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Effect of various sources and levels of sulphur on growth, yield and quality of Indian Mustard (*Brassica juncea* L.)

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Abstract

A field experiment was conducted during the *rabi* season of 2025-26 at the Agriculture Research and Development Centre, Sakatpura, Vikrant University, Gwalior (Madhya Pradesh), to evaluate the response of Indian mustard (*Brassica juncea* L.) cv. Bombay-76 to different sources and levels of sulphur. The experiment was laid out in a randomized block design with ten treatments and three replications. The treatments consisted of an absolute control and nine combinations of 100% recommended dose of fertilizer with gypsum, single super phosphate (SSP) and bentonite sulphur, each applied at 40, 50 and 60 kg S ha⁻¹. The crop responded clearly to sulphur nutrition, and the highest performance was observed with 100% RDF + bentonite @ 60 kg S ha⁻¹. This treatment recorded maximum plant height (166.80 cm), branches plant⁻¹ (8.10), dry matter accumulation (87.50 g plant⁻¹), leaf area index at 90 DAS (6.02), silique plant⁻¹ (312.00), seeds silique⁻¹ (16.10), test weight (5.32 g), seed yield (1942 kg ha⁻¹), stover yield (5795 kg ha⁻¹), total sulphur uptake (37.37 kg ha⁻¹) and oil content (42.30%). Seed yield increased by 53.5% over the absolute control. The same treatment also produced the highest gross return (₹132,934 ha⁻¹), net return (₹80,934 ha⁻¹) and B:C ratio (2.56). The results indicated that bentonite sulphur at 60 kg S ha⁻¹ along with balanced NPK fertilization was the most effective option for improving productivity, oil content and profitability of Indian mustard under the sandy loam soils of Gwalior region.

Keywords: Indian mustard, sulphur nutrition, gypsum, SSP, bentonite sulphur, oil content, nutrient uptake, economics

Introduction

Indian mustard (*Brassica juncea* L.) is a major *Rabi* oilseed crop of India and has a central role in edible oil security, rural livelihoods and crop diversification. The crop is widely cultivated in northern and central India because of its adaptability to cool and dry winter conditions, short duration and comparatively better performance under medium-input farming systems. Mustard seed is valued for edible oil, spice, green leaves and oil cake, while its nutritional importance is linked with oil, protein, fibre and biologically active compounds (Bhowmik *et al.*, 2014; Bareliya *et al.*, 2023) [2, 1].

Balanced fertilization is one of the major requirements for improving mustard productivity. Among secondary nutrients, sulphur has a specific significance in Brassica crops because it is a constituent of cysteine, cystine and methionine, and is involved in chlorophyll formation, enzyme activation, oil biosynthesis and glucosinolate metabolism. A shortage of sulphur reduces vegetative growth, delays reproductive development, decreases nutrient use efficiency and ultimately lowers seed yield and oil quality (Falk *et al.*, 2007; Havlin *et al.*, 2013; Singh *et al.*, 2015) [7, 9, 24].

Sulphur deficiency has become more common in intensive cropping systems due to reduced use of organic manures, limited recycling of crop residues and increasing application of high-analysis sulphur-free fertilizers. Oilseed crops remove a larger quantity of sulphur than cereals, and their response to sulphur fertilization is therefore more pronounced (Khalid *et al.*, 2011; Tiwari and Gupta, 2006) [13, 26]. For mustard growers, the choice of sulphur source is as important as the dose because gypsum, SSP and bentonite sulphur differ in solubility, nutrient composition and release pattern.

Gypsum supplies sulphur in readily available sulphate form, SSP provides sulphur along with phosphorus, whereas bentonite sulphur releases sulphate gradually after microbial oxidation and may maintain availability for a longer period during crop growth. Earlier studies have reported significant improvement in growth, yield attributes, seed yield, oil content and economics of mustard with suitable sulphur sources and doses (Chattopadhyay and Ghosh, 2012; Kumar and Trivedi, 2012; Jena *et al.*, 2021; Tiwari *et al.*, 2021) [3, 16, 12, 27]. However, local validation is necessary because response varies with soil texture, native sulphur status, moisture regime and climate.

