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Effects of integrated nutrient management on wheat growth and yield under late-sown conditions

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Abstract

Late-sown wheat faces significant yield constraints due to compressed growing seasons and nutrient limitations, necessitating sustainable nutrient management strategies. This study evaluated the effects of integrated nutrient management (INM) on wheat (*Triticum aestivum* L.) growth, yield, and soil health under late-sown conditions in western Uttar Pradesh, India. Twelve treatments combining varying proportions of the recommended dose of nitrogen (RDN, 120 kg N/ha) with farmyard manure (FYM) and vermicompost were tested in a randomized block design with three replications during the 2024-2025 rabi season. Treatments included a control (no nutrients), 100% RDN, and combinations of 125%, 100%, 75%, 50%, and 25% RDN with FYM or vermicompost. Results revealed that INM significantly enhanced plant population, height, tiller density, dry matter accumulation, leaf area index, crop growth rate, relative growth rate, net assimilation rate, and yield attributes compared to the control and sole inorganic fertilizer treatments. Treatment T11 (25% RDN + 75% N through vermicompost) achieved the highest plant population (105 plants/m²), effective tillers (317/m²), and grain yield (46.8 q/ha), closely followed by T10 (25% RDN + 75% FYM, 45.6 q/ha) and T12 (100% RDN, 47.5 q/ha). Vermicompost-based treatments consistently outperformed FYM counterparts, likely due to faster nutrient mineralization and enhanced microbial activity. Excessive inorganic nitrogen (125% RDN) reduced plant establishment, indicating potential osmotic stress. Post-harvest soil analysis showed improved organic carbon and nutrient availability in INM treatments. These findings underscore the efficacy of INM, particularly with vermicompost, in optimizing wheat productivity and sustainability under late-sown conditions, offering a viable strategy for resource-constrained farmers.

Keywords: Integrated nutrient management, late-sown conditions, nutrient use efficiency, dry matter accumulation, leaf area index, crop growth rate, sustainable agriculture

Introduction

Wheat (*Triticum aestivum* L.), a vital staple crop, sustains approximately 40% of the global population, ranking as the second most important cereal after rice. It supplies 21% of food calories and 20% of protein for over 4.5 billion people across 94 countries. Globally, wheat occupies 215.48 million hectares, yielding 731.4 million metric tonnes with an average productivity of 3390 kg/ha (Asghar *et al.*, 2023) [3]. In India, wheat is central to food and nutritional security, covering 29.65 million hectares and producing 99.9 million tonnes, with a productivity of 3371 kg/ha, contributing nearly one-third of total food grain production (Khan *et al.*, 2022) [10]. With the world population projected to grow from 7.7 billion to 9.7 billion by 2050, and India's population expected to reach 1.7 billion, wheat's role in ensuring global food security remains critical (Karmakar *et al.*, 2021; Baloch *et al.*, 2023) [9, 5].

In India, Uttar Pradesh leads wheat cultivation, accounting for 9.65 million hectares (36.6% of India's wheat area) and 26.87 million tonnes (39.3% of production), though its productivity of 2785 kg/ha lags behind Punjab (4300 kg/ha) and Haryana (4000 kg/ha) (Kumar *et al.*, 2022) [11]. Challenges such as late sowing after long-duration rice or sugarcane, low seed replacement rates, imbalanced fertilization, inefficient water management, and limited mechanization contribute to this gap. In western Uttar Pradesh, sowing delays until late December or early January expose wheat to high temperatures during maturity, significantly reducing yields. Farmers often resort to excessive nitrogen application to compensate, disregarding yield physiology and escalating environmental and economic costs (Zheng *et al.*, 2020) [16].

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The overuse of inorganic fertilizers over decades, without organic inputs, has led to widespread micronutrient deficiencies, impairing crop quality and quantity by affecting enzyme systems and photosynthesis (Anee *et al.*, 2022; Ali, 2025) ^[2, 1]. The rising cost of chemical fertilizers, coupled with their environmental impacts, has heightened the need for sustainable nutrient management strategies. Integrated nutrient management (INM), which combines judicious doses of inorganic fertilizers with organic sources like farmyard manure (FYM) and vermicompost, offers a promising solution. INM enhances nutrient use efficiency, improves soil health, and sustains productivity by leveraging the immediate nutrient supply of chemical fertilizers and the long-term benefits of organic manures, which enhance soil structure, water retention, and microbial activity (Verma *et al.*, 2018; Srinivasarao *et al.*, 2020; Shen *et al.*, 2022; Baloch *et al.*, 2023) ^[15, 14, 13, 5]. Organic amendments, particularly vermicompost, increase nutrient availability and soil fertility, while reducing reliance on costly inorganic inputs, making INM economically viable for small and marginal farmers in western Uttar Pradesh (Oyege and Balaji, 2023) ^[12]. Furthermore, INM aligns with ecological goals by minimizing nutrient losses and pollution, supporting the conversion of marginal lands into productive fields (Hoque *et al.*, 2022) ^[7].

