International Journal of Plant & Soil Science

Volume 38, Issue 8, Page 303-314, 2026; Article no.IJPSS.162697
ISSN: 2320-7035

Effect of Organic Manure and Micronutrients on Growth and Yield of Indian Mustard (*Brassica juncea* L.)

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i86219

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/162697

Original Research Article

Received: 22/05/2026
Accepted: 18/07/2026
Published: 23/07/2026

Abstract

Indian mustard (*Brassica juncea* L.) is an important oilseed crop, and improving its productivity through balanced nutrient management is relevant to edible-oil production. A field experiment was conducted during the 2022-23 Rabi season at the Experimental Farm, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib, Punjab, to evaluate the effects of organic manures and micronutrients on growth and yield. The experiment comprised nine treatment combinations arranged in a factorial randomised block design with three replications. Organic-manure treatments included a control, farmyard manure at 10 t/ha and vermicompost at 5 t/ha; micronutrient treatments comprised $ZnSO_4$ at 25 kg/ha, $FeSO_4$ at 20 kg/ha and borax at 2 kg/ha. Growth parameters, including plant height, primary and secondary branches and dry matter accumulation, were recorded at successive crop stages. Seed, stover and biological yields and harvest index were assessed at harvest. Vermicompost at 5 t/ha generally produced the highest growth and yield values and was statistically at par with farmyard manure at 10 t/ha for most measured parameters. Among the micronutrients, $ZnSO_4$ at 25 kg/ha generally recorded the highest values and was statistically at par with borax at 2 kg/ha, whereas $FeSO_4$ at 20 kg/ha produced comparatively lower values. Interaction effects were non-significant for most parameters. The findings indicate that vermicompost and zinc sulphate individually supported improved growth and yield performance under the study conditions.

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Cite as: *Gill, L., & Kumar, S. (2026). Effect of Organic Manure and Micronutrients on Growth and Yield of Indian Mustard (Brassica juncea L.). International Journal of Plant & Soil Science, 38(8), 303–314. https://doi.org/10.9734/ijpss/2026/v38i86219*

Keywords: *Indian mustard; Brassica juncea; organic manure; farmyard manure; vermicompost; zinc sulphate; iron sulphate; borax; micronutrients; seed yield.*

1. Introduction

Oilseeds occupy a prominent position in Indian agriculture, second only to cereals in terms of importance. Among the major oilseed crops cultivated in India, mustard is one of the most important due to its wide adaptability, high economic value, and nutritional significance. Indian mustard (*Brassica juncea* L.), belonging to the family Brassicaceae, is primarily cultivated for its seeds, which contain a high proportion of oil and protein (Dhaliwal *et al.*, 2021). Mustard seeds and oil are extensively used as condiments in pickle preparation and for flavouring a variety of vegetables and curry dishes. The oil cake obtained after oil extraction serves as a valuable source of organic manure and livestock feed. The tender leaves of the mustard plant are also consumed as a nutritious green leafy vegetable, popularly known as "saag." Crop production practices for rapeseed and mustard in Punjab are detailed by Punjab Agricultural University (2024).

Rapeseed and mustard are major winter oilseed crops in India. During 2021-22, they occupied 8.06 million hectares and produced 11.75 million tonnes, with an average yield of 1,458 kg/ha (Department of Agriculture & Farmers Welfare, 2023). In Punjab, rapeseed and mustard were grown on 43.1 thousand hectares, producing 69.4 thousand tonnes with an average yield of 16.11 q/ha during 2023-24 (Punjab Agricultural University, 2024).

The intensive use of agrochemicals over the past five decades has undoubtedly contributed to substantial increases in agricultural production. However, neglect of the ecological principles of sustainable agriculture has led to declining growth rates and stagnation in crop productivity, raising serious environmental and agricultural concerns. The indiscriminate and excessive use of chemical fertilisers and pesticides has adversely affected soil, water and air quality, resulting in environmental pollution (Yadav *et al.*, 2013). In contrast, the application of organic manures improves soil fertility by enhancing nutrient availability through increased microbial activity, improving soil structure and root growth, and increasing the soil's water-holding capacity. Organic and integrated nutrient-management practices can build soil organic carbon and nutrient status (Panwar *et al.*, 2010), while manure application can improve crop productivity and nutrient accumulation (Koutroubas *et al.*, 2016).

The use of organic manures for improving and maintaining soil health has long been practiced, although adoption may be constrained by availability and nutrient costs. The combined use of organic and inorganic nutrient sources can sustain mustard productivity and nutrient uptake (Singh & Singh, 2014). Farmyard manure and nitrogen application influence the growth and yield attributes of Indian mustard (Patel & Meisheri, 1997), while vermicompost-based management can improve mustard productivity and energetic performance (Singh *et al.*, 2018). Sulphur, boron and farmyard manure also improve growth and yield attributes in mustard (Singh *et al.*, 2022). Continuous cropping and inadequate organic inputs may contribute to macro- and micronutrient deficiencies; sulphur and zinc nutrition significantly affect mustard yield and oil content (Sultana *et al.*, 2020). Balanced supplies of micronutrients such as boron, zinc and iron are essential for crop growth, productivity and nutritional quality (Dhaliwal *et al.*, 2021).

