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Integrated nutrient management of mustard greens (*Brassica juncea*) under Terai region of West Bengal

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ABSTRACT

The present experiment was carried to evaluate the integrated effects of organic amendments and microbial inoculants combined with reduced inorganic fertiliser rates such as 75% and 50% recommended dose of fertilisers (RDF) on the agronomic performance of mustard greens (*Brassica juncea* L.), including vegetative growth, fresh yield and biochemical quality parameters during the winter (*rabi*) seasons of 2022-23 and 2023-24 at Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal. The experiment was laid out in a randomised complete block design (RCBD) comprising 16 treatment combinations with three replications, employing the 'Pusa Sag-1' cultivar. Results revealed that the application of 75% RDF + 4 t vermicompost/ha + 5 kg *Azotobacter*/ha + 5 kg PSB/ha recorded significantly maximum plant height (49.96 cm), leaf length (44.39 cm), leaf width (14.06 cm), number of leaves/plant (10.77), leaf yield/plant (128.36 g), dry weight of leaves/plant (13.88 g), and green yield (29.92 t/ha). This treatment also showed superior quality parameters per 100 g fresh weight, including ascorbic acid (30.53 mg), total chlorophyll (60.34 mg) and β-carotene (2524.45 µg) of mustard greens. Additionally, this treatment enhanced available soil nutrients including nitrogen (195.26 kg/ha), phosphorus (26.61 kg/ha) and potassium (101.22 kg/ha), while achieving the most favourable benefit-cost ratio of 3.48. Integrated application of chemical fertilisers with vermicompost and biofertilisers significantly improved mustard greens yield attributes, quality parameters and soil fertility status, facilitating sustainable intensification of production.

Keywords: Green yield, Dry weight of leaves, Organic carbon, Soil fertility

Mustard greens (*Brassica juncea* L.) is a highly nutritious cruciferous vegetable cultivated extensively in India. While inorganic fertilisers provide readily available nutrients, their excessive application adversely affects soil microbial and enzymatic activities (Kumari *et al.* 2024). Conversely, organic amendments including farmyard manure (FYM), vermicompost and poultry manure improves physicochemical and biological soil attributes while supplying essential macro- and micronutrients (Chatterjee *et al.* 2020, Bhatt *et al.* 2023). These amendments reduce the C:N ratio by supplying nitrogen-rich substrates and stimulating microbial activity, which accelerates carbon mineralisation and enhances nitrogen availability in soil (Anjum and Khan 2021). Additionally, biofertilisers such as *Azotobacter* and phosphate-solubilising bacteria (PSB) fix atmospheric nitrogen and solubilise unavailable phosphorus, offering eco-friendly and cost-effective alternatives to synthetic inputs (Kumar *et al.* 2022). Integrated nutrient management (INM), though conceptually established decades ago, has gained renewed prominence as a comprehensive approach that systematically combines inorganic, organic and biological nutrient sources to optimise plant nutrition while maintaining long-term soil fertility and ecosystem sustainability (Panta and Parajulee 2021). Previous studies have established that 75% of the recommended fertiliser dose (RDF) frequently achieves optimal nutrient use efficiency while maintaining adequate crop performance across diverse agricultural systems (Sande *et al.* 2024). However, limited empirical evidence exists regarding the optimisation of mustard greens productivity through integrated nutrient management strategies. This study addresses the critical knowledge gap in standardising the synergistic application of organic, inorganic and biofertiliser components to enhance yield potential and resource-use efficiency. Such optimisation could substantially improve economic returns through augmented fresh biomass production while ensuring sustainable soil health in the Terai region of West Bengal, thereby fulfilling a crucial research imperative for this commercially significant leafy vegetable.

