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RESEARCH PAPER

Integrated Nutrient Management for Improving Mustard Productivity, Oil Content, and Soil Health in Red and Lateritic Soils of West Bengal

Banhisikha Roy, Pabitra Kumar Biswas* and Goutam Kumar Ghosh

Department of Soil Science and Agricultural Chemistry, Palli Siksha Bhavana, Institute of Agriculture, Visva-Bharati, Sriniketan, Dist. Birbhum, West Bengal, India

*Corresponding author: pabitrakumar.biswas@visva-bharati.ac.in (**ORCID ID:** 0000-0002-7367-5960)

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ABSTRACT

Sulphur is an important nutrient in oilseed crop nutrition as it is the main ingredient of sulphur-containing amino acids and proteins. As bio-fertilizers are economical, environmentally safe, and easily available, they play an important role in increasing soil fertility and crop yields. In this context, an experiment was conducted in the *Rabi season* of the year 2019 to assess the combined role of nitrogen, sulphur, and bio-fertilizers in increasing mustard yields and oil content, as well as improving soil properties in red lateritic soil of West Bengal. The experiment was conducted in the soil of the Agricultural Farm of Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, on the soil type of the field, namely sandy loam soil. The experiment consisted of a randomized block design with three replicates, involving three levels of sulphur application (30, 45, and 60 kg/ha) integrated with seed inoculation treatments of bio-fertilizers (*Azotobacter* and VAM). Mustard variety B-9 was taken as the test crop. The observations recorded that sulphur treatment at 60 kg/ha integrated with dual seed inoculation of VAM and *Azotobacter* increased the maximum plant height measuring 108.68 cm. Application of all levels of sulphur integrated with bio-fertilizer inoculation enhanced growth, yield, as well as yield attributes of mustard over uninoculated control soil percentage was also significantly affected by integrated nutrient management, and maximum oil percentage (45.67%) was obtained in sulphur application of 60 kg ha^{-1} along with the inoculation of VAM and *Azotobacter* compared to 25.33% in the treatment 1. It can be concluded from the above investigation that the application of sulphur at 45-60 kg ha^{-1} along with seed inoculation of VAM and *Azotobacter* is efficient in promoting the growth, yield, and oil percentage of mustard in red lateritic soil.

HIGHLIGHTS

- Application of sulphur at 60 kg/ha combined with *Azotobacter* and VAM inoculation produced the tallest plants (108.68 cm) and highest dry matter accumulation (15.39 g/m²), showing clear synergy between sulphur nutrition and biofertilizers.
- Integrated treatments significantly improved soil nutrient status—available nitrogen rose to 374.20 kg/ha, phosphorus to 71.03 kg/ha, and sulphur to 55.93 kg/ha. Oil content in mustard seeds increased from 30.67% in control to 45.67% under sulphur 60 kg/ha with dual inoculation.
- The best treatment combinations boosted pods per plant (up to 107.67), seed yield (995.33 kg/ha), and harvest index (66.49%). Nitrogen-fixing bacteria counts also rose sharply, with 22.02 *Azotobacter* colonies under sulphur 60 kg/ha + VAM + *Azotobacter* compared to only 2.58 under NPK alone, highlighting improved soil microbial activity.

Keywords: VAM, *Azotobacter*, oil content, productivity, mustard

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Rapeseed mustard (*Brassica juncea* L.) is the primary *rabi* oilseed crop in India and a vital component in fulfilling the nation's demand for edible oil. Currently available information shows that mustard is grown in an area of 8.5-9.0 million hectares every year, producing in excess of 12 million tonnes of oil annually, thus increasing in importance within programs initiated by the Indian Government regarding self-sufficiency in edible oil (Government of India, 2024; FAOSTAT, 2023). However, there is a huge scope in increasing the yield in this crop due to low fertility and poor nutrient management in the soil. The soil constraints are more evident over a large area of Indian agricultural land, which is known for its deficit of essential nutrients such as nitrogen, phosphorus, Sulphur, and micro nutrients such as zinc (Zn) or boron (B) (Rattan *et al*. 2019; Singh *et al*. 2022). Deficiency of micro nutrients, specifically zinc, has been found as a potential limiting factor for the growth efficiency of oilseed crops and nutrient use efficiency in Indian soils. Integrated Nutrient Management (INM), which requires simultaneous use of inorganic fertilizer, organic manure, and biofertilizer, has long been identified as an efficient means to promote nutrient availability, soil properties, and agricultural productivity. Recent literature on India mustard crop has depicted that integrated use of farmyard manure/vermicompost, along with biofertilizer, has a positive impact on agricultural growth, agricultural produce, nutrient uptake, and soil richness, as opposed to the use of chemical fertilizer alone (Kumar *et al.* 2021, Nagar & Suman 2025).Vermicompost improves the structure, microbial activity, and availability of easily deployable nutrients in the soil, while biofertilizers like *Azotobacter* and phosphate-solubilizing microorganisms improve biological nitrogen fixation and the availability of phosphorus. Such interaction thus enhances the efficiency of nutrient use and reduces the dependence on chemical fertilizers (Meena *et al.* 2020; Tripathi *et al.* 2022). Therefore, the adoption of INM practices becomes imperative to enhance mustard productivity by restoring soil fertility toward long-term sustainability of oilseed-based cropping systems of India.

