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Effect of integrated nutrient management on soil properties, growth, yield and quality parameters of Indian mustard (*Brassica juncea* (L.) Czern)

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Abstract
A field experiment was conducted during 2025-26 at the Student Instruction Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, to evaluate the effect of integrated nutrient management (INM) on soil fertility, growth, yield, and quality of Indian mustard (*Brassica juncea* (L.) Czern), cv. Varuna. The experiment was laid out in a Randomized Block Design with eight treatments and three replications. Soil organic carbon, available N, P, and K were significantly maximum under T_8 (100% RDF + 25% N through FYM + *Azotobacter* + PSB). T_8 recorded the highest seed yield (27.73 q ha^{-1}), representing a 143% increase over control. T_8 was statistically at par with T_6 (75% RDF + 25% N through FYM + *Azotobacter* + PSB) for most yield parameters. Maximum test weight (5.47 g) was recorded under T_4 (75% RDF + 25% N through vermicompost). Seed protein content was highest under T_8 (23.08%). Based on one-year experimental results, T_8 appeared most promising for sustainable mustard productivity; however, multi-season evaluation is required before wider recommendation.

Keywords: Integrated nutrient management, *Brassica juncea*, *Azotobacter*, phosphate-solubilizing bacteria, farm yard manure, vermicompost; soil fertility, seed yield, protein content

Introduction

India ranks fourth globally in oilseed production with oilseeds occupying approximately 27-29 million hectares and producing around 40 million tonnes annually (Government of India, 2024) [8]. Rapeseed-mustard (*Brassica* spp.) is the second most important oilseed crop after soybean in India (Shekhawat *et al*., 2012) [24]. According to ICAR-DMR (2024) [11], India's rapeseed-mustard production reached 13.19 million tonnes from 9.19 million hectares during 2023-24. Mustard seeds contain 30-45% oil and 20-25% protein. However, productivity remains low primarily due to imbalanced nutrient management.

Nitrogen (N) is the key nutrient influencing growth, yield, and quality of mustard. Sole reliance on chemical nitrogen fertilizers leads to nutrient imbalance, reduced nutrient use efficiency, and deterioration of soil health. Integrated Nutrient Management (INM), involving the combined use of inorganic fertilizers, organic manures, and biofertilizers, has emerged as a sustainable approach to improving crop productivity while maintaining soil fertility (Hegde and Dwivedi, 1994) [10]. FYM improves soil organic matter and nutrient availability. *Azotobacter* fixes atmospheric nitrogen and produces growth-promoting substances including auxins, gibberellins, and cytokinins (Subba Rao, 2001) [26]. PSB converts insoluble phosphorus to plant-available forms through secretion of organic acids (Mohammadi, 2012) [16].

Although several studies have reported positive effects of INM in mustard, information on the combined use of full RDF, FYM, *Azotobacter* and PSB under Central Plain Zone conditions of Uttar Pradesh is limited. It was hypothesized that integration of organic and biological nutrient sources with RDF would improve nutrient availability, soil fertility, and mustard productivity over sole chemical fertilization. The present investigation was planned with this objective.

Materials and Methods

Experimental Site and Design

The field experiment was conducted during 2025-26 at the Student Instruction Farm, CSAUK, Kanpur (25°26′-28°58′N; 79°31′-80°34′E; 125.9 m MSL). The experiment was laid out in Randomized Block Design (RBD) with eight treatments and three replications. Net plot size was 20 m^2 (5×4 m). Mustard cv. Varuna (T-19) was sown on 13 November 2025 at a spacing of 45 cm × 15 cm and seed rate of 5 kg ha^{-1}. The crop season received total rainfall of approximately 89 mm; mean temperatures ranged from 5.1 °C to 31.5 °C; mean relative humidity ranged 36-96%.

Initial Soil Characteristics

Initial soil (0-15 cm) was sandy loam with bulk density 1.35 Mg m^{-3}, pH 7.80, EC 0.23 dSm^{-1}, organic carbon 0.48%, available N 149.0 kg ha^{-1} (Low), available P 15.8 kg ha^{-1} (Medium), and available K 212.0 kg ha^{-1} (Medium).

Treatment Details

The Recommended Dose of Fertilizers (RDF) for mustard was NPK @ 120:60:40 kg ha^{-1}. Eight treatments were evaluated:

T_1-Absolute Control (no fertilizer)
T_2-100% RDF through chemical fertilizers
T_3-75% RDF + 25% N through FYM
T_4-75% RDF + 25% N through Vermicompost
T_5-75% RDF + *Azotobacter* + PSB
T_6-75% RDF + 25% N through FYM + *Azotobacter* + PSB
T_7-50% RDF + 50% N through FYM + *Azotobacter* + PSB
T_8-100% RDF + 25% N through FYM + *Azotobacter* + PSB

Note on T_8 nutrient balance: In T_8, 25% N through FYM was applied additionally to 100% RDF, resulting in approximately 125% effective N input. Superiority of T_8 may partly reflect higher total N input alongside true INM synergistic effects.

