



Performance of Wheat (*Triticum aestivum* L.) as Influenced by Bio-organics and Micronutrient Fertilization

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: <https://doi.org/10.9734/ijpss/2026/v38i106389>

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://pr.sdiarticle5.com/review-history/168586>

Original Research Article

Received: 09/08/2026

Accepted: 17/10/2026

Published: 24/10/2026

Abstract

Wheat (*Triticum aestivum* L.) productivity may be influenced by the combined use of bio-organics and micronutrient fertilisers. A field experiment was conducted on the sandy loam soils of the Agronomy Farm, S.K.N. College of Agriculture, Jobner (Jaipur, Rajasthan), for two consecutive *rabi* seasons to assess the performance of wheat under bio-organics and micronutrient fertilization. The results revealed that the application of FYM @ 5 t ha⁻¹ + V.C. @ 2.5 t ha⁻¹ + *Azotobacter* + PSB recorded significant increases in growth attributes, yield attributes, viz., number of effective tillers, number of grains per spike and test weight; grain, straw and biological yields; and the harvest index of wheat over the control. The results further revealed that the growth parameters (plant height, dry matter accumulation and growth indices), yield attributes (number of effective tillers, grains per spike and test weight), yields (grain, straw and biological) and the harvest index of wheat were significantly higher with soil application of Zn @ 2.5 kg ha⁻¹.

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¹ + foliar application of Fe @ 0.5% over the control. Application of FYM @ 5 t ha⁻¹ + V.C. @ 2.5 t ha⁻¹ + *Azotobacter* + PSB in combination with soil application of Zn @ 2.5 kg ha⁻¹ + foliar application of Fe @ 0.5% registered significantly higher grain and straw yields of wheat. An economic analysis based on the net returns from the various treatment combinations showed that application of FYM @ 10 t ha⁻¹ along with soil application of Zn @ 2.5 kg ha⁻¹ + foliar application of Fe @ 0.5% generated the highest net return compared with the remaining treatments. The combined application of FYM @ 10 t ha⁻¹ with the soil application of Zn @ 5 kg ha⁻¹ recorded the highest B:C ratio among the treatment combinations.

Keywords: *Azotobacter*; economics; farm yard manure; growth; phosphate-solubilising bacteria; vermicompost; wheat; yield attributes.

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important staple food crops worldwide, including in India. In India, it is the second most important staple food crop after rice. Wheat provides 20% of the human dietary energy supply and serves as the main source of protein in developing nations (Braun *et al.*, 2010). India has the largest area under wheat cultivation, covering approximately 32.8 million hectares, with a productivity of 3,595 kg ha⁻¹ (Ministry of Finance, Government of India, 2025). Wheat is grown mainly in the states of Uttar Pradesh, Madhya Pradesh, Punjab, Haryana, Rajasthan, Bihar, Gujarat and Maharashtra. Among the different states of India, Uttar Pradesh ranks first in area and total production, while Punjab ranks first in productivity. The increasing use of chemical fertilisers without adequate organic recycling has not only aggravated multi-nutrient deficiencies in the soil-plant system but also deteriorated soil health and contributed to environmental pollution. Organic materials are intrinsic and essential components of soils, making soil a living, dynamic system that supports life and plays a vital role in improving physical, chemical and biological properties of the soil. Besides influencing nutrient dynamics in soils, organic matter acts as a temporary nutrient sink through an array of biochemical processes, ranging from adsorption reactions to the formation of organo-nutrient compounds. It is well known that organic materials increase soil enzyme activities, which play a vital role in nutrient transformation and organic recycling, thereby improving soil quality. The sustainability of agricultural production systems also depends on maintaining sufficient reserves of soil organic matter to protect soil biomass and productivity. It is widely recognised that maintaining an adequate level of soil organic matter should be a guiding principle in developing appropriate soil management practices, as any decline in soil organic matter may reduce soil productivity (Nambiar & Abrol, 1989). A systematic review has also identified potential benefits of integrating vermicompost, phosphate-solubilising microorganisms and mineral fertilisers for crop growth and soil properties (Sande *et al.*, 2024).

