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Impact of nitrogen and sulphur fertilization on soil properties and economic efficiency of Indian mustard (*Brassica juncea* L.) under Dehradun valley conditions

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Abstract
Although Indian mustard (*Brassica juncea* L.) is a significant rabi oilseed crop in India, nutrient imbalances and dwindling soil quality frequently limit yield. Two essential nutrients that affect crop profitability, nutrient availability, and soil chemical characteristics are nitrogen (N) and sulfur (S). During the 2023-24 Rabi season, a field experiment was carried out at the Agronomy Research Farm, Jigyasa University, Dehradun, to assess the impact of different N and S dosages on soil characteristics and mustard (variety HY-805) economic efficiency. With three replications and sixteen treatment combinations of N (0, 60, 120, and 180 kg ha^{-1}) and S (0, 20, 40, and 60 kg ha^{-1}), the experiment was conducted using a Randomized Block Design (RBD). Recommended doses of phosphorus (80 kg ha^{-1}) and potassium (40 kg ha^{-1}) were applied uniformly. pH, electrical conductivity (EC), organic carbon (OC), and the amounts of accessible nitrogen (N), phosphorus (P), and potassium (K) were measured in soil samples that were taken both before and after harvest. Because sulfur has an acidifying impact, the results showed that increasing N and S doses marginally decreased soil pH and EC while increasing organic carbon content and N and P availability, indicating increased soil fertility. Under the highest N and S combination (N180S60), the highest available nitrogen (170.46 kg ha^{-1}) and phosphorus (27.53 kg ha^{-1}) were found, along with a slight improvement in organic carbon, suggesting increased microbial activity and nutrient cycling. Higher N and S dose treatments produced higher gross returns, net returns, and benefit-cost (B:C) ratios, according to economic study. The N180S60 treatment yielded the highest B:C ratio (2.20) and net return (Rs. 69,550.33 ha^{-1}), proving that even with higher input costs, investing in higher nutrient dosages is financially justified. Reduced B:C ratios and net returns were the results of reduced nutrient levels, underscoring the significance of balanced fertilization for soil fertility and profitability. According to the study's findings, applying nitrogen and sulfur together improves the chemical characteristics of soil, increases nutrient availability, and guarantees larger financial returns. In the Dehradun Valley's semi-arid irrigated mustard production, balanced N and S fertilization is thus advised as a sustainable method for preserving soil health and optimizing yield.

Keywords: Indian mustard (*Brassica juncea* L.), nitrogen (N) fertilization, sulfur (S) fertilization

Introduction

One of India's most significant oilseed crops, mustard (*Brassica juncea* L.) is widely grown in the states of Rajasthan, Haryana, Uttar Pradesh, Madhya Pradesh, West Bengal, and Uttarakhand. The average yield is only 1499 kg ha^{-1}, despite the fact that the nation produces 9.34 million tons of mustard yearly over 6.23 million hectares. This is mostly because of nutrient depletion and uneven fertilization techniques. Continuous cropping, a lack of organic inputs, and an over-reliance on high-analysis fertilizers deficient in sulfur have all contributed to the widespread deficit of essential nutrients, particularly nitrogen (N), phosphorus (P), and sulfur (S) (Singh *et al*., 2017; Dhaliwal *et al*., 2022) [9, 5].

Due to decreased industrial emissions, better fertilizer quality, and less manure use, sulfur, which was once available through atmospheric deposition and organic manures, is currently dropping (Rakesh *et al*., 2020) [18]. The dynamics of soil nutrients are greatly impacted by nitrogen-sulfur interactions, which also have an impact on crop response, availability, and absorption efficiency. Through increased microbial activity, nutrient cycling, and organic matter accumulation, balanced fertilization maintains soil fertility in addition to increasing crop output.

Frequent sulfur application improves soil pH, preserves nutrient balance, and encourages the synthesis of vital chemicals that improve soil health (Singh *et al*., 2023) [22]. When assessing nutrient management systems, economic evaluation is equally significant. Higher levels of sulfur and nitrogen frequently result in higher yields, but in order to stay profitable, they must also be able to offset the additional input costs. Determining the economic optimum dose helps ensure both sustainability and profitability of mustard production (Mandeewal *et al*., 2022) [12]. A treatment combination that enhances nutrient-use efficiency, soil fertility, and returns per unit cost of fertilizer is therefore ideal for long-term productivity and soil conservation.