Azotobacter chroococcum and *Bacillus megaterium* (PSB) cultures containing 10^8 CFU g^{-1} were applied as seed inoculants at 25 g kg^{-1} seed using peat-based carrier. FYM contained N: 0.5%, P: 0.25%, K: 0.4%; vermicompost contained N: 1.5%, P: 1.0%, K: 0.5%. Nitrogen was applied through urea (46% N) and DAP (18% N); phosphorus through DAP (46% P_2O_5); potassium through MOP (60% K_2O).

Observations and Methods

Soil samples (pre-sowing and post-harvest) were analysed for bulk density (core sampler, Singh 1980), pH and EC (1:2.5 soil: water, Jackson 1973) [12], organic carbon (Walkley-Black, Jackson 1973) [12], available N (alkaline permanganate, Subbaiah and Asija 1956) [27], available P (Olsen's method, Olsen *et al*., 1954), and available K (flame photometer, Jackson 1973) [12]. Growth parameters were recorded from five randomly selected plants per plot. Plant population was counted from a 1 m^2 quadrat at 15 DAS. Harvest index (HI) was calculated as: HI (%) = [Seed yield/Biological yield] × 100. Nitrogen content in seed was estimated by Kjeldahl's method; protein content = N% × 6.25. Nitrogen uptake (kg ha^{-1}) = [Seed yield (kg ha^{-1}) × N content (%)]/100.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) for RBD as per Fisher (1974) [5]. Significance of treatment effects was tested by F-test, and treatment means were compared using Critical Difference (CD) at p = 0.05. Standard Error of Mean (SEm±) and Coefficient of Variation (CV%) are reported in respective tables.

Results and Discussion

Effect of Integrated Nutrient Management on Soil Properties

Bulk Density, pH and EC

Bulk density, soil pH, and EC showed non-significant differences among treatments (Table 1). Bulk density ranged from 1.30 (T_8) to 1.35 Mg m^{-3} (T_1), representing a 3.7% reduction under T_8 over control, a practically meaningful improvement in soil tilth. The declining trend in bulk density under T_8 is attributable to organic matter addition through FYM, which improves soil aggregation and porosity (Kansotia *et al*., 2015) [14]. The slight pH reduction under integrated treatments results from organic acids released during FYM decomposition and CO_2 produced in the rhizosphere by biofertilizers (Kumar *et al*., 2021) [15]. EC values remained within the safe range (0.23-0.26 dSm^{-1}) confirming no salt stress.

Organic Carbon

Soil organic carbon (OC) was significantly influenced by INM treatments (CD = 0.06; SEm ± = 0.02; CV = 5.2%). Maximum OC (0.61%) was recorded under T_8, followed by T_6 (0.57%); minimum (0.48%) under T_1, a 27.1% improvement under T_8. Higher OC is attributed to direct carbon addition through FYM and stimulation of soil microbial biomass turnover by *Azotobacter* and PSB. These findings agree with Kumar *et al*., (2021) [15] and Singh and Pal (2011) [25].

Available N, P and K

Available N, P, and K were all significantly influenced by treatments (Table 1). T_8 recorded the highest available N (198.4 kg ha^{-1}), P (24.2 kg ha^{-1}), and K (246.5 kg ha^{-1}). Higher available N under T_8 is attributed to chemical N supply, FYM mineralization, and biological N fixation by *Azotobacter*. Elevated available P reflects PSB-mediated phosphorus solubilization through organic acid secretion that converts insoluble Ca-P to plant-available orthophosphate (Mohammadi, 2012) [16]. Initial and post-harvest soil NPK changes are presented in Table 4.

Effect of Integrated Nutrient Management on Growth and Yield Parameters

Plant Population and Plant Height

Plant population was not significantly influenced (F-cal. 0.240 < F-tab. 2.764), ranging from 14.32 (T_1) to 16.95 plants m^{-2} (T_8), confirming uniform establishment. Plant height at 60 DAS was maximum under T_8 (84.44 cm), at par with T_6 (83.58 cm). At harvest, T_8 attained 177.57 cm, followed by T_6 (175.08 cm). Taller plants under integrated treatments reflect better N availability. *Azotobacter* produces indole acetic acid (IAA) and gibberellins (GA_3) that enhance root proliferation and shoot elongation through cell division promotion in the shoot apex (Subba Rao, 2001; Jaiswal *et al*., 2021) [26].

