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Integrated nutrient management strategies for optimizing growth and yield of wheat (*Triticum aestivum* L.) in the central indo-gangetic plains

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Abstract
To assess the impact of integrated nutrient management (INM) on the growth, yield, nutrient use efficiency, and economics of wheat (*Triticum aestivum* L., cv. PBW 590), a field experiment was carried out during the Rabi season of 2024-2025 at the Agronomy Research Farm, Maharishi University of Information Technology, Lucknow (U.P.). T_1 (control), T_2 (100% RDF), T_3 (75% RDF + 25% RDN through FYM), T_4 (50% RDF + 50% RDN through FYM), T_5 (75% RDF + biofertilizer—Azotobacter + PSB), T_6 (50% RDF + 25% RDN through FYM + biofertilizer), and T_7 (100% organic: FYM + vermicompost + biofertilizer) were the seven treatments that were set up in a randomized block design. Following technical guidelines, both organic and inorganic nutrition sources were used, and the crop was consistently maintained until it reached physiological maturity and was harvested. Growth parameters, yield attributes, grain yield, nutrient use efficiency, and net income were all highest when 50% RDF + 25% RDN was applied through FYM + biofertilizer, according to the results. These values were statistically comparable to those obtained with 75% RDF + biofertilizer (Azotobacter + PSB). The research shows that INM techniques can successfully lessen reliance on chemical fertilizers while maintaining high wheat production and profitability.

Keywords: Wheat, FYM, bio-fertilizer, PSB, grain yield etc.

Introduction

The most significant staple food crop in the world and the foundation of India's food security is wheat (*Triticum aestivum* L.), a plant in the Poaceae family. China, India, the United States, Russia, France, and Australia are the top producers, while it is grown in almost every country. In terms of worldwide area (227.02 Mha) and output (779.21 MMT), wheat is the most productive cereal crop, with an average productivity of 3.49 t ha^{-1}. It is referred to as the "king of cereals" because of its large acreage and high productivity. Wheat, which contributes 113.92 million tons from 38.65 Mha with an average yield of 3.37 t ha^{-1}, is the most common rabi crop in India (Anonymous, 2023-24) [2]. Wheat growth and production are greatly improved by nutrient management, and integrated nutrient management (INM) has become a successful long-term crop productivity and soil fertility method. INM maximizes nutrient availability, improves soil health, and boosts crop performance through the prudent and coordinated application of inorganic fertilizers, organic manures, and biofertilizers (Patel *et al.*, 2017; Gupta *et al.*, 2011) [5, 10]. By improving structure, humus content, cation exchange capacity, and microbial activity, as well as by increasing the availability of plant nutrients, the consistent application of organic manures enhances the physical and chemical characteristics of soil (Hegde, 2008) [6]. According to Kaushik *et al.* (2012) and Singh *et al.* (2007) [7, 13], using both organic and inorganic sources together increases yield, maintains soil fertility, and encourages sustainable agricultural production. Nitrogen is a nutrient that is very important for wheat since it affects quality metrics, grain yield, and biomass output. On the other hand, nitrate leaching, nitrous oxide emissions, and environmental damage can result from applying too much nitrogen—beyond the crop's capacity to absorb it. Therefore, effective nitrogen management is crucial to striking a balance between sustainability and production. By fixing 25-30 kg of nitrogen per hectare and generating growth-promoting compounds, enzymes, and antibiotics, biofertilizers like Azotobacter, a free-living nitrogen-fixing bacteria, can lessen reliance on chemical fertilizers (Sharma *et al.*, 2007) [12]. Phosphate-solubilizing bacteria (PSB) also improve phosphorus absorption and availability. In addition to boosting productivity and profitability, INM adoption protects soil health and environmental purity by combining FYM, vermicompost, and biofertilizers with chemical fertilizers. Therefore, creating and supporting effective INM methods for wheat is essential to attaining high production and guaranteeing agricultural sustainability over the long run.

