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Effect of different levels of nitrogen and sulphur on growth, yield and quality of mustard (*Brassica juncea* L.)

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Abstract

A field investigation was carried out at the Agronomy Research Farm of Shri Khushal Das University, Hanumangarh, Rajasthan, to assess how varying levels of nitrogen and sulphur influence the productivity and economic performance of mustard. Twenty-five treatment combinations five nitrogen levels (0, 40, 80, 120 and 160 kg N ha⁻¹) in the main plots and five sulphur levels (0, 25, 35, 45 and 55 kg S ha⁻¹) in the sub-plots were laid out in a Factorial Randomized Block Design (FRBD) with three replications. Across both years of the study (2023-24 and 2024-25), nitrogen applied at 120 kg ha⁻¹ (N3) and sulphur applied at 55 kg ha⁻¹ (S4) produced the strongest response in growth, yield attributes and yield, outperforming the lowest sulphur level, S1 (25 kg S ha⁻¹). Growth parameters plant height, leaf area index, dry matter accumulation, and the number of primary and secondary branches together with yield attributes and yield, improved most under the N3–S4 combination, followed closely by N2 (80 kg N ha⁻¹) and S3 (45 kg S ha⁻¹). This combination also delivered the highest gross return, net return and benefit-cost ratio, whereas withholding sulphur (S0) depressed all three economic indicators. Correspondingly, the poorest net return and benefit-cost ratio occurred where neither nitrogen (N0) nor sulphur (S0) was applied.

Keywords: Mustard, nutrient management, production potential, profitability

Introduction

Among India's edible oilseed crops, rapeseed and mustard rank third after groundnut and soybean in overall importance. Although the country holds 12–15% of the world's oilseed-growing area, this translates into only 6–7% of global oilseed output a shortfall that must still meet the requirements of roughly 17% of the world's population. Global figures for 2023-24 place the rapeseed-mustard crop at 36.12 million hectares, yielding 72.29 million metric tonnes at an average productivity of 2000 kg ha⁻¹. Within this global picture, India occupies the second-largest area (after Canada) and the fourth-largest production position (behind Canada, the European Union and China), cultivating the crop over 8.20 million hectares to produce 10.4 million tonnes, at a comparatively modest average yield of 1040 kg ha⁻¹ (USDA report, 2022-23). Within the country, Uttar Pradesh contributes the second-largest cultivated area (0.69 million hectares) and ranks fourth in production (0.89 million tonnes), with an average productivity of 1290 kg ha⁻¹ (Ministry of Agriculture and Farmers Welfare, 2022-23). India's population continues to expand, with projections placing it at 1.42 billion by 2025 and 1.48 billion by 2030. Rising living standards are simultaneously pushing up per-capita consumption of edible oil, with demand projected to grow at 3.54% annually between 2011 and 2030. On this trajectory, per-capita consumption is expected to climb from the current 16.38 kg per year to 23.1 kg per year by 2030. Meeting this demand without import dependence would require an estimated 34.10 million tonnes of edible oil, equivalent to roughly 102.3 million tonnes of oilseeds (DRMR, 2011). Rapeseed and mustard already contribute about 8% of India's edible oil output, giving the crop real potential to narrow the oilseed self-sufficiency gap. Yet national productivity, at only 1040 kg ha⁻¹, trails far behind the global average of 2000 kg ha⁻¹ and is dwarfed by yields of 3810 kg ha⁻¹ in Chile and 3150 kg ha⁻¹ in the European Union (USDA report, 2022-23). Much of this shortfall traces back to the fact that rapeseed-mustard is frequently grown on marginal, resource-constrained land, where farmers lack the means to adopt improved nutrient-management practices. Under such constrained conditions, cultivation becomes correspondingly less remunerative, widening the gap between the