Considering the low available sulphur status of the experimental soil and the need to identify an efficient sulphur source for mustard cultivation in the Gwalior region, the present study was undertaken to assess the effect of various sulphur sources and levels on growth, yield, quality, nutrient uptake and economics of Indian mustard.

Materials and Methods

Experimental site and soil

The field experiment was conducted during the rabi season of 2025-26 at the Agriculture Research and Development Centre, Sakatpura, Vikrant University, Gwalior, Madhya Pradesh. The experimental site falls under a semi-arid to subtropical climatic zone with hot summers, moderate monsoon rainfall and cool dry winters. During the crop season, temperature and moisture conditions were suitable for normal germination, vegetative growth, flowering and seed development of Indian mustard.

Before sowing, composite soil samples were collected from 0-15 cm depth and analyzed using standard procedures. The soil was sandy loam in texture, nearly neutral in reaction, non-saline and low in available nitrogen, medium in available phosphorus and adequate in available potassium. The initial soil properties are presented in Table 1.

Table 1: Initial physico-chemical properties of the experimental soil.

Property	Value	Status/remark
Texture	Sandy loam	65.7% sand, 13.2% silt and 21.1% clay
pH	7.5	Nearly neutral
Electrical conductivity	0.33 dS m ⁻¹	Non-saline
Organic carbon	0.45%	Medium to low
Available N	184 kg ha ⁻¹	Low
Available P	16.7 kg ha ⁻¹	Medium
Available K	347 kg ha ⁻¹	High/adequate

Note: Soil samples were collected from 0-15 cm depth before sowing.

Experimental design, treatments and crop management

The experiment was arranged in randomized block design (RBD) with ten treatments and three replications. The gross plot size was 4.8 m × 3.6 m and the net plot size was 3.9 m × 2.7 m. Indian mustard variety Bombay-76 was sown manually with a seed rate of 5 kg ha⁻¹ at 35 cm × 10 cm spacing. The recommended fertilizer dose was 80:40:40 kg N: P₂O₅: K₂O ha⁻¹. Half nitrogen and the full dose of phosphorus, potassium and sulphur were applied at sowing as basal dose, while the remaining nitrogen was top-dressed at first irrigation.

Table 2: Treatment details used in the experiment.

Treatment	Treatment details
T ₁	Absolute control
T ₂	100% RDF + Gypsum @ 40 kg S ha ⁻¹
T ₃	100% RDF + Gypsum @ 50 kg S ha ⁻¹
T ₄	100% RDF + Gypsum @ 60 kg S ha ⁻¹
T ₅	100% RDF + SSP @ 40 kg S ha ⁻¹
T ₆	100% RDF + SSP @ 50 kg S ha ⁻¹
T ₇	100% RDF + SSP @ 60 kg S ha ⁻¹
T ₈	100% RDF + Bentonite @ 40 kg S ha ⁻¹
T ₉	100% RDF + Bentonite @ 50 kg S ha ⁻¹
T ₁₀	100% RDF + Bentonite @ 60 kg S ha ⁻¹

The crop was raised with uniform agronomic practices in all plots. Thinning and gap filling were done after establishment to maintain optimum plant population. Irrigations were applied at branching, flowering and silique development stages according to crop requirement. One hand weeding followed by hoeing was carried out during early growth, and need-based plant protection measures were adopted against insect pests and diseases.

Observations and statistical analysis

Five plants were randomly selected and tagged from each net plot for recording growth and yield attributes. Plant population

was recorded at 15 DAS and harvest. Plant height, branches plant⁻¹, dry matter accumulation and leaf area index were recorded at different crop stages. Yield attributes such as number of silique plant⁻¹, silique length, seeds silique⁻¹ and test weight were recorded at harvest. Seed and stover yields were obtained from net plot harvest and converted to kg ha⁻¹. Oil content was determined by Soxhlet extraction, while nutrient contents and uptake were estimated by standard laboratory methods. Harvest index was calculated as the ratio of seed yield to biological yield (Donald and Hamblin, 1976) [5].

