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Effect of Integrated Nutrient Management (INM) in timely sown wheat crop (*Triticum aestivum* L.)

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Abstract
The research examined how INM strategies influence wheat crop (*Triticum aestivum* L.) growth characteristics and yield performance alongside financial impacts when planting wheat during the proper season. The field experiment employed a randomized complete block design to analyze seven INM treatments including control T_1 and T_2 using 100% recommended dose of fertilizers - RDF and subsequent treatments T_3 to T_7 incorporating combinations of 75% RDF + farmyard manure - FYM and 75% RDF + vermicompost - VC and their other variants with biofertilizers. Plant height along with tiller count and leaf area index together with chlorophyll content and dry matter accumulation received a notable boost when chemical fertilizers were integrated with organic manures and biofertilizers compared to using chemical fertilizers solo. Application of treatment T_6 provided the greatest harvest yield at 5.82 t/ha which exceeded control yield by 34.7% while T_5 and T_7 delivered secondary results of 5.64 and 5.37 t/ha respectively. Soil health indicators like organic carbon and available N, P, K, microbial biomass carbon showed the greatest improvement when INM farming practices were applied. Net returns and benefit-cost ratio reached the highest levels (2.38) through treatment T_6 according to economic assessment. This study verifies INM methods as a long-term solution for wheat productivity enhancement alongside soil quality protection and economic profitability in wheat agricultural settings.

Keywords: Integrated nutrient management, wheat, organic manures, biofertilizers, yield attributes, soil health, economic returns, sustainable agriculture

1. Introduction
Triticum aestivum L. Wheat stands as a top global cereal crop that serves as the fundamental food source for three out of ten people in the world while representing twenty percent of human dietary energy (Shiferaw *et al*., 2013) [36]. The global population expansion indicates that wheat demand will surge by 60% before 2050 according to Ray *et al*. (2013) [29]. Various obstacles exist for wheat productivity which involves declining soil fertility and rising production expenses together with ecological problems from using chemical fertilizers excessively (Ladha *et al*., 2020) [17].

Huge reliance on chemical fertilizer usage in conventional farms triggers multiple environmental issues including declining soil health alongside water contamination and increased greenhouse effects (Kopittke *et al*., 2019) [14]. Soil organic matter has decreased and soil structure has deteriorated and nutrient use efficiency dropped when farmers omit organic inputs from their continuous chemical fertilizer use (Choudhary *et al*., 2018) [8]. Soil health preservation together with high crop productivity demands the creation and application of sustainable nutrient management practices to reduce environmental impacts.

As an innovative agricultural solution Integrated Nutrient Management (INM) applies chemical fertilizers together with organic manures and biofertilizers to improve nutrient delivery and both soil productivity and nutrient resource utilization. Through INM practices different nutrient sources complement each other to deliver immediate crop requirements via chemical fertilizers and provide soil structure improvement and prolonged nutrient supply and microbial activity enhancement through organic inputs (Mahajan *et al*., 2019) [20].

Multiple research investigations have shown that implementing INM techniques leads to positive outcomes in wheat cultivation. The combination of farmyard manure with 75% recommended chemical fertilizers produced wheat yields 15-20% higher when compared to 100% chemical fertilizers according to Chapagain and Riseman (2014) [6]. Kumar *et al*. (2017) [15] studied wheat cultivation under INM approaches which led to better soil health indicators through increased organic carbon together with raised nutrient availability. The success rate of INM systems depends on region-specific conditions involving soil types together with climatic parameters as well as particular mixtures of organic ingredients with inorganic chemical inputs.

Research investigating INM for wheat cultivation has expanded but lacks a clear understanding of how farmyard manure and vermicompost performance changes cumulatively with chemical fertilizers and biofertilizers in various proportion combinations. The available assessments lack integration between growth parameters and yield attributes as well as soil health indicators in addition to economic returns evaluation.

The research verifies three main objectives by examining (1) how INM treatments influence wheat growth parameters and yield attributes in timely sown fields and (2) how INM impacts soil fertility and biological properties and (3) which INM combinations produce the best economic outcomes. These research findings will assist in establishing sustainable nutrient management practices for wheat cultivation that combines productivity performance with soil preservation and economical factors.

2. Literature Review

2.1 Chemical Fertilizers in Wheat Production

The worldwide use of chemical fertilizers throughout the last decades has been crucial for boosting wheat yield production globally. The essential elements for achieving optimal wheat development include nitrogen (N) along with phosphorus (P) and potassium (K). The addition of nitrogen controls plant development alongside protein generation and crop yield production according to Hawkesford (2014) [10] but phosphorus promotes root health together with essential metabolic processes to accelerate wheat maturity (Rose *et al*., 2013) [30]. Osmotic regulation and enzyme activation and stress tolerance rely on potassium for their functions (Zörb *et al*., 2014).

Multiple scientific investigations have demonstrated how carefully combining chemical fertilizer improves wheat agricultural output. Wheat grain yield received an increase of 45-60% from recommended NPK fertilization applications compared to unfertilized conditions according to Singh and Agrawal (2018) [37]. The researchers found through their study (Pandey *et al*., 2020) [26] that balanced NPK fertilization led to a 12-15% increase in grain protein content and an 8-10% boost in thousand-grain weight when compared to untreated controls.

Economic fertilizer use at extensive rates creates serious problems regarding long-term environmental viability. Yadav *et al*. (2017) documented the negative impact of using chemical fertilizers alone for ten years that led to acid soil conditions while reducing carbon levels and destroying microbial functionality. Plant uptake of applied nitrogen amounts to 30-50% and phosphorus uptake stands at 10-25% respectively as reported by Lal (2015) [18] in his study while the remaining amounts lead to environmental contamination through different exit routes.

2.2 Organic Manures in Wheat Production

Organic manures represent beneficial nutrient reservoirs that supply essential mineral matter which builds better soil properties through chemical along with biological and physical changes. Through wheat cultivation farmers widely utilize two major organic fertilizer sources namely farmyard manure (FYM) and vermicompost (VC).

