



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(9): 288-291
Received: 19-07-2026
Accepted: 23-08-2026

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Evaluate the effect of integrated nutrient management practices on growth, productivity, nutrient uptake and economics of wheat (*Triticum aestivum* L.)

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i9d.6513>

Abstract

A field experiment was conducted during the *rabi* seasons of 2022–23 and 2023–24 at the Agricultural Research Farm, Rabindranath Tagore University, Raipur, Madhya Pradesh, to evaluate the effect of integrated nutrient management practices on growth, productivity, quality, nutrient uptake and economics of wheat. The experiment was laid out in a Randomized Block Design with eleven nutrient management treatments and three replications. The treatments comprised different levels of recommended dose of fertilizers (RDF) applied alone or in combination with farmyard manure (FYM), zinc sulphate (ZnSO_4) and biofertilizers (Azotobacter + phosphate-solubilizing bacteria, PSB). The results revealed that application of 100% RDF along with Azotobacter + PSB inoculation recorded the highest grain yield (43.62 q ha^{-1}), straw yield (66.41 q ha^{-1}), gross monetary return ($\text{₹}97,021 \text{ ha}^{-1}$), net monetary return ($\text{₹}66,552 \text{ ha}^{-1}$) and benefit: cost ratio (3.18). The same treatment also recorded the highest leaf area index, chlorophyll content (at 60DAS), crop growth rate, relative growth rate nutrient concentration and total uptake of nitrogen, phosphorus and potassium. Application of 100% RDF + FYM @ 5 t ha^{-1} and 100% RDF + ZnSO_4 @ 25 kg ha^{-1} also produced significantly higher growth, biological yield, nutrient uptake and economic returns compared with the recommended dose of fertilizers alone. The study indicated that application of 100% RDF in combination with Azotobacter and PSB inoculation is the most efficient and economically viable integrated nutrient management practice for achieving higher wheat productivity, improved nutrient uptake, superior grain quality and sustainable wheat production under the agro-climatic conditions of Madhya Pradesh.

Keywords: Wheat, integrated nutrient management, Azotobacter, phosphate-solubilizing bacteria, farmyard manure, zinc sulphate, nutrient uptake, productivity.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops and serves as a major source of calories and protein for nearly one-third of the world's population. Globally, wheat occupies about 220 million hectares with an annual production exceeding 790 million tonnes, making it one of the most widely cultivated food crops (FAOSTAT, 2023) ^[5]. India is the second-largest producer of wheat after China, contributing significantly to global wheat production. The crop plays a pivotal role in ensuring food and nutritional security and contributes substantially to the country's agricultural economy (Government of India, 2024) ^[7]. The continuous increase in food demand due to rapid population growth has necessitated higher agricultural productivity. During the last few decades, increased wheat production has largely been achieved through the intensive use of chemical fertilizers. However, continuous and imbalanced application of inorganic fertilizers has resulted in declining soil organic carbon, nutrient imbalance, reduced fertilizer use efficiency and deterioration of soil physical, chemical and biological properties (Ladha *et al.*, 2022; Bhattacharyya *et al.*, 2021) ^[10, 2]. Such practices have also affected long-term soil fertility and sustainability of crop production systems. Integrated Nutrient Management (INM) has emerged as an effective approach for sustaining crop productivity while maintaining soil health. The concept of INM involves the combined use of inorganic fertilizers, organic

manures and biofertilizers to ensure balanced nutrient supply and improve nutrient use efficiency (Mahajan *et al.*, 2021) ^[11]. Organic sources such as farmyard manure (FYM) improve soil structure, water-holding capacity, microbial activity and nutrient mineralization, while biofertilizers like Azotobacter and phosphate-solubilizing bacteria (PSB) enhance biological nitrogen fixation and phosphorus availability, thereby improving nutrient uptake and crop growth (Meena *et al.*, 2020) ^[12].

The integration of organic and inorganic nutrient sources has been reported to enhance photosynthetic efficiency, root growth, dry matter accumulation and yield attributes, ultimately leading to higher grain yield and improved grain quality (Kumar *et al.*, 2022). Furthermore, micronutrients such as zinc play a vital role in enzyme activation, chlorophyll synthesis, protein metabolism and carbohydrate translocation, which directly influence crop productivity and nutritional quality (Alloway, 2008; Cakmak, 2008) ^[1, 3].