Zinc contributes to mustard growth, seed formation and yield, and its interaction with boron affects crop metabolism (Sinha *et al.*, 2000). Zinc and sulphur applications also improve yield-attributing characters of Indian mustard (Verma *et al.*, 2018). Iron is an essential micronutrient involved in photosynthetic efficiency, biomass production and crop product quality (Briat *et al.*, 2015). Boron supports cell-wall structure, root elongation, reproductive development and several metabolic processes in plants (Shireen *et al.*, 2018). In North-West Himalayan Alfisols, boron and farmyard manure influenced the nutrient content of cauliflower (Chander *et al.*, 2010). In Indian mustard, sulphur and boron, together with integrated nutrient management, improve growth and yield performance (Singh *et al.*, 2022). Recent syntheses indicate that the agronomic effects of organic fertilisers vary with nutrient composition, mineralisation dynamics, soil properties and management conditions, emphasising the need for site-specific evaluation (Bergstrand, 2022; Allam *et al.*, 2022). Organic inputs may also influence soil organic matter and microbial processes that regulate nutrient turnover, although the magnitude of these responses depends on the agricultural system and local soil environment (Bhattacharyya *et al.*, 2022).

Research Gap: Evidence remains limited on the comparative performance of farmyard manure and vermicompost when combined with zinc sulphate, iron sulphate and borax for Indian mustard under the agro-climatic conditions of Fatehgarh Sahib, Punjab. The responses of growth, yield attributes and yield of the RLC-3 variety to these organic manure-micronutrient combinations under a common field environment therefore require evaluation.

1.1 Objective

The objective of the present study was to evaluate the individual and interactive effects of farmyard manure, vermicompost, zinc sulphate, iron sulphate and borax on the growth and yield performance of Indian mustard (*Brassica juncea* L.) under the agro-climatic conditions of Fatehgarh Sahib, Punjab.

2. Materials and Methods

A field experiment was conducted during the rabi season of 2022–23 at the Experimental Farm, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib. The experimental site is located in the subtropical plains of Punjab at an elevation of 247 metres above mean sea level. The site is situated at 30° 65′ N latitude and 76° 38′ E longitude. During the crop-growing season, total rainfall was 62.4 mm. The minimum and maximum temperatures recorded during the crop season were 0.5 °C and 29.4 °C, respectively. The maximum relative humidity ranged from 61.4% to 94.4%, while the minimum relative humidity ranged from 33.7% to 86.6%.

The experimental soil was clay loam in texture and slightly alkaline, with a pH of 7.71. It was medium in organic carbon (0.42%), available nitrogen (378.61 kg ha^{-1}), available phosphorus (19.09 kg ha^{-1}) and available potassium (160.32 kg ha^{-1}). The field had a stable cropping history and had been under a wheat–paddy rotation in the preceding season.

The experiment comprised nine treatments arranged in a factorial randomised block design (FRBD) with three replications. The treatments included three organic-manure levels (O_0 = control, O_1 = farmyard manure @ 10 t/ha and O_2 = vermicompost @ 5 t/ha) and three micronutrient levels (M_1 = $ZnSO_4$ @ 25 kg/ha, M_2 = $FeSO_4$ @ 20 kg/ha and M_3 = borax @ 2 kg/ha). The Indian mustard variety RLC-3 was sown on 13 November 2022 using a seed rate of 4 kg/ha and a spacing of 30 cm × 15 cm. A recommended basal dose of fertilisers was applied, and foliar applications of micronutrients were carried out according to the treatments. Standard intercultural operations and irrigations were followed, and the crop was harvested at full maturity on 28 March 2023.

2.1 Growth and Development Studies

Biometric observations were recorded from three randomly selected and tagged plants in each net plot. Plant height was measured from ground level to the base of the last fully opened leaf at 30, 60 and 90 days after sowing (DAS) and at harvest, and the values were averaged. To determine dry matter accumulation, plants from one running metre in each plot were sampled at 30, 60 and 90 DAS and at harvest. The entire above-ground portions of the plants were collected, sun-dried and then oven-dried at 60 ± 2 °C until a constant weight was obtained. The three selected and tagged plants were also used to count the primary and secondary branches at 30, 60 and 90 DAS and at harvest.

The total number of fully mature siliquae per plant was also counted on the three randomly tagged plants in each plot. Additionally, the 1,000-seed weight was recorded in grams from the threshed produce of each plot.

2.2 Yield Studies

The crop was harvested from a net plot area of 9.92 m² (3.15 m × 3.15 m). The number of days from sowing to harvest was recorded. After complete sun-drying, the biological yield of the unthreshed produce was measured. Following threshing and manual winnowing, the clean seed yield was recorded. Both seed and biological yields were converted to kg ha^{-1}. Stover yield was calculated by subtracting seed yield from total biological yield. The harvest index was calculated as the ratio of economic yield (seed yield) to biological yield and expressed as a percentage.

2.3 Statistical Analysis

The experimental data generated for the various parameters were statistically analysed using the standard analysis-of-variance method described by Gomez and Gomez (1984). The effects of the different treatments were tested using the F-test. The calculated F-value was compared with the tabulated F-value at the 5% level of significance. When the calculated F-value exceeded the tabulated value, the treatment effect was considered significant. Significant differences among treatment means were tested using the critical difference at the 5% level of significance.