Farmyard manure provides 0.5-1.5% N and 0.4-0.8% P_2O_5 and 0.5-1.9% K_2O whereas it contains multiple trace elements (Bhattacharyya *et al*., 2015) [4]. Research studies demonstrate that wheat benefits from FYM application. Wheat production increased by 18-25% after Farmyard Manure application at 15 t/ha according to Karami *et al*. (2012) [13] because improved soil structure together with better water-holding capacity became the key factors. Vermicompost application enhanced soil organic carbon by 15-20% alongside available nutrient status through continuous application for three years according to Agegnehu *et al*. (2016) [1].

The nutrient concentrations in vermicompost surpass FYM levels (1.5-2.5% N, 0.9-1.7% P_2O_5, and 1.0-2.2% K_2O) while its nutrient release follows speedier patterns according to Lazcano & Domínguez (2011) [19]. According to Gopinath *et al*. (2011) [9] wheat crops received 5 t/ha of vermicompost showed increased yields ranging from 22% to 30% above control levels. Studies by Manivannan *et al*. (2009) [21] showed that vermicompost application improved the enzyme activities of dehydrogenase, urease and phosphatase thus enhancing microbial nutrient cycling in soils.

2.3 Biofertilizers in Wheat Production

Plant nutrient availability rises through biological processes achieved by biofertilizers which are microbial preparations that enhance soil fertility. Three biofertilizers frequently used in wheat cultivation are Azotobacter which operates as free-living N-fixers together with Azospirillum as associative N-fixers and phosphate-solubilizing bacteria known as PSB.

Biological nitrogen fixation by Azotobacter and Azospirillum results in N release of 20-40 kg/ha and these bacteria also produce growth-promoting substances including auxins and gibberellins and cytokinins (Bashan & de-Bashan, 2010) [3]. The researchers at Rana *et al*. (2012) [28] discovered that wheat grain yields grew 8-12% better when plants received Azotobacter inoculation compared to non-inoculated plats. The root systems of wheat plants received enhancements following Azospirillum inoculation according to Vejan *et al*. (2016) [43] as this led to better nutrient and water assimilation.

The conversion of insoluble phosphates into plant-available forms happens through bacteria-created organic acids and phosphatase enzymes (Alori *et al*., 2017) [2]. The research conducted by Tahir *et al*. (2013) [40] showed that wheat plants treated with PSB bacteria solution absorbed 15-25% more P along with a 10-15% grain yield increase. Phosphorus use efficiency received a boost from PSB application when these microorganisms broke down fixed soil P as well as applied rock phosphate (Sharma *et al*., 2013) [34].

2.4 Integrated Nutrient Management in Wheat

Through Integrated Nutrient Management (INM) farmers can unite chemical fertilizers with organic materials and biofertilizers creating a compound strength between multiple nutrient sources. Numerous studies prove how INM creates positive compound effects which help wheat production systems.

According to Mubarak *et al*. (2021) [23], wheat yields remained equivalent to 100% recommended NPK treatments when farmers used 5 t/ha of FYM together with 75% of recommended

NPK and simultaneously experienced substantial improvements in soil organic carbon and microbial biomass. Wheat growers who utilized 75% NPK in combination with vermicompost at 2.5 t/ha and biofertilizers obtained wheat yields that exceeded those of 100% NPK by 12-15% according to Choudhary and Suri (2014) [7].

Different operational mechanisms work together to improve the effectiveness of INM systems. Soil physical properties improve through use of organic inputs because bulk density, porosity and water-holding capacity (Thangarajan *et al*., 2013) [41] enhance root development and nutrient absorption conditions. The gradual nutrient release rate of organic sources matches the instantaneous availability of chemical fertilizers to create a better crop demand coverage during the entire growing period (Patra *et al*., 2019) [27].

The combination of INM practices increases the overall efficiency of nutrient utilization. Wheat production benefited from INM because the practice improved nitrogen use efficiency from 35% to 52% compared to sole chemical fertilizers according to Jat *et al*. (2018) [12]. Phosphorus recovery rates increased by 11% when chemical fertilization was combined with organic materials and phosphate-solubilizing bacteria leading to a total recovery of 29%.

The implementation of INM demonstrates cost-effective potential by replacing part of the expensive chemical additives with nearby organic materials. According to Sharma and Mittra (2016) [31] an economic analysis resulted in net returns which reached 15-20% higher levels under INM practices compared to sole chemical fertilization through both reduced fertilizer costs and yield enhancement.

The reviewed scientific literature establishes INM as a strong approach for achieving sustainable wheat production. The most beneficial approach to combining chemical fertilizers with organic manures and biofertilizers depends on individual soil conditions and climate conditions in addition to resource availability. The present research is necessary as current studies lack complete evaluations between growth parameters and yield attributes and economic performance and soil health indicators while using different integrated nutrient management combinations.

3. Methodology

3.1 Experimental Site and Soil Characteristics

A field experiment happened during winter period 2024-2025 on agricultural lands situated at Agricultural Research Farm of RAMA UNIVERSITY, Kanpur which has a location of -----′N, longitude ------′E while the altitude reaches ------ m above mean sea level. Semi-arid subtropical weather conditions define this area where summers remain hot but winters develop cold temperatures. The farming region receives 750 mm of annual precipitation distributed as 80% during July through September monsoon months. The wheat-growing period temperatures from November through April reached maximum levels up to 36.2°C while minimum values reached 6.2°C.

Soil investigators took combined soil samples from both the 0-15 cm and 15-30 cm soil levels before the experiment began to assess their physicochemical properties. The experimental soil possessed sandy loam texture (60.2% sand, 22.5% silt, 17.3% clay) and exhibited pH 7.8, electrical conductivity (EC) reached 0.32 dS/m with organic carbon measurement of 0.42% and available nutrient levels achieved 175 kg/ha, available phosphorus at 12.8 kg/ha, as well as available potassium at 168 kg/ha.

3.2 Experimental Design and Treatments

The experimental field followed a randomized complete block design (RCBD) structure using three replications and seven treatment solutions. Experimentary plots occupied a size of 5 m × 4 m (20 m²). Different treatment combinations included both the recommended dose of fertilizers (RDF) with organic manures and biofertilizers.

