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Effect of organic and integrated nutrient management on soil health, growth, yield and oil quality of mustard (*Brassica juncea* L.)

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Abstract

An experiment was conducted to evaluate the effect of organic and integrated nutrient management practices on soil properties, growth, yield and oil quality of mustard. The study comprised ten treatments including RDF, individual organic manures and integrated nutrient combinations. The results revealed significant improvement in soil physico-chemical, physical and biological properties under integrated nutrient management treatments compared to sole RDF and control. Among all treatments, T₁₀ (50% RDF + 50% Organic manure mix) recorded the lowest bulk density (1.31 g cm⁻³), highest porosity (49.8%), soil organic carbon (0.52%) and greater availability of nitrogen (299 kg ha⁻¹), phosphorus (45.4 kg ha⁻¹) and potassium (231 kg ha⁻¹). Enhanced microbial biomass carbon, dehydrogenase activity and soil respiration were also observed under integrated treatments. Growth parameters including plant height, number of branches, leaf area index and dry matter accumulation were significantly improved under T₁₀ followed by T₉ (Vermicompost + Poultry manure) and T₈ (FYM + Biofertilizer). The highest plant height at harvest (200.41 cm), branches plant⁻¹ (10.96) and dry matter accumulation (118.64 g plant⁻¹) were recorded under T₁₀. Yield attributes, seed yield and oil quality were also significantly enhanced under integrated nutrient management. The highest seed yield and oil yield were recorded under T₁₀, indicating the superiority of integrated nutrient management for sustainable mustard production and soil health improvement.

Keywords: Vermicompost, soil microbial activity, oilseed crop, nutrient-use efficiency, sustainable agriculture

Introduction

Mustard (*Brassica juncea* L.) is one of the most important oilseed crops cultivated in India and contributes significantly to the edible oil economy of the country. India ranks third in global rapeseed-mustard production after China and Canada (Kumar *et al.*, 2007). Mustard seeds contain about 37-49% oil and 28-36% protein, highlighting their nutritional and economic importance (Islam *et al.*, 2019). In addition to edible oil production, mustard also provides valuable by-products such as oil cake, which is widely used as livestock feed and organic manure (Singh *et al.*, 2014).

Despite its importance, mustard productivity in India remains relatively low due to declining soil fertility, nutrient depletion and imbalanced fertilizer use. Continuous dependence on chemical fertilizers has adversely affected soil health and nutrient-use efficiency. Therefore, integrated nutrient management involving combined use of organic and inorganic nutrient sources has emerged as an effective strategy for sustaining crop productivity and maintaining soil fertility (Kumar *et al.*, 2018).

Organic nutrient sources such as farmyard manure (FYM), vermicompost and poultry manure not only supply essential macro- and micronutrients but also improve soil physical, chemical and biological properties. FYM improves soil structure and nutrient availability (Yadav and Kumar, 2000), while vermicompost enhances soil microbial activity and enzymatic processes through the action of beneficial microorganisms and earthworms. Biofertilizers further improve nutrient availability by converting nutrients into plant-accessible forms. Moreover, sulfur plays an important role in mustard production and oil synthesis, and adequate sulfur [7, 5, 14, 9, 16]

supply has been reported to enhance yield and oil quality in mustard (Kumar *et al.*, 1997).

Several studies have reported positive effects of integrated nutrient management on soil health, crop growth and productivity in mustard cultivation (Gangwar *et al.*, 2023). However, comparative information regarding different organic and integrated nutrient management combinations under mustard cultivation remains limited. Therefore, the present study was undertaken to evaluate the effect of organic and integrated nutrient management practices on soil properties, growth, yield and oil quality of mustard under field conditions [8, 13, 3].

Materials and Methods Experimental Site and Treatments

A field experiment was conducted during the Rabi season at the Agronomy Research Farm, Faculty of Agricultural Sciences and Allied Industries, Rama University, Mandhana, Kanpur, Uttar Pradesh, India. The experimental site is situated at 26.5° N latitude and 80.3° E longitude with an elevation of approximately 125 m above mean sea level. The soil of the experimental field belonged to the Indo-Gangetic alluvial tract and was sandy loam in texture. The region experiences a subtropical climate with moderate winter temperature conditions suitable for mustard cultivation.