The data were statistically analyzed as per the procedure for randomized block design described by Gomez and Gomez (1984) [8]. Treatment means were compared using the critical difference (CD) at 5% level of significance wherever the F-test was significant. Economic returns were calculated from seed and stover value and prevailing input costs.

Results and Discussion

Effect on soil properties and available nutrients after harvest

Soil pH, electrical conductivity and organic carbon were not significantly affected by sulphur sources and levels, although small numerical shifts were observed. Soil pH decreased slightly from 7.55 in the control to 7.43 under T₁₀, which may be associated with oxidation of sulphur and release of hydrogen ions. Electrical conductivity remained within the safe range for mustard growth. Organic carbon varied narrowly from 0.43 to 0.49%, indicating that short-term mineral fertilization did not cause a marked change in soil organic matter.

Available N, P and S after harvest improved with sulphur application. T₁₀ recorded the highest available N (212.40 kg ha⁻¹), P (22.30 kg ha⁻¹) and S (20.20 kg ha⁻¹), while the control recorded the lowest values. Available K showed only numerical variation and remained non-significant, probably because the initial potassium status of the soil was adequate. Better nutrient availability under sulphur treatments may be due to improved

root growth, mild acidifying effect of sulphur oxidation and sustained sulphate supply from bentonite. Similar improvements in soil nutrient availability and sulphur uptake with sulphur

fertilization were reported by Chattopadhyay and Ghosh (2012)^[3], Jena *et al.* (2021)^[12] and Dubey *et al.* (2022)^[6].

Table 3: Effect of sulphur sources and levels on soil properties and available nutrients after harvest of Indian mustard.

Treatment	pH	EC (dS m ⁻¹)	OC (%)	Avail. N (kg ha ⁻¹)	Avail. P (kg ha ⁻¹)	Avail. K (kg ha ⁻¹)	Avail. S (kg ha ⁻¹)
T ₁	7.55	0.31	0.43	185.20	16.40	341	10.10
T ₂	7.52	0.32	0.45	193.50	18.50	347	14.40
T ₃	7.50	0.33	0.46	197.80	19.30	350	15.80
T ₄	7.48	0.33	0.47	201.40	20.20	353	17.10
T ₅	7.49	0.32	0.46	199.00	20.50	351	15.30
T ₆	7.46	0.34	0.47	203.80	21.30	356	16.70
T ₇	7.44	0.34	0.48	207.60	22.00	359	18.10
T ₈	7.47	0.33	0.47	205.20	20.80	354	17.30
T ₉	7.45	0.34	0.48	209.80	21.60	360	19.00
T ₁₀	7.43	0.35	0.49	212.40	22.30	363	20.20
S.Em.±	0.06	0.02	0.02	3.19	0.53	15	0.52
CD (P=0.05)	N.S.	N.S.	N.S.	9.48	1.58	N.S.	1.55
CV (%)	1.35	7.65	7.10	7.25	8.20	8.00	8.05

N.S. = non-significant; S.Em.± = standard error of mean; CD = critical difference at 5% level.

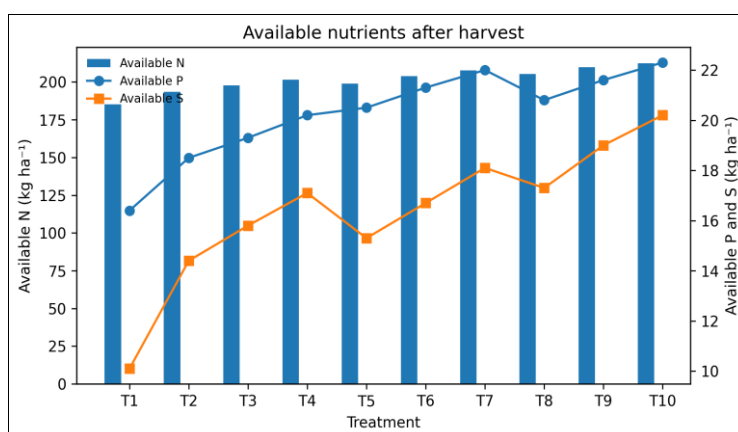


Fig 1: Effect of sulphur sources and levels on available nutrients after harvest of Indian mustard.

