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EFFECT OF SULPHUR ON GROWTH AND DEVELOPMENT ATTRIBUTES OF MUSTARD (*BRASSICA JUNCEA* L.)

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ABSTRACT

A field experiment was conducted on sandy loam soil during the *Rabi* season of 2025-26 at the Research land of the Agriculture College Garhwa, Bishumpur, Garhwa, Jharkhand to study the influence of sulphur (S) levels on the growth and development attributes of mustard crop. The experiment consisted of six sulphur levels (control, 10, 20, 30, 40 and 50 kg S ha^{-1}) and was laid out in a randomized block design with three replications. The results revealed that all growth and development attributes of mustard were significantly influenced by different sulphur levels compared to the control. Plant height, number of leaves plant^{-1}, leaf area index (LAI), number of branches plant^{-1}, dry matter accumulation plant^{-1} and number of siliques/pods plant^{-1} were significantly higher with the application of 30 kg S ha^{-1}. Significant positive correlations were observed between siliques/pods plant^{-1} and growth parameters. Therefore, the present investigation indicates that application of 30 kg S ha^{-1} in mustard cultivation enhances growth and development, leading to higher yield potential of the crop.

Key words: *Brassica juncea* L., sulphur, growth and development attributes, sandy loam soil.

Introduction

Globally, India ranks third in rapeseed-mustard production after Canada and China, contributing more than 13% of the world's total output during the period 2020-21 to 2024-25. However, India's average yield of 1,461 kg ha^{-1} in 2024-25 is only about 60.7% of the global average yield of 2,070 kg ha^{-1} (Kumar *et al.*, 2025). In Indian agriculture, oilseeds constitute the second most important crop group in terms of area and production, next only to food grains. The country's diverse agro-ecological conditions enable the cultivation of nine annual oilseed crops, namely groundnut, rapeseed–mustard, soybean, sunflower, sesame, safflower, niger seed, castor, and linseed (Patel *et al.*, 2024).

In Jharkhand, mustard is the primary and most important oilseed crop grown during the winter (*Rabi*) season, accounting for approximately 67% of the total oilseed area in the state. The average rapeseed-mustard production in Jharkhand was about 3.37 lakh tonnes during the period 2022-23 to 2024-25 (Kumar *et al.*, 2025). However, the productivity of mustard in Jharkhand, at around 811 kg ha^{-1}, is considerably lower than the national average of about 1461 kg ha^{-1}. This lower productivity is attributed to several factors, including undulating topography, inadequate irrigation facilities, climatic variability, and poor soil fertility resulting from low organic

Table 1: Physiochemical properties of the initial soil of the experimental field.

Sl. No.	Soil Property	Value	Fertility Rating
01.	Texture Sand (%) Silt (%) Clay (%)	 64.45 24.23 11.32	 Sandy loam
02.	pH (1:2.5 soil:water)	5.93	Moderately acidic
03.	Electrical conductivity (dS m^{-1})	0.212	Low
04.	Organic carbon (g kg^{-1})	4.61	Low
05.	Available nitrogen (kg ha^{-1})	294.33	Medium
06.	Available phosphorus (kg ha^{-1})	23.24	Medium
07.	Available potassium (kg ha^{-1})	253.00	Medium
08.	Available sulphur (mg kg^{-1})	9.01	Low

matter content and deficiencies of some importance essential nutrients. Fertilizer application plays a critical role in improving crop productivity, and efficient nutrient management is essential for sustaining and enhancing yield (Sultana *et al.*, 2019; Sultana *et al.*, 2015).

Sulphur (S) is the fourth essential plant nutrient after nitrogen (N), phosphorus (P), and potassium (K), and it plays a vital role in crop yield, quality, and resistance to both abiotic and biotic stresses. Sulphur is a constituent of proteinogenic amino acids such as methionine and cysteine, as well as glutathione, vitamins (biotin and thiamine), phytochelatins, chlorophyll, coenzyme A, and S-adenosyl-methionine (Li *et al.*, 2020). In addition, sulphur is involved in disulfide bond formation, regulation of enzyme activity, and redox homeostasis. It protects plants from oxidative damage through glutathione and its derivatives (AaRabi *et al.*, 2020; Leustek and Saito, 1999). Sulphur also forms an integral component of several plant secondary metabolites and is essential for normal physiological functions, growth, and development.

Nowadays, the inadequate use of organic manures and the indiscriminate application of high-analysis fertilizers with little or no sulphur content have resulted in widespread sulphur deficiencies in the soils of Jharkhand, particularly under intensive cropping systems. Research has shown that sulphur application under irrigated conditions can increase mustard yield by up to 50% (Aulakh, 2003). Therefore, considering the crucial role of sulphur in enhancing mustard growth, yield, and quality, the present study was undertaken to evaluate the effect of sulphur fertilization on mustard grown in Alfisols, with the objective of optimizing crop growth and development while maintaining soil health.

Materials and Methods

The present investigation was conducted during the *Rabi* season of 2025-26 on mustard (*Brassica juncea* L.) variety 45S35 (Pioneer hybrid) at the research field of the Department of Soil Science, Agriculture College Garhwa, Bishumpur, Garhwa (822114), Jharkhand, India, under Birsa Agricultural University, Ranchi. The experimental field is geographically located at 24°092 173 N latitude and 83°472 253 E longitude, with an altitude of 151.3 m above mean sea level.