The experiment was laid out in a Randomized Block Design (RBD) with ten treatments and three replications. The treatments included control (T_1), RDF (80:40:40 kg N:P₂O₅:K₂O ha⁻¹) (T_2), FYM @ 10 t ha⁻¹ (T_3), vermicompost @ 5 t ha⁻¹ (T_4), poultry manure @ 5 t ha⁻¹ (T_5), green manure (*Sesbania*) @ 25 t ha⁻¹ (T_6), FYM + vermicompost (T_7), FYM + biofertilizers (*Azotobacter* + PSB) (T_8), vermicompost + poultry manure (T_9) and 50% RDF + 50% organic manure mixture (T_{10}). Organic manures were incorporated into the soil 15 days before sowing to facilitate decomposition and nutrient mineralization. Recommended agronomic practices were uniformly followed throughout the crop season.

Soil Analysis and Growth Observations

Initial and post-harvest soil samples were collected from 0-15 cm depth and analyzed using standard analytical procedures. Soil pH and electrical conductivity were determined following Jackson (1973), organic carbon by Walkley and Black (1934), available nitrogen by Subbiah and Asija (1956), available phosphorus by Olsen *et al.* (1954) and available potassium by Hanway and Heidel (1952). Bulk density and particle density were estimated using the core sampler and pycnometer methods, respectively, following Blake and Hartge (1986), while soil texture was determined by the hydrometer method of Bouyoucos (1962). Soil porosity was calculated from bulk density and particle density values.

Growth observations including plant height, number of branches plant⁻¹, leaf area index (LAI) and dry matter accumulation were recorded from five randomly selected plants in each plot. Plant height was measured at 30, 60, 90 DAS and at harvest using a meter scale. Leaf area index was estimated at 60 DAS following the method of Watson (1952), while dry matter accumulation was determined after oven drying plant samples at 65 ± 5°C until constant weight was achieved [1].

Statistical Analysis

The experimental data were statistically analyzed using analysis of variance (ANOVA) appropriate for Randomized Block Design. Treatment means were compared using the critical difference (CD) test at 5% level of significance. Results were expressed as mean ± standard error (SE).

Results

3.1 Effect of Different Nutrient Management Treatments on Soil Physico-Chemical and Physical Properties After Harvest

The soil physico-chemical and physical properties after harvest were significantly influenced by different nutrient management treatments (Table 1; Fig. 1). The integrated application of organic and inorganic nutrient sources markedly improved soil fertility status and soil physical characteristics compared to the control treatment.

3.1.1 Soil Chemical Properties

Soil pH remained within the neutral to slightly alkaline range across all treatments and varied from 7.66 to 7.83 (Table 1). The highest pH (7.83) was observed under the control treatment (T_1), whereas the lowest pH (7.66) was recorded with 50% RDF + 50% organic manure mix (T_{10}). A gradual decline in soil pH under integrated and organic treatments indicated the beneficial effect of organic amendments in moderating soil reaction.

Electrical conductivity (EC) ranged from 0.21 to 0.27 dS m⁻¹. The lowest EC was recorded in the control (T_1), while the maximum EC (0.27 dS m⁻¹) was observed in Vermicompost + Poultry manure treatment (T_9). The slight increase in EC under integrated nutrient treatments may be attributed to enhanced mineralization and release of soluble ions from organic amendments.

Organic carbon (OC) content increased substantially with the application of organic manures and biofertilizers (Table 1; Fig. 1A). The lowest OC content (0.35%) was recorded under control treatment (T_1), whereas the highest OC content (0.53%) was observed in T_9 (Vermicompost + Poultry manure), followed closely by T_{10} (0.52%) and T_7 (0.51%). The improvement in soil organic carbon under integrated treatments indicated enhanced organic matter accumulation and better soil health.

3.1.2 Available Soil Nutrients

The availability of major nutrients (N, P and K) significantly improved under integrated nutrient management treatments (Table 1; Fig. 1B). Available nitrogen ranged from 206 to 307 kg ha⁻¹. The minimum available nitrogen was recorded in the control (T_1), while the maximum value (307 kg ha⁻¹) was obtained under Vermicompost + Poultry manure treatment (T_9), followed by T_{10} (299 kg ha⁻¹) and T_8 (293 kg ha⁻¹).