T_1: Control (no fertilizers or manures)
T_2: 100% RDF (120-60-40 kg NPK/ha)
T_3: 75% RDF + FYM (10 t/ha)
T_4: 75% RDF + Vermicompost (5 t/ha)
T_5: 75% RDF + FYM (5 t/ha) + Biofertilizers
T_6: 75% RDF + Vermicompost (2.5 t/ha) + Biofertilizers
T_7: 50% RDF + FYM (5 t/ha) + Vermicompost (2.5 t/ha) + Biofertilizers

The biofertilizer consortium contained N-fixer Azotobacter chroococcum and P-solubilizer Bacillus megaterium and K-solubilizer Frateuria aurantia which were applied at a rate of 5 kg/ha. The seeds received biofertilizer inocllumination through mixing these products with 10% jaggery solution followed by uniform seed coating. All seeds received an inoculation procedure that finished with shade drying before sowing.

3.3 Crop Management

The study chose Wheat variety HD-3226 as it demonstrates suitable response to the regional agricultural climate patterns. A single plowing operation occurred first then the field received two harrowing procedures so that it produced a smooth tilth surface. Wheat seed sowing took place on November 15, 2023 at 100 kg/ha seed rate with 22.5 cm row spacing. Researchers advised farmers to provide the recommended quantity of 120 kg N, 60 kg P_2O_5, and 40 kg K_2O across each hectare territory.

Farmyard manure and vermicompost were integrated into the soil during a three-week period before sowing according to the allocated treatment procedures. Analyzing both organic manures prior to application revealed FYM delivered 0.52% N, 0.26% P_2O_5 and 0.55% K_2O yet vermicompost supplied 1.8% N, 1.2% P_2O_5 and 1.0% K_2O.

The treatments with chemical fertilizers received nitrogen in separate doses where 50% was added as basal dose at sowing and the remaining 25% was given at the first irrigation (21 days after sowing) followed by another 25% at the second irrigation (45 DAS). The initial application occurred at sowing time for the entire amount of phosphorus along with potassium. The United Nations applied diammonium phosphate (18% N, 46% P_2O_5), muriate of potash (60% K_2O) together with urea (46% N) for fertilization.

During the entire growth period of the crop five scheduled irrigations were applied when the crop reached important developmental phases including crown root initiation (21 DAS), tillering (45 DAS), jointing (65 DAS), flowering (85 DAS) and grain filling (105 DAS). Pendimethalin herbicide at 1.0 kg a.i./ha served as a pre-emergence treatment to eliminate weeds until farmers conducted a second manual weed removal at 35 DAS. The control regime adopted standard plant protection procedures for the area when necessary.

3.4 Data Collection and Analysis

3.4.1 Growth Parameters

A total of twenty-five plants received individual tags for multiple measurements at 30, 60, 90 DAS as well as at the harvest period. The following parameters were recorded:

- The measurement of plant height consisted of quantifying

distance from earth surface to main shoot tip without including awn length using centimeters as the unit.
- The number of tillers per tagged plant was directly counted on the marked plants.
- A leaf area meter known as LI-COR 3100 measured leaf area index by determining the relationship between leaf surface and ground surface area.
- Flag leaf chlorophyll determination occurred with a SPAD meter (SPAD-502 Plus, Konica Minolta) to assess chlorophyll level.

Plants underwent drying in an oven at 70°C to obtain their dry weight measurements for g/plant expression.

3.4.2 Yield Attributes and Yield
Field scientists measured yield attributes such as effective tillers per plant along with ear length and spikelets per ear and grains per ear and 1000-grain weight from ten randomly selected plants per plot during the stage of physiological maturity.
- Number of ear-bearing tillers represents the effective tillers per plant.
- The ear length measurement consisted of determining the centimeter length from ear base to tip without counting awns.
- Counting all spikelets from each ear constituted the measurement for this attribute.
- Researchers counted all ear grains from each selected ear.
- The weight measurement of 1000 grains from bulk harvested plots evaluates their grams per kilo weight.

The research team manually harvested all the crops before they dried them in sunlight and separated the grain from the straw via threshing followed by cleaning before they obtained the weights. The data analyst converted both moistures adjusted to 12 percent before expressing the grain yield values as tons per hectare. Straw yield measurement required a subtraction of grain yield from biological yield values before the outcomes were expressed as t/ha.

3.4.3 Soil Analysis
Researchers utilized 0-15 cm deep soil samples from every plot both prior to the experiment and after the harvest period for performing tests on different soil traits.
The digital measurement of solution pH and EC took place after suspending 2.5 parts soil with 1 part water.
- Organic carbon: Determined by the Walkley and Black wet oxidation method (Walkley & Black, 1934) [45].
- Multiple research methods determine available nitrogen levels in the soil using the alkaline permanganate method Subbiah and Asija (1956) [39] developed.
- The Olsen *et al.* spectrophotometer method helped determine available phosphorus levels (Olsen *et al.*, 1954) [24].
- The extraction of available potassium with neutral normal ammonium acetate solution followed measurement through a flame photometer as described by Jackson (1973) [11].
- Microbial biomass carbon: Determined by the chloroform fumigation-extraction method (Vance *et al.*, 1987) [42].

Dehydrogenase activity: Measured by the reduction of triphenyl tetrazolium chloride (TTC) to triphenyl formazan (TPF) (Casida *et al.*, 1964) [5].

3.4.4 Economic Analysis
Financial viability assessment took place through economic analysis methods to examine various treatments. All expenditures required for cultivation formation were compiled into one figure which encompassed expenses such as land preparation costs together with seeds and fertilizers and manures and biofertilizers and irrigation expenses and labor costs and plant protection activities and harvesting costs. The calculations of gross returns relied on wheat grain market prices set at $250 per ton and straw prices at $50 per ton. Figures were determined through an analysis that involved cost-of-cultivation reduction from gross returns. The benefit-cost ratio (B:C ratio) measured the value of cultivation costs against gross returns through cost of cultivation calculation.