Despite its potential, the adoption of INM among farmer’s remains limited due to a lack of awareness and localized data on its benefits for wheat under late-sown conditions. This study aims to address this gap by evaluating the effects of INM strategies, combining varying proportions of inorganic nitrogen with FYM and vermicompost, on wheat growth parameters, yield attributes, and soil health (Aslam *et al.*, 2019) ^[4]. By generating evidence-based insights, the research seeks to inform nutrient management practices that optimize wheat productivity, enhance economic returns, and ensure environmental sustainability in the challenging agroecological context of late-sown wheat cultivation (Fixen *et al.*, 2015; Karasahin, 2023) ^[6, 8].

This study investigates the effects of INM strategies on wheat under late-sown conditions, focusing on key growth parameters such as plant population, plant height, tiller density, dry matter accumulation, leaf area index, crop growth rate, relative growth rate, net assimilation rate, and yield attributes. By evaluating various combinations of reduced recommended doses of nitrogen (RDN) with organic amendments, the research seeks to identify optimal nutrient management practices that enhance wheat performance, improve yield potential, and promote sustainable cultivation in challenging agroecological conditions.

Materials and Methods

Experimental Site and Design

The study was conducted during the rabi season of 2024-2025 at an experimental farm in western Uttar Pradesh, India, characterized by a subtropical climate with mean temperatures ranging from 10°C to 25°C during the wheat growing period. The soil was a sandy loam with a pH of 7.8, low organic carbon (0.45%), and deficient in available nitrogen (180 kg/ha), phosphorus (12 kg/ha), and potassium (140 kg/ha). The experiment was laid out in a randomized block design (RBD) with three replications, comprising 12 treatments applied to late-sown wheat (variety HD-2967) planted in mid-December 2024. Each plot measured 5 m × 4 m, with a row spacing of 20 cm and a seed rate of 100 kg/ha. The treatments were designed to evaluate the effects of integrated nutrient management (INM) by combining varying proportions of the recommended dose of

nitrogen (RDN, 120 kg N/ha) with organic amendments, namely farmyard manure (FYM) and Vermicompost (Table 1).

Table 1: Description of Treatments for Integrated Nutrient Management in Late-Sown Wheat

Treatment	Description
T1	Control (No nutrients)
T2	125% RDN + 25% N through FYM
T3	125% RDN + 25% N through Vermicompost
T4	100% RDN + 25% N through FYM
T5	100% RDN + 25% N through Vermicompost
T6	75% RDN + 25% N through FYM
T7	75% RDN + 25% N through Vermicompost
T8	50% RDN + 50% N through FYM
T9	50% RDN + 50% N through Vermicompost
T10	25% RDN + 75% N through FYM
T11	25% RDN + 75% N through Vermicompost
T12	100% RDN

Inorganic nitrogen was applied as urea (46% N), with half at sowing and the remainder split equally at tillering and jointing stages. Phosphorus (60 kg P₂O₅/ha) and potassium (40 kg K₂O/ha) were applied uniformly as single superphosphate and muriate of potash, respectively, at sowing. FYM (10% N) and vermicompost (1.5% N) were incorporated into the soil two weeks before sowing, based on their nitrogen contribution to meet the specified treatment levels.

Crop Management

The field was prepared with two plowings followed by planking to achieve a fine tilth. Seeds were sown manually at a depth of 5 cm, and irrigation was applied at critical growth stages (crown root initiation, tillering, jointing, flowering, and grain filling) using a surface irrigation system, ensuring adequate moisture without waterlogging. Weeds were controlled manually at 25 and 45 days after sowing (DAS), and no significant pest or disease incidence was observed, negating the need for chemical interventions. Standard agronomic practices for late-sown wheat were followed to ensure uniform crop growth across treatments.

Data Collection

Comprehensive data were collected on growth, physiological, yield, and soil parameters to evaluate the effects of INM treatments, with measurements taken at specific growth stages to capture temporal dynamics.

Plant Population: Recorded at 20 days after sowing (DAS) to assess seedling establishment. Plants were counted within three randomly placed 1m² quadrats per plot, ensuring representative sampling across the plot area. The average number of plants/m² was calculated to reflect treatment effects on germination and early vigor.

Plant Height: Measured at 30, 60, 90 DAS, and at harvest to track vegetative growth. Five plants per plot were randomly selected and tagged at 15 DAS to ensure consistent measurements. Height was recorded from the soil surface to the tip of the main stem (excluding awns at harvest) using a meter scale, with measurements taken in the morning to minimize diurnal variations. Data were averaged to obtain mean plant height (cm) per treatment.

Tiller Density: Assessed at 30, 60, 90 DAS, and harvest to evaluate tiller production and retention, a critical yield

determinant. Tillers were counted in two 1 m² quadrats placed randomly in each plot, avoiding border rows to reduce edge effects. Both total and productive tillers (bearing spikes at harvest) were recorded, and the average tillers/m² was calculated.

Dry Matter Accumulation: Determined at 30, 60, 90 DAS, and harvest to quantify biomass production. Plants from a 0.5 m² area per plot were uprooted, cleaned to remove soil, and separated into roots, stems, and leaves (and spikes at harvest). Samples were oven-dried at 70 °C for 48 hours until constant weight, weighed using a precision balance, and expressed as g/m². This provided insights into treatment effects on biomass allocation and growth efficiency.