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demand for mustard and its domestic production. As a Rabi-season oilseed, mustard ranks just behind sunflower in importance and is valued for its 30–40% protein content and strong nutritive profile. The crop performs best under cool growing conditions with adequate soil moisture, followed by a dry spell at harvest, which is why sub-temperate climates suit it particularly well, although it is also cultivated as a cold-weather crop in select tropical and sub-tropical tracts. Indian mustard is remarkably tolerant of climatic variation, withstanding annual precipitation between 500 and 4200 mm, temperatures ranging from 6°C to 27°C, and soil pH from as low as 4.3 to as high as 8.3. Botanically, mustard belongs to the genus *Brassica* within the family Cruciferae, and the wider rapeseed-mustard group encompasses Indian mustard, yellow sarson, brown sarson, raya and toria. Indian mustard [*Brassica juncea* (L.) Czernj and Cosson] is grown predominantly across Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh and Gujarat, with a growing presence in non-traditional southern tracts such as Karnataka, Tamil Nadu and Andhra Pradesh, and adapts well to both irrigated and rainfed cultivation. Brown sarson (*B. rapa* ssp. sarson) exists as two ecotypes, lotni and toria, while yellow sarson (*B. rapa* var. trilocularis) is the preferred Rabi crop in Assam, Bihar, Odisha and West Bengal, and serves mainly as a catch crop in Punjab, Haryana, Uttar Pradesh, Himachal Pradesh and Madhya Pradesh. Taramira (*Eruca sativa*) suits the drier tracts of north-western India spanning Rajasthan, Haryana and Uttar Pradesh, whereas gobhi sarson (*B. napus* L. ssp. oleifera DC. var. annua L.) and karan rai (*Brassica carinata*) remain more recent additions to the oilseed basket, cultivated over comparatively limited areas. Gobhi sarson, a long-duration crop confined mainly to Haryana, Punjab and Himachal Pradesh, stands out for its high yield potential, broad adaptability and superior oil content and quality. Collectively, these Brassica crops serve multiple purposes beyond oil as vegetables, fodder, condiments, and raw material for hair oils, medicines, soap-making and green manure with their stems and leaves also providing valuable cattle fodder. Given the steadily rising global population, demand for these high-quality vegetable oils continues to climb. Mustard oil cake, though valuable as manure, carries a bitter compound (sinigrin) that limits its palatability to livestock. The pungency of mustard itself can trigger mild allergic reactions such as watering eyes and throat irritation, and the crop's characteristically high erucic acid content (40–50%) has been linked to cardiac dysfunction on excessive consumption. Its sulphur-rich glucosinolate compounds, present at levels of up to 80–160 micromoles per gram, are similarly implicated as precursors of goitrogenic substances (Pachauri, 2001). Sustained, long-term application of NPK fertilizers has been shown to release nutrients gradually and in step with the plant's developmental needs, while also stimulating microbial populations that help mobilize complex soil nutrients for plant uptake. Sulphur, for its part, participates directly and indirectly in several metabolic pathways, contributing to the biosynthesis of oil, carbohydrates, proteins and fats a role significant enough that it is now regarded as the fourth major plant nutrient after nitrogen, phosphorus and potassium. Combined application of nitrogen and sulphur has repeatedly been found to raise both oil content and overall productivity in mustard while simultaneously safeguarding soil fertility, supporting the long-term sustainability of the cropping system (Kumar *et al.*, 2019) ^[11]. Sulphur's influence on the chemical make-up of mustard tissue stems largely from its close functional relationship with nitrogen: both elements are indispensable for