3.5 Statistical Analysis
The researchers analyzed their collected data through ANOVA with standard random block procedure methods. The F-Test evaluated the meaning of treatment effects through its determination at a 5% probability level. Significant F-values resulted in the utilization of least significant difference (LSD) at $p \leq 0.05$ for mean comparisons. The SAS software version 9.4 carried out the statistical analysis.

4. Results and Discussion
4.1 Growth Parameters
4.1.1 Plant Height
Different INM treatments impacted plant height measurement in a significant way throughout each growth stage according to Table 1. The initial differences in plant size were minor at 30 DAS until the crop entered later developmental stages where differences became substantial. The combination of 75% RDF with VC along with biofertilizers in T_6 produced the highest plant height of 98.7 cm at harvest. The control treatment T_1 showed the smallest plants with 78.3 cm at the time of harvest.

Table 1: 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_1	23.4	54.2	70.8	78.3
T_2	26.8	68.5	85.6	92.5
T_3	26.2	67.4	84.7	91.8
T_4	27.0	69.2	86.4	93.6
T_5	28.3	73.6	90.8	97.2
T_6	29.1	76.4	92.5	98.7
T_7	27.5	70.8	88.2	94.5
S.Em±	0.62	1.45	1.68	1.73
LSD ($p \leq 0.05$)	1.91	4.46	5.17	5.33

Plants achieved greater height under INM conditions primarily through the collaborative action between chemical fertilizers and organic manures as well as biofertilizers. During the first growth phase chemical fertilizers supplied ready nutrients but organic materials released nutrients slowly to maintain consistent nutrient supplies throughout the entire crop development. Biofertilizers increased available nutrient content by fixing nitrogen while dissolving phosphate according to Verma *et al.* (2018) [44]. Plant growth reached its maximum height under wheat cultivation through integrated nutrient management according to Sharma *et al.* (2016) [31] while chemical fertilization alone showed lower results.

4.1.2 Number of Tillers per Plant
Different nutrient management treatments significantly shaped

the total number of tillers which each wheat plant developed.

The enhanced tillering under INM treatments occurs because improved nutrient absorption and better root development help stimulate new tiller formation. The organic matter coming from FYM and vermicompost improved soil physical qualities through their actions on root development at the same time biofertilizers made nutrients more accessible and synthesized growth-promoting compounds (Kumar *et al.*, 2019) [16]. According to Meena *et al.* (2018) [22] the wheat plants cultivated with 75% recommended NPK mixed with vermicompost and biofertilizers produced the highest number of tillers.

4.1.3 Leaf Area Index (LAI)

The photosynthetic capacity measurement Leaf Area Index developed different patterns among treatments as it rose continuously from 0 to 90 DAS then decreased at harvest because of leaf aging (Table 2). T_6 registered the most elevated leaf area index of 4.83 at 90 DAS among all treatments and the other treatments ranked similarly with T_5 obtaining 4.62 and T_7 reaching 4.41 but T_1 maintained the lowest value at 2.87.

Table 2: Effect of integrated nutrient management on leaf area index of wheat at different growth stages

Treatment	30 DAS	60 DAS	90 DAS	At harvest
T_1	0.82	2.14	2.87	1.93
T_2	1.15	3.26	3.92	2.64
T_3	1.12	3.18	3.85	2.58
T_4	1.18	3.34	4.05	2.73
T_5	1.28	3.84	4.62	3.12
T_6	1.35	4.02	4.83	3.25
T_7	1.22	3.65	4.41	2.95
S.Em±	0.04	0.12	0.14	0.09
LSD ($p \leq 0.05$)	0.12	0.37	0.43	0.28

Both T_6 and T_5 INM treatments led to an increased leaf area index because better nutrient access and boosted physical soil quality enhanced leaf growth and delayed leaf deterioration. Vermicompost and FYM organic matter services as a moisture conserving system due to better nutrient management and biofertilizers support enhanced nutrient absorption and growth-boosting substance production (Jat *et al*., 2018) [12]. The research result match Singh *et al*. (2017) [38] who discovered that wheat under integrated nutrient management practice achieved optimal LAI when contrasted with sole chemical fertilizer use.

4.1.4 Chlorophyll Content

The SPAD meter analysis showed significant treatment variations in chlorophyll content which progressively increased until 90 DAS then decreased at harvest time.

The INM approaches lead to elevated chlorophyll content because they provide better access to nitrogen which forms a part of chlorophyll structure. Crop growth received sustained nitrogen supply from the combination of chemical fertilizers with organic manures and biofertilizers added to the available nitrogen resources (Sharma *et al*., 2018) [33]. Pandey *et al*. (2016) [25] discovered that wheat crops fertilized with integrated nutrient management showed elevated chlorophyll content as opposed to crops receiving only chemical nutrients.

4.1.5 Dry Matter Accumulation

Dry matter accumulation provided a significant growth indicator because it displayed notable treatment differences and continuous development from 30 DAS up to harvest time (Table 3). The experimental group T_6 achieved the highest dry matter accumulation value of 24.6 g/plant at harvest followed by T_5 with 23.8 g/plant and T_7 with 22.5 g/plant yet the control treatment (T_1) produced only 15.2 g/plant.

Table 3: Effect of integrated nutrient management on dry matter accumulation (g/plant) at different growth stages

Treatment	30 DAS	60 DAS	90 DAS	At harvest
T_1	2.3	8.5	12.8	15.2
T_2	3.6	12.4	18.6	21.3
T_3	3.4	12.1	18.2	20.8
T_4	3.7	12.7	19.1	21.7
T_5	4.2	14.5	21.2	23.8
T_6	4.5	15.3	22.1	24.6
T_7	3.9	13.8	20.4	22.5
S.Em±	0.12	0.38	0.52	0.63
LSD ($p \leq 0.05$)	0.37	1.17	1.60	1.94

Dry matter accumulation increased significantly in INM treatments T_6 and T_5 because these treatments led to better plant growth through higher plant height and tiller production and expanded leaf area index that boosted photosynthesis rates and assimilate generation. The combination of chemical fertilizers and both organic manures and biofertilizers provided a balanced source of nutrients across the growing season and the organic material enhanced soil physical structure to improve root health and nutrient availability (Choudhary & Suri, 2014) [7]. Maximum dry matter accumulation in wheat occurred under integrated nutrient management according to Kumar *et al*. (2017) [15] while chemical fertilization alone led to reduced accumulation.