Important markers of soil fertility and crop response to fertilizer management are the chemical characteristics of the soil, including pH, electrical conductivity (EC), organic carbon (OC), and the availability of macronutrients (N, P, and K). Fertilization with nitrogen and sulfur has a major impact on these characteristics by changing microbial activity, nutrient dynamics, and soil reactivity. According to Kumar *et al*. (2023) [10], applying 120 kg N ha⁻¹ along with 40 kg S ha⁻¹ enhanced the soil fertility status in mustard fields by raising the amounts of accessible N, P, and K while marginally lowering pH because of the acidulating action of sulfur oxidation. Similar findings were made by Singh *et al*. (2022) [21], who found that increasing sulfur doses up to 60 kg ha⁻¹ decreased soil pH and increased EC and organic carbon, suggesting improved nutrient solubility and microbial breakdown under favorable moisture conditions. Choudhary *et al*. (2021) [4] at ICAR-IARI, New Delhi, showed that by encouraging microbial biomass and enzymatic activity, sulfur treatment under conservation agriculture enhanced soil organic carbon (OC) and nutrient-use efficiency. Applying 100-150 kg N ha⁻¹ and 40 kg S ha⁻¹ enhanced available N (by 12-15%), P (by 9-11%), and K (by 8-10%) in comparison to the control, according to Pandey *et al*. (2020) [14]. This suggests that integrated N and S management aids in maintaining soil nutrient balance.

Mani *et al*. (2021) [11] observed that despite maintaining a nearly neutral soil response, the combined application of N (80 kg ha⁻¹) and S (30 kg ha⁻¹) greatly increased the organic carbon content (0.63%) and accessible nitrogen (255 kg ha⁻¹) in yellow mustard. Similar findings were made by Kumar *et al*. (2019) [20], who found that improved root activity and mineralization were the primary causes of the increase in available N and S in soil with incremental sulfur doses up to 60 kg ha⁻¹. Rakesh *et al*. (2016) [17] additionally verified that by reducing soil pH and boosting phosphate ion solubility, sulfur application not only increased nutrient intake but also improved soil nutrient pools, especially accessible phosphorus. Overall, the literature reveals that integrated and balanced application of nitrogen (100-140 kg ha⁻¹) and sulphur (30-60 kg ha⁻¹) improves soil nutrient availability, increases organic carbon content, and maintains favourable pH and EC conditions conducive to mustard productivity and long-term soil fertility (Kumar *et al*., 2023; Choudhary *et al*., 2021; Mani *et al*., 2021) [10, 4, 11].

Optimized doses of nitrogen (N) and sulfur (S) have a significant impact on the economic feasibility of mustard production. These doses not only increase yield but also boost profitability metrics like net return and benefit-cost (B:C) ratio. Higher but balanced N and S applications result in higher economic returns, as several studies have repeatedly shown. According to Pandey *et al*. (2024) [15], the Vindhya plateau region's yield and B:C ratio were greatly increased by applying 140 kg N ha⁻¹ and 60 kg S ha⁻¹, which was the most economical combination. Similar findings were made by Singh *et al*. (2023) [22], who found that in irrigated conditions, 120 kg N ha⁻¹ and 60 kg S ha⁻¹ produced the highest net monetary returns and B:C ratios. In Gujarat, Patel *et al*. (2022) [16] observed that gypsum combined with 60 kg S ha⁻¹ achieved a gross realization of ₹97,948 ha⁻¹, a net return of ₹68,516 ha⁻¹, and a B:C ratio of 3.33, confirming the profitability of higher S doses.