Available phosphorus content varied from 26.5 to 46.9 kg ha⁻¹. The highest phosphorus availability was observed in T_9 (46.9 kg ha⁻¹), whereas the lowest was found in the control treatment. Similarly, available potassium ranged from 169 to 236 kg ha⁻¹, with the maximum value recorded under T_9 followed by T_{10} and T_8 . The increased nutrient availability under integrated treatments could be attributed to enhanced nutrient mineralization, improved microbial activity and reduced nutrient fixation in soil.

3.1.3 Soil Physical Properties

Soil physical properties also showed marked improvement due to nutrient management practices (Table 1; Fig. 1C). Bulk density decreased from 1.49 g cm⁻³ in the control treatment to 1.31 g cm⁻³ in T_{10} , indicating improved soil structure and aggregation with organic amendments. Lower bulk density under integrated treatments may be associated with increased organic matter incorporation and enhanced pore space.

Particle density showed slight variation among treatments and ranged from 2.61 to 2.66 g cm⁻³. The lowest particle density was recorded under T_9 and T_{10} , whereas the highest was observed in the control treatment.

Porosity increased considerably with integrated nutrient

management practices and ranged from 43.9 to 49.8%. The highest porosity was observed in T₁₀, closely followed by T₉ and T₈, while the lowest porosity was recorded in the control treatment. Increased porosity under organic and integrated nutrient treatments reflected improved soil aeration and water holding capacity.

All treatments maintained sandy loam soil texture throughout the experimental period, indicating that nutrient management practices influenced soil fertility and physical conditions without altering the inherent textural class of the soil.

3.1.4 Heatmap and Cluster Analysis: The hierarchical clustering and heatmap analysis (Fig. 1D) further illustrated the differential influence of nutrient management treatments on soil properties. Integrated nutrient treatments, particularly T₉, T₁₀ and T₈, formed distinct clusters associated with higher organic carbon, nutrient availability and porosity, along with lower bulk density. In contrast, the control treatment (T₁) clustered separately due to comparatively poor soil fertility and physical characteristics. The clustering pattern confirmed the positive impact of integrated nutrient management practices on overall soil health and sustainability.

Table 1: Physico-Chemical and Physical Properties of Soil After Harvest as Influenced by Different Nutrient Management Treatments

Treat-ment	Dose / Treatment Details	pH	EC (dS m ⁻¹)	OC (%)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)	Bulk Density (g cm ⁻³)	Soil Texture	Particle Density (g cm ⁻³)	Porosity (%)
T ₁	Control (No manure/fertilizer)	7.83 ± 0.35	0.21 ± 0.010	0.35 ± 0.016	206 ± 12.5	26.5 ± 1.5	169 ± 9.8	1.49 ± 0.069	Sandy loam	2.66 ± 0.04	43.9 ± 1.86
T ₂	RDF (80:40:40 NPK kg ha ⁻¹)	7.79 ± 0.33	0.24 ± 0.011	0.39 ± 0.018	259 ± 14.8	35.1 ± 2.0	213 ± 12.4	1.45 ± 0.067	Sandy loam	2.65 ± 0.04	45.3 ± 1.92
T ₃	FYM @ 10 t ha ⁻¹	7.75 ± 0.31	0.23 ± 0.011	0.46 ± 0.021	244 ± 14.1	32.8 ± 1.9	206 ± 11.9	1.39 ± 0.064	Sandy loam	2.64 ± 0.03	47.3 ± 1.78
T ₄	Vermicompost @ 5 t ha ⁻¹	7.71 ± 0.30	0.25 ± 0.012	0.48 ± 0.022	270 ± 15.6	38.7 ± 2.2	219 ± 13.0	1.36 ± 0.062	Sandy loam	2.63 ± 0.03	48.3 ± 1.72
T ₅	Poultry manure @ 5 t ha ⁻¹	7.73 ± 0.31	0.24 ± 0.011	0.45 ± 0.021	276 ± 16.0	41.6 ± 2.4	211 ± 12.5	1.37 ± 0.063	Sandy loam	2.63 ± 0.03	47.9 ± 1.75
T ₆	Green manure (Sesbania @ 25 t ha ⁻¹)	7.76 ± 0.34	0.22 ± 0.010	0.43 ± 0.020	233 ± 13.5	29.9 ± 1.7	193 ± 11.1	1.41 ± 0.066	Sandy loam	2.64 ± 0.04	46.6 ± 1.84
T ₇	FYM + Vermicompost (1:1 basis)	7.69 ± 0.29	0.25 ± 0.012	0.51 ± 0.023	287 ± 16.7	42.8 ± 2.5	226 ± 13.5	1.34 ± 0.061	Sandy loam	2.62 ± 0.03	48.9 ± 1.69
T ₈	FYM + Biofertilizer	7.68 ± 0.30	0.26 ± 0.012	0.50 ± 0.023	293 ± 17.1	44.3 ± 2.6	229 ± 13.8	1.33 ± 0.060	Sandy loam	2.62 ± 0.03	49.2 ± 1.67
T ₉	Vermicompost + Poultry manure	7.67 ± 0.28	0.27 ± 0.013	0.53 ± 0.024	307 ± 17.9	46.9 ± 2.7	236 ± 14.2	1.32 ± 0.059	Sandy loam	2.61 ± 0.03	49.6 ± 1.65
T ₁₀	50% RDF + 50% Organic manure mix	7.66 ± 0.32	0.25 ± 0.012	0.52 ± 0.024	299 ± 17.4	45.4 ± 2.6	231 ± 14.0	1.31 ± 0.060	Sandy loam	2.61 ± 0.03	49.8 ± 1.63
SEm (±)	—	0.31	0.011	0.021	15.6	2.2	12.8	0.063	—	0.03	1.75
CD	—	0.89	0.032	0.06	44.7	6.3	36.6	0.18	—	0.09	5.02