Effect on growth and phenology

Growth characters improved consistently with sulphur application. At harvest, maximum plant height (166.80 cm), branches plant⁻¹ (8.10) and dry matter accumulation (87.50 g plant⁻¹) were recorded under T₁₀. The same treatment also recorded the highest LAI at 90 DAS (6.02) and at harvest (4.55). The improvement was mainly due to better nutrient absorption, enhanced chlorophyll synthesis and greater photosynthetic surface under adequate sulphur nutrition. T₁₀ was statistically at par with T₉, T₈ and selected higher-sulphur treatments for

several growth traits, showing that the response was strongest when balanced NPK was combined with higher sulphur supply. Days to 50% flowering decreased from 51.20 days in the control to 46.40 days under T₁₀. Earlier flowering under sulphur nutrition may be linked with better vegetative vigor and timely transition from vegetative to reproductive growth. Similar beneficial effects of sulphur sources on plant height, leaf area development, branches and dry matter production have been observed by Kumar *et al.* (2015)^[15], Kumar *et al.* (2017)^[17], Singh *et al.* (2021)^[23] and Jena *et al.* (2021)^[12].

Table 4: Effect of sulphur sources and levels on growth and phenology of Indian mustard

Treatment	Plant population at harvest (plants m ⁻²)	Plant height at harvest (cm)	Branches plant ⁻¹ at harvest	Dry matter at harvest (g plant ⁻¹)	LAI at 90 DAS	LAI at harvest	Days to 50% flowering
T ₁	11.70	132.40	5.40	60.50	3.65	2.72	51.20
T ₂	12.40	143.50	6.00	67.20	4.12	3.12	49.70
T ₃	12.90	148.20	6.30	70.50	4.42	3.35	49.10
T ₄	13.20	151.90	6.60	73.80	4.72	3.55	48.60
T ₅	13.10	150.40	6.40	72.40	4.56	3.48	48.90
T ₆	13.60	156.20	6.80	76.50	4.98	3.76	48.10
T ₇	14.10	160.10	7.10	79.40	5.28	3.96	47.50
T ₈	14.60	162.80	7.40	82.00	5.48	4.18	47.20
T ₉	15.10	165.40	7.70	84.80	5.76	4.38	46.80
T ₁₀	15.40	166.80	8.10	87.50	6.02	4.55	46.40
S.Em.±	0.45	3.86	0.35	3.30	0.26	0.19	0.64
CD (P=0.05)	1.35	11.47	1.05	9.81	0.78	0.57	1.90
CV (%)	8.05	7.85	8.45	8.42	9.20	9.10	2.65

DAS = days after sowing; LAI = leaf area index.

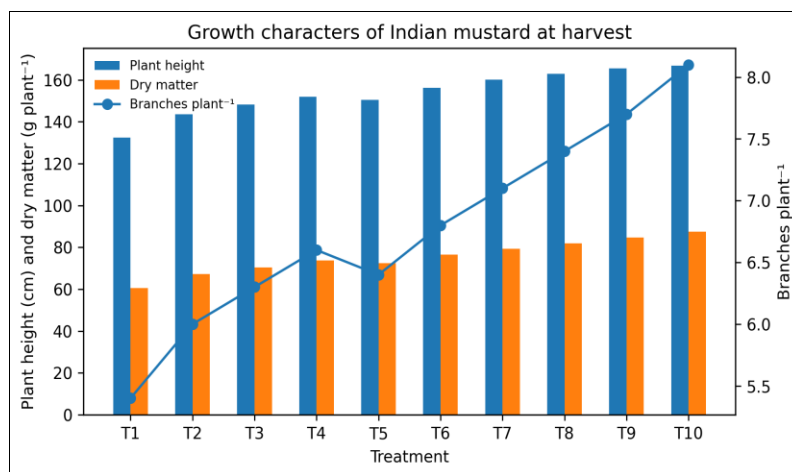


Fig 2: Effect of sulphur sources and levels on growth characters of Indian mustard at harvest.