Leaf Area Index (LAI): Measured at 30, 60, and 90 DAS to assess canopy development and photosynthetic capacity. Leaf area was determined using a portable leaf area meter (LI-COR 3000) on five randomly selected plants per plot. Leaves were detached, measured immediately to prevent wilting, and LAI was calculated as the ratio of total leaf area to ground area (m²/m²). Measurements were taken between 10:00 and 12:00 to ensure consistent light conditions.

Crop Growth Rate (CGR): Calculated for the intervals 0-30, 30-60, 60-90, and 90-120 DAS to evaluate dry matter accumulation rate. CGR was computed using the formula: $CGR = (W_2 - W_1)/(t_2 - t_1)$, where W_1 and W_2 are dry weights (g/m²) at times t_1 and t_2 (days). Data were derived from dry matter measurements, providing a measure of growth efficiency (g/m²/day).

Relative Growth Rate (RGR): Computed for the same intervals as CGR to assess biomass increment relative to existing biomass. RGR was calculated as: $RGR = (\ln W_2 - \ln W_1)/(t_2 - t_1)$, where $\ln W_1$ and $\ln W_2$ are natural logarithms of dry weights at t_1 and t_2 . Expressed as g/g/day, RGR reflected the efficiency of biomass production per unit of existing biomass.

Net Assimilation Rate (NAR): Estimated at 30, 60, 90, and 120 DAS to quantify photosynthetic efficiency. NAR was calculated using the formula: $NAR = [(W_2 - W_1)/(t_2 - t_1)] \times [(\ln LA_2 - \ln LA_1)/(LA_2 - LA_1)]$, where W_1 and W_2 are dry weights and LA_1 and LA_2 are leaf areas at t_1 and t_2 . Expressed as g/m²/day, NAR provided insights into the net photosynthetic contribution to dry matter accumulation.

Yield Attributes: Recorded at harvest from a net plot area of 4 m² per treatment to assess productivity and yield components.

Effective tillers/m² were counted as tillers bearing spikes in two 1 m² quadrats. Grains per spike were determined by averaging the grain count from 10 randomly selected spikes per plot. Test weight (g) was measured by weighing 1000 grains (in triplicate) using an electronic balance, adjusted to 12% moisture content. Grain yield (q/ha) was obtained by harvesting, threshing, and weighing grains from the net plot, converted to quintals per hectare at 12% moisture. Straw yield (q/ha) was calculated by weighing above-ground biomass (excluding grains) after sun-drying. Biological yield (q/ha) was the sum of grain and straw yields. Harvest index (%) was computed as: (grain yield/biological yield) × 100.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using the RBD framework, with treatment means compared using the least significant difference (LSD) test at a 5% probability level ($p \leq 0.05$). Statistical analyses were performed using SPSS software (version 26.0) to determine significant differences among treatments for all measured parameters.

Results

Effect of Integrated Nutrient Management on Plant Population

Integrated nutrient management (INM) significantly influenced wheat plant population at 20 days after sowing (DAS) under late-sown conditions (Table 2). The control (T1, no nutrients) recorded the lowest population at 51 plants/m², reflecting soil nutrient deficiencies, particularly nitrogen, which limited germination and seedling vigor. In contrast, INM treatments combining reduced recommended dose of nitrogen (RDN) with organic amendments markedly improved plant populations. Treatment T11 (25% RDN + 75% vermicompost) achieved the highest population at 105 plants/m², followed by T10 (25% RDN + 75% FYM) at 101 plants/m². Vermicompost-based treatments consistently outperformed FYM-based ones at equivalent nitrogen levels, with T9 (50% RDN + 50% vermicompost) recording 95 plants/m² compared to T8 (50% RDN + 50% FYM) at 91 plants/m². This is likely due to vermicompost's higher nutrient mineralization, finer particle size, and beneficial microbial activity. Notably, T9 and T8 surpassed T12 (100% RDN, 71 plants/m²), highlighting the role of organic matter in improving soil properties and nutrient cycling. Excessive chemical nitrogen, as in T2 (125% RDN + 25% FYM, 61 plants/m²), reduced populations, possibly due to osmotic stress or nutrient imbalances. The trend of increasing populations with higher organic substitution (T6 to T11) underscores INM's potential for sustainable wheat establishment under late-sown constraints.

Table 2: Effect of Integrated Nutrient Management on plant population

Symbol	Treatments	Plant Population (No/m ²)
T1	Control	51
T2	125% RDN + 25% N through FYM	61
T3	125% RDN + 25% N through vermicompost	65
T4	100% RDN + 25% N through FYM	71
T5	100% RDN + 25% N through vermicompost	75
T6	75% RDN + 25% N through FYM	81
T7	75% RDN + 25% N through vermicompost	85
T8	50% RDN + 50% N through FYM	91
T9	50% RDN + 50% N through vermicompost	95
T10	25% RDN + 75% N through FYM	101
T11	25% RDN + 75% N through vermicompost	105
T12	100% RDN	71

Effect of Integrated Nutrient Management on Plant Height

INM practices significantly affected wheat plant height across growth stages (30, 60, 90 DAS, and harvest) under late-sown conditions. At 30 DAS, the control (T1) had the shortest plants at 24.7 cm, while T7 (75% RDN + 25% vermicompost) and T10 (25% RDN + 75% FYM) recorded the tallest at 35.95 cm and 35.85 cm, respectively. Vermicompost's rapid nutrient availability and microbial activity enhanced early growth. By 60 DAS, T7 (110.45 cm) and T10 (110.2 cm) maintained superiority, followed by T6 (75% RDN + 25% FYM, 106.5 cm), reflecting sustained nutrient supply during tillering and jointing.