Madhya Pradesh is one of the leading wheat-producing states of India. However, continuous cultivation and inadequate replenishment of nutrients have resulted in declining soil fertility and nutrient-use efficiency in many wheat-growing regions. Under these conditions, integrated nutrient management offers a promising strategy for improving crop productivity, maintaining soil fertility and enhancing economic returns. Although several studies have demonstrated the beneficial effects of integrated nutrient management in cereal crops, information on the comparative performance of different nutrient management strategies under the agro-climatic conditions of central Madhya Pradesh remains limited. Therefore, the present investigation to evaluate the effect of different integrated nutrient management practices on growth, physiological parameters, yield, grain quality, nutrient uptake and economics of wheat, and to identify an efficient and sustainable nutrient management strategy for wheat cultivation under the prevailing agro-climatic conditions of Madhya Pradesh.

Materials and Methods

A field experiment was conducted during two consecutive *rabi* seasons (2022–23 and 2023–24) at the Agricultural Research Farm, Rabindranath Tagore University, Raisen, Madhya Pradesh, India, to evaluate the effect of integrated nutrient management (INM) practices on the growth, productivity, quality, nutrient uptake and economics of wheat (*Triticum aestivum* L.). The experiment was laid out in a Randomized Block Design (RBD) with three replications comprising eleven nutrient management treatments. The treatments included: T₁–Control, T₂–50% RDF (60:30:20 kg N:P₂O₅:K₂O ha⁻¹), T₃–75% RDF (90:45:30 kg N:P₂O₅:K₂O ha⁻¹), T₄–100% RDF (120:60:40 kg N:P₂O₅:K₂O ha⁻¹), T₅–125% RDF (150:75:50 kg N:P₂O₅:K₂O ha⁻¹), T₆–150% RDF (180:90:60 kg N:P₂O₅:K₂O ha⁻¹), T₇–100% RDF + FYM @ 5 t ha⁻¹, T₈–100% RDF + ZnSO₄ @ 25 kg ha⁻¹, T₉–100% RDF + Azotobacter + phosphate-solubilizing bacteria (PSB), T₁₀–75% RDF + FYM @ 5 t ha⁻¹ and T₁₁–75% RDF + ZnSO₄ @ 25 kg ha⁻¹. The experimental soil was sandy clay loam in texture with nearly neutral reaction (pH 7.78 and 7.82), medium in organic carbon (0.52 and 0.56%), low in available nitrogen (245.60 and 252.40 kg ha⁻¹), medium in available phosphorus (16.80 and 17.25 kg ha⁻¹) and available potassium (315.40 and 322.80 kg ha⁻¹) during 2022–23 and 2023–24, respectively. The recommended dose of fertilizers was supplied through urea, diammonium phosphate (DAP) and muriate of potash (MOP). Full doses of phosphorus and potassium along with half of the nitrogen were applied as

basal at the time of sowing, while the remaining nitrogen was top-dressed in two equal splits at the first irrigation (Crown Root Initiation stage) and before the second irrigation. Farmyard manure was incorporated into the soil approximately two weeks before sowing in the respective treatments. Zinc sulphate and biofertilizers (Azotobacter and PSB) were applied as per treatment details, with wheat seeds inoculated with the respective biofertilizer cultures immediately before sowing. The wheat crop was raised following the recommended package of agronomic practices for the region. Observations on growth parameters, physiological traits, yield attributes, grain and straw yield, chlorophyll content, crop growth rate, relative growth rate, nutrient content, nutrient uptake and economics were recorded using standard procedures.