FYM is a major source of organic matter, but its availability is inadequate and declining. Appropriate and economically justified recycling of crop residues in the form of FYM, compost, vermicompost, green manure, etc., and the use of biofertilisers may provide a substantial supply of nutrients to the soil-plant system (Dixit & Gupta, 2000). Vermicompost is increasingly gaining importance as an alternative to other organic manures. Vermicompost has been advocated as a good source of organic manure for use in integrated cultivation practices for field crops. It is well known that the incorporation of organic residues in the soil-plant system directly or indirectly improves the physical, chemical and biological properties of soil and helps sustain crop production and soil fertility (Choudhary, 2016). It is also a rich source of macro- and micronutrients, vitamins, enzymes, antibiotics and growth hormones. Biofertilisers are another source of bio-organics that play an important role in meeting crop nutrient requirements through biological nitrogen fixation (BNF), solubilisation of insoluble native phosphorus sources, stimulation of plant growth and acceleration of the decomposition of plant residues. *Azotobacter* bacteria are important bio-inoculants for cereal crops and fix atmospheric nitrogen non-symbiotically. Phosphate-solubilising bacteria (PSB) are considered important because they help mineralise organic phosphates. Field studies on biofertilisers have shown variable benefits in terms of fertiliser savings and improved P fertiliser-use efficiency through phosphate solubilisers and VAM in principal crops and succeeding crops (Parihar, 2016). A field study on wheat reported improvements in grain yield and economic returns when vermicompost, *Azotobacter* and mineral fertilisers were applied together (Niranjan *et al.*, 2024). Another wheat study observed differences in grain yield among vermicompost and inorganic fertiliser combinations, supporting the evaluation of nutrient sources and application rates together (Gosa *et al.*, 2025). Micronutrients are as essential as major nutrients for the normal growth of plants. Deficiencies of micronutrients drastically affect the growth, metabolism and reproductive phase in plants. Pot-based research has also shown that combined nitrogen and zinc fertilisation can influence wheat growth, physiological traits and yield (Shehzadi *et al.*, 2024). Zn and Fe deficiencies have been recognised as important factors affecting both human health and crop production. In India, almost 48% of soils are deficient in Zn, whereas 12% are deficient in Fe (Singh, 2009). A synthesis of field studies reported that wheat grain yield and zinc and iron concentrations can respond to zinc and iron fertiliser applications, with responses influenced by soil and management conditions (Devkota *et al.*, 2026). Nevertheless, the growth, yield and economic responses of wheat to the bio-organic treatments evaluated here, in combination with the specified soil and foliar zinc and iron applications under the sandy loam conditions of Jobner require direct field assessment. In view of these considerations, the present study was conducted to assess the effects of bio-organics and micronutrient fertilisers on the performance of wheat.

2. Material and Methods

The field experiments during the *rabi* seasons of 2014–15 and 2015–16 were conducted at the same field location at the Agronomy Farm, S.K.N. College of Agriculture, Jobner (Jaipur), Rajasthan, India. The experiment comprised 21 treatment combinations involving three levels of bio-organics and seven levels of micronutrients, arranged in a split-plot design with four replications. The three treatments of bio-organics [control (B₀), FYM @ 10 t ha⁻¹ (B₁) and FYM @ 5 t ha⁻¹ + V.C. @ 2.5 t ha⁻¹ + *Azotobacter* + PSB (B₂)] were applied in the main plots and seven treatments of micronutrients [control (M₀), soil application of Zn @ 5 kg ha⁻¹ (M₁), foliar application of Zn @ 0.5% (M₂), soil application of Fe @ 10 kg ha⁻¹ (M₃), foliar application of Fe @ 0.5% (M₄), soil application of Zn @ 2.5 kg ha⁻¹ + foliar application of Fe @ 0.5% (M₅) and soil application of Fe @ 5 kg ha⁻¹ + foliar application of

Zn @ 0.5% (M₆) were applied in the subplots. The wheat variety Raj-4037 was used as the test crop. The treatments were allocated randomly using a random number table (Fisher & Yates, 1963). The bio-organic and micronutrient treatments were applied at the recommended doses. The recommended quantities of FYM and V.C. were procured from the college dairy farm and the V.C. unit, respectively. FYM was applied 21 days before sowing in the respective beds and thoroughly incorporated into the soil.