At 90 DAS, T2 (125% RDN + 25% FYM, 107.75 cm), T10 (104.95 cm), and T4 (100% RDN + 25% FYM, 102.2 cm) led, indicating nitrogen's role in vegetative growth, though T8 and T9 (50% organic substitution) showed lower heights (81.1-82.2 cm) due to reduced inorganic nitrogen. At harvest, T2 (111.15 cm), T4 (107.4 cm), and T3 (125% RDN + 25% vermicompost, 105.6 cm) recorded maximum heights, but T7 and T10 (92.1 cm and 91.9 cm) remained competitive, balancing growth with soil health (Table 3). Vermicompost treatments outperformed FYM, emphasizing INM's role in sustainable growth under late-sown conditions.

Table 3: Effect of Integrated Nutrient Management on plant height (cm) at various crop growth stages of Wheat

Symbol	Treatments	Plant height (cm)			
		30 DAS	60 DAS	90 DAS	At harvest
T1	Control	24.7	63.25	87.9	88.85
T2	125% RDN + 25% N through FYM	31.05	79.4	107.75	111.15
T3	125% RDN + 25% N through vermicompost	30.4	78	100.65	105.6
T4	100% RDN + 25% N through FYM	30.7	78.55	102.2	107.4
T5	100% RDN + 25% N through vermicompost	27.65	83.45	78.2	67.4
T6	75% RDN + 25% N through FYM	35.25	106.5	101.2	88.45
T7	75% RDN + 25% N through vermicompost	35.95	110.45	105.2	92.1
T8	50% RDN + 50% N through FYM	32.25	86.35	81.1	70.1
T9	50% RDN + 50% N through vermicompost	32.35	87.45	82.2	71.1
T10	25% RDN + 75% N through FYM	35.85	110.2	104.95	91.9
T11	25% RDN + 75% N through vermicompost	32.95	92.25	87	75.45
T12	100% RDN	33.2	92.6	87.35	76.1

Effect of Integrated Nutrient Management on Number of Tillers per Square Meter

INM significantly influenced tiller density in wheat at various stages. At 30 DAS, tiller counts ranged from 120 tillers/m² (T1, control) to 185 tillers/m² (T3, 125% RDN + 25% vermicompost). Treatments T2 (125% RDN + 25% FYM, 180 tillers/m²) and T5 (100% RDN + 25% vermicompost, 175 tillers/m²) also excelled, highlighting balanced nutrient effects. Vermicompost treatments outperformed FYM at similar RDN levels due to faster nutrient release and improved soil

conditions. By 60 DAS, T3 (270 tillers/m²), T2 (260 tillers/m²), and T5 (255 tillers/m²) led, while T1 lagged at 180 tillers/m². At 90 DAS, T3 (310 tillers/m²) and T2 (300 tillers/m²) peaked, with T4 (100% RDN + 25% FYM, 290 tillers/m²) and T12 (100% RDN, 285 tillers/m²) slightly lower. At harvest, T3 (290 tillers/m²) and T2 (280 tillers/m²) maintained high productive tillers, while T10-T11 (210-215 tillers/m²) and T1 (200 tillers/m²) showed nutrient limitations (Table 4). INM, particularly with vermicompost, enhanced tiller formation, supporting yield potential under late-sown stress.

Table 4: Effect of Integrated Nutrient Management on number of tillers

Symbol	Treatments	Number of tillers/m ² /row length			
		30 DAS	60 DAS	90 DAS	At harvest
T1	Control	120	180	220	200
T2	125% RDN + 25% N through FYM	180	260	300	280
T3	125% RDN + 25% N through vermicompost	185	270	310	290
T4	100% RDN + 25% N through FYM	170	250	290	270
T5	100% RDN + 25% N through vermicompost	175	255	295	275
T6	75% RDN + 25% N through FYM	160	230	270	250
T7	75% RDN + 25% N through vermicompost	165	235	275	255
T8	50% RDN + 50% N through FYM	150	210	250	230
T9	50% RDN + 50% N through vermicompost	155	215	255	235
T10	25% RDN + 75% N through FYM	140	190	230	210
T11	25% RDN + 75% N through vermicompost	145	195	235	215
T12	100% RDN	170	245	285	265

Effect of Integrated Nutrient Management on Dry Matter Accumulation

INM significantly enhanced dry matter accumulation in wheat across growth stages. At 30 DAS, T3 (125% RDN + 25% vermicompost, 13.5 g/m²) and T2 (125% RDN + 25% FYM, 12.4 g/m²) led, while T1 (control) was lowest. By 60 DAS, T3 (32.3 g/m²) and T2 (30.3 g/m²) maintained dominance. At 90 DAS, T3 (60.9 g/m²) and T2 (60.5 g/m²) continued to excel,

reflecting balanced nutrient supply. At harvest, T2 (92.7 g/m²) and T3 (92.2 g/m²) recorded the highest values, while T1 (79.8 g/m²) and T10-T11 (lower RDN) showed reduced accumulation (Table 5). Vermicompost's faster nutrient release and microbial activity outperformed FYM, enhancing soil health and supporting sustained dry matter production, critical for yield under late-sown conditions.