Materials and Methods

To find out how integrated nutrient management (INM) affected wheat (*Triticum aestivum* L.) growth and yield, a field experiment was carried out during the 2024-2025 rabi season at the Research Farm, Department of Agronomy, Maharishi University of Information Technology, Lucknow, Uttar Pradesh, India. The experimental soil had a sandy loam texture, was non-alkaline in reactivity, had a medium amount of accessible phosphorus, a high amount of available potassium, and a low amount of available nitrogen. Seven nutrient management treatments were used in the experiment, which had three replications and was set up as follows: T_1, control (no fertilizer); T_2, 100% recommended dose of fertilizer (RDF); T_3, 75% RDF + 25% recommended dose of nitrogen (RDN) through farmyard manure (FYM); T_4, 50% RDF + 50% RDN through FYM; T_5, 75% RDF + biofertilizer (Azotobacter + phosphate-solubilizing bacteria, PSB); T_6, 50% RDF + 25% RDN through FYM + biofertilizer; and T_7, 100% organic (FYM + vermicompost + biofertilizer). At planting, 50% of the nitrogen and the entire amount of potassium and phosphorus were administered; the remaining nitrogen was top-dressed in two equal splits at the first and second irrigations. On December 8, 2024, the wheat variety PBW 590 was planted using a seed drill at a seed rate of 125 kg ha^{-1}. To provide the best possible seed-soil contact, planking was then applied. In order to maintain ideal moisture levels, irrigation (5.0 cm depth) was planned based on crop phenology and soil moisture status. It began at the crown root initiation (CRI) stage (21 days after planting) and continued through tillering, late jointing, blooming, milking, and dough phases. Each plot was harvested independently after the crop reached physiological maturity. After four days of sun drying, the harvested bundles were threshed using a power thresher. Following winnowing, grain yield was measured, and the difference between total biological yield and grain yield was used to calculate straw yield. All yields were reported in tonnes per hectare (t ha^{-1}). For further statistical analysis, growth and yield attribute observations were made in accordance with accepted agronomic practices.

Table 1: Initial plant population (m^{-2}) at 20 DAS and plant height (cm) at successive growth stages of wheat crop as influenced by various integrated nutrient management practices

Treatments		Plant Population (m^{-2})	Plant height (cm)			
			30 DAS	60 DAS	90 DAS	At harvest
Ti	Control	153.00	22.20	51.00	66.30	67.60
t_2	100% RDF	156.60	23.60	59.00	76.70	78.20
t_3	75% RDF + 25% RDN through FYM	169.20	25.00	63.10	82.00	83.60
t_4	50% RDF + 50% RDN through FYM	158.40	23.90	59.90	77.90	79.50
T_5	75% RDF + Bio-fertilizer (Azotobacter +PSB)	172.00	25.90	67.10	87.30	89.00
t_6	50% RDF +25% RDN through FYM & Bio-fertilizer	175.60	26.20	69.20	90.00	91.80
T_7	100% organic (FYM +Vermicompost + Bio-fertilizer)	167.40	24.70	60.70	78.90	80.40
SEm (+)		7.79	7.79	0.90	2.28	3.88
CD at 5%		NS	NS	2.65	6.73	11.45

Table 2: Number of tillers per m^{-2} of wheat as influence by various integrated nutrient management practices

Treatments		Number of Tillers (m^{-2})			
		30 DAS	60 DAS	90 DAS	At harvest
T_1	Control (No fertilizer)	168.00	243.30	256.10	248.60
T_2	100% RDF	174.00	306.00	322.00	312.70
T_3	75% RDF + 25% RDN through FYM	188.00	329.60	347.00	336.80
T_4	50% RDF + 50% RDN through FYM	176.00	307.80	323.80	314.40
T_5	75% RDF + Bio-fertilizer (Azotobacter +PSB)	191.00	347.70	366.00	355.40
T_6	50% RDF + 25% RDN through FYM $ Bio-fertilizer	195.00	355.40	374.00	363.20
T_7	100% organic (FYM +Vermicompost + Bio-fertilizer)	186.00	324.20	341.20	331.20
SEm(±)		SEm(±)	6.65	13.12	12.07
CD at 5%		CD at 5%	19.62	38.70	35.60

Table 3: Dry matter accumulation (g m^{-2}) at successive growth stages of wheat crop as influenced by various integrated nutrient management practices