Effect on yield attributes and yield

Yield attributes followed the same trend as growth characters. The application of 100% RDF + bentonite @ 60 kg S ha⁻¹ recorded the highest number of siliqua plant⁻¹ (312.00), siliqua length (5.78 cm), seeds siliqua⁻¹ (16.10) and test weight (5.32 g). These values were substantially higher than the control, which recorded 198.00 siliqua plant⁻¹, 4.10 cm siliqua length, 11.60 seeds siliqua⁻¹ and 4.12 g test weight. The improvement in reproductive characters can be attributed to better assimilate production, higher dry matter partitioning and sustained sulphur supply during flowering and siliqua development. Seed yield increased significantly with sulphur application. T₁₀

recorded the highest seed yield (1942 kg ha⁻¹), stover yield (5795 kg ha⁻¹) and biological yield (7737 kg ha⁻¹), representing a 53.5% increase in seed yield over the absolute control. T₁₀ was statistically at par with T₉, T₈ and T₇ for seed yield, but it remained numerically superior. Harvest index did not show a significant response, suggesting that sulphur improved total biomass and seed production in a nearly proportional manner. These findings agree with Kumar and Trivedi (2012) [16], Tiwari *et al.* (2021) [27], Chauhan *et al.* (2022) [4] and Solanki *et al.* (2022) [25], who reported higher seed yield and yield attributes of mustard with improved sulphur nutrition.

Table 5: Effect of sulphur sources and levels on yield attributes and yield of Indian mustard.

Treatment	Siliqua plant ⁻¹	Siliqua length (cm)	Seeds siliqua ⁻¹	Test weight (g)	Seed yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index (%)
T ₁	198.00	4.10	11.60	4.12	1265	3635	4900	25.82
T ₂	230.00	4.62	13.00	4.50	1508	4380	5888	25.61
T ₃	247.00	4.84	13.50	4.63	1586	4620	6206	25.56
T ₄	260.00	5.02	14.00	4.78	1662	4875	6537	25.42
T ₅	255.00	4.95	13.80	4.72	1618	4755	6373	25.39
T ₆	272.00	5.18	14.50	4.90	1710	5035	6745	25.35
T ₇	284.00	5.34	15.00	5.00	1786	5285	7071	25.26
T ₈	292.00	5.47	15.30	5.10	1828	5428	7256	25.19
T ₉	304.00	5.62	15.70	5.22	1888	5625	7513	25.13
T ₁₀	312.00	5.78	16.10	5.32	1942	5795	7737	25.10
S.E.m.±	11.78	0.19	0.55	0.17	76	209	269	-
CD (P=0.05)	35.00	0.58	1.65	0.50	225	620	800	N.S.
CV (%)	8.50	8.30	8.20	8.15	8.00	8.00	8.00	-

Harvest index was statistically non-significant.

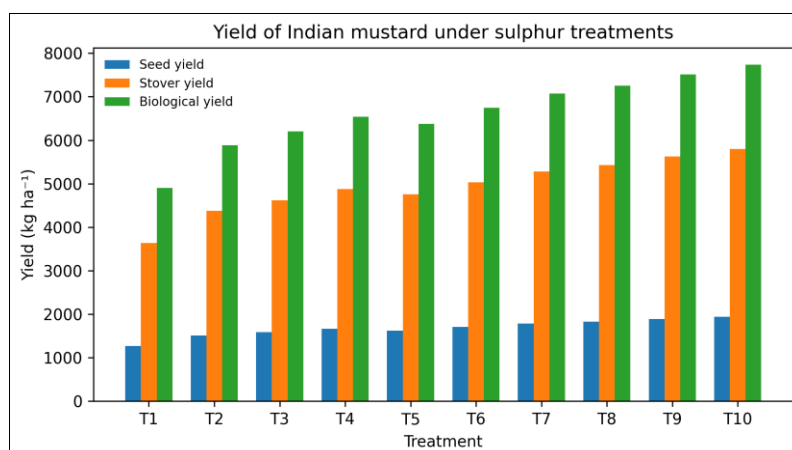


Fig 3: Effect of sulphur sources and levels on seed, stover and biological yield of Indian mustard