MATERIALS AND METHODS

The present experiment was carried out during the winter (*rabi*) seasons of 2022 and 2023 at Uttar Banga Krishi Viswavidyalaya, Pundibari (26°19'86" N, 89°23'53" E; at

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an elevation of 43 m amsl), West Bengal. The soil of the experimental site was characterised as sandy loam type with coarse texture and acidic *p*H (5.8). Initial soil before the experiment contained organic carbon (OC) 0.65% with low nitrogen (173.9 kg N/ha) and potassium (93.6 kg K_2O/ha) and medium phosphorus (22.2 kg P_2O_5/ha). Sixteen treatment combinations of various organic sources of nutrients and inorganic fertilsers were evaluated using a randomised complete block design (RCBD) with three replications using the 'Pusa Sag-1' variety of mustard greens (Table 1). Each plot was 3 m × 1.5 m in size and was raised to 15 cm and the spacing was maintained at 30 cm × 10 cm. Fully developed tender leaves were harvested 40 days after sowing (DAS). Five plants from each plot were tagged for easy identification and following growth and yield parameters were recorded: plant height, leaf length, leaf width, number of leaves/plant, leaf yield/plant, dry weight of leaves/plant and green yield/ha. Standard analytical methods were used to evaluate ascorbic acid, chlorophyll and β-carotene content. After each harvest, soil samples were collected from five randomly selected points per plot treatment-wise using a soil auger. Soil parameters were analysed using standard methods, *p*H measurement via digital meter in 1:2.5 soil-water suspension (Jackson 1973), organic carbon and mineralisable nitrogen were analysed using chromic acid oxidation (Walkley and Black 1934) and alkaline permanganate methods (Subbiah and Asija 1956), respectively, available phosphorus by using the blue colour technique extracted by Bray-I reagent (Bray and Kurtz 1945) and available potassium by flame photometer using neutral ammonium acetate extraction at *p*H 7.0 (Metson 1956).

Table 1 Treatment details

Code	Treatments
T_1	100% RDF (Control)
T_2	75% RDF + 12 t FYM/ha
T_3	75% RDF + 12 t FYM/ha + 5 kg PSB/ha
T_4	75% RDF + 12 t FYM/ha+ 5 kg *Azotobacter*/ha
T_5	75% RDF + 12 t FYM/ha + 5 kg *Azotobacter*/ha + 5 kg PSB/ha
T_6	75% RDF + 4 t VC/ha
T_7	75% RDF + 4 t VC/ha + 5 kg PSB/ha
T_8	75% RDF + 4 t VC/ha + 5 kg *Azotobacter*/ha
T_9	75% RDF + 4 t VC/ha + 5 kg *Azotobacter*/ha + 5 kg PSB/ha
T_{10}	75% RDF + 2 t PM/ha
T_{11}	75% RDF + 2 t PM/ha + 5 kg PSB/ha
T_{12}	75% RDF + 2 t PM/ha + 5 kg *Azotobacter*/ha
T_{13}	75% RDF + 2 t PM/ha + 5 kg *Azotobacter*/ha + 5 kg PSB/ha
T_{14}	50% RDF + 12 t FYM/ha + 5 kg *Azotobacter*/ha + 5 kg PSB/ha
T_{15}	50% RDF + 4 t VC/ha + 5 kg *Azotobacter*/ha + 5 kg PSB/ha
T_{16}	50% RDF + 2 t PM/ha + 5 kg *Azotobacter*/ha + 5 kg PSB/ha

PM, Poultry manure; VC, Vermicompost; FYM, Farm yard manure; PSB, Phosphate solubilising bacteria; RDF, Recommended dose of fertilisers (N: P_2O_5: K_2O @120:80:60 kg/ha) (Devkota *et al.* (2020).

Data collected over two years for various parameters were pooled and analysed with ANOVA technique via data analysis tools. The mean differences were assessed via a significant critical difference (CD) test based on the methodology proposed by Panse and Sukhatme (1989). Economic parameters including total cultivation expenditure, gross income, net profit and benefit-cost ratio were computed based on fresh green yield.