MATERIAL AND METHODS

Experimental Site

A Field experiment in winter season Mustard (B9) was conducted at the Agricultural Farm of the Institute of Agriculture (Palli Siksha Bhavana), Visva-Bharati, Sriniketan, West Bengal during winter season of 2019. The farm is situated at 23.68°North and 87.64°East longitude and is located at the heart of the sub humid, subtropical belt.

Experimental soil

The soil of the experimental plot was sandy loam in texture, acidic in soil reaction. The physico-chemical properties of the experimental soil have been presented in the Table 1. The chemical analysis of the top 15 cm soil showed that the soil was slightly acidic in reaction, low level of organic carbon, available nitrogen and potassium content and medium in available phosphorus (Table 2).

Table 1: Mechanical and chemical analysis

Particulars	Values obtain	Method of analysis
(a) Mechanical analysis		
(i) Sand (%)	52.5	International pipette method (Piper, 1942)
(ii) Silt (%)	11.5	International pipette method (Piper, 1942)
(iii) Clay (%)	26.0	International pipette method (Piper, 1942)
(b) Chemical analysis		
(i) Organic carbon (%)	0.31	Walkley and Black method, (1934)
(ii) Available N (kg/ha)	75.26	Alkali permanganate method, (Subbiah and Asijia, 1956)
(iii) Available P(kg/ha)	81.76	Bray and Kurtz method (Bray and Kurtz, 1945)
(iv) Available K(kg/ha)	108.64	Flame photometer method (Toth and Prince, 1949)
(v) Available S(kg/ha)	11.59	Turbid metric method (Williams and Steinbergs, 1959)
(vii) P^H (1:2.5 soil: water suspension)	6.1	Blackman's Xeromatic pH meter method, (Jackson, 1973)
(viii) Electrical conductivity (dS/m)	46.2	Conductivity bridge (Syrtronics Model-304)

Table 2: The range of organic carbon, available nitrogen, phosphorus and potassium in

Particulars	Low	Medium	High
Organic carbon (%)	<0.5	0.5 to 0.75	>0.75
Available nitrogen (kg/ha)	<250	250 to 500	>500
Available phosphorus (kg/ha)	<22.5	22.5 to 56	>56
Available potassium (kg/ha)	<120	120 to 280	>280
Available Sulphur (kg/ha)	<10	10-20	>20

Meteorological Data during the field investigation

The field experiment was conducted at Sriniketan, West Bengal, India, which falls under the sub-humid tropical agro-climatic zone. The region experiences three distinct seasons: *pre-kharif* (March–June), *kharif* (July–October), and *rabi* (November–February). The present study was carried out during the *rabi* season of 2019-20. Climatic conditions during the experimental period were generally favourable for crop growth. The long-term average maximum and minimum temperatures ranged from 33.32 °C to 17.70 °C, while the minimum temperature during the cropping season varied between 17.26 °C and 22.41 °C, indicating a relatively stable thermal environment. Relative humidity fluctuated between 48.43 % and 96.29 % throughout the growing period. Although the southwest monsoon typically withdraws by October, occasional winter rainfall was recorded during the experimental season. Total rainfall from November to the last week of February amounted to 18.22 mm, with the highest monthly rainfall (18.96 mm) occurring in February. Sunshine duration ranged from 4.04 to 9.66 h day^{-1}, while the long-term average sunshine hours varied between 6.31 and 7.80 h day^{-1}, ensuring adequate solar radiation during crop growth.