Effect on nutrient uptake and oil content

Sulphur application enhanced nutrient concentration and total nutrient uptake by the crop. T₁₀ recorded the highest seed sulphur content (0.85%), stover sulphur content (0.36%) and total uptake of N (118.78 kg ha⁻¹), P (21.68 kg ha⁻¹), K (106.70 kg ha⁻¹) and S (37.37 kg ha⁻¹). The higher uptake was mainly due to higher biomass and improved nutrient concentration in plant parts. Sulphur is closely associated with nitrogen metabolism and protein synthesis; therefore, balanced sulphur

nutrition can improve the efficiency of applied NPK fertilizers. Oil content increased from 37.30% under the control to 42.30% under T₁₀. The improvement in oil content under sulphur fertilization is expected because sulphur participates in oil biosynthesis and glucosinolate metabolism in Brassica crops. These results are in line with Falk *et al.* (2007) [7], Singh *et al.* (2015) [24], Dubey *et al.* (2022) [6] and Sharma *et al.* (2023) [22], who reported enhancement in oil quality and nutrient uptake of mustard with adequate sulphur supply.

Table 6: Effect of sulphur sources and levels on sulphur content, total nutrient uptake and oil content of Indian mustard.

Treatment	Seed S content (%)	Stover S content (%)	Total N uptake (kg ha ⁻¹)	Total P uptake (kg ha ⁻¹)	Total K uptake (kg ha ⁻¹)	Total S uptake (kg ha ⁻¹)	Oil content (%)
T ₁	0.55	0.18	64.03	9.99	56.55	13.50	37.30
T ₂	0.66	0.24	80.67	13.31	71.56	20.46	38.80
T ₃	0.70	0.27	86.97	14.65	77.00	23.58	39.40
T ₄	0.75	0.30	93.20	16.07	82.96	27.09	40.10
T ₅	0.70	0.26	90.01	15.82	79.79	23.69	39.60
T ₆	0.75	0.29	98.08	17.58	87.32	27.43	40.30
T ₇	0.79	0.32	104.78	19.13	93.36	31.02	40.90
T ₈	0.78	0.31	106.48	18.71	95.12	31.09	41.00
T ₉	0.82	0.34	113.14	20.30	101.15	34.61	41.70
T ₁₀	0.85	0.36	118.78	21.68	106.70	37.37	42.30
S.Em.±	0.03	0.01	3.15	0.76	5.30	0.89	0.89
CD (P=0.05)	0.09	0.04	9.36	2.25	15.75	2.65	2.65
CV (%)	8.30	8.60	8.00	8.55	8.20	8.35	4.15

Values are treatment means. Nutrient uptake values represent total uptake by seed and stover.

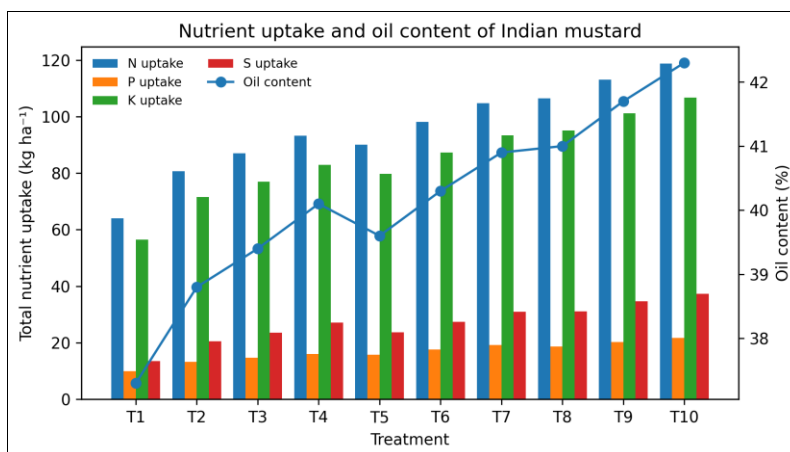


Fig 4: Effect of sulphur sources and levels on nutrient uptake and oil content of Indian mustard.