protein synthesis, with sulphur specifically supplying the building blocks for the amino acids cysteine and methionine. Ranked among the 16 essential elements for crop growth, sulphur carries particular weight for oilseed crops, whose demand for it exceeds that of most other annual crops. Although conventionally classed as a secondary macronutrient alongside calcium and magnesium, it is nonetheless critical to achieving maximum yield and quality, and is frequently placed immediately after nitrogen, phosphorus and potassium in its importance to overall productivity (Piri *et al.*, 2012) ^[14]. Its adequacy is thus indispensable for oilseed crops and has been linked to superior nutritional and market quality of the harvested produce (Rajput *et al.*, 2018) ^[17]. Mustard's elevated sulphur requirement, in particular, reflects its dependence on sulphur-containing amino acids methionine, cysteine and cystine and on glucosinolates, both of which enhance seed protein content and oil quality (Jat *et al.*, 2019) ^[7]. Where sulphur is deficient, mustard typically shows chlorosis, stunted growth and poor seed filling, whereas its adequate supply has been repeatedly shown to raise seed yield, oil content and overall nutrient uptake (Singh *et al.*, 2020). Mustard responds markedly to fertilizer inputs, with NPK and sulphur both essential to its healthy development and typically absorbed by the plant in broadly comparable proportions. Present in plant tissue at concentrations of 0.1–0.4%, sulphur is taken up mainly as sulphate ions, occurring in soil in both monovalent and divalent forms, and its availability is fundamental to establishing a healthy root system. When sulphur is scarce, plants show stunted growth, and under severe deficiency the stems and leaves may develop a distinct purple discoloration. Notably, oil content in mustard has been shown to rise when fertilizers of comparatively lower nutrient analysis are used (Ahmad *et al.*, 2005). In practice, many farmers apply inorganic fertilizers indiscriminately in an effort to overcome nutrient deficiencies and lift yields, yet the high cost of these inputs often puts even a single bag out of reach for resource-poor cultivators making this an unsustainable route to higher productivity. A more viable alternative, as several authors have argued, lies in integrating organic and inorganic sources to sustain soil fertility over the longer term (Tandon, 1998; Lampe, 2000), a combination that the wider literature consistently associates with more productive and sustainable crop production. Balanced nutrition is central to achieving both high yield and good quality in mustard, with sulphur playing a dual role in nutrient balance and amino acid synthesis. Because Cruciferae-family crops are naturally rich in glucosinolates, their sulphur demand runs correspondingly high (Rathore and Manohar, 1992), with mustard's sulphur requirement typically falling between 20 and 60 kg S ha⁻¹ depending on the soil's existing sulphur status and yield potential. Sulphur is, moreover, the nutrient chiefly responsible for oil synthesis and for the characteristic pungency of mustard oil, which is why Indian mustard responds so strongly to sulphur application, both for seed quality and seed development.

Materials and Methods

This field study took place at the Agronomy Research Farm of Shri Khushal Das University, Hanumangarh, Rajasthan, across the 2023-24 and 2024-25 Rabi seasons, with the aim of evaluating how nitrogen and sulphur nutrition jointly shape the productivity and profitability of mustard. Five nitrogen levels (0, 40, 80, 120 and 160 kg N ha⁻¹) were assigned to the main plots and five sulphur levels (0, 25, 35, 45 and 55 kg S ha⁻¹) to the sub-plots, generating 25 treatment combinations (Table 1) that were laid out

in a Factorial Randomized Block Design and replicated three times. Weather during the cropping period ranged from a maximum of 40.0 °C to a minimum of 4.6 °C, with relative humidity fluctuating between 37% and 83% and mean annual rainfall of 650–805 mm. The experimental soil was a sandy loam, alkaline in reaction (pH 7.9) with an electrical conductivity of 0.41 dS m⁻¹; it tested low in available nitrogen (215.0 kg ha⁻¹) and organic carbon (0.40%), and medium in available phosphorus (18.5 kg ha⁻¹), potassium (207.0 kg ha⁻¹), zinc (0.70 kg ha⁻¹) and sulphur (14.5 kg ha⁻¹). The mustard variety Narendra-8501 was sown on 16 and 18 October in 2023 and 2024, respectively, and harvested on 1 and 2 March of the following years, at a seed rate of 5 kg ha⁻¹. Seed was pre-treated with Azotobacter at 200 g per 10 kg of seed, dosed according to treatment, prior to sowing. Nitrogen corresponding to each treatment level was split into two equal applications half applied as basal dressing and the remaining half top-dressed in two equal installments at the first and second irrigations while potassium (40 kg ha⁻¹, as muriate of potash) and phosphorus (40 kg ha⁻¹, as DAP) were both applied in full as basal doses, the potassium placed 8–10 cm deep alongside the first half of the nitrogen dose ahead of sowing. Sulphur was supplied strictly according to each treatment's assigned level (0, 25, 35, 45 or 55 kg S ha⁻¹) and thoroughly incorporated into the soil at sowing. A single thinning operation thirty days after sowing brought plant spacing to approximately 15 cm, and weeding together with hoeing was carried out manually following the first and second irrigations, timed to

coincide with optimal soil moisture. At harvest, the number of siliquae per plant, 1000-seed weight, seed yield and straw yield were recorded for each plot. Cultivation costs were derived from the actual operations performed and inputs used including fertilizers, seed and labour while returns were computed using prevailing market prices for both inputs and outputs, allowing gross return, net return and benefit-cost ratio to be worked out for every treatment. All data were subjected to analysis of variance appropriate to the experimental design using SPSS, with treatment means compared at the 5% probability level and critical difference (CD) values calculated accordingly.