Primary Branches and Siliquae per Plant

Primary branches ranged from 4.07 (T_1) to 7.30 (T_8) per plant (CD = 0.45; SEm ± = 0.15; CV = 7.2%). Siliquae per plant ranged from 216.67 (T_1) to 312.33 (T_8), with T_8 at par with T_6 (311.33) (CD = 14.66; SEm ± = 4.83; CV = 5.1%). Higher branching and pod number under integrated treatments are attributed to adequate N promoting axillary bud development and PSB-mediated P availability enhancing energy metabolism critical for floret development (Hadiyal *et al*., 2017; Gora *et al*., 2022) [9, 6].

Test Weight

Test weight ranged from 4.33 g (T_1) to 5.47 g (T_4), with T_4 significantly superior to all treatments (CD = 0.17; SEm ± = 0.06; CV = 3.0%). Superior seed filling under T_4 is attributed to the slow and steady nutrient release profile of vermicompost that synchronises nutrient supply during grain filling, enhancing photosynthate translocation to developing seeds (Yashi *et al*., 2023; Pardhi *et al*., 2025) [31, 18].

Seed Yield, Biological Yield and Harvest Index

Seed yield ranged from 11.40 q ha^{-1} (T_1) to 27.73 q ha^{-1} (T_8), a 143.2% increase over control (CD = 1.24; SEm ± = 0.41; CV = 4.9%). T_8 was statistically at par with T_6 (25.99 q ha^{-1}). Biological yield ranged from 42.28 q ha^{-1} (T_1) to 95.36 q ha^{-1} (T_8). Harvest index (26.79-29.26%) was significantly influenced by treatments (CD = 1.06%), with T_8 and T_3 recording the highest HI (29.08%) and T_7 the minimum (26.79%). These results agree with Yadav *et al*., (2018) [30] and Gora *et al*., (2022) [6].

Effect of Integrated Nutrient Management on Nitrogen Content and Uptake

Nitrogen content in seed ranged from 3.300% (T_1) to 3.693% (T_8); N uptake by seed ranged from 37.62 kg ha^{-1} (T_1) to 102.41 kg ha^{-1} (T_8). Both were significantly influenced (CD 5%: N content 0.18%; N uptake 3.35 kg ha^{-1}). The N uptake for T_8 was verified as: 2773 kg ha^{-1} × 3.693/100 ≈ 102.4 kg ha^{-1}. Higher seed N content is attributed to sustained N supply, biological N fixation by *Azotobacter*, and PSB-mediated P availability that promoted glutamine synthetase and nitrate reductase enzyme activity during grain filling (Dubey *et al*., 2021; Gora *et al*., 2023) [4, 6].

Effect of Integrated Nutrient Management on Seed Protein Content

Seed protein content was significantly influenced by treatments (CD = 1.12%; SEm ± = 0.37%; CV = 4.2%). Maximum protein content (23.08%) was recorded under T_8, followed by T_6 (22.81%), while minimum (20.62%) was under T_1. Since protein content = N% × 6.25, integrated treatments ensuring higher seed N concentration naturally resulted in higher protein. This superiority is attributed to balanced and sustained N supply from chemical fertilizers, progressive organic N release from FYM during grain filling, and biofertilizer-mediated nutrient mobilization (Bora *et al*., 2021; Sharma *et al*., 2023) [1, 23]. Oil content determination was not included in the present study; future investigations should incorporate seed oil content as a key quality parameter.

Table 1: Effect of integrated nutrient management on soil properties after harvest of mustard.

Treatment	Details	BD (Mg m^{-3})	pH	EC (dSm^{-1})	OC (%)	Avail. N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
T_1	Absolute Control	1.35	7.80	0.23	0.48	149.0	15.8	212.0
T_2	100% RDF	1.34	7.74	0.24	0.51	164.2	18.6	221.4
T_3	75% RDF + 25% N FYM	1.33	7.71	0.24	0.53	171.4	19.8	228.6
T_4	75% RDF + 25% N Vermicompost	1.33	7.69	0.25	0.55	174.8	20.4	231.2
T_5	75% RDF + Azotobacter + PSB	1.32	7.72	0.24	0.52	167.6	19.2	224.8
T_6	75% RDF + 25% N FYM + Azoto. + PSB	1.31	7.65	0.25	0.57	184.6	22.2	238.4
T_7	50% RDF + 50% N FYM + Azoto. + PSB	1.33	7.67	0.25	0.54	179.2	21.4	234.6
T_8	100% RDF + 25% N FYM + Azoto. + PSB	1.30	7.61	0.26	0.61	198.4	24.2	246.5
SEm±	—	—	—	—	0.02	3.12	0.58	3.06
CD (5%)	—	NS	NS	NS	0.06	9.46	1.76	8.92
CV (%)	—	—	—	—	5.2	4.8	7.6	3.4

BD = Bulk Density; OC = Organic Carbon; Avail. = Available; NS = Non-Significant; Azoto. = Azotobacter

Table 2: Effect of integrated nutrient management on growth, yield, and harvest index of mustard.