Experimental design and treatments

The experiment was laid out in a Randomized Block Design (RBD) comprising nine treatments with three replications. Individual plot size was 4 m × 3 m, and plots were separated by irrigation channels to ensure uniform water application. The treatments consisted of different combinations of inorganic fertilizers, organic manure, and biofertilizers as follows:

T_1: 100% recommended dose of NPK

T_2: T_1 + farmyard manure (FYM) + *Azotobacter*

T_3: T_2 + vesicular arbuscular mycorrhizae (VAM)

T_4: T_1 + sulphur @ 30 kg ha^{-1} + VAM

T_5: T_1 + sulphur @ 45 kg ha^{-1} + *Azotobacter* + VAM

T_6: T_1 + sulphur @ 60 kg ha^{-1} + *Azotobacter* + VAM

T_7: T_2 + sulphur @ 30 kg ha^{-1} + VAM

T_8: T_2 + sulphur @ 45 kg ha^{-1} + VAM

T_9: T_2 + sulphur @ 60 kg ha^{-1} + VAM

Crop management practices

The experimental field was prepared by cross-ploughing followed by planking to obtain a fine tilth. Fertilizers were applied at the recommended rate of 100:60:60 kg N:P_2O_5: K_2O ha^{-1} using urea, diammonium phosphate, and muriate of potash. Sulphur was applied as elemental sulphur according to treatment. Half of the nitrogen and the full dose of phosphorus, potassium, and sulphur were applied as basal, while the remaining nitrogen was top-dressed at 30 days after sowing (DAS). Seeds were treated with *Azotobacter* and VAM before sowing. Mustard was sown on 13 November 2019 at a spacing of 30 cm and a depth of approximately 5 cm. Thinning was carried out at 21 and 30 DAS to maintain optimum plant population. Weed control was performed manually at 20 and 35 DAS. Aphid infestation was managed by spraying dimethoate at 0.75 ml L^{-1} twice during the cropping period. The crop was harvested at physiological maturity, sun-dried, and threshed for yield estimation.

Observations recorded

Plant height and dry matter accumulation were recorded at 60 and 90 DAS using randomly selected plants from each plot. Yield attributes such as number of siliquae per plant, seeds per siliqua, test weight, seed yield, and harvest index were recorded at harvest. Oil content was determined using the Soxhlet extraction method, and oil yield was calculated accordingly. Composite soil samples (0–15 cm) were collected before sowing and after harvest for the analysis of organic carbon, available nitrogen, phosphorus, potassium, and sulphur using standard laboratory procedures. Soil microbial population was estimated by the serial dilution plate count technique using Jensen's medium and expressed as colony forming units (CFU) g^{-1} soil.

Statistical analysis

The experimental data were analysed using analysis of variance (ANOVA) appropriate for a randomized block design following Panse and Sukhatme (1978). Treatment means were compared using Fisher's 'F' test at a 5% probability level. Standard error of mean (SEm±) and critical difference (CD) values were calculated where treatment effects were significant.

RESULTS AND DISCUSSION

Effect of treatments on Mustard growth characteristics

Plant height of mustard increased progressively from 60 DAS to harvest under all treatments. Integrated nutrient management significantly enhanced plant height compared to the uninoculated control, with the highest values recorded under sulphur application at 60 kg ha^{-1} combined with *Azotobacter* and VAM inoculation (102 cm at 60 DAS and 108.68 cm at harvest). In contrast, the 100% recommended dose of NPK showed lower plant height (82.20 cm and 91.53 cm, respectively). Overall, plant height increased by 0.99–1.22 times at 60 DAS and 0.99–1.19 times at harvest over the control. The improvement was attributed to the role of sulphur in protein synthesis and enhanced enzymatic activity, along with improved root growth, nutrient uptake, and growth-promoting effects of *Azotobacter* and VAM, confirming the effectiveness of integrated use of sulphur and biofertilizers in improving mustard growth. Dry matter accumulation (DMA) of mustard increased steadily with crop age and was significantly higher under all nutrient management treatments compared to the uninoculated control.

Table 3: Effect of treatments on Plant height and DMA of mustard

Treatments	Plant height (cm)		DMA (gm-²)	
	60DAS	90DAS	60DAS	90DAS
T_1 = 100% recommended dose of NPK	83.30	91.56	10.46	12.36
$T_2 = T_1$ + FYM + *Azotobacter*	96.81	101.76	12.34	13.34
$T_3 = T_2$ + VAM	94.15	97.86	14.11	14.11
T_4 = T1 + S@30Kg/ha + *Azotobacter* + VAM	93.54	104.13	11.89	11.89
$T_5 = T_1$ + S@45 Kg/ha + *Azotobacter* + VAM	86.48	101.47	13.76	13.76
$T_6 = T_1$ + S@60 Kg/ha + *Azotobacter* + VAM	93.00	100.04	14.27	15.39
$T_7 = T_2$ + S@30 Kg/ha + VAM	82.30	91.53	13.12	13.12
$T_8 = T_2$ + S@30 Kg/ha + VAM	91.09	101.27	14.12	14.12
$T_9 = T_2$ + S@60 Kg/ha + VAM	102.00	108.68	14.26	14.26
SE (±)	1.10	1.48	0.51	0.53
CD (5%)	2.73	3.67	1.26	1.33
CV (%)	2.09	2.57	7.23	6.43
RBR (0.05)	S	S	S	S