RESULTS AND DISCUSSION

The comprehensive analysis of pooled data showed that INM strategies significantly influenced morphological growth parameters in mustard greens, with statistically significant variations observed across all evaluated treatments (Table 2). Compared with the other treatments, treatment T_9 (75% RDF + 4 t VC/ha + 5 kg *Azotobacter*/ha + 5 kg PSB/ha) resulted in significantly greater plant height (49.96 cm), leaf length (44.39 cm), leaf width (14.06 cm) and number of leaves/plant (10.77) that might be attributed to the positive interactions among synthetic fertilisers, organic nutrient amendments and microbial inoculants which create synergistic effects. Combining these diverse nutrient sources enhances nutrient release, transformation and availability for plant uptake through the continuous supply of readily available macro- and micronutrients. This integrated approach improves the physiochemical properties of soil and augments soil fertility levels, which in turn enhances plant growth (Aasfar *et al.* 2021). The application of organic amendments, particularly vermicompost, positively impacted plant growth by enhancing soil porosity, moisture retention capacity, micronutrient supply and nutrient accessibility. The nitrogen content in vermicompost is especially crucial for leafy vegetables, as it serves as a constituent in chlorophyll synthesis and leaf development (Changkija *et al.* 2017). Additionally, vermicompost promotes soil aggregation and promotes root growth, enabling more efficient nutrient uptake and maximising overall plant growth. Biofertiliser inoculation enhances the morpho-physiological growth attributes of plants through multiple mechanisms, including nitrogen fixation and enhanced nutrient mobilisation (Aasfar *et al.* 2021). Furthermore, biofertilisers improve the production of phytohormones which accelerate cell division, proliferation and elongation in meristematic regions (Sreethu *et al.* 2023), followed by cell differentiation and tissue development, ultimately leading to improved morphological growth of plants. Similar results were reported by Changkija *et al.* (2017) and Singh *et al.* (2023).

Table 2 Effect of integrated nutrient management on various growth, yield and quality parameters of mustard greens (pooled for two consecutive harvesting years)