Treatments		Dry matter accumulation (g m^{-2})			
		30 DAS	**60 DAS**	**90 DAS**	**At harvest**
T_1	Control (No fertilizer)	68.82	389.60	519.50	611.20
T_2	100% RDF	73.16	512.80	683.80	804.50
T_3	75% RDF + 25% RDN through FYM	77.50	564.20	752.30	885.00
T_4	50% RDF + 50% RDN through FYM	74.09	518.60	691.40	813.50
T_5	75% RDF + Bio-fertilizer (Azotobacter +PSB)	80.29	592.90	790.50	930.00
T_6	50% RDF + 25% RDN through FYM & Bio-fertilizer	81.22	602.80	803.60	945.50
T_7	100% organic (FYM +Vermicompost + Bio-fertilizer)	76.57	553.00	737.40	867.50
SEm(±)		3.60	19.38	26.75	35.02
CD at 5%		10.62	57.16	78.91	103.29

Table 4: Leaf area index at successive growth stages of wheat crop as influenced by various integrated nutrient management practices.

Treatments		Leaf area index (LAI)		
		30 DAS	60 DAS	90 DAS
T_1	Control (No fertilizer)	1.42	3.87	3.93
T_2	100% RDF	1.45	4.54	4.61
T_3	75% RDF + 25% RDN through FYM	1.52	4.80	4.90
T_4	50% RDF + 50% RDN through FYM	1.48	4.59	4.65
T_5	75% RDF + Bio-fertilizer (Azotobacter +PSB)	1.55	5.10	5.20
T_6	50% RDF + 25% RDN through FYM & Bio-fertilizer	1.58	5.26	5.35
T_7	100% organic (FYM +Vermicompost + Bio-fertilizer)	1.51	4.61	4.70
SEm(±)		0.07	0.17	0.20
CD at 5%		0.21	0.51	0.58

Table 5: Yield attributes of wheat crop as influenced by integrated nutrient management practices

Treatments		Number of spikes (m^{-2})	Length of spike (cm)	No. of grains $spike^{-1}$	Test weight (g)
T_1	Control (No fertilizer)	293.40	8.80	38.00	32.90
T_2	100% RDF	313.60	9.80	40.20	35.30
T_3	75% RDF + 25% RDN through FYM	337.00	10.12	41.20	35.45
T_4	50% RDF + 50% RDN through FYM	315.30	9.85	40.40	35.35
T_5	75% RDF + Bio-fertilizer (Azotobacter +PSB)	345.00	10.25	41.60	35.65
T_6	50% RDF + 25% RDN through FYM & Bio-fertilizer	352.60	10.30	42.00	35.70
T_7	100% organic (FYM +Vermicompost + Bio-fertilizer)	331.60	10.05	41.00	35.40
SEm(±)		11.26	0.36	1.64	1.31
CD at 5%		33.21	NS	NS	NS

Table 6: Effect of integrated nutrient management practices on Grain yield, straw yield, biological yield and harvest index of wheat crop

Treatments		Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological Yield (t ha^{-1})	Harvest Index (%)
T_1	Control (No fertilizer)	3.22	4.12	7.34	39.59
T_2	100% RDF	3.36	4.68	8.04	41.77
T_3	75% RDF + 25% RDN through FYM	3.72	5.13	8.85	42.03
T_4	50% RDF + 50% RDN through FYM	3.40	4.73	8.13	41.79
T_5	75% RDF + Bio-fertilizer (Azotobacter +PSB)	3.92	5.38	9.30	42.15
T_6	50% RDF + 25% RDN through FYM & Bio-fertilizer	3.99	5.46	9.45	42.20
T_7	100% organic (FYM +Vermicompost + Bio-fertilizer)	3.64	5.03	8.67	41.96
SEm(±)		0.13	0.233	0.289	1.50
CD at 5%		0.39	0.70	0.85	NS

Table 7: NPK content (%) in wheat crop as influenced by various integrated nutrient management practices