The highest DMA was recorded with sulphur application at 60 kg ha^{-1} combined with dual inoculation of *Azotobacter* and VAM (14.26 g m^{-2} at 60 DAS and 15.39 g m^{-2} at 90 DAS), while the control showed the lowest values. Sulphur

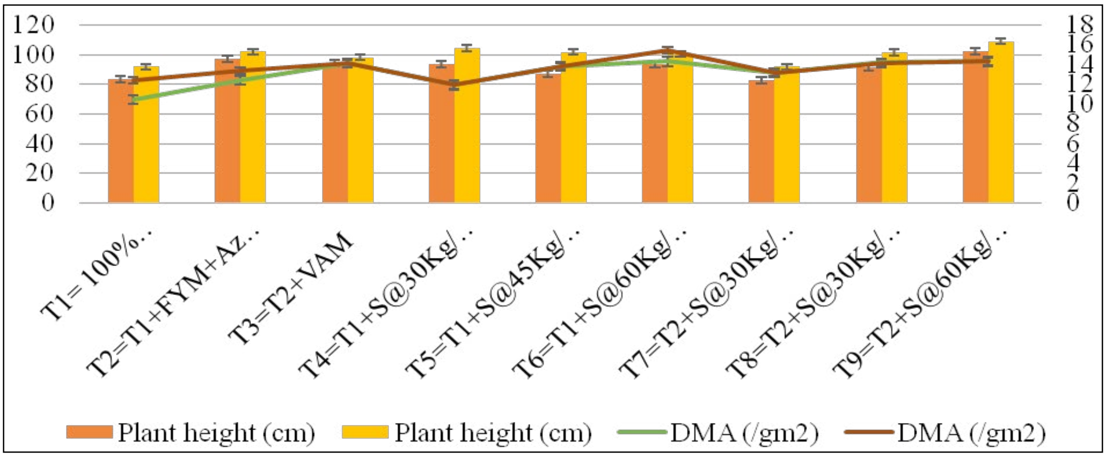

Fig. 1: Effect of treatments on Plant Hight and DMA of mustard

application along with biofertilizer inoculation enhanced biomass production by improving protein synthesis, nutrient uptake, and growth-promoting hormonal activity.

Table 4: Effect of treatments on soil properties

Treatments	Soil properties		
	pH (1:2)	**EC (dS/m)**	**Organic carbon(%)**
T_1 = 100% recommended dose of NPK	5.31	0.32	0.33
T_2 = T_1 + FYM + *Azotobacter*	5.25	0.31	0.47
T_3 = T_2 + VAM	5.30	0.33	0.58
T_4 = T_1 + S@30 Kg/ha + *Azotobacter* + VAM	5.26	0.32	0.37
T_5 = T_1 + S@45 Kg/ha + *Azotobacter* + VAM	5.30	0.33	0.35
T_6 = T_1 + S@60 Kg/ha + *Azotobacter* + VAM	5.30	0.34	0.46
T_7 = T_2 + S@30 Kg/ha + VAM	5.32	0.33	0.34
T_8 = T_2 + S@30 Kg/ha + VAM	5.32	0.32	0.38
T_9 = T_2 + S@60 Kg/ha + VAM	5.35	0.34	0.34
SE (±)	0.28	12.33	0.01
CD (5%)	0.82	34.00	0.04
CV (%)	9.30	5.38	8.43
RBR (0.05)	NS	NS	S

Overall, DMA increased by 1.18–1.37 times at 60 DAS and 0.96–1.24 times at 90 DAS over the control, demonstrating the effectiveness of integrated sulphur and biofertilizer application in improving mustard biomass production. Dry matter accumulation (DMA) in mustard plants increased progressively with plant age, influenced by different combinations of seed inoculation and basal fertilizer application.

Treatments enhanced DMA significantly compared to the uninoculated control, with the highest values (14.26 g/m² at 60 DAS and 15.39 g/m² at 90 DAS) observed under the integrated use of sulphur at 60 kg/ha and dual inoculation of *Azotobacter* and VAM. This increase is attributed to improved nutrient uptake, enhanced synthesis of proteins, and hormonal stimulation by VAM. Overall, the treatments increased DMA by up to 1.37 times at 60 DAS and 1.24 times at 90 DAS over the control.