Crop Growth Rate was calculated by using the following formula

$$\text{Crop Growth Rate} = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{1}{P}$$

Where,

W₁ = Dry matter weight at time t₁

W₂ = Dry matter weight at time t₂

t₂ – t₁ = Time interval in days

P = Ground area occupied by the crop

RGR was calculated by using the following formula

$$\text{Relative Growth Rate} = \frac{\ln W_2 - \ln W_1}{T_2 - T_1}$$

Where,

W₁ = Dry matter weight at time t₁

W₂ = Dry matter weight at time t₂

t₂ – t₁ = Time interval in days

Nitrogen content in grain and straw was estimated by the micro-Kjeldahl method, phosphorus by the vanadomolybdate yellow colour method and potassium using a flame photometer. Nutrient uptake was calculated by multiplying nutrient concentration with the respective grain and straw yields. The data obtained during both years were subjected to analysis of variance (ANOVA) appropriate for a Randomized Block Design as described by Gomez and Gomez (1984) ^[6]. Treatment means were compared using the critical difference (CD) test at the 5% level of significance. Since the error variances were homogeneous over the years, pooled analysis was performed and the pooled results are presented and discussed.

Results and Discussion

Growth and physiological attributes

Integrated nutrient management (INM) treatments significantly influenced the physiological growth parameters of wheat, viz., Leaf Area Index (LAI), chlorophyll content (SPAD value), Crop Growth Rate (CGR) and Relative Growth Rate (RGR) (Table 1). The combined application of inorganic fertilizers with organic and biological nutrient sources consistently enhanced crop growth over the sole application of chemical fertilizers and the control. The highest LAI (3.45) was recorded under T₉ (100% RDF +

Azotobacter + PSB inoculation), which was significantly superior to all other treatments. This was closely followed by T₇ (100% RDF + FYM @ 5 t ha⁻¹) and T₈ (100% RDF + ZnSO₄ @ 25 kg ha⁻¹), recording LAI values of 3.33 and 3.29, respectively, whereas the lowest LAI (2.88) was observed under the control (T₁). The increase in LAI under integrated nutrient management treatments may be attributed to balanced nutrient availability, enhanced cell division and expansion, and improved canopy development resulting from better soil fertility and microbial activity. A similar trend was observed for chlorophyll content (SPAD value). Treatment T₉ recorded the highest SPAD value (42.15), followed by T₇ (41.55) and T₈ (40.60), while the control treatment recorded the lowest value (32.85). The higher chlorophyll content under integrated nutrient management treatments may be due to improved nitrogen availability through the combined application of fertilizers and biofertilizers. Azotobacter enhances biological nitrogen fixation, whereas PSB improves phosphorus availability, thereby promoting chlorophyll synthesis, delaying leaf senescence and improving photosynthetic efficiency. Zinc supplementation further contributes to chlorophyll formation and enzyme activation. Crop Growth Rate (CGR) also differed significantly among the treatments. The maximum CGR (10.50 g m⁻² day⁻¹) was recorded under T₉, followed by T₇ (10.25 g m⁻² day⁻¹) and T₈ (9.75 g m⁻² day⁻¹), whereas the lowest CGR (7.00 g m⁻² day⁻¹) was recorded under the control treatment. The enhanced CGR under integrated nutrient management may be attributed to sustained nutrient availability throughout the crop growth period, resulting in greater dry matter production and efficient utilization of solar radiation. A similar response was observed for Relative Growth Rate (RGR). Treatment T₉ registered the highest RGR (0.062 g g⁻¹ day⁻¹), followed by T₇ (0.060 g g⁻¹ day⁻¹) and T₈ (0.058 g g⁻¹ day⁻¹), whereas the minimum RGR (0.044 g g⁻¹ day⁻¹) was recorded under the control. The improvement in RGR indicates enhanced physiological efficiency and biomass accumulation under integrated nutrient management. The combined application of FYM, ZnSO₄ and biofertilizers improved soil physical, chemical and biological properties, resulting in better root growth, higher nutrient uptake and increased photosynthetic activity. Similar findings have also been reported by Meena *et al.* (2020) [12], Mahajan *et al.* (2021) [11], Kumar *et al.* (2022) [9] and Ladha *et al.* (2022) [10], who observed that integrated nutrient management significantly improved physiological growth traits through enhanced nutrient availability and soil health.

