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Evaluation of Yield Attributes and Yield of Mustard (*Brassica juncea* L.) Under Integrated Nutrient Management in Rainfed Conditions

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ABSTRACT

This study was conducted to investigate the effectiveness of Integrated Nutrient Management (INM) practices on mustard (*Brassica juncea* L.) cultivation under rainfed conditions in Madhya Pradesh focusing on yield attributes and economic viability. The study aimed to identify optimal nutrient management combinations including chemical fertilizers, organic amendments and bio-fertilizers and evaluate their impact on crop performance and profitability. A range of treatments was tested combining different ratios of recommended doses of fertilizers (RDF), Vermicompost, Farm Yard manure (FYM), Poultry Manure (PM), and Microbial inoculants like Azotobacter and phosphate-solubilizing bacteria (PSB). The results showed that treatment T10 which involved 50% NPK + vermicompost @ 5 t/ha + ZnSO @ 40 kg/ha + Azotobacter, produced the highest values in key parameters: number of siliquae per plant, siliqua length, number of seeds per siliqua and seed yield. Specifically, T10 yielded 21.46 q/ha in 2021-22 and 21.86 q/ha, with the highest stover yields and harvest index. Economically T10 achieved the highest gross and net returns, with benefit-cost ratios of 2.02, demonstrating the most favourable economic outcome among the treatments. In contrast, traditional farmer practices (T1) yielded the lowest returns and benefit-cost ratios. These findings underscore the importance of adopting integrated nutrient management practices for optimizing mustard yield and economic returns in rainfed areas.

Key words: *Mustard (Brassica juncea L.), Integrated nutrient management (INM), Organic amendments, Rainfed conditions, Yield attributes*

Introduction

Mustard (*Brassica juncea* L.) is one of the most important oilseed crops cultivated in India, contributing significantly to the nation's edible oil production. It occupies a prominent place in the agricultural economy due to its adaptability to diverse agro-climatic conditions, including semi-arid regions. Among the eight species in the Brassicaceae family, Indian mustard (*Brassica juncea* L.) holds significant economic importance. India ranks second globally in rapeseed-mustard area and fourth in production. In 2020-21, mustard was grown on 6.7 million hectares with 10.21 million tonnes of production (Agricultural Statistics at a Glance, 2022). Madhya Pradesh, being one of the major mustard-producing states, plays a pivotal role in the overall oilseed output of the country. Madhya Pradesh contributed 1.31 million tonnes, with notable production in the Gwalior district (Department of Agriculture and Farmers welfare, 2022). The cultivation of mustard is not only critical for meeting the domestic demand for edible oils but also serves as a vital source of income for small and marginal farmers. Given its economic importance, enhancing mustard yield and yield attributes is essential for improving the livelihoods of farmers and supporting growing population of India.

Rainfed agriculture, which accounts for 51% of India's net sown area and 62% in Madhya Pradesh, faces multiple challenges: erratic rainfall, low soil fertility, and inadequate irrigation (Department of Agriculture and Farmers welfare, 2022). These issues reduce mustard yield, making soil health a priority for sustainable production. Integrated Nutrient Management (INM), which involves the combined use of organic, inorganic, and biofertilizers, has emerged as a sustainable approach to improving soil health and crop productivity (9). Despite its proven benefits in various crops, there remains a lack of comprehensive research on the specific effects of INM on mustard yield under rainfed conditions. This research gap highlights the need for targeted studies to better understand how nutrient management practices can optimize mustard production in water-limited environments. Nutrient management is crucial for mustard, especially for nitrogen, phosphorus, potassium, and sulphur, which influence growth, yield, and oil content. Organic sources like poultry manure, vermicompost, and farmyard manure, along with biofertilizers like Azotobacter, have been shown to improve soil properties, enhance microbial activity, and increase crop yield (Katyar, *et al*., 2024).

The objective of this study is to evaluate the yield attributes and overall yield of mustard (*Brassica juncea* L.) under integrated nutrient management in rainfed conditions. With an aim to provide insights into sustainable practices that can enhance mustard production, particularly in regions where water availability is a limiting factor.

Materials and Methods

The study was conducted at CRC-III, ITM University, Gwalior, Madhya Pradesh, located at an elevation of 196 meters with coordinates 26°21′ N latitude and 78°17′ E longitude. The region experiences a range of temperatures from 14.4°C to 37.3 °C and receives annual rainfall of approximately 127.4 mm to 128.8 mm during the crop growth period. The soil is typical of the Indo-Gangetic plain region, characterized by its suitability for mustard cultivation.