Effect of Treatments on Soil Fertility Status and Oil Content

The application of different nutrient management treatments significantly influenced the soil fertility status after mustard cultivation. The available nitrogen content in soil was enhanced notably by seed inoculation with *Azotobacter*, particularly when combined with a basal application of sulphur. The treatment involving sulphur @30 kg/ha along with *Azotobacter* and phosphate-solubilizing bacteria (PSB) recorded the highest available nitrogen (374.20 kg/ha), compared to the uninoculated control (299.76 kg/ha). Similarly, available phosphorus content was significantly increased with the application of vesicular arbuscular mycorrhizae (VAM). The treatment comprising sulphur @45 kg/ha with *Azotobacter* and VAM recorded the highest phosphorus availability (71.03 kg/ha), whereas the

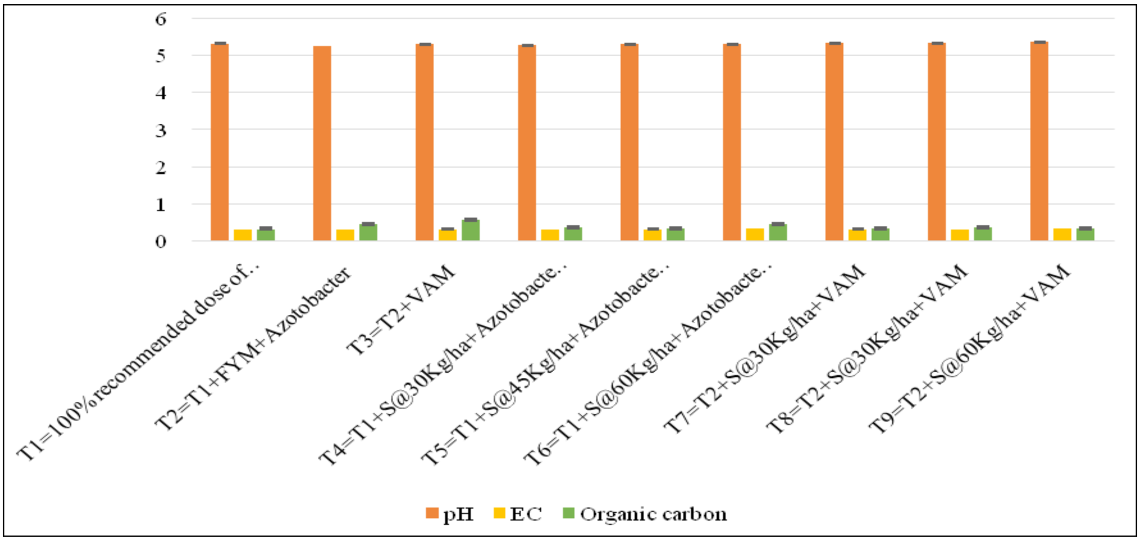

Fig. 2: Effect of treatments on soil properties

control plot showed only 39.52 kg/ha. In the case of available potassium, the highest value (74.96 kg/ha) was recorded in the treatment receiving sulphur @30 kg/ha along with co-inoculation of *Azotobacter* and VAM. Sulphur availability in the soil was also significantly affected by treatments, with the maximum recorded value of 55.93 kg/ha under sulphur @45 kg/ha with VAM and *Azotobacter*, while the 100% recommended dose of NPK had only 29.05 kg/ha. Additionally, the oil content in mustard seeds ranged from 30.67% to 45.67%, with the highest oil percentage obtained under the treatment of sulphur @60 kg/ha along with combined seed inoculation of VAM and *Azotobacter*, followed by sulphur @45 kg/ha with the same biofertilizers (42.00%). This suggests a positive correlation between integrated nutrient management and enhanced oil synthesis in mustard seeds.

Effect of Treatments on Yield Attributes and Yield of Mustard

The yield attributes and productivity of mustard were significantly influenced by integrated application of sulphur and biofertilizers. The maximum number of branches per plant was observed in the treatment receiving a higher dose of sulphur along with co-inoculation of *Azotobacter* and VAM, indicating enhanced vegetative growth under improved nutrient availability. Conversely, the 100% recommended dose of NPKtreatment recorded the

Table 5: Effect of treatments on available nutrients status in soil and oil content

Treatments	Available nutrient(kg/ha)				Oil content (%)
	N	P	K	S	
T_1 = 100% recommended dose of NPK	299.76	39.52	27.59	29.05	30.67
$T_2 = T_1$ + FYM + *Azotobacter*	307.09	46.01	31.84	32.84	27.00
$T_3 = T_2$ + VAM	337.85	31.19	48.16	35.12	25.33
$T_4 = T_1$ + S@30 Kg/ha + *Azotobacter* + VAM	316.83	34.07	36.35	41.52	30.00
$T_5 = T_1$ + S@45 Kg/ha + *Azotobacter* + VAM	307.37	71.03	38.25	46.28	33.00
$T_6 = T_1$ + S@60 Kg/ha + *Azotobacter* + VAM	337.85	28.30	31.31	55.93	37.33
$T_7 = T_2$ + S@30 Kg/ha + VAM	335.93	56.67	74.96	38.48	39.33
$T_8 = T_2$ + S@30 Kg/ha + VAM	374.20	65.69	53.36	50.84	42.00
$T_9 = T_2$ + S@60 Kg/ha + VAM	346.21	33.11	62.92	48.99	45.67
SE (±)	12.28	2.76	1.16	0.90	0.64
CD (5%)	30.41	6.83	2.87	2.23	1.58
CV (%)	6.46	10.62	4.47	3.71	3.21
RBD (0.05)	S	S	S	S	S