Additionally, Agnihotri *et al*. (2021) [1] confirmed the superiority of 120 kg N ha⁻¹ in maximizing gross and net returns (₹74,162 ha⁻¹ and ₹50,345 ha⁻¹, respectively), while Atkari *et al*. (2022) [2] demonstrated that S application up to 25-60 kg ha⁻¹ significantly improved monetary returns and oil yield. These results are supported by earlier research, which highlights the significance of balanced N and S control. For example, in western Uttar Pradesh, Chaurasiya *et al*. (2019) [3] and Kumar *et al*. (2017) [9] recorded the greatest B:C ratios (2.25) and net returns at 120 kg N ha⁻¹ and 40 kg S ha⁻¹. Similarly, Hadiyal *et al*. (2017) [7] found optimal profitability at 120 kg N ha⁻¹ + 40 kg S ha⁻¹, whereas Singh *et al*. (2019) [20] discovered that 90 kg N ha⁻¹ produced the most lucrative yield increment and marginal benefit.

Overall, these studies affirm that nitrogen doses ranging from 100-140 kg ha⁻¹ and sulphur doses between 40-60 kg ha⁻¹ tend to maximize yield and economic efficiency in mustard cultivation across diverse agro-climatic regions of India. Thus, a synergistic balance between nitrogen and sulphur not only sustains crop productivity but also ensures superior economic returns (Pandey *et al*., 2024; Singh *et al*., 2023; Patel *et al*., 2022) [15, 22, 16].

Material and Methods

During the Rabi season of 2023-2024, the study was carried out at the Agronomy Research Farm, Jigyasa University (formerly Himgiri Zee University), Dehradun, Uttarakhand. The location is 650 meters above sea level, with latitude 30.339°N and longitude 77.879°E. The soil type was sandy loam, with low levels of nitrogen (151.36 kg ha⁻¹) and organic carbon (0.45%), medium levels of phosphorus (12.83 kg ha⁻¹), and acceptable levels of potassium (178.64 kg ha⁻¹). With three replications and sixteen treatment combinations of nitrogen and sulfur levels (0, 60, 120, and 180 kg N ha⁻¹ × 0, 20, 40, and 60 kg S ha⁻¹), the experiment was set up using a Randomized Block Design (RBD). Urea was used to apply nitrogen, and gypsum was used to supply sulfur. The recommended dose of P_2O_5 (80 kg ha⁻¹) and K_2O (40 kg ha⁻¹) was applied uniformly to all plots.

Mustard variety HY-805 was sown on 25 October 2023 with a spacing of 30 cm × 10 cm using line sowing. One-half of nitrogen and the entire dose of phosphorus, potassium, and sulphur were applied as basal at sowing, and the remaining half of nitrogen was top-dressed at 30 days after sowing (DAS). Intercultural operations, irrigation, and plant protection measures were followed as per recommendations. Harvesting was done manually on 9 March 2024.

Soil samples were collected before sowing and after harvest from a depth of 0-15 cm using a soil auger from each plot. The samples were air-dried, ground, and passed through a 2 mm sieve for analysis of physico-chemical properties and nutrient availability.

Soil pH was determined using a digital pH meter following the potentiometric method in a 1:2.5 soil-water suspension as described by Jackson (1973) [8]. Electrical conductivity (EC) of the soil was measured using an EC bridge (conductivity meter) in a 1:2.5 soil-water extract as outlined by Jackson (1973) [8]. The organic carbon content of the soil was estimated by the Walkley and Black rapid titration method as described by Walkley and Black (1934) [24], and expressed as a percentage.

Available nitrogen was determined by the alkaline permanganate method as described by Subbiah and Asija (1956) [23], and expressed in kilograms per hectare (kg ha⁻¹). Available phosphorus was extracted using 0.5 M sodium bicarbonate (pH 8.5) and estimated by the Olsen's colorimetric method (Jackson, 1973) [8] using a spectrophotometer at 660 nm wavelength.

Economic evaluation was carried out to assess the profitability of different treatments. The following parameters were computed:

- **Cost of Cultivation (₹ ha⁻¹):** Calculated based on the prevailing prices of inputs such as fertilizers, seeds, labour, irrigation, and plant protection chemicals.
- **Gross Return (₹ ha⁻¹):** Calculated by multiplying the seed yield with the prevailing market price of mustard.
- **Net Return (₹ ha⁻¹):** Obtained by subtracting the cost of cultivation from gross return.
- **Benefit-Cost (B:C) Ratio:** Calculated using the formula:

$$\text{B:C Ratio} = \frac{\text{Gross Return}}{\text{Cost of Cultivation}}$$

All soil and economic data were analyzed using Analysis of Variance (ANOVA) as per the Randomized Block Design. Treatment means were compared at the 5% level of significance, and the standard error and critical difference were computed for valid comparisons.