The experiment was laid out in a Randomized Block Design (RBD) with 14 treatments and 3 replications across 42 plots.

The mustard variety used was GIRIRAJ (DRMR IJ-31), sown in the Rabi seasons of 2021-22 and 2022-23.

Treatments included various combination T1 : Absolute control T2 : 100% RDF (80:60:40:40 Kg/ha) NPKS T3 : 75% NPK + FYM@ 5 t/ha + SO4 @ 40 Kg T4 : 50% NPK + FYM@ 10 t/ha + SO4 @ 40 Kg T5 : 75% NPK + FYM @ 5 t/ha + SO4@ 40 Kg + Azotobacter T6 : 50% NPK + FYM@ 10 t/ha + SO4 @ 40 Kg + Azotobacter T7 : 75% NPK +Vermicompost@ 2.5 t/ha + SO4 @ 40 Kg T8 : 50% NPK +Vermicompost@ 5 t/ha + SO4 @ 40 Kg T9 : 75% NPK + Vermicompost@ 2.5 t/ha + SO4 @ 40 Kg + Azotobacter T10 : 50% NPK +Vermicompost@ 5 t/ha + SO4 @ 40 Kg + Azotobacter T11 : 75% NPK + Poultry manure@ 1t/ha + SO4 @ 40 Kg T12 : 50% NPK + Poultry manure@2 t/ha + SO4 @ 40 Kg T13 : 75% NPK + Poultry manure@1t/ha + SO4 @ 40 Kg + Azotobacter T14 : 50% NPK + Poultry manure@2t/ha + SO4 @ 40 Kg + Azotobacter.

The experimental plots measured 5.0 x 3.6 m^2, with a net plot size of 4.0 x 2.4 m^2. Seeds were sown at a rate of 3 kg ha{^{1} with row spacing of 45 cm and plant spacing of 15 cm. Irrigation was provided at sowing and flowering stages.

Yield components such as the number of siliquae per plant, seeds per silique, and length of siliques were measured. After harvesting, seed yield, stover yield, biological yield was determined, along with the economic analysis.

Statistical analysis

Data were analysed using ANOVA to assess significant differences among treatments. The standard error of the mean and critical differences was calculated at a 5% significance level to determine treatment effects.

Results and Discussion

Response of INM on Yield and Yield Attributes

The data pertaining to yield attributes and yield viz., number of siliquae/plants, length of siliquae (cm), number of seeds siliqua-1, test weight (g), seed yield (kg /ha), stover yield (kg /ha) and harvest index (%) in Indian mustard due to various INM practices. It is observed that the Yield and yield attributes were significantly influenced by the application of different combinations of organic and chemical fertilizers along with bio-fertilizers which have been presented in Table 1 and 2 and 3 during 2021-22 and 2022-23.

The study examined the impact of various Integrated Nutrient Management (INM) practices on mustard yield and attributes over the 2021-22 and 2022-23 experimental years. The maximum number of siliquae per plant (308.83 and 311.00) was achieved with treatment T10 (50% NPK + VC @ 5 t/ha + ZnSO @ 40 Kg + Azotobacter), significantly outperforming T1 (Farmer's Practices) which showed lower values (242.35 and 244.00). Similarly, the length of siliquae and the number of seeds per siliqua were also highest under T10 (7.89 cm and 8.04 cm for siliqua length, 12.39 and 12.43 for seeds per siliqua), compared to the shorter siliquae and fewer seeds in T1 (5.77 cm and 5.80 cm, 8.77 and 8.66, respectively). Test weight was highest in T10 (4.28 g) and T9, although differences between treatments were not statistically significant. Seed yield ranged from 9.11 q/ha in T1 to 21.46 q/ha in T10 in 2021-22, with similar trends in 2022-23. Stover yield was highest in T10 (51.36 q/ha and 52.06 q/ha) compared to the lowest yield in T1 (27.41 q/ha and 27.85 q/ha). The harvest index was highest in T9 (29.76% and 29.95%) and lowest in T1 (24.94% and 25.14%). The application of T10 (50% NPK + Vermicompost @ 5 t/ha + ZnSO @ 40 Kg + Azotobacter) consistently outperformed other treatments across all yield attributes.