The vermicompost treatments were applied before sowing. Representative homogeneous samples of FYM and V.C. were taken and oven-dried to determine nitrogen, phosphorus, potassium and moisture contents. NPK fertilisers were applied uniformly before sowing through urea, SSP and MOP, respectively. Before treatment with biofertilisers, the seeds were first treated with carbendazim and then with chlorpyrifos. Seeds were inoculated with *Azotobacter* and PSB culture according to the treatments and dried in the shade just before sowing. The different levels of iron and zinc were supplied through ZnSO₄.7H₂O and FeSO₄.7H₂O, respectively, according to the treatments, through soil and foliar applications, either individually or in combination. Foliar sprays of micronutrients were applied at the maximum tillering and panicle initiation stages of the wheat crop. The harvested material of each plot was tied into bundles, tagged and kept on the threshing floor for sun-drying. Dried bundles from each plot were weighed separately to record biological yield. Threshing was done manually followed by winnowing. After cleaning, grain yield per plot was recorded and subsequently converted into yield per hectare. The straw yield in kg per plot was obtained by subtracting the grain yield from the biological yield recorded earlier for each treatment. The economics of the different treatments were calculated by taking into account the cost of inputs and income obtained from the output based on the prevailing market price. Statistical analysis of the data was carried out using standard analysis of variance (Gomez & Gomez, 1984).

3. Results and Discussion

3.1 Growth Parameters of Wheat

The growth parameters of wheat including plant height, dry matter accumulation, leaf area index, crop growth rate, total chlorophyll content and total number of tillers were significantly influenced by different treatments of bio-organics (Table 1). Application of FYM @ 5 t ha⁻¹ + V.C. @ 2.5 t ha⁻¹ + *Azotobacter* + PSB recorded the significantly highest plant height (98.0 cm), dry matter accumulation (221.19 g/m row length), LAI (3.52), CGR (2.08 g/m²/day), total chlorophyll content in leaves (1.97 mg/g) and total number of tillers (105.9/m row length) compared with the control and the sole application of FYM @ 10 t/ha. The increase in growth parameters might be due to better availability of essential plant nutrients in balanced form throughout the growth period of the crop in addition to improving the physical and microbial properties of the soil, which are responsible for mineralisation of the native nutrients in the soil. Furthermore, the application of *Azotobacter* improves the availability of nitrogen in the soil by fixation of atmospheric nitrogen and may also contribute through the synthesis of biologically active substances such as vitamins, auxin and gibberellins, which in turn might have stimulated the plant growth parameters. These results are consistent with the findings of Tripathi et al. (2011).

Table 1. Effect of bio-organics and micronutrient fertilization on growth parameters of wheat (Pooled mean of two year)