3. Results and Discussion

3.1 Growth Studies

3.1.1 Plant Height (cm)

The data presented in Table 1 and Fig. 1 showed that the different treatments significantly influenced mustard plant height at various growth stages. Plant height increased progressively with crop growth and continued to increase until harvest, reaching an average of 166-172 cm.

Plant height at 30 DAS was not significantly affected by the treatments. However, significant differences were observed at 60 DAS, 90 DAS and harvest. Among the organic-manure treatments, the maximum plant height at 60 DAS, 90 DAS and harvest was recorded with vermicompost @ 5 t/ha (O_2), which was statistically at par with FYM @ 10 t/ha (O_1) and significantly superior to the remaining treatment.

Among the micronutrient treatments, $ZnSO_4$ @ 25 kg/ha (M_1) produced the maximum plant height at 60 DAS, 90 DAS and harvest. However, it was statistically at par with borax @ 2 kg/ha (M_3). These findings agree with those reported by Reddy *et al.* (2020).

The interaction between organic manures and micronutrients had a non-significant effect on plant height at all stages of crop growth. Nevertheless, the highest plant height was recorded under T_7 (vermicompost @ 5 t/ha + $ZnSO_4$ @ 25 kg/ha), followed by T_6 (FYM @ 10 t/ha + borax @ 2 kg/ha), whereas the lowest plant height was observed under T_2 (control + $FeSO_4$ @ 20 kg/ha).

Table 1. Effect of organic manure and micronutrients on Plant height (cm) of mustard

Treatments	30 days	60 days	90 days	At harvest
Effect of Organic Manure				
O_0- @ Control	10.44	59.07	149.11	166.78
O_1- Farm Yard Manure @ 10 t/ha	12.11	63.99	153.78	171.89
O_2- Vermicompost @ 5 t/ha	12.44	64.97	154.00	172.00
SE (m)±	**0.71**	**1.27**	**0.85**	**0.90**
CD at 5%	**1.51**	**2.70**	**1.80**	**1.90**
Effect of Micronutrients				
M_1- $ZnSo_4$@ 25 kg/ha	12.00	64.05	153.33	171.44
M_2- $FeSo_4$@ 20 kg/ha	11.22	60.13	150.78	168.67
M_3- Borax @ 2 kg/ha	11.78	63.84	152.78	170.56
SE (m) ±	**0.82**	**1.47**	**0.98**	**1.03**
CD at 5%	**1.74**	**3.11**	**2.08**	**2.19**
Interaction (O×M)				
O_0 @ Control + M_1 @ 25 kg/ha	11.0	61.4	150.0	167.0
O_0 @ Control + M_2 @ 20 kg/ha	9.7	57.3	147.3	165.0
O_0 @ Control + M_3 @ 2 kg/ha	10.7	58.5	150.0	168.3
O_1 @ 10 t/ha + M_1 @ 25 kg/ha	12.0	62.5	154.0	172.3
O_1 @ 10 t/ha + M_2 @ 20 kg/ha	10.7	65.4	152.7	169.7
O_1 @ 10 t/ha + M_3 @ 2 kg/ha	13.4	69.0	154.7	173.7
O_2 @ 5 t/ha + M_1 @ 25 kg/ha	13.6	71.3	156.0	175.0
O_2 @ 5 t/ha + M_2 @ 20 kg/ha	13.3	61.2	152.3	171.3
O_2 @ 5 t/ha + M_3 @ 2 kg/ha	11.0	65.5	153.7	169.7
SE (m) ±	**1.42**	**2.54**	**1.70**	**1.79**
CD at 5%	**NS**	**NS**	**NS**	**NS**