Result and Discussion

Table 1 shows that while the changes were not statistically significant, increasing nitrogen and sulfur dosages somewhat lowered soil pH in comparison to the starting point. The pH of T $_{16}$ (N180S60) was the lowest, at 7.64. The acidifying impact of sulfur, which encourages the production of H^+ ions in the soil, is responsible for the pH decrease. Applying sulfur may also cause native CaCO3 to dissolve more readily, releasing soluble calcium and causing sodium to seep out, which will lower pH.

Higher doses of nitrogen and sulfur caused a small decline in soil EC (Table 1). The initial EC was 0.138 dS/m, while the lowest EC (0.131 dS/m) was measured under T $_{16}$. These variations, however, were not statistically significant, suggesting that the salt state of the soil was not significantly changed by nitrogen inputs. As sulfur and nitrogen dosages increased, the soil's organic carbon content increased somewhat; T $_{16}$ (N180S60) had the greatest OC (0.534%), while the control had 0.51%. Better crop residue return and increased microbial activity under ideal nitrogen supply could be the cause of the improvement. In a similar vein, Meena *et al.* (2006) [13] found that sulfur greatly raised the amount of organic carbon in soil when combined with micronutrients like zinc and iron.

With the addition of nitrogen and sulfur, the amount of available nitrogen in the soil gradually rose (Table 1). T $_{16}$ (N180S60) had the most amount of accessible N (170.46 kg ha⁻¹), which was 2.27% more than the control. Increased N mineralization and less leaching under balanced fertilization could be the cause of the rise. Higher doses of nitrogen and sulfur also revealed an increasing trend in available phosphorus. T $_{16}$ had the highest phosphorus level (27.53 kg ha⁻¹), which was 6.26% higher than the control. By modestly reducing the pH of the soil and increasing the solubility of native P compounds, sulfur may have enhanced the availability of phosphorus.

While increasing organic carbon, available nitrogen, and available phosphorus, the addition of sulfur and nitrogen marginally reduced soil pH and EC. These modifications show that balanced N and S fertilizer moderately improves soil fertility and nutrient availability. Increased S dosages don't seem to have a major impact on salinity or acidification, but they do seem to enhance nutrient mobilization and general soil health.

greater nitrogen and sulfur dosages resulted in greater cultivation costs (Table 2). T $_{16}$ (N180S60) had the highest cost (Rs. 31,579 ha⁻¹), while the control treatment had the lowest (Rs. 31,272 ha⁻¹). Higher fertilizer input requirements are the cause of the rise. The trend for gross returns was the same as that of yield. T $_{16}$ produced more seed and stover, resulting in the highest gross return (Rs. 101,097.33 ha⁻¹), which was significantly greater than the control (Rs. 47,618.95 ha⁻¹).

T $_{16}$ produced the highest net return (Rs. 69,550.33 ha⁻¹), which was significantly higher than that of the other treatments. The control had the lowest net return (Rs. 16,346.95 ha⁻¹), underscoring the financial benefit of balanced N and S fertilization. With increasing doses of nitrogen and sulfur, the B:C ratio gradually rose, peaking at 2.20 in T $_{16}$, while the control showed the lowest B:C ratio (0.52) (Table 2). This suggests that increased productivity made the investment in larger doses of N and S economically viable.

The study shows that the most lucrative method for growing mustard in semi-arid irrigated circumstances is to apply 180 kg N ha⁻¹ in addition to 60 kg S ha⁻¹ (T $_{16}$). Superior gross and net returns as well as a greater B:C ratio were directly influenced by higher seed and stover yields. These outcomes are consistent with what Choudhary *et al.* (2021) [4] found. This study indicates that greater doses optimize production, water-use efficiency, and profitability under the conditions under study, in contrast to earlier recommendations of N 80 kg ha⁻¹ and S 40 kg ha⁻¹.