Treatments		Nitrogen content (%)		Phosphorus content *(%)*		Potassium content *(%)*	
		Grain	Straw	Grain	Straw	Grain	Straw
Ti	Control (No fertilizer)	1.72	0.54	0.34	0.10	0.36	1.39
T_2	100% RDF	1.73	0.54	0.34	0.10	0.36	1.4
T_3	75% RDF + 25% RDN through FYM	1.75	0.55	0.35	0.10	0.37	1.42
T_4	50% RDF + 50% RDN through FYM	1.74	0.55	0.34	0.10	0.37	1.41
T_5	75% RDF + Bio-fertilizer (Azotobacter +PSB)	1.76	0.55	0.35	0.11	0.37	0.43
T_6	50% RDF + 25% RDN through FYM & Bio-fertilizer	1.77	0.56	0.35	0.11	0.37	1.43
T_7	100% organic (FYM +Vermicompost + Bio-fertilizer)	1.74	0.55	0.35	0.10	0.37	1.41
SEm(±)		0.08	0.02	0.01	0.05	0.03	0.03
CD at 5%		NS	NS	NS	NS	NS	0.111

Table 8: NPK uptake (kg ha^{-1}) by wheat crop as influenced by various integrated nutrient management practices

Treatments		Itrogen uptake (kg ha *)			Phosphorus Uptake (kg ha^x)			potassium uptake (kg ha^1)		
		Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T_1	Control (No fertilizer)	51.62	22.93	74.56	10.22	4.91	14.14	10.71	56.31	68.03
T_2	100% RDF	58.12	25.29	83.42	11.62	5.05	16.68	12.09	65.59	77.68
T_3	75% RDF + 25% RDN through FYM	65.10	28.21	93.31	13.02	5.59	18.61	13.76	72.84	86.61
T_4	50% RDF + 50% RDN through FYM	59.16	26.04	85.20	11.83	5.16	16.99	12.58	66.76	79.34
T_5	75% RDF + Bio-fertilizer (Azotobacter +PSB)	68.99	29.59	98.58	13.79	5.91	19.71	14.50	23.13	37.63
T_6	50% RDF + 25% RDN through FYM $ Biofertilizer	70.62	30.60	101.22	14.12	6.06	20.19	14.76	78.14	92.91
T_7	100% organic (FYM +Vermicompost + Biofertilizer)	63.33	27.69	91.02	12.74	5.48	18.22	13.46	70.99	84.46
SEm(±)		2.08	0.89	1.86	0.61	0.17	0.66	0.64	2.30	2.23
CD at 5%		6.15	2.64	5.49	1.80	0.52	1.95	1.89	6.80	6.59

Table 9: Nutrient use efficiency of wheat crop as influenced by integrated nutrient management practices

Treatments		Nitrogen use efficiency (kg ha *)			Phosphorus use efficiency (kg ha'1)			potassium use efficiency (kg ha *)		
		PFP	AE	CRE	PFP	AE	CRE	PFP	AE	CRE
Ti	Control (No fertilizer)	0	0	0	0	0	0	0	0	0
T_2	100% RDF	42.00	11.75	0.273	61.09	17.09	0.083	67.20	18.80	0.353
T_3	75% RDF + 25% RDN through FYM	46.50	16.25	0.397	62.33	21.67	0.108	93.00	32.50	0.655
T_4	50% RDF + 50% RDN through FYM	42.50	12.25	0.296	58.29	16.80	0.083	68.01	19.60	0.386
T_5	75% RDF + Bio-fertilizer (Azotobacter +PSB)	49.00	18.75	0.463	65.33	25.00	0.126	98.00	37.50	0.790
T_6	50% RDF + 25% RDN through FYM $ Bio-fertilizer	49.88	19.63	0.496	66.50	26.17	0.134	99.75	39.25	0.822
T_7	100% organic (FYM +Vermicompost + Bio-fertilizer)	45.50	15.00	0.368	60.67	20.33	0.101	91.00	30.50	0.611

Table 10: Effect of various integrated nutrient management practices on available nutrient in soil