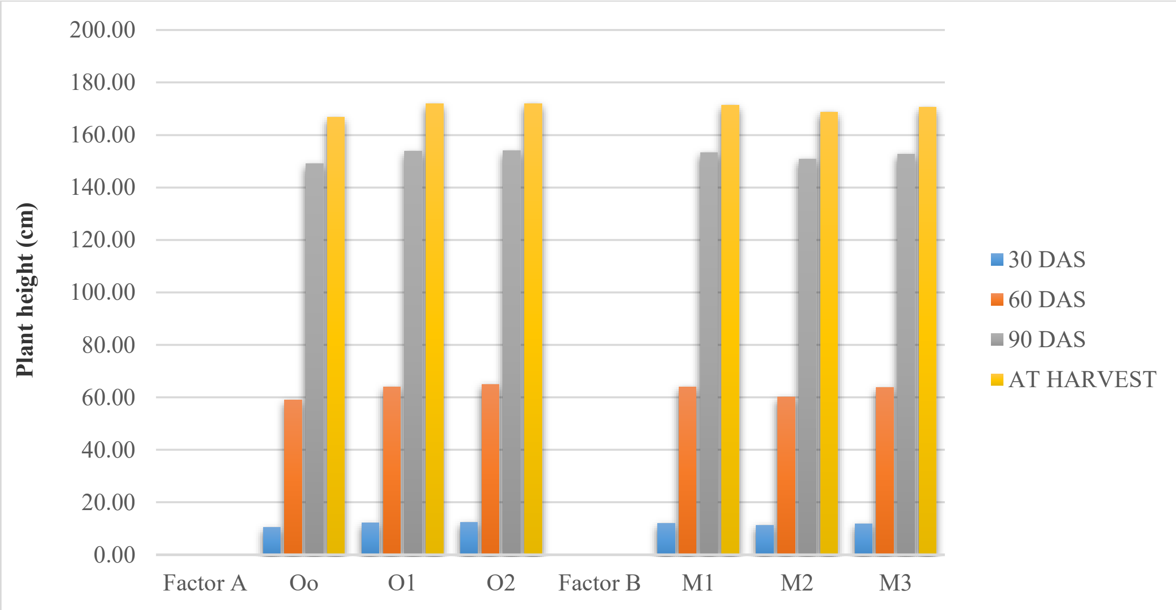

Fig. 1. Graph showing Effect of organic manure and micronutrients on plant height (cm) of mustard

3.1.2 Number of Primary and Secondary Branches per Plant

The data presented in Tables 2 and 3 and Figs. 2 and 3 indicated that the numbers of primary and secondary branches per plant in mustard increased significantly as crop growth advanced up to harvest. The numbers of primary and secondary branches at 30 DAS were not significantly influenced by the treatments. At 60 DAS, 90 DAS and harvest, the maximum numbers of primary and secondary branches among the organic-manure treatments were recorded with vermicompost @ 5 t/ha, which was statistically at par with farmyard manure @ 10 t/ha and significantly superior to the remaining treatment. Among the micronutrient treatments, the maximum numbers at 60 DAS, 90 DAS and harvest were recorded with M_1 ($ZnSO_4$ @ 25 kg/ha), which was statistically at par with M_3 (borax @ 2 kg/ha). The interaction between organic manures and micronutrients had a non-significant effect on the numbers of primary and secondary branches at the different growth stages.

Table 2. Effect of organic manure and micronutrients on number of primary branches of mustard

Treatments	30 days	60 days	90 days	At harvest
Effect of Organic Manure				
O_0- @ Control	1.81	3.37	5.07	6.24
O_1- Farm Yard Manure @ 10 t/ha	2.04	3.80	5.87	6.84
O_2- Vermicompost @ 5 t/ha	2.08	4.00	6.18	7.09
SE (m)±	**0.19**	**0.15**	**0.10**	**0.15**
CD at 5%	**0.41**	**0.31**	**0.22**	**0.32**
Effect of Micronutrients				
M_1- $ZnSo_4$@ 25 kg/ha	2.02	4.00	6.00	7.00
M_2- $FeSo_4$@ 20 kg/ha	2.01	3.49	5.50	6.46
M_3- Borax @ 2 kg/ha	1.90	3.68	5.61	6.71
SE (m) ±	**0.22**	**0.17**	**0.12**	**0.17**
CD at 5%	**0.48**	**0.36**	**0.25**	**0.37**
Interaction (O×M)				
O_0 @ Control + M_1 @ 25 kg/ha	1.9	3.8	5.5	6.6
O_0 @ Control + M_2 @ 20 kg/ha	1.8	3.2	4.9	6.0
O_0 @ Control + M_3 @ 2 kg/ha	1.8	3.1	4.8	6.2
O_1 @ 10 t/ha + M_1 @ 25 kg/ha	2.1	3.9	5.9	6.8
O_1 @ 10 t/ha + M_2 @ 20 kg/ha	2.3	3.4	5.7	6.6

Treatments	30 days	60 days	90 days	At harvest
O_1 @ 10 t/ha + M_3 @ 2 kg/ha	1.7	4.1	6.0	7.1
O_2 @ 5 t/ha + M_1 @ 25 kg/ha	2.1	4.2	6.6	7.7
O_2 @ 5 t/ha + M_2 @ 20 kg/ha	2.0	3.9	5.9	6.8
O_2 @ 5 t/ha + M_3 @ 2 kg/ha	2.2	3.9	6.1	6.9
SE (m) ±	**1.42**	**0.29**	**0.21**	**0.30**
CD at 5%	**NS**	**NS**	**NS**	**NS**

3.1.3 Dry Matter Accumulation per Plant (g)

The data on dry matter accumulation presented in Table 4 and Fig. 4 showed that accumulation increased with crop age up to harvest. At 30 DAS, 60 DAS, 90 DAS and harvest, the maximum dry matter accumulation among the organic-manure treatments was recorded with vermicompost @ 5 t/ha, which was statistically at par with farmyard manure @ 10 t/ha and significantly superior to the remaining treatment. Among the micronutrient treatments, the maximum dry matter accumulation at 60 DAS, 90 DAS and harvest was recorded with $ZnSO_4$ @ 25 kg/ha, which was statistically at par with M_3 (borax @ 2 kg/ha). The interaction between organic manures and micronutrients had a non-significant effect on dry matter accumulation at the different growth stages.