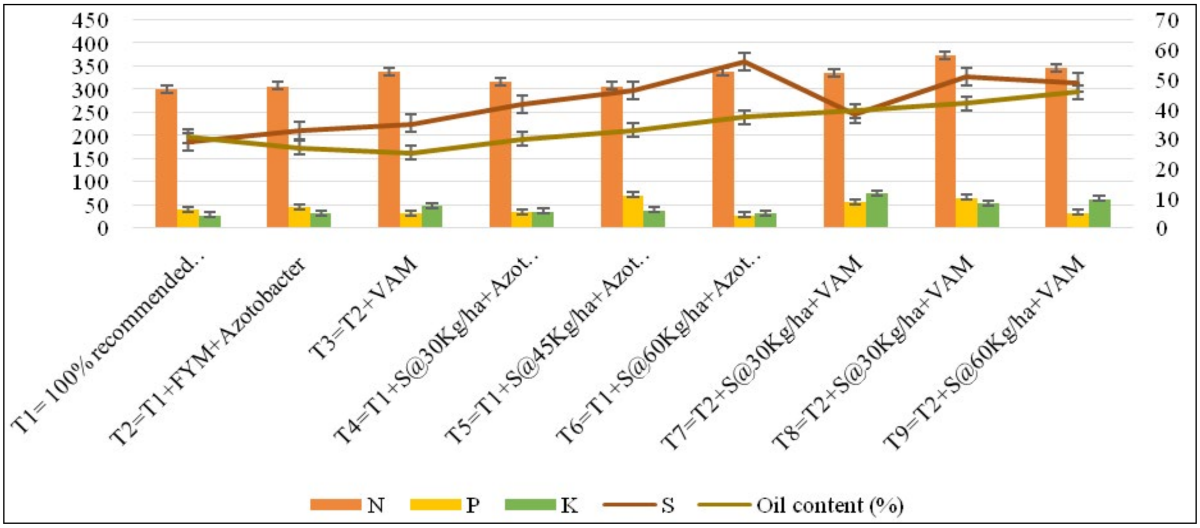

Fig. 3: Effect of treatments on available nutrients status in soil and oil content

lowest number of branches. Similarly, the number of pods per plant was significantly affected by sulphur application. The highest pod number (107.67) was recorded under the treatment with sulphur @45 kg/ha, which was substantially greater than that of the control (59.73). The increased number of pods per plant can be attributed to the improvement in plant growth parameters such as plant height and branch number, as well as enhanced photosynthetic efficiency due to better nutrient uptake facilitated by sulphur and biofertilizer application. These findings underscore the importance of integrating chemical fertilizers with bio-inoculants to maximize both growth and yield attributes in mustard cultivation.

Effects of Treatments on Number of Nitrogen-Fixing Bacteria

The enumeration of nitrogen-fixing bacteria in the soil was undertaken to evaluate the impact of crop growth on the microbial population. The data, summarized in Table 6, provides a comparative analysis of nitrogen-fixing bacterial counts recorded at different stages, particularly emphasizing the status at the time of harvest. The results indicate a notable variation in the population of these beneficial microbes with the progression of the crop cycle. An increase in the number of nitrogen-fixing bacteria was observed

Table 6: Effect of Treatments on Yield Attributes and Yield of Mustard

Treatments	Branches/ plant	Pod per plant	Seed yield	Stalk yield	Biological yield	Harvest index (%)
T_1= 100% recommended dose of NPK	4.87	59.73	601.33	371.03	972.37	61.82
T_2 = T_1 + FYM + *Azotobacter*	5.80	75.07	733.00	431.43	1164.43	62.89
T_3 = T_2 + VAM	6.77	87.20	667.67	455.97	1123.63	59.41
T_4 = T_1 + S@30 Kg/ha + *Azotobacter* + VAM	5.07	72.53	769.00	476.16	1245.16	61.75
T_5 = T_1 + S@45 Kg/ha + *Azotobacter* + VAM	7.80	93.37	675.67	456.13	1131.80	59.69
T_6 = T_1 + S@60 Kg/ha + *Azotobacter* + VAM	7.20	62.20	606.67	466.23	1072.90	56.45
T_7 = T_2 + S@30 Kg/ha + VAM	7.43	72.53	729.00	470.40	1199.40	60.74
T_8 = T_2 + S@30 Kg/ha + VAM	5.00	107.67	507.00	480.60	987.60	51.22
T_9 = T_2 + S@60 Kg/ha + VAM	6.40	95.73	995.33	490.80	1486.13	66.49
SE (±)	5.49	0.51	1.23	3.86	47.88	3.88
CD (5%)	1.26	1.28	3.05	9.55	118.77	8.668
CV (%)	5.19	14.36	4.02	1.61	7.84	1.61
RBD (0.05)	S	S	S	S	S	S