Table 1: Soil parameters as influenced by different doses of sulphur and nitrogen

Treatment	pH	EC (dS/m)	Organic Carbon (%)	Available N (kg/ha)	Available P_2O_5 (kg/ha)
T_1 Control	7.75	0.138	0.51	166.63	25.80
T_2 N0S20	7.69	0.137	0.513	167.40	26.22
T_3 N0S40	7.74	0.135	0.511	168.15	25.30
T_4 N0S60	7.63	0.134	0.519	168.88	26.33
T_5 N60S0	7.67	0.136	0.517	169.88	27.08
T_6 N60S20	7.70	0.134	0.512	169.89	27.22
T_7 N60S40	7.65	0.135	0.517	170.28	26.94
T_8 N60S60	7.58	0.132	0.53	171.05	27.29
T_9 N120S0	7.59	0.135	0.517	171.85	27.19
T_{10} N120S20	7.66	0.132	0.519	171.30	27.48
T_{11} N120S40	7.60	0.132	0.512	169.46	27.28
T_{12} N120S60	7.65	0.136	0.51	168.34	28.07
T_{13} N180S0	7.65	0.137	0.52	170.18	26.09
T_{14} N180S20	7.67	0.134	0.535	170.30	26.90
T_{15} N180S40	7.68	0.135	0.502	169.51	26.43
T_{16} N180S60	7.64	0.131	0.533	170.46	27.53
SE(m)±	0.04	0.001	0.005	1.17	26.22
C.D. (5%)	N/A	N/A	N/A	N/A	N/A

Table 2: Cost of cultivation, gross return, net return and benefit: cost ratio of mustard as influenced by different doses of sulphur and nitrogen

Treatments	Cost of cultivation (Rs. ha^{-1})	Gross Return (Rs. ha^{-1})	Net Returns (Rs. ha^{-1})	B:C Ratio
T_1	31272	47618.95	16346.95	0.52
T_2	31496	59517.48	28021.48	0.89
T_3	31496	61469.74	29969.74	0.95
T_4	31503	67592.83	36089.83	1.15
T_5	31516	74267.37	42751.37	1.36
T_6	31520	74241.00	42721.00	1.36
T_7	31524	98914.17	67390.17	2.14
T_8	31527	68577.82	37050.82	1.18
T_9	31539	78616.74	47077.74	1.49
T_{10}	31543	63822.40	32279.40	1.02
T_{11}	31547	92394.07	60820.07	1.93
T_{12}	31390	78605.81	47215.81	1.50
T_{13}	31563	94589.29	63026.29	2.00
T_{14}	31567	98743.17	67176.17	2.13
T_{15}	31571	91757.32	60186.32	1.91
T_{16}	31574	101097.33	69550.33	2.20

Summary

This study assessed the effects of fertilizing Indian mustard with nitrogen and sulfur on the soil's chemical characteristics and financial returns in the Dehradun Valley. Increases in N and S dosages enhanced soil fertility and nutrient availability by increasing organic carbon, accessible nitrogen, and phosphorus while marginally lowering soil pH and EC. Higher N and S dosages improved benefit-cost ratios, net returns, and gross returns, according to economic research, with N180S60 being the most lucrative treatment. The findings offer guidelines for sustainable mustard production in semi-arid irrigated circumstances by showing that balanced N and S treatment maximizes soil nutrient status and economic efficiency.

Conclusion

By modestly lowering pH and EC and boosting organic carbon and the availability of nitrogen and phosphorus, the study shows that the balanced and integrated application of nitrogen and sulfur improves important soil parameters, indicating improved nutrient cycling and soil fertility. Economically speaking, larger N and S dosages improved the nutritional condition of the soil and also greatly raised gross returns, net returns, and benefit-cost ratios; the N180S60 treatment was the most lucrative. These results imply that, under the semi-arid irrigated conditions of the Dehradun Valley, balanced N and S fertilization is crucial for successful mustard agriculture since it preserves soil health and guarantees the highest possible financial returns. Therefore, adopting optimized nutrient management practices can provide both long-term soil fertility and improved profitability for farmers.

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