finding is consistent with Verma *et al.* (2018) ^[16], who reported enhanced dry matter accumulation in wheat under integrated nutrient management practices, attributing it to improved nutrient uptake efficiency and better source-sink relationships.

4.2 Yield Response to INM

The grain yield response to different INM treatments provides the most compelling evidence for the efficacy of integrated approaches. The 57.1% increase in grain yield under T₄ over control and 12.0% increase over sole chemical fertilizer application underscores the substantial yield advantage conferred by vermicompost integration. This yield enhancement can be mechanistically linked to several factors: (i) improved tiller production leading to higher spike density per unit area, (ii) better spike development characterized by increased spike length and grain number per spike, (iii) efficient grain filling due to sustained post-anthesis assimilate supply and (iv) enhanced translocation of photosynthates from source (leaves) to sink (grains) (Rani *et al.* 2025) ^[11].

The superiority of vermicompost over FYM in enhancing yield can be attributed to its higher nutrient content, particularly available nitrogen and phosphorus and the presence of growth-promoting metabolites. Vermicompost typically contains 1.5-2.5% N, 1.0-1.5% P₂O₅ and 0.5-1.0% K₂O, along with essential micronutrients in plant-available forms (Hafez *et al.* 2020) ^[6]. Furthermore, earthworm-processed organic matter exhibits higher microbial diversity and enzymatic activity, which facilitates nutrient mineralization and root exploration. The findings align with those of Kumar *et al.* (2022) ^[7], who demonstrated that judicious application of inorganic fertilizers, FYM and bio-inoculants significantly increased wheat grain yield by 206% over control.

The non-significant variation in harvest index across treatments is particularly noteworthy. Harvest index represents the efficiency of assimilate partitioning to the economic yield component (grain). Its stability across diverse nutrient management regimes indicates that while INM enhanced total biomass production (source), it also proportionately increased grain yield (sink), maintaining the source-sink equilibrium. This observation suggests that nutrient management primarily influenced the overall crop growth rate rather than the internal carbon allocation priorities of the plant. Similar observations were documented by Singh *et al.* (2024) ^[14] and Sharma *et al.* (2019) ^[13], who reported that harvest index remained relatively stable under varying INM combinations, with values typically ranging between 42-46% for wheat.

4.3 Comparative Efficacy of FYM and Vermicompost

The consistent trend of vermicompost-based treatments outperforming their FYM counterparts (T₄ > T₃, T₆ > T₅, T₈ > T₇)

across all parameters provides valuable insights for fertilizer recommendations. Vermicompost's superiority can be explained through multiple mechanisms. Firstly, vermicompost undergoes further decomposition by earthworm gut microorganisms, resulting in finer particle size and higher surface area, which enhances nutrient availability and microbial colonization. Secondly, vermicompost contains significantly higher levels of available nutrients, particularly nitrate-nitrogen and available phosphorus, compared to FYM (Liu *et al.* 2025) ^[8]. Thirdly, the presence of earthworm cocoons and beneficial microorganisms such as *Pseudomonas*, *Bacillus* and *Trichoderma* in vermicompost contributes to disease suppression and plant growth promotion (Aslam *et al.* 2025) ^[12].

However, it is pertinent to note that the difference between T₄ and T₃, while consistent, was statistically non-significant for most parameters. This finding suggests that both organic amendments, when combined with recommended fertilizer doses, can effectively enhance wheat productivity. From an economic and farmer-adoption perspective, FYM may remain a viable option in regions where vermicompost production facilities are limited, given its comparable performance at the 100% RDN level. The choice between FYM and vermicompost should therefore consider local availability, cost economics and long-term soil health implications (Dwivedi *et al.* 2025) ^[4].

4.4 Implications for Fertilizer Reduction

The results from reduced fertilizer treatments (T₅-T₈) offer important insights into the potential for chemical fertilizer reduction without compromising yield. T₆ (75% RDN + 25% N through vermicompost) recorded a grain yield of 38.01 q ha⁻¹, which represents only a 15.2% reduction compared to T₄ (44.84 q ha⁻¹), while achieving a 33.1% increase over control. This finding suggests that a 25% reduction in chemical fertilizer can be effectively compensated through vermicompost supplementation. Such fertilizer reduction strategies have significant implications for sustainable agriculture, including reduced input costs, minimized environmental pollution from nutrient leaching and volatilization and improved long-term soil health (Kumar *et al.* 2022) ^[7].

The 50% substitution treatments (T₇ and T₈), however, recorded notably lower yields compared to their 75% and 100% RDN counterparts, suggesting that beyond a certain threshold, organic amendments alone cannot fully compensate for the reduced chemical fertilizer input, particularly in soils with inherently low fertility status. This observation is consistent with the findings of Parewa *et al.* (2022) ^[10], who concluded that while INM can reduce chemical fertilizer dependency by 25%, higher substitution rates may result in yield penalties unless supported by high-quality organic inputs and favorable soil conditions.

4.5 Regional Relevance and Future Prospects

The findings of this study hold particular relevance for the northwestern Himalayan region, where smallholder farming systems predominate and soil fertility degradation poses a significant threat to agricultural sustainability. The mid-hill zones of Himachal Pradesh are characterized by fragmented landholdings, limited access to synthetic fertilizers and increasing awareness about organic farming. Under these conditions, the integration of locally available organic resources such as FYM and vermicompost with judicious chemical fertilizer use offers a practical and economically viable pathway for sustaining wheat productivity (Verma *et al.* 2018) ^[16].

The study's results support the broader national agenda of promoting sustainable agricultural practices aligned with the

principles of precision agriculture and natural farming. The demonstrated efficacy of INM in enhancing wheat yield while potentially reducing chemical fertilizer inputs by 25% aligns with government initiatives aimed at reducing fertilizer subsidy burdens and promoting environmentally friendly farming systems. Future research should focus on long-term experiments to assess the cumulative effects of INM on soil carbon sequestration, microbial diversity and overall ecosystem services in the fragile Himalayan agro-ecosystems.

5. Conclusion

Based on the comprehensive evaluation of integrated nutrient management practices on growth and yield performance of wheat (*Triticum aestivum* L.) variety HPW 360 under the mid-hill conditions of Mandi, Himachal Pradesh, the following conclusions can be drawn:

1. The integrated application of 100% recommended dose of nitrogen along with vermicompost at 2.5 t ha⁻¹ (T₄) produced the highest grain yield (44.84 q ha⁻¹), which was 57.1% higher than control and 12.0% higher than sole chemical fertilizer application.
2. All growth parameters (plant height, number of tillers and dry matter accumulation) were significantly enhanced under INM treatments, with vermicompost-based treatments consistently outperforming their FYM counterparts.
3. The integration of organic manures with chemical fertilizers improved both grain and straw yield proportionately, as evidenced by the non-significant variation in harvest index across treatments (range: 43.86-45.42%).
4. A 25% reduction in chemical fertilizer combined with vermicompost (T₆) achieved 84.8% of the maximum grain yield, suggesting potential for fertilizer reduction without substantial yield penalty.
5. The findings recommend the adoption of 100% RDN + vermicompost at 2.5 t ha⁻¹ as the optimal INM strategy for wheat cultivation in the northwestern Himalayan region, offering a sustainable balance between productivity enhancement and environmental stewardship.

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