Yield studies

Integrated nutrient management significantly improved grain yield, straw yield and biological yield of wheat, whereas harvest index remained statistically non-significant (Table 1). Among the treatments, T₉ (100% RDF + Azotobacter + PSB inoculation) recorded the highest grain yield (43.62 q ha⁻¹), straw yield (66.41 q ha⁻¹) and biological yield (107.65 q ha⁻¹), followed by T₇ (42.42, 65.33 and 107.74 q ha⁻¹, respectively) and T₈ (41.78, 64.12 and 107.74 q ha⁻¹, respectively). The lowest grain, straw and biological yields (34.84, 57.85 and 92.69 q ha⁻¹, respectively) were recorded under the control (T₁). It might be due to the higher yield under integrated nutrient management treatments may be

attributed to balanced nutrient supply, improved nutrient availability and enhanced nutrient use efficiency, which promoted better crop growth, higher dry matter accumulation and efficient translocation of photosynthates to developing grains. The combined application of Azotobacter, PSB, FYM and ZnSO₄ also improved soil biological activity and nutrient uptake, thereby increasing crop productivity. Similar results have also been reported by Jat *et al.* (2018) [8], Patel *et al.* (2020) [13] and Choudhary *et al.* (2021) [4]. Harvest index was not significantly influenced by the treatments; however, the highest value (40.49%) was recorded under T₈, followed by T₁₀ (40.00%) and T₇ (39.37%), while the lowest (37.52%) was observed under T₂. The non-significant variation in harvest index indicates that both grain yield and biomass increased proportionately under integrated nutrient management practices. Comparable results were reported by Verma *et al.* (2021) [17] and Yadav *et al.* (2017) [18].

Nutrient uptake

Integrated nutrient management (INM) significantly influenced nutrient uptake by grain and straw as well as the economics of wheat cultivation (Table 2). Among the different treatments, T₉ (100% RDF + Azotobacter + PSB inoculation) recorded the highest nutrient uptake by grain, with 65.43 kg N ha⁻¹, 13.09 kg P ha⁻¹ and 17.45 kg K ha⁻¹, followed by T₇ (63.63, 12.73 and 16.97 kg ha⁻¹, respectively) and T₈ (62.67, 12.53 and 16.71 kg ha⁻¹, respectively). Similarly, the highest nutrient uptake by straw was also observed under T₉, recording 33.34 kg N ha⁻¹, 7.37 kg P ha⁻¹ and 87.20 kg K ha⁻¹, whereas the lowest uptake by grain (52.26, 10.45 and 13.94 kg ha⁻¹ of N, P and K, respectively) and straw (23.72, 4.39 and 68.26 kg ha⁻¹, respectively) was recorded under the control treatment (T₁). The increased nutrient uptake under integrated nutrient management treatments may be attributed to balanced nutrient supply, improved root growth, enhanced microbial activity and greater nutrient use efficiency. The combined application of Azotobacter, PSB, FYM and ZnSO₄ improved nitrogen fixation, phosphorus solubilization and nutrient availability throughout the crop growth period, resulting in greater nutrient absorption and accumulation in both grain and straw. Similar findings have been reported by Singh *et al.* (2006) [16], Roy *et al.* (2014) [14] and Sharma *et al.* (2019) [15].

Economics

The economic analysis further revealed significant differences among the nutrient management treatments. Treatment T₉ proved to be the most profitable, recording the highest net return (₹66,552 ha⁻¹) and benefit:cost ratio (3.18), followed by T₇ (₹62,632 ha⁻¹ and 2.97) and T₁₀ (₹61,369 ha⁻¹ and 3.02). The control treatment recorded the lowest net return (₹42,217 ha⁻¹) and B:C ratio (2.64). The higher profitability under integrated nutrient management treatments was mainly due to higher grain yield, improved nutrient use efficiency and better economic utilization of applied inputs, which compensated for the additional cost of FYM, biofertilizers and zinc application. These findings are in close agreement with those reported by Roy *et al.* (2014) [14], Kumar *et al.* (2022) [9] and Mahajan *et al.* (2021) [11].