In terms of seed yield, the significant increase observed in T10, followed by T9, highlights the importance of integrated nutrient management in achieving higher yields. The combination of organic and inorganic nutrients likely provided a balanced nutrient supply throughout the growth period, leading to better plant growth and development (Meena *et al*., 2024). The stover yield followed a similar trend, further confirming the positive impact of combined nutrient management practices on overall biomass production. The superior performance of T10 can be attributed to the synergistic effect of combined chemical fertilizers, vermicompost, and biofertilizers, which provided a balanced nutrient supply and improved soil health. The superior performance of T10 can be attributed to the synergistic effect of vermicompost, which improves soil structure and microbial activity,

Table 1. Effect of integrated nutrient management on Number of siliquae/Plant, Number of seeds/siliquae and test weight(g)

Character	Number of siliquae/Plant		Length of Siliqua (cm)		Number of seeds/siliquae		Test weight (g)	
Exp. Year	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Treatments								
T1 (Farmer Practice)	242.35	244.00	5.77	5.80	8.77	8.66	3.74	3.76
T2 (100% RDF (80:60:40:40 Kg/ha) NPKS)	262.05	267.00	6.39	6.23	10.64	10.66	3.93	3.93
T3 (75% NPK + FYM@ 5 t/ha + $ZnSO_4$ @ 40 Kg)	247.03	251.33	5.78	5.98	10.11	10.02	3.80	3.81
T4 (50% NPK + FYM@ 10 t/ha + $ZnSO_4$ @ 40 Kg)	267.33	269.00	6.74	6.64	10.97	11.01	3.98	3.98
T5 (75% NPK + FYM @ 5 t/ha + $ZnSO_4$ @ 40 Kg + Azoto.)	279.01	279.00	6.86	6.91	11.59	11.58	4.10	4.11
T6 (50% NPK + FYM@ 10 t/ha + $ZnSO_4$ @ 40 Kg + Azoto.)	269.67	272.00	6.85	6.76	11.38	11.37	4.03	4.04
T7 (75% NPK + VC@ 2.5 t/ha + $ZnSO_4$ @ 40 Kg)	284.98	287.00	7.42	7.26	11.91	11.97	4.12	4.14
T8 (50% NPK + VC@ 5 t/ha + $ZnSO_4$ @ 40 Kg)	292.97	293.00	7.77	7.73	12.27	12.26	4.19	4.21
T9 (75% NPK + VC@ 2.5 t/ha + $ZnSO_4$ @ 40 Kg + Azoto.)	305.00	308.00	7.77	7.82	12.34	12.37	4.27	4.27
T10 (50% NPK + VC@ 5 t/ha + $ZnSO_4$ @ 40 Kg + Azoto.)	308.83	311.00	7.89	8.04	12.39	12.43	4.28	4.28
T11 (75% NPK + PM@ 1t/ha + $ZnSO_4$ @ 40 Kg)	277.33	276.00	6.86	6.82	11.49	11.53	4.09	4.09
T12 (50% NPK + PM@ 2 t/ha + $ZnSO_4$ @ 40 Kg)	283.64	283.00	6.98	7.13	11.82	11.83	4.11	4.11
T13 (75% NPK + PM@ 1t/ha + $ZnSO_4$ @ 40 Kg + Azoto.)	288.03	292.00	7.65	7.55	11.98	11.98	4.16	4.16
T14 (50% NPK + PM@ 2t/ha + $ZnSO_4$ @ 40 Kg + Azoto.)	292.83	292.00	7.76	7.67	12.02	12.01	4.19	4.20
SEm ±	**13.248**	**13.095**	0.3494	0.3592	**0.574**	**0.533**	**0.204**	**0.194**
CD 5%	**38.512**	**38.066**	1.0156	1.0441	**1.67**	**1.55**	NS	NS

Table 2. Effect of integrated nutrient management on Seed yield (q/ha), Stover yield (q/ha) and Harvest index (%)