Treatments		Available N (kg ha^J)	Available P (kg ha'1)	Available K (kg ha'1)	EC (%)	OC (%)	pH
T_1	Control (No fertilizer)	156.6	15.6	251.5	0.24	0.32	8.8
T_2	100% RDF	160.1	16.1	256	0.26	0.34	8.7
T_3	75% RDF + 25% RDN through FYM	163.7	16.5	261.8	0.25	0.35	8.54
T_4	50% RDF + 50% RDN through FYM	160.6	16.2	256.96	0.25	0.35	8.65
T_5	75% RDF + Bio-fertilizer (Azotobacter +PSB)	166.1	16.7	265.7	0.25	0.37	8.45
T_6	50% RDF + 25% RDN through FYM & Bio-fertilizer	168	16.9	268.8	0.24	0.37	8.41
T_7	100% organic (FYM +Vermicompost + Bio-fertilizer)	162.6	16.3	260.1	0.26	0.35	8.57
SEm(±)		7.55	0.59	9.37	0.09	0.16	0.32
CD at 5%		NS	NS	NS	NS	NS	NS

Table 11: Economics (Rs. ha^{-1}) of wheat as influenced by various integrated nutrient management practices

Treatments		Total cost (Rs. ha^1)	Gross income (Rs. ha^1)	Net income (Rs. ha^1)	B:C ratio
T_1	Control (No fertilizer)	29890	69693	39803	1.33
T_2	100% RDF	45112	106390	61278	1.36
T_3	75% RDF + 25% RDN through FYM	38429	115998	77569	2.02
T_4	50% RDF + 50% RDN through FYM	37048	105184	68136	1.84
T_5	75% RDF + Bio-fertilizer (Azotobacter +PSB)	36829	122028	84199	2.11
T_6	50% RDF + 25% RDN through FYM $ Bio-fertilizer	39629	124078	84449	2.13
T_7	100% organic (FYM +Vermicompost + Bio-fertilizer)	35629	113626	77997	2.01

Results and Discussion: The various integrated nutrient management (INM) techniques had no discernible effect on the initial plant population (m^{-2}). However, the administration of 50% RDF + 25% RDN through FYM + biofertilizer (T_6) greatly improved all main growth metrics, including plant height (cm), number of tillers (m^{-2}), dry matter accumulation (g m^{-2}), and leaf area index, during all crop growth stages. Among yield-attributing traits, the highest number of spikes (m^{-2}), spike length (cm), grains spike^{-1}, and test weight were recorded with T_6, followed by 75% RDF + biofertilizer (Azotobacter + PSB) (T_5), and then T_3, T_7, T_4, T_2, and T_1 in descending order. Grain yield, straw yield, and biological yield were significantly influenced by nutrient management treatments, with T_6 producing the highest grain yield (3.90 t ha^{-1}), straw yield (5.46 t ha^{-1}), and biological yield (9.45 t ha^{-1}). Harvest index and test weight were not significantly affected by the treatments, corroborating earlier findings by Singh *et al.* (2020) and Akhtar *et al.* (2018) [1, 14].

In plants, growth is defined as an irreversible increase in size, dry weight, or volume. Environmental factors and nutrient availability are the main determinants of yield qualities and ultimate output. With the exception of plant height, which grew until heading because of continuous internodal elongation, all growth metrics in the current research increased gradually until maturity. Increased nutrient availability during the vegetative phase may be the cause of the higher values of plant height, tiller density, and leaf area index under T_6, which encourage quicker development during the exponential stage. Assimilates were redirected toward grain filling rather than vegetative expansion during the transition to the reproductive stage, which is probably why the rate of rise after the active vegetative phase declined. Similar trends have been reported by Maurya *et al.* (2018) [9].

Greater photosynthetic activity, bolstered by higher tiller density and plant height, results in improved synthesis and translocation of assimilates, which accounts for the greatest dry matter accumulation under T_6. They concur with the findings of Maurya *et al.* (2018) and Fazily *et al.* (2021) [4, 9]. While there was no significant difference in the percentage of N, P, and K nutrients in either grain or straw, the total nutrient intake (grain + straw) was considerably higher under T_6, suggesting better nutrient assimilation efficiency. Due mainly to greater grain and straw yields, T_6's improved performance also translated into the greatest net return (₹84,449 ha^{-1}) and benefit-cost ratio (2.13). These results are in line with those of Kumari *et al.* (2021) [8], who found that using biofertilizer in conjunction with integrating organic and inorganic nutrient sources improved wheat's nutritional availability, production, and financial profitability.

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