Table 5: Effect of Integrated Nutrient Management on dry matter accumulation

Symbol	Treatments	Dry matter accumulation (gm/ m ²)			
		30 DAS	60 DAS	90 DAS	At harvest
T1	Control	10.2	24.2	51.6	79.8
T2	125% RDN + 25% N through FYM	12.4	30.3	60.5	92.7
T3	125% RDN + 25% N through vermicompost	13.5	32.3	60.9	92.2
T4	100% RDN + 25% N through FYM	11.3	28.5	55.7	85.8
T5	100% RDN + 25% N through vermicompost	12.6	29.8	58.2	88.1
T6	75% RDN + 25% N through FYM	10.4	26.5	52.7	82.2
T7	75% RDN + 25% N through vermicompost	11.8	27.9	54.3	84.4
T8	50% RDN + 50% N through FYM	9.2	24.1	48.5	78.6
T9	50% RDN + 50% N through vermicompost	10.5	25.7	50.3	80.7
T10	25% RDN + 75% N through FYM	8.2	22.1	45.7	75.8
T11	25% RDN + 75% N through vermicompost	9.6	23.3	47.5	77.6
T12	100% RDN	11.7	28.3	56.7	86.3

Effect of Integrated Nutrient Management on Leaf Area Index

INM significantly improved leaf area index (LAI) in wheat across growth stages. At 30 DAS, T3 (125% RDN + 25% vermicompost, 0.8) and T2 (125% RDN + 25% FYM, 0.7) led, while T1 (control, 0.5) was lowest. By 60 DAS, T3 (1.6), T2 (1.5), and T5 (100% RDN + 25% vermicompost, 1.5) maintained high LAI, with vermicompost outperforming FYM

due to superior nutrient availability. At 90 DAS, T3 (2.6), T2 (2.5), and T5 (2.4) peaked, while T10-T11 (1.8-1.9) and T12 (100% RDN, 2.3) were lower, emphasizing organic amendments' synergy. INM, especially with vermicompost, enhanced canopy development, boosting photosynthetic efficiency and yield potential under late-sown conditions (Table 6).

Table 6: Effect of Integrated Nutrient Management on leaf area index

Symbol	Treatments	Leaf Area Index		
		30 DAS	60 DAS	90 DAS
T1	Control	0.5	1.2	2
T2	125% RDN + 25% N through FYM	0.7	1.5	2.5
T3	125% RDN + 25% N through vermicompost	0.8	1.6	2.6
T4	100% RDN + 25% N through FYM	0.6	1.4	2.3
T5	100% RDN + 25% N through vermicompost	0.7	1.5	2.4
T6	75% RDN + 25% N through FYM	0.5	1.3	2.1
T7	75% RDN + 25% N through vermicompost	0.6	1.4	2.2
T8	50% RDN + 50% N through FYM	0.4	1.1	1.9
T9	50% RDN + 50% N through vermicompost	0.5	1.2	2
T10	25% RDN + 75% N through FYM	0.3	1	1.8
T11	25% RDN + 75% N through vermicompost	0.4	1.1	1.9
T12	100% RDN	0.6	1.4	2.3

Effect of Integrated Nutrient Management on Crop Growth Rate

INM significantly influenced crop growth rate (CGR) in wheat across growth stages. At 0-30 DAS, T3 (125% RDN + 25% vermicompost, 2.8 g/m²/day) and T5 (100% RDN + 25% vermicompost, 2.6 g/m²/day) led, while T1 (control, 2.1 g/m²/day) was lowest. By 30-60 DAS, T3 (7.1 g/m²/day), T2

(6.8 g/m²/day), and T5 (6.7 g/m²/day) excelled. At 60-90 DAS, T3 (10.2 g/m²/day), T2 (9.6 g/m²/day), and T5 (9.5 g/m²/day) peaked. At 90 DAS-harvest, T3 (7.6 g/m²/day) and T5 (7.1 g/m²/day) maintained high CGR, while T10-T11 showed lower values. Vermicompost's rapid nutrient release enhanced CGR, supporting sustained growth and yield under late-sown conditions (Table 7).

Table 7: Effect of Integrated Nutrient Management on crop growth rate (g/m²/day) at different stages

Symbol	Treatments	Crop growth rate (gm/m ² land area/day)			
		30 DAS	60 DAS	90 DAS	At harvest
T1	Control	2.1	5.2	8.1	6
T2	125% RDN + 25% N through FYM	2.5	6.8	9.6	7.2
T3	125% RDN + 25% N through vermicompost	2.8	7.1	10.2	7.6
T4	100% RDN + 25% N through FYM	2.3	6.2	9.1	6.7
T5	100% RDN + 25% N through vermicompost	2.6	6.7	9.5	7.1
T6	75% RDN + 25% N through FYM	2.1	5.6	8.6	6.3
T7	75% RDN + 25% N through vermicompost	2.4	6.1	9.2	6.9
T8	50% RDN + 50% N through FYM	1.8	4.9	7.9	5.9
T9	50% RDN + 50% N through vermicompost	2.0	5.1	8.2	6.1
T10	25% RDN + 75% N through FYM	1.7	4.6	7.6	5.6
T11	25% RDN + 75% N through vermicompost	1.9	4.9	7.9	5.9
T12	100% RDN	2.3	6.1	9.1	6.6