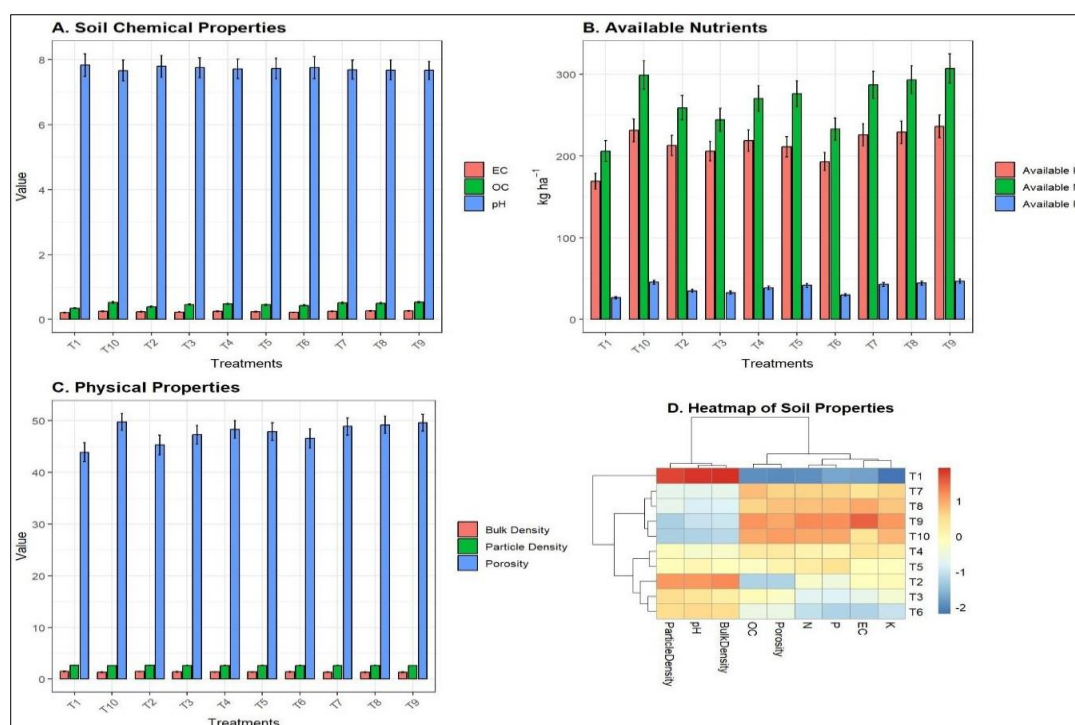


Fig 1: Effect of treatments on soil

Fig.1 Effect of different nutrient management treatments on soil chemical properties, available nutrients and physical properties after harvest. Panel A shows soil chemical properties (pH, EC and organic carbon), Panel B represents available N, P and K, Panel C depicts physical properties including bulk density, particle density and porosity, while Panel D illustrates hierarchical clustering and heatmap analysis of soil properties under different treatments. Values are presented as mean $\pm$ SE.