Treatments	PH[1] (cm)	LL (cm)	LW (cm)	NLP	LYP (g)	DWLP (g)	GY (t/ha)	AA (mg/100 g fresh weight)	TC (mg/100 g fresh weight)	β-carotene (µg/100 g fresh weight)
T_1	36.05^{i}	30.75^{j}	10.13^{h}	8.73^{de}	77.93^{j}	8.03^{g}	18.27^{h}	29.32^{a-c}	50.88^{c-f}	2178.40^{i}
T_2	40.66^{gh}	35.90^{f-h}	11.65^{fg}	9.47^{c-e}	96.21^{f-i}	10.57^{b-e}	22.18^{e-g}	26.91^{d-f}	48.63^{ef}	2369.35^{c-g}
T_3	43.01^{d-g}	36.81^{e-g}	12.47^{b-f}	9.83^{a-d}	108.15^{d-g}	10.69^{b-e}	25.26^{b-e}	27.48^{c-e}	50.12^{d-f}	2381.01^{c-f}
T_4	43.63^{c-g}	38.05^{d-f}	12.69^{b-e}	9.98^{a-c}	109.52^{c-f}	11.77^{bc}	26.29^{a-d}	28.80^{a-d}	56.25^{a-e}	2408.51^{b-e}
T_5	46.47^{a-d}	41.71^{b}	13.11^{a-c}	10.60^{ab}	125.30^{ab}	13.85^{a}	28.63^{ab}	30.14^{a}	59.57^{ab}	2438.56^{a-d}
T_6	44.91^{b-f}	39.10^{c-e}	12.42^{c-f}	8.87^{c-e}	106.45^{d-g}	11.97^{b}	24.29^{c-e}	23.93^{i}	51.33^{b-f}	2423.81^{b-e}
T_7	46.99^{a-c}	41.09^{bc}	13.43^{ab}	9.30^{c-e}	115.03^{a-d}	13.50^{a}	27.25^{a-c}	24.31^{hi}	52.51^{a-f}	2453.74^{a-c}
T_8	47.86^{ab}	42.16^{ab}	13.88^{a}	9.50^{b-e}	123.40^{a-c}	13.84^{a}	28.83^{ab}	26.23^{e-h}	57.90^{a-d}	2485.66^{ab}
T_9	49.96^{a}	44.39^{a}	14.06^{a}	10.77^{a}	128.36^{a}	13.88^{a}	29.92^{a}	30.53^{a}	60.34^{a}	2524.45^{a}
T_{10}	37.56^{hi}	33.74^{hi}	11.37^{g}	8.73^{de}	86.79^{h-j}	9.63^{ef}	20.24^{f-h}	25.27^{f-i}	45.68^{f}	2309.67^{f-h}
T_{11}	41.46^{fg}	34.61^{gh}	11.83^{e-g}	8.80^{de}	94.73^{g-i}	9.66^{ef}	22.00^{e-h}	26.85^{d-g}	55.76^{a-e}	2338.23^{e-h}
T_{12}	42.11^{e-g}	35.85^{f-h}	11.99^{d-g}	9.30^{c-e}	96.42^{f-i}	11.16^{b-d}	22.30e-g	28.03^{b-e}	57.19^{a-d}	2362.83^{d-g}
T_{13}	45.56^{b-e}	38.67^{de}	12.81^{b-d}	9.50^{b-e}	113.35^{b-e}	11.21^{bc}	24.72^{c-e}	29.62^{ab}	58.60^{a-c}	2390.43^{c-f}
T_{14}	41.96^{fg}	35.99^{f-h}	12.01^{d-g}	8.90^{c-e}	99.69^{e-h}	9.75^{d-f}	23.40^{d-f}	25.41^{f-i}	50.38^{c-f}	2259.55^{hi}
T_{15}	44.50^{b-f}	39.93^{b-d}	12.84^{b-d}	9.57^{b-e}	105.59^{d-g}	10.43^{c-e}	25.24^{b-e}	27.20^{d-f}	53.64^{a-f}	2392.06^{c-f}
T_{16}	35.85^{i}	31.82^{ij}	11.25^{g}	8.47^{e}	82.63^{ij}	8.35^{fg}	19.35^{gh}	24.85^{g-i}	51.79^{b-f}	2288.10^{gh}
SEM±	1.21	0.82	0.34	0.39	5.10	0.50	1.31	0.85	2.93	29.77
CD (p=0.05)	3.52	2.37	0.98	1.14	14.80	1.45	3.80	2.00	8.49	86.40

PH, Plant height; LL, Leaf length; LW, Leaf width; NLP, Number of leaves/plant; LYP, Leaf yield/plant; DWLP, Dry weight of leaves/plant; GY, Green yield; AA, Ascorbic acid; TC, Total chlorophyll. Letters over the numeric values are used to separate treatment means at 5% significance level.

Incorporating inorganic fertilisers and organic manures also significantly influenced various yield parameters in mustard greens, including leaf yield/plant, dry weight of leaves/plant and green yield. Treatments demonstrated statistically significant influences on all yield components. Treatment T_9 yielded significantly higher leaf yield/plant (128.36 g), dry weight of leaves/plant (13.88 g) and total green yield (29.92 t/ha) compared to other treatments. However, no statistically significant difference was observed between T_9 and treatments T_5 (125.30 g, 13.85 g, 28.63 t/ha), T_8 (123.40 g, 13.84 g, 28.83 t/ha) and T_7 (115.03 g, 13.50 g, 27.25 t/ha), respectively. The enhanced efficiency observed with INM is likely attributable to optimal nutrient availability and increased soil microbial activity, ensuring a consistent nutrient supply throughout the growth cycle and resulting in higher leaf in fresh and dry weights basis. These findings corroborate the results reported by Paithankar and Gore (2019) in Indian spinach. The increase in yield might be attributed to the complementary effects of using both organic and inorganic nutrient sources, further augmented by the inoculation of *Azotobacter* and PSB. These biofertilisers facilitate phosphorus mobilisation and nitrogen fixation, leading to increased soluble nutrient availability. This, in turn, stimulates root development, nutrient uptake, photosynthesis and improved source-sink relations.