Treatments	Plant height (cm)	Dry matter accumulation per metre row length (g)	LAI at 90 DAS	CGR (90 DAS to harvest) (g/m ² /day)	Chlorophyll content (mg g ⁻¹ fresh wt. of leaf)	Total number of tillers per metre row length
Bio-organics						
B ₀ (Control)	83.3	194.26	2.89	1.83	1.81	87.40
B ₁ (FYM @ 10 t ha ⁻¹)	91.7	208.52	3.21	1.92	1.88	99.51
B ₂ (FYM @ 5 t ha ⁻¹ + V.C. @ 2.5 t ha ⁻¹ + <i>Azotobacter</i> + PSB)	98.0	221.19	3.52	2.08	1.97	105.92
SEm±	0.7	1.60	0.03	0.02	0.02	0.76
CD (P = 0.05)	2.2	4.94	0.08	0.05	0.06	2.35
Micronutrient fertilization						
M ₀ (Control)	81.9	187.07	2.88	1.75	1.71	88.39
M ₁ (SA of Zn @ 5 kg ha ⁻¹)	91.7	209.59	3.06	1.96	1.82	96.43
M ₂ (FA of Zn @ 0.5%)	90.9	207.71	3.16	1.94	1.84	94.90
M ₃ (SA of Fe @ 10 kg ha ⁻¹)	90.3	206.28	3.23	1.93	1.99	94.17
M ₄ (FA of Fe @ 0.5%)	91.3	208.59	3.31	1.95	1.92	95.97
M ₅ (SA of Zn @ 2.5 kg ha ⁻¹ + FA of Fe @ 0.5%)	96.4	220.23	3.36	2.06	1.93	107.32
M ₆ (SA of Fe @ 5 kg ha ⁻¹ + FA of Zn @ 0.5%)	94.7	216.44	3.41	2.03	1.96	106.06
SEm±	0.7	1.66	0.03	0.02	0.03	0.78
CD (P = 0.05)	2.0	4.65	0.07	0.04	0.08	2.18

* Treatment not applied FYM = Farm yard manure V.C. = Vermicompost SA = Soil Application FA = Foliar Application

Micronutrient fertilization also had a significant effect on different growth parameters of wheat (Table 1). Soil application of Zn @ 2.5 kg ha⁻¹ + foliar application of Fe @ 0.5%, which was statistically at par with soil application of Fe @ 5 kg ha⁻¹ + foliar application of Zn @ 0.5%, recorded significantly higher values of plant height, dry matter accumulation, CGR and total chlorophyll content in leaves of wheat plants than the other treatments of micronutrient fertilization. However, in terms of LAI, soil application of Fe @ 5 kg ha⁻¹ + foliar application of Zn @ 0.5% was at par with soil application of Zn @ 2.5 kg ha⁻¹ + foliar

application of Fe @ 0.5% and was significantly better than the remaining treatments. A significantly higher value of total chlorophyll content in leaves of wheat (1.99 mg/g) was recorded following soil application of Fe @ 10.0 kg ha⁻¹ compared with the control, soil application of Zn @ 5 kg ha⁻¹ and foliar application of Zn @ 0.5%. The increase in growth parameters might be attributed to increased seed respiration, oxygen transport, auxin metabolism, cytochrome synthesis and 714ertilization of ribosomal fractions, as well as faster cell division, cell elongation, root and shoot development, greater photosynthetic activity and chlorophyll synthesis due to zinc and iron 714ertilization resulting in better vegetative growth and ultimately increased plant height of wheat. Rahevalet al. (2015) also reported similar results.

3.2 Yields Attributes and Yield of Wheat

Application of bio-organics resulted in significant improvements in yield attributes and yield of wheat (Table 2). Application of FYM @ 5 t ha⁻¹ + V.C. @ 2.5 t ha⁻¹ + *Azotobacter* + PSB recorded the significantly highest number of effective tillers (76.8/m row length), number of grains per spike (46.61), test weight (45.10 g), grain yield (3.841 t/ha), straw yield (5.415 t/ha), biological yield (9.256 t/ha) and harvest index (41.49 per cent) compared with the other bio-organic treatments. The favourable improvements in yield attributes might have been due to better availability of nutrients in balanced form throughout the crop growth period, effective 714ertilization of nutrients, and increased microbial populations and activity through the supply of substrates to soil microorganisms responsible for 714ertilization native nutrients (Tripathi et al., 2011; Singh et al., 2014). The increase in grain yield might be due to an improved nutritional environment and better soil physical conditions, thereby resulting in better growth and development leading to improved yield attributes and higher grain and straw yields (Yadav et al., 2013).