Treatment	Plant Ht. 60 DAS (cm)	Plant Ht. Harvest (cm)	Primary Branches/Plant	Siliquae/Plant	Test Wt. (g)	Seed Yield (q ha^{-1})	Biol. Yield (q ha^{-1})	HI (%)
T_1	62.19	161.17	4.07	216.67	4.33	11.40	42.28	26.96
T_2	72.33	167.51	6.93	270.67	4.85	15.54	55.11	28.20
T_3	77.81	168.83	5.57	254.33	5.03	19.74	67.88	29.08
T_4	76.10	170.44	5.73	259.33	5.47	20.68	72.73	28.43
T_5	73.90	166.93	4.87	252.67	4.90	15.34	52.43	29.26
T_6	83.58	175.08	7.27	311.33	5.33	25.99	93.42	27.82
T_7	75.42	169.15	4.87	237.33	4.66	12.36	46.14	26.79
T_8	84.44	177.57	7.30	312.33	5.28	27.73	95.36	29.08
SEm±	1.11	1.98	0.155	4.83	0.059	0.41	1.34	—
CD (5%)	3.36	6.00	0.45	14.66	0.17	1.24	4.06	1.06
CV (%)	4.1	3.1	7.2	5.1	3.0	4.9	5.7	—

DAS = Days After Sowing; Biol. = Biological; HI = Harvest Index; Azoto. = Azotobacter

Table 3: Effect of integrated nutrient management on N content, N uptake, protein content, and percent increase in seed yield of mustard over control.

Treatment	Details	N Content in Seed (%)	N Uptake by Seed (kg ha^{-1})	Seed Protein Content (%)	% Increase in Seed Yield over T_1
T_1	Absolute Control	3.300	37.62	20.62	—
T_2	100% RDF	3.360	52.21	21.00	36.3
T_3	75% RDF + 25% N FYM	3.380	66.72	21.12	73.2
T_4	75% RDF + 25% N Vermicompost	3.400	70.31	21.25	81.4
T_5	75% RDF + Azotobacter + PSB	3.350	51.39	20.94	34.6
T_6	75% RDF + 25% N FYM + Azoto. + PSB	3.650	94.86	22.81	128.0
T_7	50% RDF + 50% N FYM + Azoto. + PSB	3.520	43.51	22.00	8.4
T_8	100% RDF + 25% N FYM + Azoto. + PSB	3.693	102.41	23.08	143.2
SEm±	—	0.06	1.10	0.37	—
CD (5%)	—	0.18	3.35	1.12	—
CV (%)	—	4.7	6.1	4.2	—

Azoto. = Azotobacter

Table 4: Initial (pre-sowing) and post-harvest available NPK status (kg ha^{-1}) in soil under integrated nutrient management treatments.

Treatment	Details	Avail. N Before (kg ha^{-1})	Avail. N After (kg ha^{-1})	Avail. P Before (kg ha^{-1})	Avail. P After (kg ha^{-1})	Avail. K Before (kg ha^{-1})	Avail. K After (kg ha^{-1})
T_1	Absolute Control	149.0	149.0	15.8	15.8	212.0	212.0
T_2	100% RDF	149.0	164.2	15.8	18.6	212.0	221.4
T_3	75% RDF + 25% N FYM	149.0	171.4	15.8	19.8	212.0	228.6
T_4	75% RDF + 25% N Vermicompost	149.0	174.8	15.8	20.4	212.0	231.2
T_5	75% RDF + Azoto. + PSB	149.0	167.6	15.8	19.2	212.0	224.8
T_6	75% RDF + 25% N FYM + Azoto. + PSB	149.0	184.6	15.8	22.2	212.0	238.4
T_7	50% RDF + 50% N FYM + Azoto. + PSB	149.0	179.2	15.8	21.4	212.0	234.6
T_8	100% RDF + 25% N FYM + Azoto. + PSB	149.0	198.4	15.8	24.2	212.0	246.5

Initial values (before sowing) were identical across all treatments; post-harvest values reflect treatment effects after one crop season.

Conclusion

The present investigation demonstrated that integrated application of chemical fertilizers, organic manures, and biofertilizers significantly improved soil fertility, crop growth, yield, and quality of Indian mustard under Kanpur conditions during 2025-26. T_8 (100% RDF + 25% N through FYM + *Azotobacter* + PSB) proved most effective for soil fertility improvement, seed yield (27.73 q ha^{-1}; 143.2% over control), and seed protein content (23.08%), and was at par with T_6 for most parameters. T_4 recorded maximum test weight (5.47 g) reflecting superior seed-filling by vermicompost. Based on one-year experimental results, T_8 appeared most promising; however, multi-season evaluation is required before wider recommendation. Future studies should incorporate oil content as a key quality parameter.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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