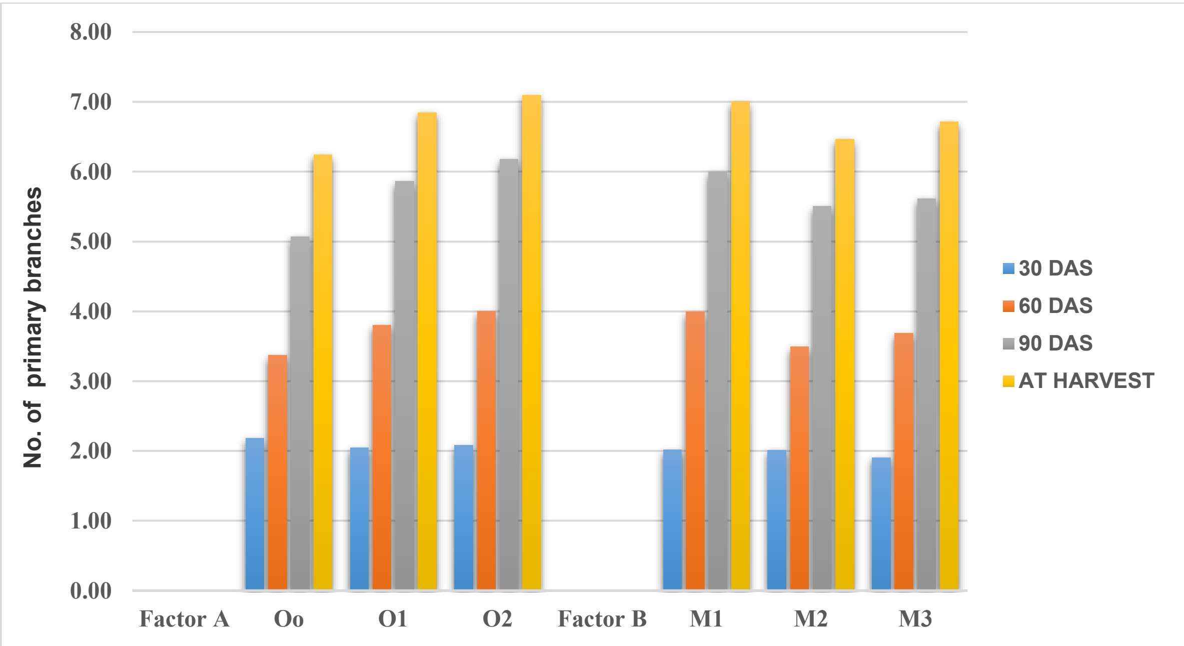

Fig. 2. Graph showing Effect of organic manure and micronutrients on primary branches of mustard

3.2 Yield Studies

3.2.1 Grain Yield (q/ha)

The data on grain yield obtained under the different treatments are presented in Table 5 and Fig. 5. Among the organic-manure treatments, the maximum seed yield (18.85 q/ha) was recorded with vermicompost @ 5 t/ha, which was statistically at par with farmyard manure @ 10 t/ha and significantly superior to the remaining treatment. Among the micronutrient treatments, the maximum seed yield (18.15 q/ha) was recorded with $ZnSO_4$ @ 25 kg/ha, which was statistically at par with borax @ 2 kg/ha. The interaction between organic manures and micronutrients had a non-significant effect on seed yield. These findings are consistent with those reported by Verma *et al.* (2018).

3.2.2 Stover Yield (q/ha)

Stover yield was significantly affected by the treatments, as presented in Table 5 and illustrated in Fig. 5. Among the organic-manure treatments, the maximum stover yield (37.42 q/ha) was recorded with vermicompost

@ 5 t/ha, which was statistically at par with farmyard manure @ 10 t/ha and significantly superior to the remaining treatment. Among the micronutrient treatments, the maximum stover yield (37.36 q/ha) was recorded with $ZnSO_4$ @ 25 kg/ha, which was statistically at par with M_3 (borax @ 2 kg/ha). The interaction between organic manures and micronutrients had a non-significant effect on stover yield.

Table 3. Effect of organic manure and micronutrients on number of secondary branches of mustard

Treatments	60 days	90 days	At harvest
Effect of Organic Manure			
O_0- @ Control	10.48	27.25	38.02
O_1- Farm Yard Manure @ 10 t/ha	12.59	28.99	40.63
O_2- Vermicompost @ 5 t/ha	13.03	29.44	41.12
SE (m)±	**0.35**	**0.60**	**0.50**
CD at 5%	**0.73**	**1.27**	**1.07**
Effect of Micronutrients			
M_1- $ZnSo_4$@ 25 kg/ha	12.60	29.36	40.75
M_2- $FeSo_4$@ 20 kg/ha	11.50	27.49	39.21
M_3- Borax @ 2kg/ha	11.98	28.83	39.81
SE (m) ±	**0.40**	**0.69**	**0.57**
CD at 5%	**0.85**	**1.47**	**1.22**
Interaction (O×M)			
O_0 @ Control + M_1 @ 25 kg/ha	10.6	27.0	39.6
O_0 @ Control + M_2 @ 20 kg/ha	9.9	26.8	37.3
O_0 @ Control + M_3 @ 2 kg/ha	11.0	27.9	37.2
O_1 @ 10 t/ha + M_1 @ 25 kg/ha	12.8	29.5	40.0
O_1 @ 10 t/ha + M_2 @ 20 kg/ha	11.9	27.0	40.5
O_1 @ 10 t/ha + M_3 @ 2 kg/ha	13.0	30.4	41.4
O_2 @ 5 t/ha + M_1 @ 25 kg/ha	14.4	31.5	42.6
O_2 @ 5 t/ha + M_2 @ 20 kg/ha	12.7	28.6	39.9
O_2 @ 5 t/ha + M_3 @ 2 kg/ha	11.9	28.1	40.9
SE (m) ±	**0.69**	**1.20**	**1.42**
CD at 5%	**NS**	**NS**	**NS**