Application of micronutrients alone or in combinations significantly improved the yield attributes of wheat, as well as the productivity and harvest index of the crop (Table 2). Soil application of Zn @ 2.5 kg ha⁻¹ + foliar application of Fe @ 0.5%, which was at par with soil application of Fe @ 5 kg ha⁻¹ + foliar application of Zn @ 0.5%, was significantly better than the remaining treatments in terms of number of grains per spike (45.33). A significantly higher number of effective tillers (78.19/m row length), test weight (45.17 g), grain yield (3.548 t/ha), straw yield (5.230 t/ha) and biological yield (8.778 t/ha) was observed following soil application of Zn @ 2.5 kg ha⁻¹ + foliar application of Fe @ 0.5% compared with the remaining micronutrient 714ertilization treatments. However, the micronutrient treatments were reported as being statistically at par with one another with respect to the harvest index. These increases in yield attributes and yield with the application of Zn and Fe might be attributed to their critical roles in crop growth, including photosynthesis, respiration, other biochemical and physiological activities, and the initiation of reproductive primordia, which may facilitate the translocation of metabolites to yield-contributing plant parts (Kulhareet al., 2014).

Table 2. Effect of bio-organics and micronutrient fertilization on yield attributes, yield and economics of wheat (Pooled mean of two year)

Treatments	Number of effective tillers per metre row length	No. of grains per spike	Test weight (g)	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest index (%)	Net returns (₹ha ⁻¹)	B:C ratio
Bio-organics									
B ₀ (Control)	63.85	40.35	40.10	2.849	4.543	7.392	38.52	40170	2.43
B ₁ (FYM @ 10 t ha ⁻¹)	73.27	43.50	43.20	3.507	5.163	8.670	40.45	51803	2.72
B ₂ (FYM @ 5 t ha ⁻¹ + V.C. @ 2.5 t ha ⁻¹ + <i>Azotobacter</i> + PSB)	76.80	46.61	45.10	3.841	5.415	9.256	41.49	51497	2.39
SEm±	0.52	0.43	0.32	0.022	0.029	0.050	0.04	488	0.01
CD (P = 0.05)	1.62	1.31	1.00	0.067	0.090	0.155	0.13	1503	0.04
Micronutrient fertilization									
M ₀ (Control)	64.40	40.59	38.34	3.084	4.619	7.703	39.82	42375	2.40
M ₁ (SA of Zn @ 5 kg ha ⁻¹)	71.95	43.82	43.43	3.445	5.110	8.555	40.15	49555	2.60
M ₂ (FA of Zn @ 0.5%)	70.87	43.43	42.83	3.426	5.061	8.486	40.27	48381	2.54
M ₃ (SA of Fe @ 10 kg ha ⁻¹)	70.20	43.13	42.59	3.421	5.096	8.517	40.08	47854	2.49
M ₄ (FA of Fe @ 0.5%)	71.58	43.61	43.05	3.435	5.098	8.533	40.14	48702	2.54
M ₅ (SA of Zn @ 2.5 kg ha ⁻¹ + FA of Fe @ 0.5%)	78.19	45.33	45.17	3.548	5.230	8.778	40.33	50554	2.57
M ₆ (SA of Fe @ 5 kg ha ⁻¹ + FA of Zn @ 0.5%)	71.93	44.50	44.20	3.436	5.069	8.505	40.29	47343	2.44
SEm±	0.59	0.40	0.34	0.030	0.041	0.068	0.11	657	0.02
CD (P = 0.05)	1.66	1.11	0.95	0.084	0.115	0.190	0.31	1841	0.06

*B₀ = Control, B₁ = FYM @ 10 t ha⁻¹, B₂ = FYM @ 5 t ha⁻¹ + Vermicompost @ 2.5 t ha⁻¹ + *Azotobacter* + PSB, SA = Soil Application, FA = Foliar Application

The interaction between bio-organics and micronutrient 714ertilization was also found to be significant for grain and straw yield of wheat (Table 3). The combination of B₂M₅ produced the significantly highest grain yield of wheat (3.936 t/ha) compared with the other combinations of bio-organics and micronutrient 714ertilization, except B₂M₁, B₂M₂, B₂M₃, B₂M₄ and B₂M₆. Similarly, the straw yield of wheat was also the significantly highest (5.552 t/ha) under B₂M₅, although this treatment was statistically at par with B₂M₁, B₂M₂, B₂M₃, B₂M₄, B₂M₆ and B₁M₅. The integration of chemical fertilisers with organic manures has also been observed to be promising for maintaining higher productivity and imparting greater stability to crop production (Nambiar & Abrol, 1989). The

favourable effect of V.C. together with ferrous sulphate was probably associated with the chelating action of organic matter and the release of H_2SO_4 during the degradation of ferrous sulphate. This, in turn, may have increased the 715 fertilization 715 of nutrients present in unavailable forms in the soil, the release of adsorbed iron and the reduction of unavailable forms of Fe. Similar findings have also been reported by Choudhary *et al.* (2016).