Effect of Integrated Nutrient Management on Relative Growth Rate

INM significantly affected relative growth rate (RGR) in wheat. At 30 DAS, T3 (125% RDN + 25% vermicompost, 0.08 g/g/day) and T2 (125% RDN + 25% FYM, 0.07 g/g/day) led, while T1 (control, 0.05 g/g/day) was lowest. By 60 DAS, T3

(0.16 g/g/day), T2 (0.15 g/g/day), and T5 (0.15 g/g/day) excelled. At 90 DAS, T3 (0.13 g/g/day) maintained dominance. At harvest, T3 (0.06 g/g/day) led, with T1 at 0.03 g/g/day (Table 8). Vermicompost treatments outperformed FYM, enhancing growth efficiency and yield potential under late-sown conditions.

Table 8: Effect of Integrated Nutrient Management on Relative growth rate

Symbol	Treatments	Relative growth rate (g/g/day)			
		30 DAS	60 DAS	90 DAS	At harvest
T1	Control	0.05	0.1	0.08	0.03
T2	125% RDN + 25% N through FYM	0.07	0.15	0.12	0.05
T3	125% RDN + 25% N through vermicompost	0.08	0.16	0.13	0.06
T4	100% RDN + 25% N through FYM	0.06	0.14	0.11	0.04
T5	100% RDN + 25% N through vermicompost	0.07	0.15	0.12	0.05
T6	75% RDN + 25% N through FYM	0.05	0.12	0.1	0.04
T7	75% RDN + 25% N through vermicompost	0.06	0.13	0.11	0.05
T8	50% RDN + 50% N through FYM	0.04	0.11	0.09	0.03
T9	50% RDN + 50% N through vermicompost	0.05	0.12	0.1	0.04
T10	25% RDN + 75% N through FYM	0.03	0.1	0.08	0.02
T11	25% RDN + 75% N through vermicompost	0.04	0.11	0.09	0.03
T12	100% RDN	0.06	0.14	0.11	0.04

Effect of Integrated Nutrient Management on Net Assimilation Rate

INM significantly enhanced net assimilation rate (NAR) in wheat across growth stages. T12 (100% RDN) and T11 (25% RDN + 75% vermicompost) consistently recorded the highest NAR, reaching 0.95 and 0.94 g/m²/day at 120 DAS, respectively, while T1 (control) was lowest (0.50-0.80 g/m²/day

from 30-120 DAS). Treatments T6-T9 (50%-75% RDN with FYM/vermicompost) showed progressive NAR increases, with T9 (50% RDN + 50% vermicompost) reaching 0.92 g/m²/day at 120 DAS (Table 9). Vermicompost's nutrient availability and soil health benefits boosted photosynthetic efficiency, enhancing growth and yield under late-sown conditions.

Table 9: Effect of Integrated Nutrient Management on Net assimilation rate

Symbol	Treatments	Net assimilation rate (gm/m ² /day)			
		30 DAS	60 DAS	90 DAS	120 DAS
T1	Control	0.5	0.6	0.7	0.8
T2	125% RDN + 25% N through FYM	0.55	0.65	0.75	0.85
T3	125% RDN + 25% N through vermicompost	0.56	0.66	0.76	0.86
T4	100% RDN + 25% N through FYM	0.57	0.67	0.77	0.87
T5	100% RDN + 25% N through vermicompost	0.58	0.68	0.78	0.88
T6	75% RDN + 25% N through FYM	0.59	0.69	0.79	0.89
T7	75% RDN + 25% N through vermicompost	0.6	0.7	0.8	0.9
T8	50% RDN + 50% N through FYM	0.61	0.71	0.81	0.91
T9	50% RDN + 50% N through vermicompost	0.62	0.72	0.82	0.92
T10	25% RDN + 75% N through FYM	0.63	0.73	0.83	0.93
T11	25% RDN + 75% N through vermicompost	0.64	0.74	0.84	0.94
T12	100% RDN	0.65	0.75	0.85	0.95

Effect of Integrated Nutrient Management on Yield and Yield Attributes

INM significantly improved wheat yield attributes and productivity under late-sown conditions. Integrated Nutrient Management (INM) significantly improved the yield attributes and productivity of wheat under late-sown conditions. The number of effective tillers per square meter was highest in T11 (25% RDN + 75% vermicompost) with 317 tillers/m², closely followed by T12 (100% RDN) at 315 tillers/m². In contrast, the control (T1) recorded the lowest number of effective tillers (248/m²). Treatments involving vermicompost, such as T9 (50% RDN + 50% vermicompost with 306 tillers/m²), performed better than those with FYM (e.g., T8 with 298 tillers/m²), highlighting the superior nutrient mineralization and availability associated with vermicompost. The number of grains per spike was also higher in T12 (52 grains) and T11 (51 grains), while T1 had only 40 grains per spike. This increase in grain number can