Table 1: Growth, grain, straw, biological and harvest index as influenced by integrated nutrient management (Pooled data of two years)

Treatments	Growth Studies				Yield studies			
	Leaf Area Index (LAI)	SPAD value	Crop Growth Rate (g m ⁻² day ⁻¹)	Relative Growth Rate (g g ⁻¹ day ⁻¹)	Grain yield (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)	Harvest Index (%)
T ₁ : Control	2.88	32.85	7.00	0.044	34.84	57.85	92.69	37.59
T ₂ : 50% RDF (60:30:20 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	3.00	36.10	7.70	0.047	35.34	58.83	94.16	37.52
T ₃ : 75% RDF (90:45:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	3.05	36.80	8.00	0.049	36.38	60.58	96.96	37.53
T ₄ : 100% RDF (120:60:40 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	3.13	37.25	8.25	0.051	37.01	59.59	96.60	38.31
T ₅ : 125% RDF (150:75:50 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	3.20	38.40	8.75	0.054	40.24	64.19	104.43	38.54
T ₆ : 150% RDF (180:90:60 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	3.15	37.60	8.45	0.052	39.37	62.80	102.17	38.54
T ₇ : 100% RDF + FYM @ 5 t ha ⁻¹	3.33	41.55	10.25	0.060	42.42	65.33	107.74	39.37
T ₈ : 100% RDF + ZnSO ₄ @ 25 kg ha ⁻¹	3.29	40.60	9.75	0.058	41.78	64.12	107.74	40.49
T ₉ : 100% RDF + Azotobacter + PSB inoculation	3.45	42.15	10.50	0.062	43.62	66.41	107.65	38.31
T ₁₀ : 75% RDF + FYM @ 5 t ha ⁻¹	3.27	40.15	9.25	0.057	41.24	62.68	104.46	40.00
T ₁₁ : 75% RDF + ZnSO ₄ @ 25 kg ha ⁻¹	3.24	38.85	9.00	0.055	40.21	63.14	103.35	38.91
S. E. (m) ±	0.08	0.60	0.28	0.002	1.23	1.84	3.06	-
C. D. (at 5%)	0.22	1.80	0.82	0.005	3.68	5.51	9.19	-

Table 2: Nutrient uptake of wheat and economics as influenced by integrated nutrient management (Pooled data of two years)

Treatments	Nutrient Uptake (Grain)			Nutrient Uptake (straw)			Economics	
	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)	Net return (Rs/ha)	B:C ratio
T ₁ : Control	52.26	10.45	13.94	23.72	4.39	68.26	42217	2.64
T ₂ : 50% RDF (60:30:20 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	53.01	10.60	14.14	24.70	4.71	70.60	50639	2.81
T ₃ : 75% RDF (90:45:30 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	54.57	10.91	14.55	26.05	5.15	74.51	51827	2.78
T ₄ : 100% RDF (120:60:40 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	55.52	11.10	14.80	26.24	5.36	74.49	52093	2.72
T ₅ : 125% RDF (150:75:50 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	60.36	12.07	16.10	30.17	6.10	81.92	58098	2.85
T ₆ : 150% RDF (180:90:60 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	59.06	11.81	15.75	30.77	6.28	81.64	55025	2.69
T ₇ : 100% RDF + FYM @ 5 t ha ⁻¹	63.63	12.73	16.97	33.32	6.86	86.92	62632	2.97
T ₈ : 100% RDF + ZnSO ₄ @ 25 kg ha ⁻¹	62.67	12.53	16.71	31.34	6.90	83.81	61673	2.97
T ₉ : 100% RDF + Azotobacter + PSB inoculation	65.43	13.09	17.45	33.34	7.37	87.20	66552	3.18
T ₁₀ : 75% RDF + FYM @ 5 t ha ⁻¹	61.86	12.37	16.50	31.88	6.31	84.98	61369	3.02
T ₁₁ : 75% RDF + ZnSO ₄ @ 25 kg ha ⁻¹	60.32	12.06	16.08	29.04	5.68	79.56	59323	2.97
S. E. (m) ±	1.84	0.37	0.49	0.74	0.22	2.15	796.40	0.06
C. D. (at 5%)	5.51	1.10	1.47	2.21	0.65	6.45	2366.20	0.18

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