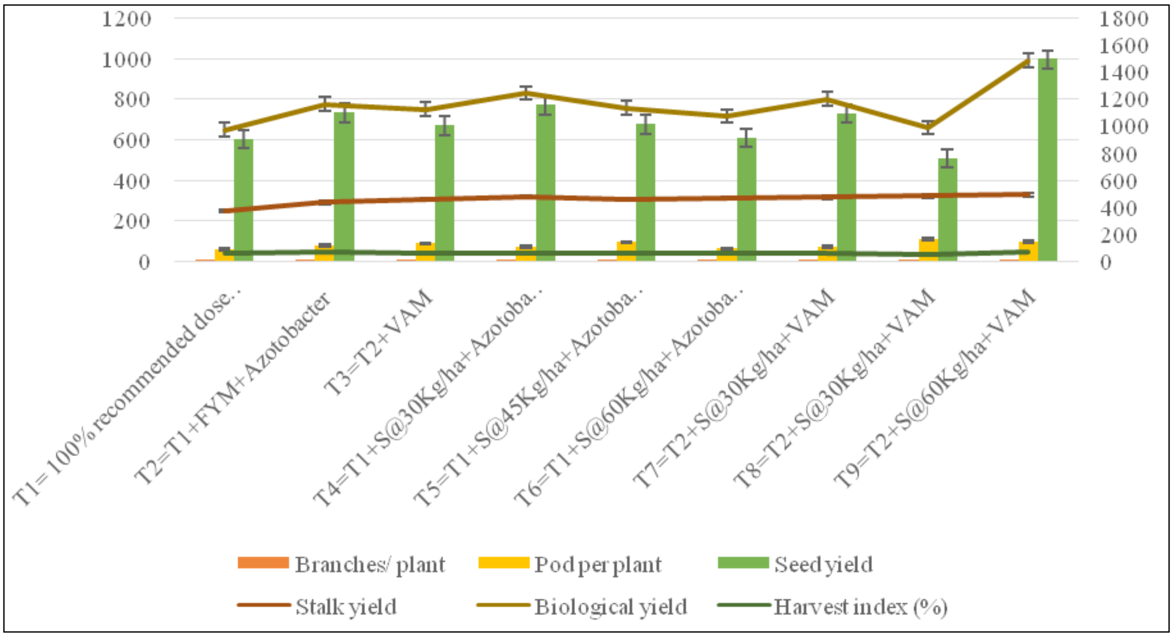

Fig. 4: Effect of Treatments on Yield Attributes and Yield of Mustard

as the crop advanced towards maturity, which is likely due to root exudates and rhizospheric activity promoting microbial proliferation. This trend is visually represented in Fig. 4, which illustrates the dynamic changes in bacterial populations during the crop growth period. Such changes in microbial abundance highlight the symbiotic relationship between plants and soil microorganisms, and underscore the importance of monitoring microbial dynamics as an indicator of soil health and fertility over the course of the cropping season. Nitrogen fixing bacteria depend largely on the concentration of different exchangeable bases and also on some micronutrients.

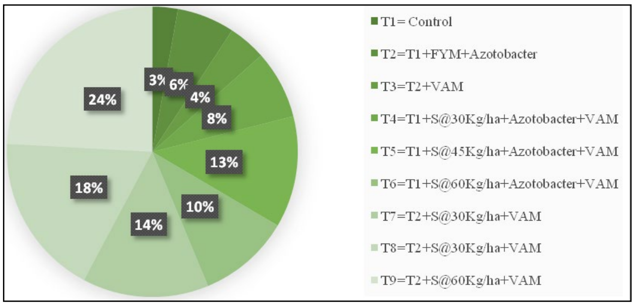

Fig. 5: Effects of treatment on no of *Azotobacter*

Table 7: Effect of treatments on number of *Azotobacter*

Treatments	*Azotobacter* (No×10^6)
T_1 = 100% recommended dose of NPK	2.58
T_2 = T_1 + FYM + *Azotobacter*	5.85
T_3 = T_2 + VAM	3.85
T_4 = T_1 + S@30 Kg/ha + *Azotobacter* + VAM	6.94
T_5 = T_1 + S@45 Kg/ha + *Azotobacter* + VAM	11.33
T_6 = T_1 + S@60 Kg/ha + *Azotobacter* + VAM	9.38
T_7 = T_2 + S@30 Kg/ha + VAM	12.82
T_8 = T_2 + S@30 Kg/ha + VAM	16.51
T_9 = T_2 + S@60 Kg/ha + VAM	22.02
SEm (±)	0.33
CD (5%)	0.82
CV (%)	6.19
RBR (0.05)	S