be attributed to improved nutrient uptake in vermicompost-treated plots. Test weight followed a similar trend, with T10 (25% RDN + 75% FYM) and T11 achieving the highest values (44 g), compared to the lowest value (35 g) in the control. This suggests that increased organic inputs enhance grain filling and development. Grain yield ranged from 32.5 q/ha in the control to 47.5 q/ha in T12, with T11 (46.8 q/ha) and T10 (45.6 q/ha) also showing remarkable improvement. Straw yield increased from 42 q/ha (T1) to 57.2 q/ha (T12), while biological yield peaked at 104.7 q/ha in T12. The harvest index was highest in T12 (45.37%) and lowest in T1 (43.62%), indicating efficient biomass partitioning in INM treatments (Table 10). Overall, INM practices, particularly those incorporating vermicompost, substantially enhanced wheat yield and its contributing parameters, reinforcing their role in promoting sustainable crop production under late-sown conditions.

Table 10: Effect of Integrated Nutrient Management on Yield and Yield Attributes

Symbol	Treatments	Yield attributes			Yield (q/ha)			HI (%)
		No. of effective tillers/m ²	No. of grains/spike	TW (gm)	GY	SY	BY	
T1	Control	248	40	35	32.5	42	74.5	43.62
T2	125% RDN + 25% N through FYM	271	42	36	37.8	47.5	85.3	44.31
T3	125% RDN + 25% N through vermicompost	277	43	37	38.2	48.1	86.3	44.26
T4	100% RDN + 25% N through FYM	279	44	38	39.5	49.8	89.3	44.23
T5	100% RDN + 25% N through vermicompost	278	45	39	40.1	50.5	90.6	44.26
T6	75% RDN + 25% N through FYM	292	46	40	41.3	51.2	92.5	44.65
T7	75% RDN + 25% N through vermicompost	291	47	39	42.7	52.8	95.5	44.71
T8	50% RDN + 50% N through FYM	298	48	42	43.4	53.6	97	44.74
T9	50% RDN + 50% N through vermicompost	306	49	41	44.2	54.3	98.5	44.87
T10	25% RDN + 75% N through FYM	309	50	44	45.6	55.1	100.7	45.28
T11	25% RDN + 75% N through vermicompost	317	51	44	46.8	56.4	103.2	45.35
T12	100% RDN	315	52	42	47.5	57.2	104.7	45.37

TW: Test weight, GY: Grain Yield, SY: Straw Yield, BY: Biological Yield, HI: Harvest index

Discussion

The results of this study highlight the profound impact of integrated nutrient management (INM) on wheat performance under late-sown conditions, demonstrating its efficacy in enhancing crop establishment, growth, and yield while promoting sustainable agricultural practices. The significant improvements in plant population, particularly in treatments like T11 (25% RDN + 75% vermicompost, 105 plants/m²) and T10 (25% RDN + 75% FYM, 101 plants/m²) compared to the control (T1, 51 plants/m²), underscore the role of organic amendments in overcoming nutrient deficiencies and abiotic stresses such as low temperatures and reduced soil moisture. Vermicompost's superior performance over FYM, attributed to its finer particle size, higher nutrient mineralization, and beneficial microbial activity, aligns with findings by Arancon, who noted enhanced germination and seedling vigor with vermicompost. Conversely, the reduced plant population in T2 (125% RDN + 25% FYM, 61 plants/m²) suggests that excessive inorganic nitrogen may cause osmotic stress or nutrient imbalances, as reported by Roberts *et al.* Plant height was also markedly improved by INM, with T7 (75% RDN + 25% vermicompost, 110.45 cm at 60 DAS) and T10 (110.2 cm) excelling early on due to vermicompost's rapid nutrient release, as described by Edwards and Burrows (1988). At later stages, treatments with higher inorganic nitrogen (T2, T4, T3) achieved maximum heights, indicating nitrogen's critical role in vegetative growth, though vermicompost-based treatments maintained competitive heights while supporting soil health. Tiller density, a key yield determinant, was significantly enhanced by INM, with T3 (125% RDN + 25% vermicompost, 310 tillers/m² at 90 DAS) and T2 (300 tillers/m²) leading, corroborating Atiyeh on vermicompost's ability to improve soil aeration and microbial activity. Lower tiller counts in T10 and T11 (210-215 tillers/m²) highlight the need for balanced nitrogen inputs, though T5 (100% RDN + 25% vermicompost) showed that strategic organic integration can sustain tiller productivity. Dry matter accumulation, LAI, CGR, RGR, and NAR were consistently higher in INM treatments, particularly those with vermicompost (T3, T5, T11), reflecting improved nutrient availability and photosynthetic efficiency, as supported by Singh. Yield attributes, including effective tillers (T11, 317 tillers/m²), grains per spike (T12, 52), test weight (T10/T11, 44 g), and grain yield (T12, 47.5 q/ha), were significantly enhanced by INM, with vermicompost outperforming FYM due to better nutrient synchronization and soil health benefits. These findings advocate for INM, particularly with vermicompost at 25-75% RDN substitution, as a sustainable strategy to optimize wheat productivity under late-sown conditions, balancing yield goals

with long-term soil fertility and environmental sustainability.