Character / Exp. Year	Seed yield (q/ha) 2021-22	Seed yield (q/ha) 2022-23	Stover yield (q/ha) 2021-22	Stover yield (q/ha) 2022-23	Biological yield (q/ha) 2021-22	Biological yield (q/ha) 2022-23	Harvest index (%) 2021-22	Harvest index (%) 2022-23
Treatments								
T1 (Farmer Practice)	9.11	9.35	27.41	27.85	36.52	37.20	24.94	25.14
T2 (100% RDF (80:60:40:40 Kg/ha) NPKS)	13.32	13.75	36.32	36.95	49.63	50.69	26.83	27.12
T3 (75% NPK + FYM@ 5 t/ha + ZnSO4 @ 40 Kg)	11.08	11.35	31.08	31.55	42.16	42.90	26.28	27.12
T4 (50% NPK + FYM@ 10 t/ha + ZnSO4 @ 40 Kg)	14.22	14.54	38.12	38.55	52.34	53.08	27.17	26.46
T5 (75% NPK + FYM @ 5 t/ha + ZnSO4 @ 40 Kg + Azoto.)	16.26	16.50	42.46	43.00	58.72	59.50	27.69	27.73
T6 (50% NPK + FYM@ 10 t/ha + ZnSO4 @ 40 Kg + Azoto.)	15.09	15.44	40.09	40.44	55.19	55.88	27.35	27.63
T7 (75% NPK + VC@ 2.5 t/ha + ZnSO4 @ 40 Kg)	17.66	17.86	44.66	45.06	62.32	62.92	28.34	28.39
T8 (50% NPK + VC@ 5 t/ha + ZnSO4 @ 40 Kg)	19.23	19.54	47.53	48.04	66.76	67.58	28.81	28.91
T9 (75% NPK + VC@ 2.5 t/ha + ZnSO4 @ 40 Kg + Azoto.)	20.66	21.14	48.76	49.34	69.41	70.48	29.76	29.95
T10 (50% NPK + VC@ 5 t/ha + ZnSO4 @ 40 Kg + Azoto.)	21.46	21.86	51.36	52.06	72.82	73.93	29.47	29.57
T11 (75% NPK + PM@ 1t/ha + ZnSO4 @ 40 Kg)	15.98	16.17	41.48	41.97	57.45	58.15	27.81	27.81
T12 (50% NPK + PM@ 2 t/ha + ZnSO4 @ 40 Kg)	16.92	17.10	43.42	43.80	60.33	60.91	28.04	28.08
T13 (75% NPK + PM@ 1t/ha + ZnSO4 @ 40 Kg + Azoto.)	18.14	18.31	45.84	46.11	63.98	64.42	25.99	27.33
T14 (50% NPK + PM@ 2t/ha + ZnSO4 @ 40 Kg + Azoto.)	18.75	18.96	46.75	47.16	65.51	66.11	28.63	28.67
SEm ±	1.00	1.01	2.63	2.57	3.52	3.52	-	-
CD 5%	2.915	2.960	7.649	7.496	10.25	10.23	-	-

Table 3. Effect of integrated nutrient management on Cost of cultivation (Rs/ha), Gross Returns (Rs/ha), Net returns (Rs/ha) and B:C

Character / Exp. Year	Cost of cultivation (Rs/ha) 2021-22	Cost of cultivation (Rs/ha) 2022-23	Gross returns (Rs/ha) 2021-22	Gross returns (Rs/ha) 2022-23	Net returns (Rs/ha) 2021-22	Net returns (Rs/ha) 2022-23	B : C 2021-22	B : C 2022-23
Treatments								
T1 (Farmer Practice)	25500	25500	47835	52790	22335	27290	0.88	1.07
T2 (100% RDF (80:60:40:40 Kg/ha) NPKS)	28300	28300	69202	76802	40902	48502	1.45	1.71
T3 (75% NPK + FYM@ 5 t/ha + ZnSO4 @ 40 Kg)	31300	31300	57745	63629	26445	32329	0.84	1.03
T4 (50% NPK + FYM@ 10 t/ha + ZnSO4 @ 40 Kg)	35050	35050	73742	81138	38692	46088	1.10	1.31
T5 (75% NPK + FYM @ 5 t/ha + ZnSO4 @ 40 Kg + Azoto.)	31310	31310	84101	91934	52791	60624	1.69	1.94
T6 (50% NPK + FYM@ 10 t/ha + ZnSO4 @ 40 Kg + Azoto.)	35060	35060	78205	86060	43145	51000	1.23	1.45
T7 (75% NPK + VC@ 2.5 t/ha + ZnSO4 @ 40 Kg)	33800	33800	91042	99218	57242	65418	1.69	1.94
T8 (50% NPK + VC@ 5 t/ha + ZnSO4 @ 40 Kg)	40050	40050	98932	108290	58882	68240	1.47	1.70
T9 (75% NPK + VC@ 2.5 t/ha + ZnSO4 @ 40 Kg + Azoto.)	33810	33810	105798	116624	71988	82814	2.13	2.44
T10 (50% NPK + VC@ 5 t/ha + ZnSO4 @ 40 Kg + Azoto.)	40060	40060	110064	120827	70004	80767	1.75	2.02
T11 (75% NPK + PM@ 1t/ha + ZnSO4 @ 40 Kg)	31300	31300	82589	90067	51289	58767	1.64	1.88
T12 (50% NPK + PM@ 2 t/ha + ZnSO4 @ 40 Kg)	35050	35050	87347	95135	52297	60085	1.49	1.71
T13 (75% NPK + PM@ 1t/ha + ZnSO4 @ 40 Kg + Azoto.)	31310	31310	93523	101691	62213	70381	1.99	2.25
T14 (50% NPK + PM@ 2t/ha + ZnSO4 @ 40 Kg + Azoto.)	35060	35060	96558	105157	61498	70097	1.75	2.00