3.2 Effect of Different Organic Manures on Plant Height

Plant height was significantly influenced by different nutrient management treatments at all growth stages (30, 60, 90 DAS and at harvest) (Table 2; Fig. 2). Plant height increased progressively with crop growth under all treatments; however, integrated nutrient management practices consistently produced taller plants compared to sole organic or inorganic applications.

At 30 DAS, the maximum plant height (31.94 cm) was recorded under T₁₀ (50% RDF + 50% Organic), which was significantly superior to all other treatments, followed by T₉ (22.18 cm) and T₈ (21.46 cm). The minimum plant height (12.36 cm) was observed

under the control treatment (T₁). A similar trend was observed at 60 DAS, where T₁₀ recorded the highest plant height (136.84 cm), followed by T₉ (131.62 cm), whereas the lowest value was recorded in T₁ (79.84 cm).

At 90 DAS and harvest, integrated treatments maintained their superiority. The highest plant height at 90 DAS (195.62 cm) and at harvest (200.41 cm) was recorded under T₁₀, followed by T₉, T₈ and T₇, while the control treatment consistently recorded the lowest plant height (121.27 and 126.41 cm, respectively). Among the sole organic manure treatments, vermicompost (T₄) and poultry manure (T₅) performed better than RDF alone (T₂), FYM (T₃) and green manure (T₆).

Overall, the integrated application of inorganic fertilizers with organic nutrient sources proved most effective in enhancing plant height throughout the crop growth period. The superior performance of T₁₀ may be attributed to balanced nutrient availability, improved soil physical properties and enhanced nutrient uptake efficiency under integrated nutrient management practices (Table 2; Fig. 2).

Table 2: Effect of Organic and Integrated Nutrient Management on Plant Height of Mustard at Different Growth Stages

Treatment	Dose	30 DAS (cm)	60 DAS (cm)	90 DAS (cm)	At Harvest (cm)
T ₁	Control	12.36 $\pm$ 0.61	79.84 $\pm$ 3.48	121.27 $\pm$ 5.02	126.41 $\pm$ 5.21
T ₂	RDF (80:40:40)	19.87 $\pm$ 0.94	109.63 $\pm$ 4.62	149.72 $\pm$ 6.55	156.18 $\pm$ 6.83
T ₃	FYM @10 t ha ⁻¹	14.28 $\pm$ 0.68	94.57 $\pm$ 3.96	134.83 $\pm$ 5.89	141.26 $\pm$ 6.04
T ₄	Vermicompost @5 t ha ⁻¹	18.74 $\pm$ 0.89	119.46 $\pm$ 4.98	160.84 $\pm$ 7.12	166.72 $\pm$ 7.31
T ₅	Poultry manure @5 t ha ⁻¹	19.31 $\pm$ 0.91	117.88 $\pm$ 4.92	158.63 $\pm$ 6.94	163.58 $\pm$ 7.18
T ₆	Green manure	13.92 $\pm$ 0.66	91.74 $\pm$ 3.84	131.26 $\pm$ 5.68	136.43 $\pm$ 5.87
T ₇	FYM + Vermicompost	17.82 $\pm$ 0.84	124.73 $\pm$ 5.21	168.91 $\pm$ 7.46	173.64 $\pm$ 7.61
T ₈	FYM + Biofertilizer	21.46 $\pm$ 1.02	128.17 $\pm$ 5.34	171.32 $\pm$ 7.58	175.96 $\pm$ 7.82
T ₉	Vermicompost + Poultry manure	22.18 $\pm$ 1.07	131.62 $\pm$ 5.48	181.47 $\pm$ 8.03	185.94 $\pm$ 8.22
T ₁₀	50% RDF + 50% Organic	31.94 $\pm$ 1.52	136.84 $\pm$ 5.71	195.62 $\pm$ 8.64	200.41 $\pm$ 8.87
SEm ($\pm$)	—	0.96	4.75	6.99	7.22
CD (P=0.05)	—	2.75	13.61	20.03	20.69
CV (%)	—	7.8	7.5	8.2	8.3