Number of nitrogen fixing bacteria i.e. *Azotobacter* in soil is increased due to inoculation of bio fertilizers with seed. The seed inoculation exerted significant effect on number of nitrogen fixing bacteria in soil. At harvest stage the number of *Azotobacter* observed highest in treatment sulphur @60 kg/ha + VAM + *Azotobacter* (22.02) which is followed by treatment sulphur @45 kg/ha +VAM + *Azotobacter* (16.51). The lowest no of *Azotobacter* was observed in 100% recommended dose of NPK 2.58. It may be concluded that application of *Azotobacter* along with fertilizer give highest response in number at different growing stage of the crop and it also give highest yield and other produced of mustard.

CONCLUSION

The results show that integrated use of sulphur and biofertilizers can greatly improve the growth, yield, quality, and soil nutrient status of mustard. Application of 60 kg sulphur per ha in the basal dose along with dual inoculation of Azotobacter and VAM increased the parameters of growth, oil content, and dry matter, while sulphur @ 45 kg per ha along with the same inoculums recorded the same yield and performance. Since the latter treatment is more economical, this treatment is recommended for growing mustard. The increased soil nutrient availability and Azotobacter counts in integrated treatments again support the concept that sulphur application in association with biofertilizers can successfully improve the productivity and sustainability of mustard.

REFERENCES

Bray, R.H. and Kurtz, L.T. 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil Science*, **59**(1): 39–46.

FAOSTAT. 2023. *Food and agriculture data*. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat

Government of India. 2024. *Agricultural statistics at a glance 2024*. Ministry of Agriculture & Farmers' Welfare.

Jackson, M.L. 1973. *Soil chemical analysis*. Prentice Hall of India.

Kumar, A., Nagar, R. and Suman, V. 2021. Integrated nutrient management for sustainable mustard production. *Indian Journal of Agronomy*, **66**(2): 145–152.

Meena, R.S., Tripathi, R. and Singh, S. 2020. Role of biofertilizers in improving nutrient use efficiency in oilseed crops. *Journal of Oilseeds Research*, **37**(3): 210–218.

Nagar, S. and Suman, V. 2025. Impact of integrated nutrient management on soil fertility and mustard productivity. *Soil & Fertilizer Science Journal*, **91**(1): 12–20.

Panse, V.G. and Sukhatme, P.V. 1978. *Statistical methods for agricultural workers* (3rd ed.). Indian Council of Agricultural Research.

Pavani, P., Reddy, K.S. and Rao, A.S. 2013. Effect of sulphur fertilization on growth and yield of Indian mustard (*Brassica juncea* L.). *Journal of Oilseeds Research*, **30**(1): 23–28.

Piper, C.S. 1942. *Soil and plant analysis*. Hans Publishers.

Rattan, R.K., Patel, K.P., Manjaiah, K.M. and Datta, S.P. 2019. Micronutrient management in Indian soils for improving crop productivity. *Indian Journal of Fertilisers,* **15**(4): 328–340.

Sattar, M.A. and Gaur, A.C. 1987. Vesicular-arbuscular mycorrhizae: Their role in plant growth and nutrient uptake. *Advances in Soil Science,* **7**: 149–190.

Singh, V., Dwivedi, B.S. and Shukla, A.K. 2022. Soil nutrient constraints and balanced fertilization for oilseed crops in India. *Indian Journal of Agronomy,* **67**(1): 1–10.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science,* **25**: 259–260.

Toth, S.J. and Prince, A.L. 1949. A rapid flame photometric method for the determination of potassium in soils. *Soil Science,* **67**(5): 439–446.

Tripathi, R., Meena, R.S. and Singh, S. 2022. Biofertilizers and their role in enhancing soil fertility in oilseed crops. *Agricultural Reviews,* **43**(2): 87–95.

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science,* **37**(1): 29–38.

Williams, C.H. and Steinbergs, A. 1959. Soil sulphur analysis: Turbidimetric method. *Soil Science Society of America Proceedings,* **23**(2): 140–142.