Variance analysis revealed that quality traits differed significantly among the treatment combinations tested. Ascorbic acid, β-carotene and total chlorophyll content of mustard greens [30.53 mg, 2524.45 µg, 60.34 mg/100 g fresh weight (FW), respectively] were recorded highest with the application of treatment T_9 (Table 2). While, lowest amount of ascorbic acid (23.93 mg/100 g FW), β-carotene (2178.40 µg/100 g FW) and total chlorophyll content (45.68 mg/100 g FW) were recorded in treatment T_6, T_1 and T_{10}, respectively. The superior performance of T_9 in ascorbic acid accumulation might be attributed to the action of specific soil nutrients that are made more readily available for plant absorption through the integrated effects of organic and inorganic fertilisers combined with bio-fertilisers. This enhanced nutrient availability might activated specific enzymes involved in vitamin C biosynthesis (Changkija *et al.* 2017). The combined application of fertilisers resulted in increased carbohydrate production, subsequently leading to enhanced vitamin C synthesis (Nath *et al.* 2023). Treatment

T_9 recorded 18.5% increase in total chlorophyll than T_1 which might be a consequence of the positive effects of fertilisers combination that provided a continuous supply of readily available macro- and micronutrients. Macronutrients, particularly nitrogen, play a crucial role in chlorophyll biosynthesis in leaves (Choudhary *et al.* 2024). Bio-fertilisers enhance chlorophyll content by stimulating the activity of antioxidant enzymes in plants, which prevents chlorophyll molecule degradation (Mamnabi *et al.* 2020). These observations align with the findings of Kujur *et al.* (2020). Likewise, T_9 observed 15.9% rise in β-carotene content than T_1. The increase in β-carotene content of mustard greens might be attributed to the secretion of phytohormones by bio-fertilisers and vermicompost, which facilitate diazotrophic activity, generate phytohormones that regulate cellular metabolism, induce nitrite synthesis and promote enhanced mineral acquisition by plants, leading to elevated antioxidant capacity (Thampi *et al.* 2019). A similar finding was reported by Choudhary *et al.* (2024) who demonstrated that the combined application of nutrient sources, including 25% RDF, 25% vermicompost, 25% *Azotobacter* and 25% PSB, significantly enhanced carotene content in spinach beet.

The integrated nutrient management treatments further demonstrated significant variation in soil chemical properties compared to the control (Table 3). Soil *p*H varied between 5.49 and 6.08 across treatments, with T_9 exhibiting the highest value (6.08) compared to T_1 and T_{10} (5.49). The alkaline properties of vermicompost and microbial production of organic acids facilitated reduced exchangeable acidity via cation exchange processes (Regasa *et al.* 2025). Organic carbon content differed markedly among treatments. T_9 recorded maximum OC (0.77%), whereas T_1 showed minimum values (0.62%). The incorporation of organic matter through the synergistic combination of organic and biofertilisers enhances soil organic carbon (SOC) management through dual sequestration mechanisms. Continuous application of organic amendments improves soil organic matter status (Kharlukhi *et al.* 2024), while vermicompost directly contributes stable carbon compounds and *Azotobacter* and PSB stimulate soil aggregate formation through polysaccharide production, thereby enhancing carbon stabilisation (Oyege and Balaji Bhaskar 2023). Treatment T_9 recorded the highest available nitrogen, phosphorus and potassium content (195.26, 26.61 and 101.22 kg/ha, respectively), while T_1 showed the lowest availability for all three nutrients (169.41, 17.40 and 69.05 kg/ha, respectively) (Table 3). The remarkable increase in

Table 3 Effect of integrated nutrient management on soil *p*H, soil available nutrients, organic carbon and economics of mustard greens (pooled for two consecutive harvesting years)