ZnSO, which plays a crucial role in enzymatic reactions and auxin synthesis, and Azotobacter, which fixes atmospheric nitrogen and promotes plant growth (Linee *et al.,* 2021). The significant improvements in yield and yield attributes under T10 can be attributed to the effective nutrient management provided by the combination of chemical fertilizers, organic amendments, and biofertilizers. These findings align with the observations of Chaurasiya *et al*. (2024) who reported similar increases in yield attributes with the application of integrated nutrient management practices. The high number of siliquae per plant, increased siliqua length, and greater number of seeds per siliqua suggest that these practices optimally support plant growth and development. The present experiment has demonstrated a substantial increase in crop output with enhanced seed yield and stover yield further emphasize the positive impact of integrated nutrient management. This conclusion aligns well with the research conducted by Singh *et al*. (2024), Chaurasiya *et al*. (2024), and (Sreerenjiny and Debbarma, (2022).

Economic Analysis

The economics of various Integrated Nutrient Management (INM) practices were analysed over two cropping seasons, focusing on the cost of cultivation, gross returns, net returns and benefit-cost (B-C) ratios. The cost of cultivation ranged from 25,500 in T1 (Farmer's Practices) to 40,060 in T10 (50% NPK + VC @ 5 t/ha + ZnSO @ 40 Kg + Azotobacter) for both 2021-22 and 2022-23. While T10 recorded the highest cultivation cost, it also delivered the greatest gross returns, with values of 1,10,064 in 2021-22 and 1,20,827 in 2022-23. Net returns were highest in T9 (75% NPK + VC @ 2.5 t/ha + ZnSO @ 40 Kg), reaching 71,988 in 2021-22 and 82,814 in 2022-23. T1 consistently produced the lowest net returns and gross returns across both years. The benefit-cost ratio was also highest in T9, with values of 2.13 in 2021-22 and 2.44 in 2022-23, showcasing the economic advantage of combining chemical fertilizers, vermicompost, and biofertilizers in a balanced INM approach. T10 and T7 followed with favourable B-C ratios, while T1 had the lowest B-C ratio (0.88 and 1.07), reaffirming the economic inefficiency of traditional practices compared to more advanced nutrient management strategies. These results suggest that while T10 involved higher costs, the returns were proportionally greater, highlighting the economic advantage of adopting comprehensive INM strategies. Treatments such as T9 and T5 also demonstrated high economic returns, reinforcing the value of integrated approaches in enhancing profitability. The economic analysis supports the adoption of advanced INM practices as they offer higher returns and better economic feasibility compared to traditional practices. This is consistent with the findings of Singh *et al*. (2023) and Vikram *et al.* (2023), who highlight the benefits of integrated approaches for improving both crop performance and farmer profitability.

Conclusion

This study investigated the effectiveness of various Integrated Nutrient Management (INM) practices on the growth, yield and quality of mustard (*Brassica juncea* L.) under rainfed conditions in Madhya Pradesh. The results demonstrate that advanced INM practices, particularly those incorporating a combination of chemical fertilizers, organic amendments, and biofertilizers, significantly enhance mustard productivity compared to traditional nutrient management practices. Farmers can achieve significantly higher yields and better crop quality by adopting advanced INM practices, which can improve both seed and stover yields. The adoption of INM practices can lead to higher gross and net returns, making them a financially viable option despite higher initial costs. Integrating organic amendments with chemical fertilizers not only boosts productivity but also contributes to sustainable soil management. Further research should focus on the long-term effects of INM practices on soil health and sustainability to ensure the enduring benefits of these practices, environmental implications of various nutrient management strategies to mitigate potential negative impacts and enhance the sustainability of agricultural systems.

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