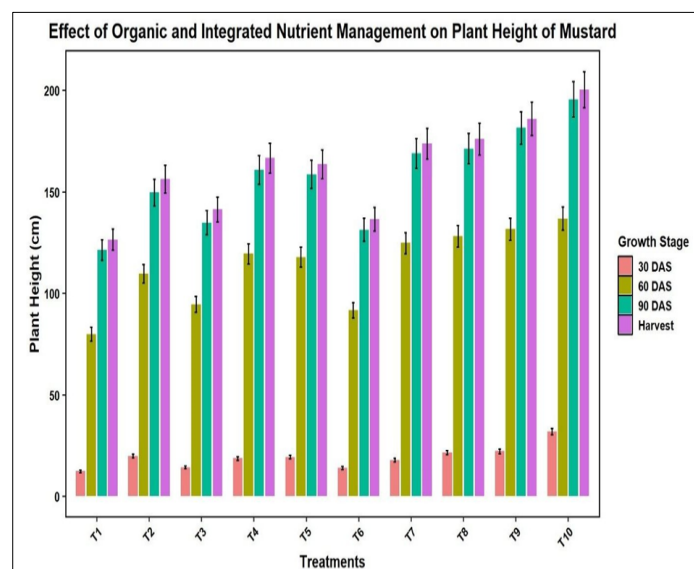


Fig 2: Effect of different organic and integrated nutrient management treatments on plant height of mustard at different growth stages.

3.3 Effect of Organic and Integrated Nutrient Management on Growth Parameters of Mustard

The growth parameters of mustard were significantly influenced by different organic and integrated nutrient management treatments (Table 3; Fig. 3). Integrated nutrient management treatments consistently recorded superior performance with respect to number of branches plant⁻¹, leaf area index (LAI) and dry matter accumulation at different growth stages.

The number of branches plant⁻¹ at 60 DAS ranged from 4.36 to 8.72. The maximum number of branches was recorded under T₁₀ (50% RDF + 50% Organic), followed by T₉ (Vermicompost + Poultry manure) and T₈ (FYM + Biofertilizer), whereas the minimum was observed under the control treatment (T₁). A similar trend was recorded at harvest, where T₁₀ produced the highest number of branches plant⁻¹ (10.96), followed by T₉ (10.18) and T₈ (9.64), while T₁ recorded the lowest value (5.82) (Table 3; Fig. 3A).

Leaf area index at 60 DAS varied significantly among treatments and ranged from 2.14 to 3.84. The highest LAI was observed under T₁₀, followed by T₉ and T₈, whereas the lowest LAI was recorded under the control treatment. Integrated application of

nutrients markedly improved canopy development and leaf expansion compared to sole organic or inorganic nutrient application (Table 3; Fig. 3B).

Dry matter accumulation increased progressively with crop growth under all treatments. At 60 DAS, dry matter accumulation ranged from 6.42 to 13.12 g plant⁻¹, with the highest value recorded under T₁₀ and the lowest under T₁. Similar trends were observed at 90 DAS and harvest, where T₁₀ recorded maximum dry matter accumulation (59.73 and 118.64 g plant⁻¹, respectively), followed by T₉ and T₈. The control treatment consistently recorded the lowest dry matter accumulation throughout the crop growth period (Table 3; Fig. 3C).

Among the sole organic manure treatments, vermicompost (T₄) and poultry manure (T₅) performed better than FYM (T₃) and green manure (T₆). Overall, the integrated nutrient management treatments, particularly T₁₀, T₉ and T₈, proved most effective in enhancing vegetative growth and biomass accumulation of mustard. The hierarchical clustering and heatmap analysis further confirmed the superiority of integrated nutrient management treatments in improving overall growth performance (Fig. 3D).

Table 3: Effect of Organic and Integrated Nutrient Management on Growth Parameters of Mustard at Different Growth Stages