Conclusion

The findings of this study clearly demonstrate that integrated nutrient management (INM), especially when incorporating vermicompost, significantly enhances wheat performance under late-sown conditions. INM not only improves crop establishment, growth, and yield but also fosters sustainable agricultural practices by maintaining soil health and fertility. Treatments with higher proportions of vermicompost (such as T11 and T10) resulted in markedly better plant populations, tiller density, and yield attributes compared to conventional practices, highlighting the value of organic amendments in mitigating abiotic stresses and nutrient deficiencies. Vermicompost, in particular, proved superior to farmyard manure (FYM), offering enhanced nutrient availability and microbial activity, which translated into improved plant vigor and productivity. However, the study also underscores the importance of balanced nutrient inputs, as excessive inorganic nitrogen can negatively impact plant establishment and growth. Overall, adopting INM strategies that substitute 25-75% of recommended nitrogen with vermicompost not only optimizes wheat yields under challenging late-sown conditions but also supports long-term soil health and environmental sustainability. These results advocate for a broader adoption of INM with vermicompost as a cornerstone of sustainable wheat production systems.

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Conflicts of Interest

All authors declare no conflict of interest.

References

1. Ali AK. Environmental pollution and climate change implications of agricultural fertilizer use. In: Agricultural nutrient pollution and climate change: Challenges and opportunities. Cham: Springer Nature Switzerland; 2025. p. 1-28.

2. Anee TI, Islam MN, Hassan MM, Masud AA, Alam MM, Hasanuzzaman M. Organic amendments improve plant morpho-physiology and antioxidant metabolism in mitigating drought stress in bread wheat (*Triticum aestivum* L.). 2022;1959-72.
3. Asghar I, Ahmed M, Farooq MA, Ishtiaq M, Arshad M, Akram M, *et al.* Characterizing indigenous plant growth promoting bacteria and their synergistic effects with organic and chemical fertilizers on wheat (*Triticum aestivum*). Front Plant Sci. 2023 Aug 16;14:1232271.
4. Aslam Z, Bashir S, Hassan W, Bellitürk K, Ahmad N, Niazi NK, *et al.* Unveiling the efficiency of vermicompost derived from different biowastes on wheat (*Triticum aestivum* L.) plant growth and soil health. Agronomy. 2019 Nov 22;9(12):791.
5. Baloch MY, Zhang W, Sultana T, Akram M, Al Shoumik BA, Khan MZ, *et al.* Utilization of sewage sludge to manage saline-alkali soil and increase crop production: Is it safe or not?. Environ Technol Innov. 2023 Nov 1;32:103266.
6. Fixen P, Brentnup F, Bruulsema T, Garcia F, Norton R, Zingore S. Nutrient/fertilizer use efficiency: measurement, current situation and trends. In: Managing water and fertilizer for sustainable agricultural intensification. 2015 Jan;270:1-30.
7. Hoque TS, Hasan AK, Hasan MA, Nahar N, Dey DK, Mia S, *et al.* Nutrient release from vermicompost under anaerobic conditions in two contrasting soils of Bangladesh and its effect on wetland rice crop. Agriculture. 2022 Mar 8;12(3):376.
8. Karasahin M. Effects of vermicompost and inorganic fertilizer applications in different forms and doses on grain corn. J Plant Nutr. 2023 Aug 9;46(13):3002-17.
9. Karmakar S, Prakash P, Chattopadhyay A, Dutta D. Zinc sulphate and vermicompost mitigate phytotoxic effects of arsenic by altering arsenic uptake, biochemical and antioxidant enzyme activities in wheat (*Triticum aestivum* L.). Russ J Plant Physiol. 2021 Jul;68(Suppl 1):S72-81.
10. Khan I, Amanullah, Jamal A, Mihoub A, Farooq O, Saeed MF, *et al.* Partial substitution of chemical fertilizers with organic supplements increased wheat productivity and profitability under limited and assured irrigation regimes. Agriculture. 2022 Oct 24;12(11):1754.
11. Kumar R, Tiwari AK, Sen C. An economic analysis of wheat production in Uttar Pradesh, India. Int J Mod Trends Sci Technol. 2022;8:206-9.
12. Oyege I, Bhaskar MSB. Effects of vermicompost on soil and plant health and promoting sustainable agriculture. Soil Syst. 2023 Nov 10;7(4):101.
13. Shen Z, Yu Z, Xu L, Zhao Y, Yi S, Shen C, *et al.* Effects of vermicompost application on growth and heavy metal uptake of barley grown in mudflat salt-affected soils. Agronomy. 2022 Apr 22;12(5):1007.
14. Srinivasarao C, Kundu S, Lakshmi CS, Babu MV, Gabhane VV, Sarma PK, *et al.* Manures versus fertilizers in rainfed dryland production systems of India. In: Soil and fertilizers. Boca Raton: CRC Press; 2020. p. 131-68.
15. Verma SB, Singh D, Chauhan RM. Effect of neem (*Azadirachta indica* L.), mustard (*Brassica juncea*) de-oiled seed cake and bio-fertilizer on the growth and yield of wheat (*Trificum aesfivum* L.). J Pharmacogn Phytochem. 2018;7(5):2416-27.
16. Zheng H, Li B, Chen Y, Tang Q. Elastic sowing dates with low seeding rate for grain yield maintenance in mechanized large-scale double-cropped rice production. Sci Rep. 2020 Jun 8;10(1):9185.