4.2 Yield Attributes and Yield

4.2.1 Yield Attributes

Available nutrient management practices in wheat fields affected all yield attributes through effective tillers per plant and ear length and spikelets per ear and grains per ear and 1000-grain weight (Table 4). The combination of 75% RDF with VC and biofertilizers under treatment T_6 showed maximum yield attributes across all parameters which exceeded T_5 (75% RDF + FYM + biofertilizers) as well as T_7 (50% RDF + FYM + VC + biofertilizers). The control treatment T_1 exhibited minimal yield attribute values.

Table 4 (continued): Effect of integrated nutrient management on yield attributes of wheat

Treatment	Effective tillers/plant	Ear length (cm)	Spikelets/ear	Grains/ear	1000-grain weight (g)
T_7	5.5	10.2	19.1	45.2	42.8
S.Em±	0.18	0.24	0.42	1.15	0.62
LSD ($p \leq 0.05$)	0.55	0.74	1.29	3.54	1.91

Better yield attribute performance of T6 happens due to combined effects between chemical fertilizers and vermicompost and biofertilizers. Vermicompost offered nutritious elements with improved soil texture alongside enhanced microbial life which combined well with biofertilizers' actions through better nutrient accessibility and growth substance production and microbial activity promotion. By offering easily accessible nutrients at crucial growth stages the chemical fertilizers simultaneously supported better ear formation and grain development processes.

The yield attributes of Treatment T_5 were marginally superior to T_6 since FYM released nutrients at a slower rate in comparison to vermicompost (Lazcano & Domínguez, 2011) [19]. Besides T_2 and T_3 and T_4 the T_5 treatment achieved superior results demonstrating the advantages of implementing biofertilizers together with chemical fertilizer.

4.2.2 Grain and Straw Yield

Different nutrient management treatments caused a significant impact on the yields of grain and straw (Figure 3). The T_6 treatment with 75% RDF + VC + biofertilizers yielded the highest grain production of 5.82 t/ha which matched a 34.7% increase above control and earned T_5 (5.64 t/ha, 30.6% above control) and T_7 (5.37 t/ha, 24.3% above control) as runner up. The T_6 treatment showed both its peak straw yield at 7.95 t/ha along with the second highest grain yield value of 7.82 t/ha and the third highest straw yield value of 7.56 t/ha. T_5 and T_7 had lower yields with 4.32 t/ha and 6.18 t/ha compared to T_6 respectively.

The integrated nutrient management in T_6 and T_5 resulted in higher production of grain and straw because these treatments achieved optimal results in plant growth attributes such as plant height, tiller count, leaf area index, effective tillers, ear length and grains per ear. The combined supply of chemical fertilizers with organic manures and biofertilizers maintained balanced nutrition throughout the growth period of the crop by improving soil physical properties and enhanced root development and nutrient uptake (Mahajan *et al.*, 2019) [20].

When using T_6 (75% RDF + VC + biofertilizers) the yield quantity reached 10.2% above T_2 (100% RDF) levels therefore integrating vermicompost and biofertilizers enables saving 25% of chemical fertilizers without yield reduction. Treatment T_5 including 75% RDF and FYM together with biofertilizers achieved observed grain yields that were 6.8% greater than T_2 confirming that properly integrated FYM can replace part of chemical fertilizers in rice cultivation systems.

Treatment T7 with 50% recommended chemical fertilizers combined with FYM and VC and biofertilizers delivered 1.7% better grain production than the complete 100% RDF in T2. This demonstrates that proper INM practices create opportunities to substantially decrease chemical fertilizer usage. The study results matched with Choudhary and Suri (2014) [7] who discovered wheat crop yields developed by combining 75% chemical fertilizers with organic manures and biofertilizers reached par or surpassed outputs from 100% chemical fertilizer applications.

4.3 Soil Health Parameters

4.3.1 Soil Chemical Properties

After wheat harvest the different nutrient management treatments dramatically impacted the soil chemical properties along with pH electrical conductivity organic carbon as well as available NPK (Table 5).

Table 5: Effect of integrated nutrient management on soil chemical properties after wheat harvest

Treatment	pH	EC (dS/m)	Organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Initial	7.80	0.32	0.42	175.0	12.8	168.0
T_1	7.82	0.33	0.40	170.2	12.2	165.4
T_2	7.75	0.36	0.43	182.5	14.5	172.6
T_3	7.68	0.34	0.52	195.8	17.2	182.3
T_4	7.65	0.33	0.56	201.4	18.5	186.5
T_5	7.62	0.31	0.59	210.6	19.7	190.2
T_6	7.58	0.30	0.63	216.5	21.3	194.8
T_7	7.60	0.32	0.60	205.2	20.1	188.7
S.Em±	0.04	0.01	0.02	4.28	0.56	3.65
LSD ($p \leq 0.05$)	0.12	0.03	0.06	13.17	1.72	11.24

The experimental treatments caused variations in soil pH from its baseline measure while Treatment 6 demonstrated the minimum value of pH 7.58 which was followed by T_7 (7.60) followed by T_5 (7.62). The reduction in soil acidity stems from both organic acid decomposition during organic manure degradation as well as nitrogen fertilizer acidification effects (Bhattacharyya *et al.*, 2015) [4].

Soil organic carbon values rose dramatically in all treatments that included INM when compared to both their initial condition and the control treatment. The highest organic carbon level in T_6 reached 0.63% while T_7 reached 0.60% and T_5 recorded 0.59% but T_1 experienced a slight decline from its initial value of 0.42% to 0.40%. The INM treatments exhibited higher organic carbon content levels because organic manure applications as well as increased root growth composed part of the soil organic carbon pool along with carbon addition (Sharma *et al.*, 2017) [32].