Treatment	Dose	Branches Plant ⁻¹ (60 DAS)	Branches Plant ⁻¹ (At Harvest)	LAI (60 DAS)	Dry Matter Accumulation (60 DAS)	Dry Matter Accumulation (90 DAS)	Dry Matter Accumulation (At Harvest)
T ₁	Control	4.36 ± 0.21	5.82 ± 0.29	2.14 ± 0.11	6.42 ± 0.31	27.84 ± 1.52	64.73 ± 3.56
T ₂	RDF (80:40:40)	6.74 ± 0.32	8.48 ± 0.41	2.86 ± 0.15	9.86 ± 0.49	41.63 ± 2.32	92.48 ± 5.18
T ₃	FYM @10 t ha ⁻¹	5.63 ± 0.27	7.16 ± 0.34	2.48 ± 0.13	8.21 ± 0.40	35.74 ± 1.98	82.16 ± 4.62
T ₄	Vermicompost @5 t ha ⁻¹	7.18 ± 0.34	8.94 ± 0.43	3.12 ± 0.17	10.94 ± 0.54	46.82 ± 2.63	101.37 ± 5.71
T ₅	Poultry manure @5 t ha ⁻¹	7.04 ± 0.33	8.72 ± 0.42	3.06 ± 0.16	10.62 ± 0.53	45.91 ± 2.57	98.64 ± 5.55
T ₆	Green manure	5.41 ± 0.26	6.88 ± 0.33	2.41 ± 0.13	7.96 ± 0.39	33.28 ± 1.84	76.43 ± 4.29
T ₇	FYM + Vermicompost	7.52 ± 0.36	9.28 ± 0.45	3.28 ± 0.18	11.47 ± 0.57	50.36 ± 2.85	107.84 ± 6.08
T ₈	FYM + Biofertilizer	7.83 ± 0.37	9.64 ± 0.47	3.36 ± 0.19	11.86 ± 0.59	52.41 ± 2.97	110.26 ± 6.23
T ₉	Vermicompost + Poultry manure	8.14 ± 0.39	10.18 ± 0.50	3.58 ± 0.20	12.34 ± 0.62	55.87 ± 3.18	113.92 ± 6.48
T ₁₀	50% RDF + 50% Organic	8.72 ± 0.42	10.96 ± 0.54	3.84 ± 0.22	13.12 ± 0.67	59.73 ± 3.41	118.64 ± 6.75
SEm (±)	—	0.33	0.42	0.16	0.51	2.53	5.24
CD (P=0.05)	—	0.95	1.21	0.46	1.46	7.24	15

Fig. 3 Effect of organic and integrated nutrient management treatments on growth parameters of mustard. Panel A represents branches plant⁻¹ at 60 DAS and harvest, Panel B shows leaf area index (LAI) at 60 DAS, Panel C depicts dry matter accumulation at different growth stages, while Panel D illustrates hierarchical clustering and heatmap analysis of growth parameters under different treatments. Values are presented as mean ± SE.

Discussion

The present investigation demonstrated that integrated nutrient management significantly improved soil properties, crop growth, yield and oil quality of mustard compared to sole organic, RDF and control treatments. Among all treatments, T₁₀ (50% RDF + 50% Organic manure mix) consistently recorded superior performance, followed by T₉ (Vermicompost + Poultry manure) and T₈ (FYM + Biofertilizer), indicating the synergistic effect of combined organic and inorganic nutrient application.

Integrated treatments improved soil physico-chemical and biological properties by reducing soil pH and bulk density while

increasing soil organic carbon, available N, P and K, porosity and microbial activity. These improvements may be attributed to enhanced organic matter decomposition, nutrient mineralization and improved soil aggregation under integrated nutrient management. Similar findings were reported by Chesti *et al.* (2015), Tomar *et al.* (2018), Bhanwaria *et al.* (2022). Enhanced microbial biomass carbon, dehydrogenase activity and soil respiration under integrated treatments further indicated improved soil biological health, which corroborates the findings of Heidari *et al.* (2016) and Jat *et al.* (2021).

Growth parameters such as plant height, number of branches, leaf area index and dry matter accumulation were significantly higher under integrated nutrient management treatments. The superior growth observed under T₁₀ may be due to balanced nutrient availability, improved nutrient uptake and sustained nutrient release throughout crop growth stages. Similar results were reported by Murali *et al.* (2018) and Reddy and Singh (2018). Yield attributes, seed yield and straw yield also increased significantly under integrated treatments. The highest seed yield

obtained under T₁₀ may be associated with improved source-sink relationship, better nutrient availability and enhanced physiological efficiency of plants. Similar findings were reported by Sahoo *et al.* (2018). Oil content and oil yield also improved under integrated nutrient management, likely due to better sulphur and micronutrient availability essential for oil biosynthesis.

Similar observations were reported by Sharma *et al.* (2023). Overall, the study suggests that integrated nutrient management, particularly the combined application of 50% RDF with 50% organic sources, is an effective and sustainable approach for improving soil health, productivity and oil quality of mustard [2, 15, 1, 4, 6, 10, 11, 12, 13].