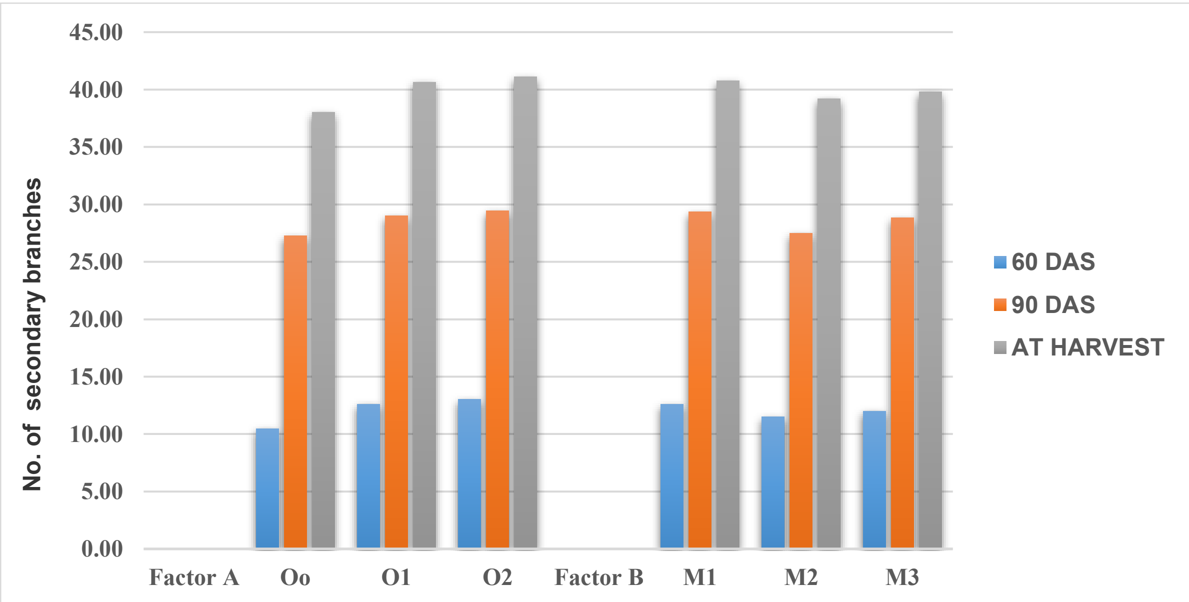

Fig. 3. Graph showing Effect of organic manure and micronutrients on secondary branches of mustard

Table 4. Effect of organic manure and micronutrients on dry matter accumulation (g/running meter) of mustard

Treatments	30 days	60 days	90 days	At harvest
Effect of Organic Manure				
O_0- @ Control	21.68	170.55	219.48	333.87
O_1- Farm Yard Manure @ 10 t/ha	23.67	174.88	226.38	337.98
O_2- Vermicompost @ 5 t/ha	25.10	177.10	227.49	338.46
SE (m)±	**1.00**	**0.78**	**0.94**	**0.83**
CD at 5%	**2.13**	**1.66**	**1.99**	**1.76**
Effect of Micronutrients				
M_1- $ZnSo_4$@ 25 kg/ha	24.14	175.06	225.95	338.00
M_2- $FeSo_4$@ 20 kg/ha	22.46	172.56	222.74	335.24
M_3- Borax @ 2 kg/ha	23.05	174.91	224.66	337.08
SE (m) ±	**1.16**	**0.90**	**1.08**	**0.96**
CD at 5%	**2.01**	**3.31**	**2.29**	**2.03**
Interaction (O×M)				
O_0 @ Control + M_1 @ 25 kg/ha	22.6	170.9	220.6	334.4
O_0 @ Control + M_2 @ 20 kg/ha	21.6	169.2	217.4	331.5
O_0 @ Control + M_3 @ 2 kg/ha	20.08	171.5	220.5	335.7
O_1 @ 10 t/ha + M_1 @ 25 kg/ha	24.02	174.8	226.1	338.3
O_1 @ 10 t/ha + M_2 @ 20 kg/ha	23.0	172.7	224.8	336.6
O_1 @ 10 t/ha + M_3 @ 2 kg/ha	24.0	177.2	228.2	339.1
O_2 @ 5 t/ha + M_1 @ 25 kg/ha	25.8	179.4	231.2	341.3
O_2 @ 5 t/ha + M_2 @ 20 kg/ha	22.8	175.8	226.0	337.6
O_2 @ 5 t/ha + M_3 @ 2 kg/ha	24.3	176.0	225.2	336.4
SE (m) ±	**2.01**	**1.56**	**1.87**	**1.66**
CD at 5%	**NS**	**NS**	**NS**	**NS**