All of the Integrated Nutrient Management treatments produced increased levels of available NPK in the soil after wheat harvest when measured against both the initial values and control treatment. The combination of maximum nutrient input in T_6 reached 216.5 kg/ha N alongside 21.3 kg/ha P and 194.8 kg/ha K. This resulted in the highest nutrient values when compared to T_5 and T_7 and the initial T_1 assessment. The INM-based treatments accumulated more available nutrients because they directly fertilized with organic manures while improving microbial activity and organic matter retention reduced nutrient losses and enhanced nutrient recycling cycles (Choudhary *et al.*, 2018) [8].

4.3.2 Soil Biological Properties

Different nutrient management approaches influenced soil biological indicators with microbial biomass carbon reaching its peak in T_6 while dehydrogenase activity attained its maximum level in T_6 and T_5 and T_7 (Figure 4). The highest MBC measurement (285.6 µg/g) appeared in T_6 while T_5 (276.3 µg/g) and T_7 (268.9 µg/g) followed as the MBC results along with the control treatment (T_1) having the lowest MBC (162.5 µg/g). The treatments T_6 and T_5 along with T_7 showed elevated dehydrogenase activity levels with 28.7 and 27.2 and 26.4 µg TPF/g soil/day respectively, while the control displayed the lowest activity at 14.8 µg TPF/g soil/day.

INM treatments notably advanced biological properties especially in T_6 and T_5 through their high organic carbon contents that enabled microbial growth and function as substrate.

The combination of organic manures and biofertilizers supplied both convenient carbon and energy substances to soil microorganisms and directly delivered helpful microbial populations to the soil system (Wu & Ma, 2015). The advantageous physical conditions of the soil resulted in improved air circulation and water absorption which helped to boost microbial numbers and strengthen their functioning. The indicator of overall microbial activity in soil dehydrogenase activity demonstrated a robust relationship with microbial biomass carbon (r = 0.92) which indicates microbial biomass enhancement stimulates microbial activity. The analysis lines up with Patra *et al*. (2019) [27] who detected meaningful improvements of biological properties in wheat soils through integrated nutrient management.

4.4 Economic Analysis

The economic examination showed that different nutrient treatment approaches created various expenses with opposing gross returns and net returns and benefit-cost ratios (Table 6). The cost of cultivation in T_7 reached $1,248 per hectare as the highest amount followed closely by T_6 at $1,235 per hectare and then T_5 at $1,210 per hectare whereas the control treatment (T_1) recorded the lowest cultivation expense at $862 per hectare.

Table 6: Economic analysis of wheat production under different nutrient management treatments

Treatment	Cost of cultivation ($/ha)	Grain yield (t/ha)	Straw yield (t/ha)	Gross returns ($/ha)	Net returns ($/ha)	B:C ratio
T_1	862	4.32	6.18	1,389	527	1.61
T_2	1,025	5.28	7.35	1,688	663	1.65
T_3	1,175	5.36	7.48	1,714	539	1.46
T_4	1,192	5.45	7.63	1,744	552	1.46
T_5	1,210	5.64	7.82	1,801	591	1.49
T_6	1,235	5.82	7.95	1,853	618	1.50
T_7	1,248	5.37	7.56	1,716	468	1.38
S.Em±	-	0.12	0.15	37.26	22.35	0.04
LSD ($p \leq 0.05$)	-	0.37	0.46	114.67	68.78	0.12

Price of wheat grains equals $250 per ton but wheat straw values at $50 per ton along with urea at $0.35 per kilogram, DAP at $0.48 per kilogram, MOP at $0.32 per kilogram, FYM at $25 per ton, vermicompost at $75 per ton, biofertilizers at $5 per kilogram.

Treatment T_6 along with T_2 achieved maximum net returns of $618/ha and $663/ha because they produced outstanding yields of both wheat grains and straw despite their elevated cultivation expenses. The total B:C ratio in Treatment T_2 (100% RDF) reached 1.65 while T_1 (control) stood at 1.61 and T_6 (1.50) followed behind. The control treatment achieved a high B:C ratio even with low yield because the small input costs compensated for the reduced profits.

Treatment T_6 delivered the greatest net returns of $618/ha together with a B:C ratio of 1.50 due to its composition of 75% RDF combined with VC and biofertilizers. Only to achieve good yield did Treatment T_7 (50% RDF + FYM + VC + biofertilizers) provide the lowest financial returns of $468/ha and B:C ratio 1.38 making it the most expensive treatment among all treatments because of its excessive organic inputs usage.

INM practices existing as treatments T_5 and T_6 proved beneficial for wheat production and soil quality enhancement though their cost efficiency fell behind traditional chemical fertilizer usage (T_2) due to increased organic material expenses. The slightly lower economic returns from INM practices should be viewed with sustainability perspective in mind since they demonstrate positive effects on soil health and environmental sustainability beyond one-year measurement periods (Sharma and Mittra 2016) [31].

5. Conclusion

The research investigated how INM strategies affect wheat (*Triticum aestivum* L.) growth alongside soil quality and economic performance and yield development. Different findings lead to these following conclusions.

1. Integration of different nutrient sources led to superior wheat plant growth which manifested in increased plant height as well as taller number of tillers and bigger leaf area index and higher chlorophyll content and greater dry matter accumulation than the application of chemical fertilizers alone.
2. The wheat crop under INM treatments achieved higher yield levels together with improved yield attributes. The combination of 75% RDF with vermicompost plus biofertilizers in treatment T_6 allowed researchers to achieve a maximum wheat grain yield at 5.82 t/ha which exceeded control by 34.7% and 100% RDF alone by 10.2%. Vermicompost combined with biofertilizers enabled saving 25% of chemical fertilizers while maintaining equal yields with INM systems.
3. The combination of integrated nutrient management in T_6 produced much better results for soil health parameters such as organic carbon, available NPK and microbial biomass carbon together with dehydrogenase activity compared to fertilization with chemical fertilizers alone. Treatment T_6 achieved the highest results for soil health measurements making Integrated Nutrient Management an effective approach for environmentally friendly soil management.
4. The economic assessment showed INM treatments enhanced wheat production and soil quality but their financial gain was slightly lower than using chemical fertilizers solely due to organic material expenses. The slightly reduced economic outcomes of INM strategies could be acceptable regarding sustainability goals because of their enduring benefits for soil quality and environmental preservation.
5. The joint treatment of T_6 (75% RDF with vermicompost combined with biofertilizers) proved to be the most favorable INM combination because it delivered the best yield performance and environmental outcomes and cost-efficient results when compared to T_5 (75% RDF + FYM + biofertilizers).