Results and discussion

Growth parameters

Table 1 and Figure 1 present the growth response of mustard plant height, the number of primary and secondary branches per plant, and dry matter accumulation to the nitrogen and sulphur treatments. By harvest, plant height under N3 (120 kg N ha⁻¹) had reached a season high of 206.22 cm and 207.96 cm in 2023-24 and 2024-25 respectively a response statistically on par with N2 (80 kg N ha⁻¹) while N0 (0 kg N ha⁻¹) produced the shortest plants in both years. This represented an average height gain of 11.16% and 11.06% for N3 over N1 (40 kg N ha⁻¹) in the two seasons. Sulphur showed a parallel pattern: S4 (55 kg S ha⁻¹) produced the tallest plants, statistically at par with S3 (45 kg S ha⁻¹) and S2 (35 kg S ha⁻¹), while the untreated S0 control gave the shortest plants.

Table 1: Effect of different levels of nitrogen and sulphur on plant height (cm), number of primary and secondary branches per plant, and dry matter accumulation (g/plant) at harvest

Symbols	Treatment (kg ha ⁻¹)	Plant height 2023-24	Plant height 2024-25	Primary br./plant 2023-24	Primary br./plant 2024-25	Secondary br./plant 2023-24	Secondary br./plant 2024-25	Dry wt (g/plant) 2023-24	Dry wt (g/plant) 2024-25
Levels of Nitrogen (A)									
N0	0	167.82	170.36	5.77	5.80	10.65	10.67	50.48	50.96
N1	40	185.51	187.25	6.07	6.12	10.82	10.86	53.16	53.70
N2	80	196.40	198.31	6.90	6.94	11.55	11.59	58.42	58.98
N3	120	206.22	207.96	7.21	7.26	11.86	11.90	60.19	60.80
N4	160	192.09	194.20	6.19	6.23	11.35	11.37	56.35	56.92
SEm±		3.82	3.96	0.11	0.12	0.15	0.16	0.57	0.58
CD (P=0.05)		12.46	12.91	0.34	0.36	0.46	0.51	1.85	1.87
Levels of Sulphur (B)									
S0	0	175.66	178.37	5.96	6.00	10.57	10.62	53.10	53.43
S1	25	181.39	184.67	6.17	6.20	11.04	11.09	55.28	55.84
S2	35	195.80	196.21	6.21	6.25	11.30	11.34	55.56	56.11
S3	45	198.88	200.34	6.55	6.60	11.75	11.78	55.96	56.52
S4	55	205.85	206.86	6.78	6.81	12.02	12.06	56.34	56.91
SEm±		3.81	3.90	0.16	0.16	0.20	0.20	0.82	0.83
CD (P=0.05)		10.91	11.17	0.47	0.48	0.61	0.60	2.48	2.52

The same treatment, N3, also generated the greatest number of primary and secondary branches and the highest dry matter accumulation, again statistically comparable to N2, with N0 trailing on every count in both years. Sulphur followed the identical hierarchy S4 topped these parameters, closely matched by S3, while S0 again lagged furthest behind, in both 2023-24 and 2024-25.