Treatments	*p*H[2]	OC (%)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	CE (₹/ha)	GI (₹/ha)	NP (₹/ha)	BCR
T_1	5.45^{i}	0.62^{h}	169.41^{l}	17.40^{i}	69.05^{k}	64,858	219,180^{h}	154,322^{g}	2.38^{e-h}
T_2	5.60^{g}	0.68^{e-g}	180.18^{hi}	22.67^{ef}	82.01^{h}	95,946	266,180^{e-g}	170,234^{fg}	1.77^{i}
T_3	5.87^{d}	0.74^{a-c}	185.37^{ef}	23.74^{cd}	91.53^{de}	97,445	303,120^{b-e}	205,675^{c-f}	2.11^{g-i}
T_4	5.87^{d}	0.71^{b-f}	189.12^{cd}	23.07^{c-f}	89.36^{f}	98,696	315,520^{a-d}	216,824^{c-e}	2.20^{g-i}
T_5	5.98^{c}	0.74^{a-c}	190.37^{bc}	23.54^{c-e}	92.86^{cd}	100,195	343,540^{ab}	243,345^{a-c}	2.43^{e-g}
T_6	5.80^{e}	0.73^{a-d}	183.63^{fg}	23.21^{c-f}	89.16^{f}	75,946	291,500^{c-e}	215,554^{c-e}	2.84^{b-f}
T_7	5.99^{bc}	0.75^{a-c}	189.96^{bc}	23.87^{bc}	96.57^{b}	77,445	326,980^{a-c}	249,535^{a-c}	3.22^{a-c}
T_8	6.04^{ab}	0.75^{ab}	192.07^{b}	24.80^{b}	94.35^{c}	78,696	345,940^{ab}	267,244^{ab}	3.40^{ab}
T_9	6.08^{a}	0.77^{a}	195.26^{a}	26.61^{a}	101.22^{a}	80,195	359,040^{a}	278,845^{a}	3.48^{a}
T_{10}	5.49^{hi}	0.65^{gh}	175.50^{k}	19.22^{gh}	76.16^{j}	67,946	242,860^{f-h}	174,914^{e-g}	2.57^{d-g}
T_{11}	5.59^{g}	0.67^{f-h}	177.36^{jk}	22.30^{f}	82.95^{h}	69,445	263,960^{e-h}	194,515^{d-g}	2.80^{c-f}
T_{12}	5.59^{g}	0.65^{gh}	180.73^{hi}	20.07^{g}	79.42^{i}	70,696	267,580^{e-g}	196,884^{d-g}	2.78^{c-f}
T_{13}	5.77^{e}	0.70^{c-f}	182.22^{gh}	22.81^{d-f}	87.05^{g}	72,195	296,660^{c-e}	224,465^{b-d}	3.11^{a-d}
T_{14}	5.70^{f}	0.69^{d-g}	181.13^{g-i}	22.50^{f}	85.38^{g}	98,282	280,800^{d-f}	182,518^{d-g}	1.86^{hi}
T_{15}	5.90^{d}	0.72^{b-e}	187.16^{de}	23.16^{c-f}	90.81^{ef}	78,282	302,880^{b-e}	224,598^{b-d}	2.87^{b-e}
T_{16}	5.52^{h}	0.64^{gh}	179.28^{ij}	18.57^{h}	80.95^{hi}	70,282	232,140^{gh}	161,858^{fg}	2.30^{f-i}
SEM±	0.02	0.02	0.87	0.34	0.70	-	156,92.81	15,692.81	0.20
CD (*p*=0.05)	0.05	0.05	2.51	0.99	2.02	-	45,543.35	45,543.35	0.57

OC, Organic carbon; N, Available nitrogen; P_2O_5, Available phosphorus; K_2O, Available potassium; CE, Cultivation expenditure; GI, Gross income; NP, Net profit; BCR, Benefit:cost ratio. Letters over the numeric values are used to separate treatment means at 5% significance level.