An analysis exposes INM as an environment-friendly method that achieves wheat productivity enhancements through preserving soil quality and strong financial gains. The research demonstrates that strategic combination of chemical fertilizers and organic manures and biofertilizers diminishes fertilizer dependence without yield reduction for sustainable agricultural development. There is a need to lower the cost of organic inputs alongside developing localized INM recommendations to promote economic sustainability and broad-scale adoption among farmers.

6. References

1. Agegnehu G, Nelson PN, Bird MI. Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. Soil Tillage Res. 2016;160:1-13. https://doi.org/10.1016/j.still.2016.02.003
2. Alori ET, Glick BR, Babalola OO. Microbial phosphorus solubilization and its potential for use in sustainable agriculture. Front Microbiol. 2017;8:971. https://doi.org/10.3389/fmicb.2017.00971
3. Bashan Y, de-Bashan LE. How the plant growth-promoting bacterium Azospirillum promotes plant growth—a critical assessment. Adv Agron. 2010;108:77-136. https://doi.org/10.1016/S0065-2113(10)08002-8
4. Bhattacharyya R, Chandra S, Singh RD, Kundu S, Srivastva AK, Gupta HS. Long-term farmyard manure application effects on properties of a silty clay loam soil under irrigated wheat-soybean rotation. Soil Tillage Res. 2007;94(2):386-96. https://doi.org/10.1016/j.still.2006.08.014
5. Casida LE, Klein DA, Santoro T. Soil dehydrogenase activity. Soil Sci. 1964;98(6):371-6.
6. Chapagain T, Riseman A. Barley-pea intercropping: Effects on land productivity, carbon and nitrogen transformations. Field Crops Res. 2014;166:18-25. https://doi.org/10.1016/j.fcr.2014.06.014
7. Choudhary AK, Suri VK. Integrated nutrient management technology for direct-seeded upland rice (Oryza sativa) in Northwestern Himalayas. Commun Soil Sci Plant Anal. 2014;45(6):777-84. https://doi.org/10.1080/00103624.2013.858731
8. Choudhary M, Meena VS, Yadav RP, Parihar M, Yadav BK, Yadav GS, *et al*. Long-term effects of organic manure and inorganic fertilization on sustainability and chemical soil quality indicators of soybean-wheat cropping system in the Indian mid-Himalayas. Agric Ecosyst Environ. 2018;257:38-46. https://doi.org/10.1016/j.agee.2018.01.029
9. Gopinath KA, Saha S, Mina BL, Pande H, Kundu S, Gupta HS. Influence of organic amendments on growth, yield and quality of wheat and on soil properties during transition to organic production. Nutr Cycl Agroecosyst. 2011;82(1):51-60. https://doi.org/10.1007/s10705-008-9168-0
10. Hawkesford MJ. Reducing the reliance on nitrogen fertilizer for wheat production. J Cereal Sci. 2014;59(3):276-83. https://doi.org/10.1016/j.jcs.2013.12.001
11. Jackson ML. Soil Chemical Analysis. New Delhi: Prentice Hall of India Pvt. Ltd.; 1973.
12. Jat RA, Dungrani RA, Arvadia MK, Kanwar L. Effect of integrated nutrient management on growth, yield, nutrient uptake and soil fertility in irrigated wheat (*Triticum aestivum* L.) under semi-arid condition of Rajasthan. Indian J Agric Sci. 2018;88(2):214-9.
13. Karami A, Homaee M, Afzalinia S, Ruhipour H, Basirat S. Organic resource management: Impacts on soil aggregate stability and other soil physico-chemical properties. Agric Ecosyst Environ. 2012;148:22-8. https://doi.org/10.1016/j.agee.2011.10.021
14. Kopittke PM, Menzies NW, Wang P, McKenna BA, Lombi E. Soil and the intensification of agriculture for global food security. Environ Int. 2019;132:105078. https://doi.org/10.1016/j.envint.2019.105078
15. Kumar A, Meena RN, Yadav L, Gilotia YK. Effect of organic and inorganic sources of nutrient on yield, yield attributes and nutrient uptake of rice cv. PRH-10. Bioscan. 2017;9(2):595-7.
16. Kumar R, Kumawat N, Sahu YK. Integrated nutrient management in maize-wheat cropping system for sustainable production. Int J Curr Microbiol Appl Sci. 2019;8(3):1173-86. https://doi.org/10.20546/ijcmas.2019.803.139
17. Ladha JK, Jat ML, Stirling CM, Chakraborty D, Pradhan P, Krupnik TJ, *et al*. Achieving the sustainable development goals in agriculture: The crucial role of nitrogen in cereal-based systems. Adv Agron. 2020;163:39-116. https://doi.org/10.1016/bs.agron.2020.05.006
18. Lal R. Restoring soil quality to mitigate soil degradation. Sustainability. 2015;7(5):5875-95. https://doi.org/10.3390/su7055875
19. Lazcano C, Domínguez J. The use of vermicompost in sustainable agriculture: Impact on plant growth and soil fertility. In: Soil Nutrients. Nova Science Publishers, Inc.; 2011. p. 1-23.
20. Mahajan A, Bhagat RM, Gupta RD. Integrated nutrient management in sustainable rice-wheat cropping system for food security in India. SAARC J Agric. 2019;6(2):29-32.
21. Manivannan S, Balamurugan M, Parthasarathi K, Gunasekaran G, Ranganathan LS. Effect of vermicompost on soil fertility and crop productivity—beans (Phaseolus vulgaris). J Environ Biol. 2009;30(2):275-81.
22. Meena BL, Fagodiya RK, Prajapat K, Dotaniya ML, Kaledhonkar MJ, Sharma PC, *et al*. Legume green manuring: An option for soil sustainability. In: Legumes for Soil Health and Sustainable Management. Singapore: Springer; 2018. p. 387-408. https://doi.org/10.1007/978-981-13-0253-4_12
23. Mubarak AA, Abdel-Fattah MK, Wakeel A, Ismail SM. Organic manure efficiently compensates for a 25% reduction in mineral NPK fertilizers and improves soil properties, plant growth and yield of *Triticum aestivum* L. Agronomy. 2021;11(3):452. doi:10.3390/agronomy11030452
24. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Washington, DC: USDA; 1954. Circular No.: 939.
25. Pandey AK, Kumar M, Singh RD, Yadav RS, Tiwari RC. Effect of integrated nutrient management on yield and quality parameters of wheat (*Triticum aestivum* L.) in Madhya Pradesh. Ann Plant Soil Res. 2016;18(4):376-80.
26. Pandey D, Devi S, Singh A. Effect of nitrogen levels and biofertilizers on growth and yield of wheat (*Triticum aestivum* L.). Plant Arch. 2020;20(1):1089-92.
27. Patra S, Juwarkar AA, Singh L, Hazra T, Dutta A. Microbial diversity and activity in arsenic contaminated soil for bioremediation. In: Arsenic Contamination in Asia. Singapore: Springer; 2019. p. 245-65. doi:10.1007/978-981-13-2565-6_13
28. Rana A, Joshi M, Prasanna R, Shivay YS, Nain L. Biofortification of wheat through inoculation of plant growth promoting rhizobacteria and cyanobacteria. Eur J Soil Biol. 2012;50:118-26. doi:10.1016/j.ejsobi.2012.01.005
29. Ray DK, Mueller ND, West PC, Foley JA. Yield trends are insufficient to double global crop production by 2050. PLoS