Table 3. Interaction effects of bio-organics and micronutrient fertilization on grain and straw yield (Pooled mean of two year)

Treatments	Grain yield ($t\ ha^{-1}$)				Straw yield ($t\ ha^{-1}$)			
	Bio-organics			Mean	Bio-organics			Mean
	B ₀	B ₁	B ₂		B ₀	B ₁	B ₂	
Micronutrient fertilization								
M ₀ (Control)	2.307	3.305	3.640	3.084	3.780	4.902	5.177	4.619
M ₁ (SA of Zn @ 5 kg ha^{-1})	2.855	3.578	3.902	3.445	4.573	5.267	5.488	5.110
M ₂ (FA of Zn @ 0.5%)	2.933	3.520	3.824	3.426	4.662	5.155	5.365	5.061
M ₃ (SA of Fe @ 10 kg ha^{-1})	2.950	3.474	3.840	3.421	4.704	5.140	5.443	5.096
M ₄ (FA of Fe @ 0.5%)	2.917	3.477	3.910	3.435	4.643	5.148	5.504	5.098
M ₅ (SA of Zn @ 2.5 kg ha^{-1} + FA of Fe @ 0.5%)	3.013	3.695	3.936	3.548	4.742	5.397	5.552	5.230
M ₆ (SA of Fe @ 5 kg ha^{-1} + FA of Zn @ 0.5%)	2.969	3.503	3.834	3.436	4.699	5.132	5.377	5.069
Mean	2.849	3.507	3.841		4.543	5.163	5.415	
SEm±	0.052				0.071			
CD (P=0.05)	0.145				0.199			

B₀ = Control, B₁ = FYM @ 10 t ha^{-1} , B₂ = FYM @ 5 t ha^{-1} + Vermicompost @ 2.5 t ha^{-1} + Azotobacter + PSB, SA = Soil Application, FA = Foliar Application

3.3 Economics

The data presented in Table 2 indicated that the application of different bio-organics and levels of micronutrients (Fe & Zn) had a significant effect on the economics of wheat. Application of FYM @ 10 t ha^{-1} which was at par with the application of FYM @ 5 t ha^{-1} + V.C. @ 2.5 t ha^{-1} + Azotobacter + PSB generated the significantly highest net returns of ₹ 51,803/ha compared with the control. In terms of B:C ratio, application of FYM @ 10 t ha^{-1} was significantly superior to the remaining treatments of bio-organics. Among micronutrient 715 fertilization treatments, soil application of Zn @ 2.5 kg ha^{-1} + foliar application of Fe @ 0.5% was at par with soil application of Zn @ 5 kg ha^{-1} and generated the significantly highest net returns of ₹ 50,554/ha compared with the other treatments. However, the same treatment (M₅) recorded a significantly higher B:C ratio (2.57) compared with the control, SA of Fe @ 10 kg ha^{-1} and SA of Fe @ 5 kg ha^{-1} + FA of Zn @ 0.5%. The combined application of different bio-organics and micronutrients (Fe & Zn) also had a significant effect on the economics of wheat (Table 4). Among the bio-organic and micronutrient treatment combinations, B₁M₅, which was at par with B₁M₁, B₂M₁, B₂M₄ and B₂M₅, generated the significantly highest net returns of ₹ 55,376 per ha compared with the other treatment combinations. Treatment combination B₁M₁ was at par with B₁M₅ and recorded the significantly highest B:C ratio (2.84) compared with the remaining treatment combinations. The higher net returns and B:C ratio under the respective treatments might be attributed to greater yield-related returns relative to the associated costs. Similar findings were also reported by Kumar *et al.* (2016).