Yield and quality parameters

Table 2 and Figure 2 summarize how nitrogen and sulphur management shaped seed yield, stover yield, biological yield and harvest index. Seed yield responded most strongly to N3 (120 kg N ha⁻¹), reaching 15.85 and 17.04 q ha⁻¹ across the two years

figures statistically indistinguishable from N2 (80 kg N ha⁻¹) and N4 (160 kg N ha⁻¹) while N0, with no nitrogen applied, gave the lowest yields of 10.04 and 11.13 q ha⁻¹. Relative to N1 (40 kg N ha⁻¹), this amounted to seed-yield gains of 17.49% and 19.24% for N3, and 8.96% and 9.37% for N2, in 2023-24 and 2024-25 respectively. Sulphur produced a similar gradient, with S4 (55 kg S ha⁻¹) giving the highest seed yield (17.37 and 18.56 q ha⁻¹), statistically at par with S3 (45 kg S ha⁻¹), and S0 giving the lowest. The yield advantage under sulphur application likely reflects sulphur's tendency to slow nutrient release, thereby curbing nitrogen loss and promoting more efficient uptake of both macro- and micronutrients.

Table 2: Effect of different levels of nitrogen and sulphur on seed, stover and biological yield (q ha^{-1}) and harvest index (%) during 2023-24 and 2024-25

Symbols	Treatment (kg ha^{-1})	Seed yield 2023-24	Seed yield 2024-25	Stover yield 2023-24	Stover yield 2024-25	Biological yield 2023-24	Biological yield 2024-25	Harvest index % 2023-24	Harvest index % 2024-25
Levels of Nitrogen (A)									
N0	0	10.04	11.13	56.30	57.28	66.34	68.41	14.98	16.12
N1	40	13.49	14.29	65.95	66.90	79.45	81.19	16.64	17.25
N2	80	14.70	15.63	68.94	69.91	83.64	85.53	17.18	17.92
N3	120	15.85	17.04	69.34	70.64	85.19	87.68	17.98	18.85
N4	160	14.20	15.14	68.58	69.36	82.79	84.50	16.80	17.53
SEm±		0.65	0.68	1.05	1.25	1.82	1.94	0.28	0.34
CD (P=0.05)		2.12	2.23	3.10	3.72	5.40	5.80	0.82	1.01
Levels of Sulphur (B)									
S0	0	6.84	7.55	45.35	46.15	52.19	53.71	13.11	14.02
S1	25	13.63	14.59	67.31	68.13	80.95	82.73	16.71	17.61
S2	35	14.87	15.82	69.30	70.21	84.18	86.04	17.57	18.32
S3	45	15.56	16.69	70.22	71.28	85.78	87.97	17.95	18.84
S4	55	17.37	18.56	76.93	78.31	94.30	96.87	18.23	18.88
SEm±		0.62	0.68	2.25	2.54	2.85	3.02	0.21	0.41
CD (P=0.05)		1.89	2.08	6.72	7.58	8.57	9.01	0.60	1.17

Stover yield followed a comparable pattern to seed yield. N3 again led with 69.34 and 70.64 q ha^{-1} across the two seasons, statistically on par with N2 and N4, whereas N0 produced the least stover (56.30 and 57.28 q ha^{-1}). Sulphur mirrored this trend: S4 delivered the highest stover yield (76.93 and 78.31 q ha^{-1}), at par with S3, with S0 again at the bottom. Biological yield tracked the same hierarchy for both nutrients. Harvest index, too, peaked under N3 (17.98% and 18.85%) and fell to its lowest under N0, while among sulphur levels it peaked under S4 (18.23% and 18.88%, at par with S3) and dropped to its minimum under S0.

These gains in stover yield can reasonably be attributed to the accompanying improvements in plant height and branching, with the combined application of NPK and sulphur evidently enhancing nutrient availability enough to drive stronger vegetative growth a pattern consistent with the observations of Bhagat and Soni (2000) ^[2], Bhalerao (2001) ^[3] and Singh *et al.* (2002).

The influence of nitrogen and sulphur management on oil content, oil yield, protein content and protein yield is summarized in Table 3 and Figure 3.