Effect on economics

Economic analysis showed that the increase in yield under sulphur fertilization compensated for the added cost of sulphur sources. The highest cost of cultivation was observed under T₁₀ (₹52,000 ha⁻¹), but this treatment also produced the maximum gross return (₹132,934 ha⁻¹), net return (₹80,934 ha⁻¹) and B:C ratio (2.56). T₉ and T₈ were the next best treatments with B:C

ratios of 2.52 and 2.51, respectively. The lower B:C ratio under gypsum treatments at lower sulphur levels reflected smaller yield advantage in relation to cost. Similar economic superiority of higher-yielding sulphur treatments has been reported by Kumar and Trivedi (2012) [16], Kushwaha *et al.* (2020) [18], Chauhan *et al.* (2022) [4] and Solanki *et al.* (2022) [25].

Table 7: Effect of sulphur sources and levels on economics of Indian mustard

Treatment	Cost of cultivation (₹ ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B:C ratio
T ₁	39,000	86,172	47,172	2.21
T ₂	48,000	102,866	54,866	2.14
T ₃	49,500	108,227	58,727	2.19
T ₄	51,000	113,514	62,514	2.23
T ₅	47,500	110,536	63,036	2.33
T ₆	49,000	116,850	67,850	2.38
T ₇	50,500	122,122	71,622	2.42
T ₈	49,800	125,050	75,250	2.51
T ₉	51,200	129,211	78,011	2.52
T ₁₀	52,000	132,934	80,934	2.56

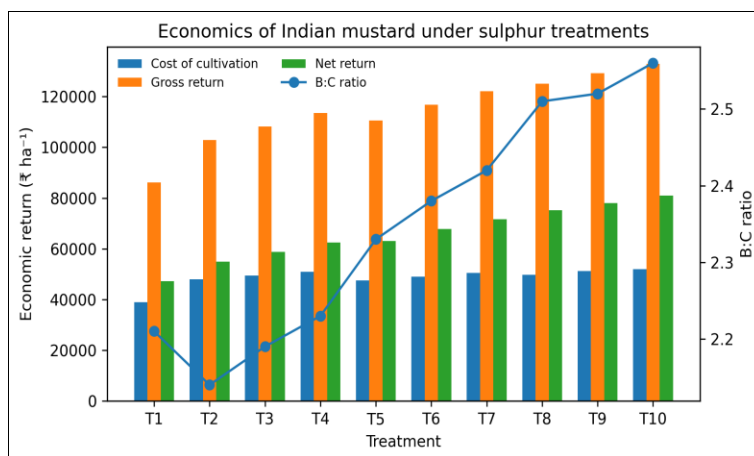


Fig 5: Effect of sulphur sources and levels on economics of Indian mustard.

Conclusion

The study confirmed that Indian mustard responded positively to sulphur application under the sandy loam soil conditions of Gwalior. Application of sulphur with the recommended NPK dose improved growth, yield attributes, seed yield, oil content, nutrient uptake and profitability over the absolute control.

Among the evaluated treatments, 100% RDF + bentonite @ 60 kg S ha⁻¹ was the most productive and remunerative treatment. It recorded the highest seed yield (1942 kg ha⁻¹), oil content (42.30%), total sulphur uptake (37.37 kg ha⁻¹), net return (₹80,934 ha⁻¹) and B:C ratio (2.56). The treatment was followed by 100% RDF + bentonite @ 50 kg S ha⁻¹ and 100% RDF + bentonite @ 40 kg S ha⁻¹.

On the basis of one-season field results, application of bentonite sulphur at 60 kg S ha⁻¹ along with 100% RDF can be recommended for improving productivity, quality and economic return of Indian mustard in sulphur-deficient sandy loam soils. Multi-season validation under different soil conditions may further refine the recommendation.

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