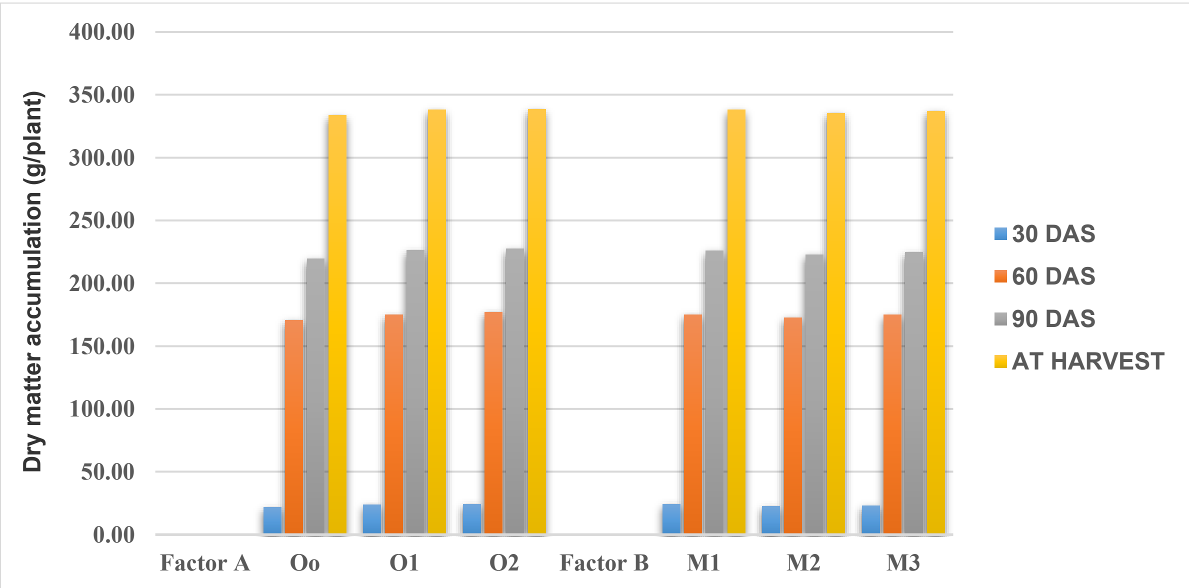

Fig. 4. Graph showing Effect of organic manure and micronutrients on dry matter accumulation of mustard

3.2.3 Biological Yield (q/ha)

Biological yield was significantly influenced by the various treatments, as presented in Table 5 and illustrated in Fig. 5. Among the organic-manure treatments, the maximum biological yield (55.47 q/ha) was recorded with vermicompost @ 5 t/ha, which was statistically at par with farmyard manure @ 10 t/ha and significantly superior to the remaining treatment. Among the micronutrient treatments, the maximum biological yield (54.59 q/ha) was recorded with $ZnSO_4$ @ 25 kg/ha, which was statistically at par with M_3 (borax @ 2 kg/ha). The interaction between organic manures and micronutrients had a non-significant effect on biological yield.

3.2.4 Harvest Index (%)

The harvest-index data are presented in Table 5 and illustrated in Fig. 5. The treatments did not significantly affect the harvest index of mustard. Among the organic-manure treatments, the highest harvest index was recorded with vermicompost @ 5 t/ha (O_2), followed by FYM @ 10 t/ha (O_1). Similarly, among the micronutrient treatments, the highest harvest index was recorded with $ZnSO_4$ @ 25 kg/ha (M_1), followed by borax @ 2 kg/ha (M_3). However, the differences among the treatments were statistically non-significant. The interaction between organic manures and micronutrients also had a non-significant effect on the harvest index.