Table 3: Effect of different levels of nitrogen and sulphur on oil content (%), oil yield (kg ha^{-1}), and protein content (%) and protein yield (kg ha^{-1}) during 2023-24 and 2024-25

Symbols	Treatment (kg ha^{-1})	Oil content % 2023-24	Oil content % 2024-25	Oil yield kg/ha 2023-24	Oil yield kg/ha 2024-25	Protein content % 2023-24	Protein content % 2024-25	Protein yield kg/ha 2023-24	Protein yield kg/ha 2024-25
Levels of Nitrogen (A)									
N0	0	36.43	36.76	365.76	409.14	14.25	14.38	143.07	160.05
N1	40	40.82	41.16	550.66	588.18	14.88	15.00	200.73	214.35
N2	80	42.28	42.61	621.52	665.99	16.19	16.38	237.99	256.02
N3	120	42.56	42.90	674.58	731.02	18.13	18.31	287.36	312.00
N4	160	40.86	41.19	580.21	623.62	15.94	16.06	226.35	243.15
SEm±		1.25	1.21	25.92	31.48	0.65	0.71	16.62	19.08
CD (P=0.05)		4.08	3.96	84.42	102.54	1.97	2.16	49.88	57.28
Levels of Sulphur (B)									
S0	0	39.48	39.82	270.04	300.64	14.88	15.00	101.78	113.25
S1	25	40.54	40.87	552.56	596.29	15.63	15.75	213.04	229.79
S2	35	41.03	41.37	610.12	654.47	16.50	16.69	245.36	264.04
S3	45	41.31	41.65	642.78	695.14	17.06	17.25	265.45	287.90
S4	55	41.52	41.82	721.20	776.18	18.56	18.81	322.39	349.11
SEm±		0.12	0.10	28.39	34.85	0.74	0.78	20.37	24.63
CD (P=0.05)		0.33	0.28	85.15	104.48	2.21	2.36	61.02	73.85

Oil content peaked under N3, reaching 42.56% and 42.90% in the two years significantly ahead of N2 and bottomed out under N0 at 36.43% and 36.76%. Across the sulphur levels, oil content climbed steadily from a low of 39.48–39.82% up to 41.52–41.82%, with S4 recording the highest values (41.52% and 41.82%), followed in descending order by S3 (41.31% and 41.65%) and S2 (41.03% and 41.37%). This ranking $S4 > S3 > S2 > S1 > S0$ held consistently across both 2023-24 and 2024-25, with the untreated S0 control giving the lowest oil content in each year.

Oil yield showed the same nitrogen response, with N3 delivering the highest values (674.58 and 731.02 kg ha^{-1} across the two

years), statistically at par with N2 (621.52 and 665.99 kg ha^{-1}), while N0 again trailed with the lowest oil yield (365.76 and 409.14 kg ha^{-1}). Sulphur levels spanned a wide range, from 270.04–300.64 kg ha^{-1} under S0 up to 721.20–776.18 kg ha^{-1} under S4, with S4 significantly ahead of every other treatment though statistically comparable to S3 (642.78 and 695.14 kg ha^{-1}). The consistent superiority ranking of $S4 > S3 > S2 > S1 > S0$ held across both seasons, echoing the findings reported by Singh and Thenua (2016) and Gurjar *et al.* (2017) ^[6].

Protein content followed the identical nitrogen pattern: N3 produced the highest values (18.13% and 18.31%), statistically on par with N2, while N0 gave the lowest (14.25% and 14.38%).

Among sulphur levels, protein content rose from 14.88–15.00% under S0 to a peak of 18.56–18.81% under S4, with S4 statistically comparable to S3 (17.06% and 17.25%) and S2 (16.50% and 16.69%); the superiority sequence $S4 > S3 > S2 > S1 > S0$ again held across both years, with S0 consistently producing the lowest protein content. Protein yield mirrored this trend, peaking under N3 (287.36 and 312.00 kg ha⁻¹, at par with N2) and falling to its lowest under N0 (143.07 and 160.05 kg ha⁻¹). Across sulphur levels, protein yield ranged from 101.78–113.25 kg ha⁻¹ under S0 to 322.39–349.11 kg ha⁻¹ under S4, the latter statistically at par with S3 (265.45 and 287.90 kg ha⁻¹); the ranking $S4 > S3 > S2 > S1 > S0$ again applied in both years, with S0 remaining the lowest throughout consistent with the results reported by Potdar *et al.* (2019)^[15].

Conclusion

Taken together, these results indicate that combining nitrogen at 120 kg ha⁻¹ (N3) with sulphur at 55 kg ha⁻¹ (S4) consistently delivered the best growth response and the highest seed yield in mustard across both years of the study.

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