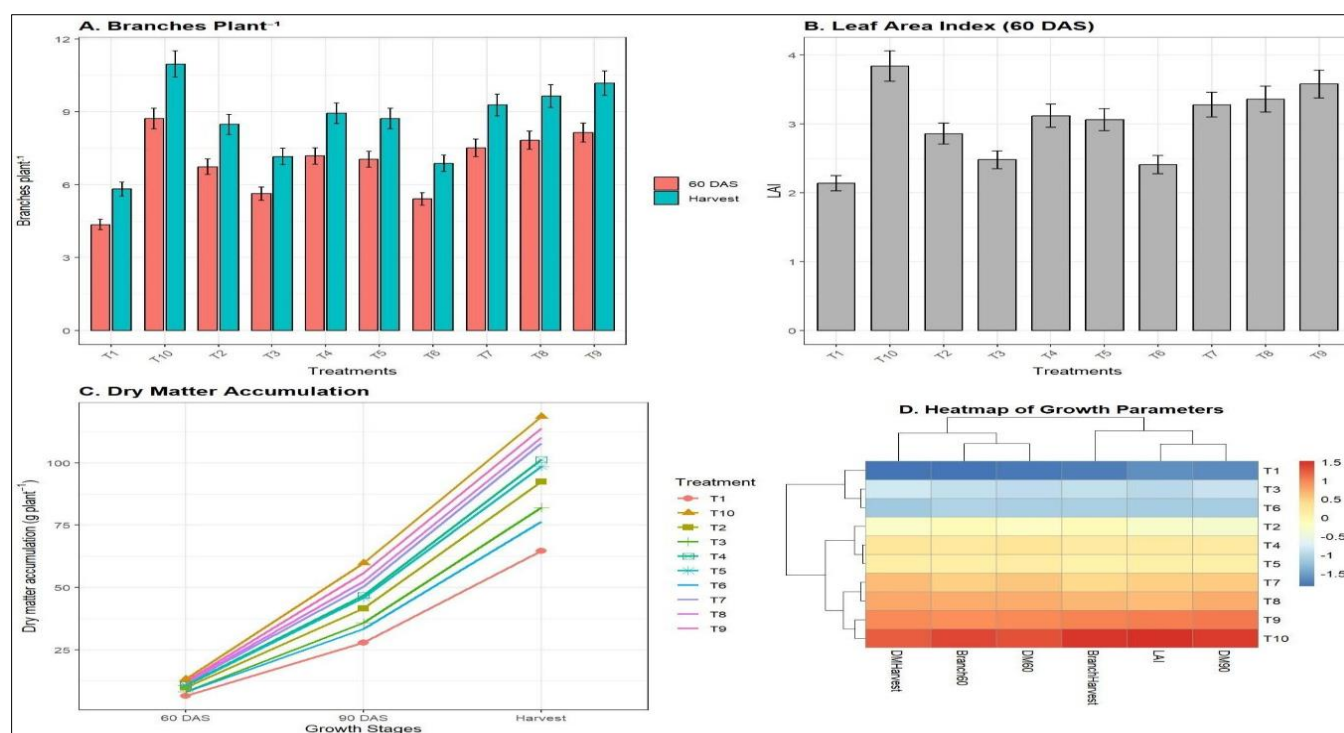


Fig 3: Growth parameters and clustering analysis

Conclusion: The present study demonstrated that organic and integrated nutrient management practices significantly influenced soil health, growth, productivity and oil quality of mustard. Among the different treatments, T₁₀ (50% RDF + 50% Organic manure mix) proved to be the most effective, followed by T₉ (Vermicompost + Poultry manure) and T₈ (FYM + Biofertilizer). Integrated nutrient management markedly improved soil physico-chemical and biological properties by enhancing soil organic carbon, available N, P and K, microbial activity and porosity while reducing bulk density compared to sole RDF and control treatments.

Improved soil conditions under integrated treatments positively influenced crop growth parameters, including plant height, number of branches, leaf area index and dry matter accumulation, which ultimately resulted in higher yield attributes, seed yield and straw yield. The highest seed yield and oil yield were recorded under T₁₀, indicating the beneficial synergistic effect of combining organic and inorganic nutrient sources. Enhanced oil content under integrated treatments further highlighted the role of balanced nutrition in improving crop quality.

Overall, the findings suggest that partial substitution of chemical fertilizers with organic nutrient sources is an effective and sustainable strategy for enhancing mustard productivity while maintaining soil fertility and biological health. Therefore, integrated nutrient management involving 50% RDF combined with organic manures can be recommended for sustainable mustard cultivation and long-term soil health improvement.

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