Table 4. Interaction effects of bio-organics and micronutrient fertilization on net returns and B:C ratio (Pooled mean of two year)

Treatments	Net returns (₹ ha^{-1})				B:C ratio			
	Bio-organics			Mean	Bio-organics			Mean
	B ₀	B ₁	B ₂		B ₀	B ₁	B ₂	
Micronutrient fertilization								
M ₀ (Control)	29386	48955	48784	42375	2.11	2.72	2.38	2.40
M ₁ (SA of Zn @ 5 kg ha^{-1})	41062	54102	53500	49555	2.49	2.84	2.47	2.60
M ₂ (FA of Zn @ 0.5%)	42133	52003	51008	48381	2.50	2.73	2.38	2.54
M ₃ (SA of Fe @ 10 kg ha^{-1})	41989	50551	51021	47854	2.46	2.65	2.36	2.49
M ₄ (FA of Fe @ 0.5%)	41776	51261	53070	48702	2.49	2.70	2.43	2.54
M ₅ (SA of Zn @ 2.5 kg ha^{-1} + FA of Fe @ 0.5%)	43183	55376	53104	50554	2.50	2.80	2.41	2.57
M ₆ (SA of Fe @ 5 kg ha^{-1} + FA of Zn @ 0.5%)	41664	50370	49994	47343	2.42	2.61	2.31	2.44
Mean	40170	51803	51497		2.43	2.72	2.39	
SEm±	1138				0.03			
CD (P=0.05)	3189				0.10			

B₀ = Control, B₁ = FYM @ 10 t ha^{-1} , B₂ = FYM @ 5 t ha^{-1} + Vermicompost @ 2.5 t ha^{-1} + Azotobacter + PSB, SA = Soil Application, FA = Foliar Application

4. Conclusions

Across two consecutive *rabi* seasons, both bio-organic amendments and micronutrient fertilisation influenced wheat growth, yield attributes and economic returns under the sandy loam conditions of Jobner, Rajasthan. Among the bio-organic treatments, the combined application of farmyard manure at 5 t ha⁻¹, vermicompost at 2.5 t ha⁻¹, *Azotobacter* and phosphate-solubilising bacteria resulted in the highest pooled grain yield (3.841 t ha⁻¹), together with a straw yield of 5.415 t ha⁻¹. Among the micronutrient treatments, soil application of Zn at 2.5 kg ha⁻¹ with foliar Fe at 0.5% yielded 3.548 t ha⁻¹ of grain. The interaction between these treatments produced the highest observed grain yield (3.936 t ha⁻¹) and straw yield (5.552 t ha⁻¹). However, yield-maximising and economically preferable combinations were not identical. Farmyard manure at 10 t ha⁻¹ combined with soil Zn at 2.5 kg ha⁻¹ and foliar Fe at 0.5% generated the greatest observed net return (₹55,376 ha⁻¹), whereas farmyard manure at 10 t ha⁻¹ with soil Zn at 5 kg ha⁻¹ generated the highest benefit–cost ratio (2.84). These conclusions apply to the treatments and conditions evaluated in this two-season experiment.

5. Limitations

The experiment was undertaken at a single field site in Jobner during two *rabi* seasons using one wheat variety (Raj-4037). Consequently, responses may differ under other soils, climates, varieties or input prices. Although grain and straw yields and economic returns were measured, the tables do not report direct measurements of post-harvest soil fertility, changes in soil health or . These outcomes therefore cannot grain micronutrient concentrations be established from the presented results. Longer-term, multi-location evaluation would be required before generalising the treatment rankings.

Acknowledgement

Authors are grateful to Department of Soil Science & Agricultural Chemistry, S.K.N. College of Agriculture, Jobner (Sri Karan Narendra Agriculture University, Jobner-303 329, Jaipur, Rajasthan) for providing necessary facilities of research and support to academic work.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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