available nitrogen under T_9 demonstrates the complementary action of biological nitrogen fixation by *Azotobacter* and mineralisation of organic nitrogen from vermicompost (Ali *et al.* 2025). This biological process reduces dependency on synthetic fertilisers, thereby minimising nitrous oxide emissions and energy-intensive fertiliser production. Phosphorus-solubilising bacteria enhanced P bioavailability by releasing bound phosphorus forms via organic acid secretion and phosphatase enzymatic pathways (Pan and Cai 2023). The superior performance of combined *Azotobacter* and PSB treatments suggests synergistic effects, where nitrogen-fixing microorganisms improve nitrogen accessibility through organic acid-mediated decomposition of soil organic matter. The integration of vermicompost with microbial inoculants further enhanced phosphorus availability, as vermicompost organic matrices facilitate gradual phosphorus release while minimising mineral fixation processes in soil systems. The release of organic acids during decomposition and the additional potassium supplied by organic manures have been shown to enhance the soil's ability to keep potassium in a readily available form (Yaduvanshi *et al.* 2013). Regular applications of organic manure and bio-fertilisers, alongside inorganic fertilisers can improve soil fertility and promote more sustainable crop yields (Paramesh *et al.* 2023). Moreover, INM in acidic, nutrient-poor soils enhances the availability of soil nutrients (Mishra *et al.* 2019). INM enhances agricultural sustainability and climate resilience through two primary mechanisms: carbon sequestration within soil matrices and mitigation of greenhouse gas emissions associated with synthetic fertiliser application. The integration of organic amendments with reduced synthetic fertiliser rates decreases dependency on chemical inputs, thereby lowering the carbon footprint associated with fertiliser production and transportation (Amanullah *et al.* 2023). The adoption of INM practices effectively mitigates nutrient losses through both leaching into subsurface layers and surface runoff, thereby improving nutrient use efficiency (Paramesh *et al.* 2023).

The expenses of cultivation is closely linked to various inputs, including the costs of chemical fertilisers, farmyard manure, vermicompost, poultry manure and biofertilisers. Integrated nutrient management demonstrated substantial influence on economic parameters including gross income, net profit and benefit-cost ratio (Table 3). The lowest cultivation cost (₹64,858/ha) was observed in T_1 (100% RDF) due to reduced input requirements, while T_5 recorded the highest cultivation cost (₹100,195/ha), primarily attributed to the additional expenses associated with farmyard manure application. Treatment T_9 exhibited remarkable economic performance, achieving 63.81% higher gross income and 80.69% greater net profit compared to the sole chemical fertiliser treatment (T_1). Treatment T_9 also registered the highest benefit-cost ratio of 3.48, followed by treatments T_8 and T_7. Improved economic viability under organic nutrient supplementation regimes is linked to amelioration of soil structural stability, nutrient availability and microbial functionality, which synergistically contribute to elevated crop yields and enhanced financial returns (Kumar *et al.* 2024). Nath *et al.* (2023) and Singh *et al.* (2023) also recorded higher B: C ratio in treatments with combined application of organic manures, inorganic fertilisers and biofertilisers as compared to sole chemical fertilisers. The economic viability demonstrated through improved net profit and favourable benefit-cost ratio represents a crucial factor influencing farmer's acceptance and widespread adoption of INM practices (Mdoda *et al.* 2025). These results highlight the capacity of INM approaches to simultaneously improve crop yields and economic returns.

Based on the results, it can be concluded that the optimal treatment combination of 75% RDF + 4 t vermicompost/ha + 5 kg *Azotobacter*/ha + 5 kg PSB/ha significantly improved plant growth parameters, green yield and phytochemical constituents including ascorbic acid, β-carotene and chlorophyll content. Furthermore, this treatment enhanced soil chemical properties and organic matter content while maximising net returns and benefit-cost ratio in the Terai agroclimatic conditions of West Bengal. The synergistic application of organic manures and bio-fertilisers with reduced inorganic fertilisers effectively addressed the limitations of sole chemical fertilisation, which often fails to maintain optimal nutrient balance and soil organic matter equilibrium. The integration of chemical fertilisers, organic amendments and bio-inoculants proved superior in sustaining soil health, optimising nutrient availability and ensuring economic viability in mustard greens production systems. These findings underscore the potential of INM practices as a sustainable approach for intensive vegetable cultivation while maintaining long-term soil productivity and environmental stewardship.

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