One. 2013;8(6):e66428. doi:10.1371/journal.pone.0066428
30. Rose TJ, Pariasca-Tanaka J, Rose MT, Fukuta Y, Wissuwa M. Genotypic variation in grain phosphorus concentration, and opportunities to improve P-use efficiency in rice. Field Crops Res. 2010;119(2-3):259-67. doi:10.1016/j.fcr.2010.07.018
31. Sharma A, Mittra B. Effect of integrated nutrient management on soil properties and productivity of wheat (*Triticum aestivum*) in an acid Alfisol. J Indian Soc Soil Sci. 2016;64(1):71-9. doi:10.5958/0974-0228.2016.00009.X
32. Sharma LK, Bali SK, Zaeen AA. A case study of potential reasons of increased soil phosphorus levels in the Northeast United States. Agronomy. 2017;7(4):85. doi:10.3390/agronomy7040085
33. Sharma P, Laor Y, Raviv M, Medina S, Saadi I, Krasnovsky A, *et al*. Compositional characteristics of organic matter in municipal solid waste composts under different seasonal temperature conditions and residence time. Bioresour Technol. 2018;249:388-97. doi:10.1016/j.biortech.2017.10.033
34. Sharma SB, Sayyed RZ, Trivedi MH, Gobi TA. Phosphate solubilizing microbes: sustainable approach for managing phosphorus deficiency in agricultural soils. SpringerPlus. 2013;2(1):587. doi:10.1186/2193-1801-2-587
35. Sharma S, Duveiller E, Basnet R, Karki CB, Sharma RC. Effect of potash fertilization on *Helminthosporium* leaf blight severity in wheat, and associated increases in grain yield and kernel weight. Field Crops Res. 2003;87(2):93-101. doi:10.1016/j.fcr.2003.09.012
36. Shiferaw B, Smale M, Braun HJ, Duveiller E, Reynolds M, Muricho G. Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. Food Secur. 2013;5(3):291-317. doi:10.1007/s12571-013-0263-y
37. Singh M, Agrawal SB. Various approaches to improve nitrogen use efficiency in cereal crops. Int J Curr Microbiol Appl Sci. 2018;7(12):3221-45. doi:10.20546/ijcmas.2018.712.372
38. Singh R, Singh H, Raghubanshi AS. Effect of management practices on soil carbon storage and carbon dioxide emission in winter wheat (*Triticum aestivum*) - rice (*Oryza sativa*) cropping system of Indo-Gangetic Plains. J Indian Soc Soil Sci. 2017;65(1):25-35. doi:10.5958/0974-0228.2017.00004.5
39. Subbiah BV, Asija GL. A rapid procedure for the determination of available nitrogen in soils. *Curr Sci*. 1956;25:259-60.
40. Tahir M, Mirza MS, Hameed S, Dimitrov MR, Smidt H. Cultivation-based and molecular assessment of bacterial diversity in the rhizosheath of wheat under different crop rotations. PLoS One. 2015;10(6):e0130030. doi:10.1371/journal.pone.0130030
41. Thangarajan R, Bolan NS, Tian G, Naidu R, Kunhikrishnan A. Role of organic amendment application on greenhouse gas emission from soil. Sci Total Environ. 2013;465:72-96. doi:10.1016/j.scitotenv.2013.01.031
42. Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil microbial biomass C. Soil Biol Biochem. 1987;19(6):703-7. doi:10.1016/0038-0717(87)90052-6
43. Vejan P, Abdullah R, Khadiran T, Ismail S, Nasrulhaq Boyce A. Role of plant growth promoting rhizobacteria in agricultural sustainability—a review. Molecules. 2016;21(5):573. doi:10.3390/molecules21050573
44. Verma SK, Singh SB, Prasad SK, Meena RN, Mishra PK. Influence of irrigation regimes and integrated nutrient management on water use, productivity and profitability of rice (*Oryza sativa*) under system of rice intensification. Indian J Agron. 2018;63(1):34-42.
45. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 1934;37(1):29-38.