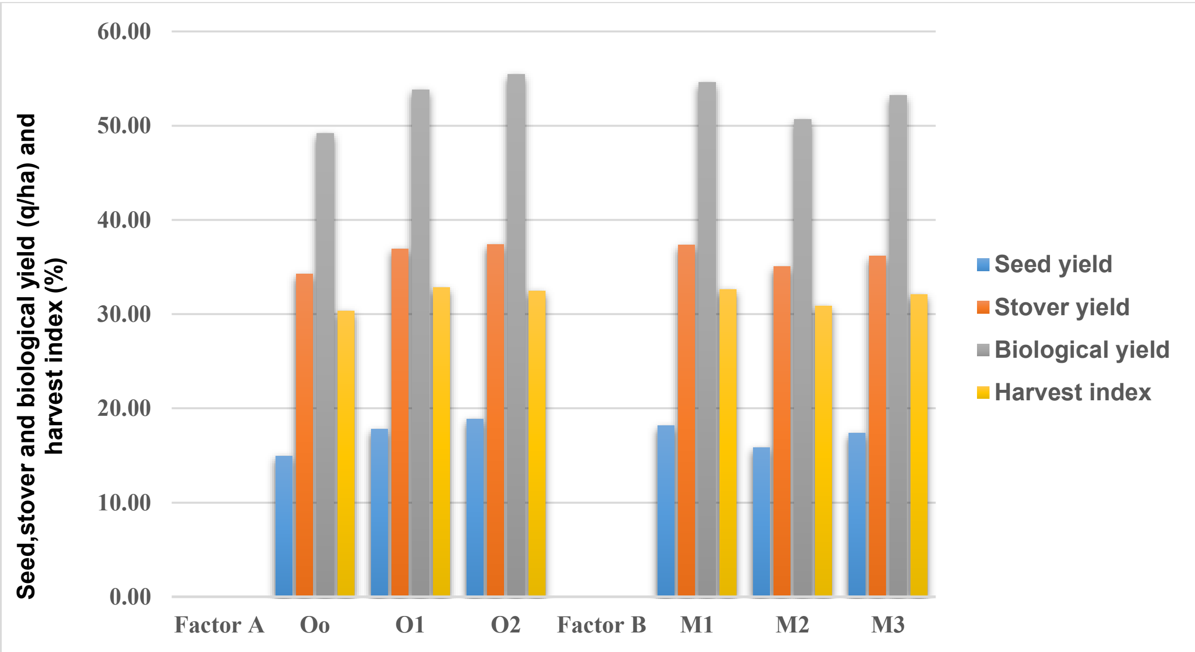

Fig. 5. Graph showing Effect of organic manure and micronutrients on crop yield (q/ha), Stover yield (q/ha), biological yield (q/ha) and harvest index (%) of crop of mustard

Table 5. Effect of organic manure and micronutrients on crop yield (q/ha), Stover yield (q/ha), Biological yield (q/ha) and harvest index (%) of crop

Treatments	Grain yield (q/ha)	Stover yield (q/ha)	Biological yield (q/ha)	Harvest index (%)
Effect of Organic Manure				
O_0- @ Control	14.94	34.27	49.20	30.33
O_1- Farm Yard Manure @ 10 t/ha	17.81	36.01	53.82	32.84
O_2- Vermicompost @ 5 t/ha	18.85	37.42	55.47	32.44
SE (m)±	0.57	0.73	1.05	0.87
CD at 5%	1.22	1.55	2.23	1.84
Effect of Micronutrients				
M_1- $ZnSo_4$@ 25 kg/ha	18.15	37.36	54.59	32.61
M_2- $FeSo_4$@ 20 kg/ha	15.83	35.08	50.68	30.89
M_3- Borax @ 2 kg/ha	17.37	36.17	53.22	32.11
SE (m) ±	0.66	0.84	1.22	1.00
CD at 5%	1.41	1.79	2.58	2.12

Treatments	Grain yield (q/ha)	Stover yield (q/ha)	Biological yield (q/ha)	Harvest index (%)
Interaction (O×M)				
O_0 @ Control + M_1 @ 25 kg/ha	15.7	34.5	50.2	31.2
O_0 @ Control + M_2 @ 20 kg/ha	13.3	32.9	46.2	28.7
O_0 @ Control + M_3 @ 2 kg/ha	15.7	35.4	51.1	30.7
O_1 @ 10 t/ha + M_1 @ 25 kg/ha	17.2	36.3	53.5	32.1
O_1 @ 10 t/ha + M_2 @ 20 kg/ha	17.7	35.7	53.4	33.1
O_1 @ 10 t/ha + M_3 @ 2 kg/ha	18.6	37.2	55.8	33.3
O_2 @ 5 t/ha + M_1 @ 25 kg/ha	20.5	39.6	60.1	34.1
O_2 @ 5 t/ha + M_2 @ 20 kg/ha	16.5	36.7	53.2	31.0
O_2 @ 5 t/ha + M_3 @ 2 kg/ha	17.2	35.9	53.1	32.3
SE (m) ±	**1.41**	**1.46**	**2.11**	**1.73**
CD at 5%	**NS**	**NS**	**NS**	**NS**

4. Conclusion

The present study demonstrated that the application of organic manures and micronutrients significantly improved the growth and yield performance of Indian mustard under the agro-climatic conditions of Fatehgarh Sahib, Punjab. Among the organic manure treatments, vermicompost recorded the highest values for plant height, number of primary and secondary branches per plant, dry matter accumulation, seed yield, stover yield, and biological yield, and was statistically at par with farmyard manure for most of the parameters studied. Among the micronutrient treatments, the application of $ZnSO_4$ @ 25 kg/ha produced the highest values for most growth and yield attributes, followed by borax @ 2 kg/ha, whereas $FeSO_4$ @ 20 kg/ha generally recorded comparatively lower values.

The interaction effect between organic manures and micronutrients was found to be non-significant for most of the parameters evaluated, indicating that the individual effects of organic manures and micronutrients were more pronounced than their combined interaction under the conditions of the present investigation. Overall, the results suggest that the application of vermicompost in combination with $ZnSO_4$ can be considered an effective nutrient management strategy for enhancing the growth and productivity of Indian mustard while contributing to the maintenance of soil fertility under the central plain region of Punjab.

5. Limitation

The study was conducted during a single rabi season at one experimental location; therefore, the findings may not be directly applicable to all agro-climatic regions, soil types, or seasonal conditions. The study evaluated only selected organic manure and micronutrient treatments and did not assess post-harvest changes in soil nutrient dynamics in detail. Furthermore, economic analysis, nutrient uptake, oil content, and other quality parameters were beyond the scope of the present investigation. As the interaction effects between organic manures and micronutrients were non-significant for most of the parameters studied, recommendations regarding their combined application should be interpreted with caution. Therefore, further multi-location and multi-season studies are required to validate the consistency of the results and to develop more comprehensive nutrient management recommendations for Indian mustard.

Acknowledgement

The researchers express their gratitude to the Deptt. of Agriculture, Mata Gujri College, Fatehgarh Sahib, Punjab-140407 for providing their facilities.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement and reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). 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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Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/162697