During the crop growth and development periods (From 30th October 2025 to 3rd February 2026), the weekly mean maximum temperature ranged from 24.5 to 28.3 °C, with an average of 26.5 °C, while the weekly mean minimum temperature ranged from 8.3 to 16.9 °C, with an average of 12.6 °C. The total rainfall received during the crop growth and development periods was 0.0 mm.

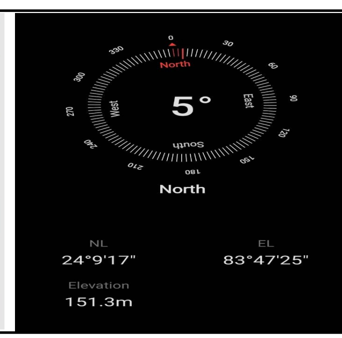
The soil of the experimental field was sandy loam in texture and moderately acidic in reaction (pH 5.93) with low electrical conductivity. It was low in organic carbon and available sulphur, and medium in available nitrogen, phosphorus, and potassium (Table 1).

The experiment consisted of six treatments, including a control and was laid out in a randomized block design (RBD) with three replications. The details of the 18 experimental plots are presented in Table 2.

The main field preparation was done with 2 ploughings and beds were prepared with the help of moldboard plough, rotavator and leveller. Soil was prepared by appropriate amount of well rotted organic manure at rate

Table 2: detail of Experimental plots, design of layout and GPS reading.

Treatment	Replication		
	R_1	R_2	R_3
T_1: 00.0 kg S ha^{-1}	T_1R_1	T_1R_2	T_1R_3
T_2: 10.0 kg S ha^{-1}	T_2R_1	T_2R_2	T_2R_3
T_3: 20.0 kg S ha^{-1}	T_3R_1	T_3R_2	T_3R_3
T_4: 30.0 kg S ha^{-1}	T_4R_1	T_4R_2	T_4R_3
T_5: 40.0 kg S ha^{-1}	T_5R_1	T_5R_2	T_5R_3
T_6: 50.0 kg S ha^{-1}	T_6R_1	T_6R_2	T_6R_3
S mean Sulphur			



of 5.0 tones ha^{-1} and fertilizer at the rate of 80:40:40 kg N, P_2O_5, and K_2O ha^{-1} was applied uniformly to all plots. Half of the nitrogen and the full dose of phosphorus and potassium were applied as a basal dose, while the remaining half of nitrogen was applied in two split doses at 25 and 45 days after sowing (DAS). Nitrogen, phosphorus, and potassium were supplied through urea (46% N), diammonium phosphate (DAP, 46% P_2O_5), and muriate of potash (MoP, 60% K_2O), respectively. Sulphur was applied as bentonite sulphur (90% S) as a basal dose. The crop was sown at a seed rate of 5.0 kg ha^{-1} on surface soil in 3.0 cm deep furrows with 30 cm spacing between rows and 10 cm between plants in the plots that were sized 14.0 m^2 (3.50 m × 4.0 m).

As mustard is a shallow-rooted crop, supplementary light irrigation was provided. Within 90 days after sowing (DAS), five light irrigations were applied: the first immediately after sowing followed by irrigations at 25, 45, 70 and 90 DAS. There were 2 hand weeding were done within 8 weeks of sowing. To control aphids, the insecticide TITLIS (Thiamethoxam 12.6% + Lambda-cyhalothrin 9.5% ZC) was applied at a rate of 1.0 ml L^{-1}. Insecticide was applied three times, starting at 55 DAS, at 15-day intervals.

The collected soil samples were air-dried, ground using a wooden pestle and mortar, and passed through 0.5 and 2.0 mm sieves. The processed samples were stored in properly labeled cloth bags for further analysis. Soil pH and electrical conductivity (EC) were determined in a 1:2.5 soil–water suspension following the method outlined by Jackson (1973). Organic carbon content was estimated using the potassium dichromate–sulfuric acid method described by Walkley and Black (1934). Available nitrogen was determined by the alkaline permanganate method (Subbiah and Asija, 1956). Available phosphorus and potassium were analyzed using the method of Bray and Kurtz (1945) and Gupta (2000), respectively. Available sulfur was determined using 0.15% $CaCl_2$ as the extractant, following the method of Williams and Steinbergs (1959).

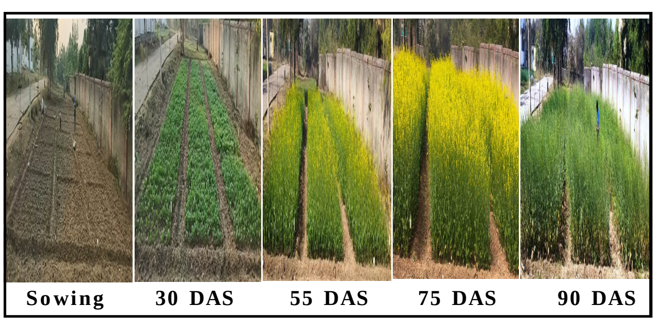


Fig. 1: Some photographs of research field of mustard crop.

Following readings were taken during growing and development periods of mustard crop:

Plant height:

Plant height was measured on 35 randomly selected plants from each plot at four critical growth stages, namely branching (30 DAS), pre-flowering (45 DAS), siliqua/pod formation (65 DAS), and siliqua development/ripening (90 DAS). Measurements were taken from the base of the stem to the tip of the tallest leaf using a measuring scale or tape. The mean plant height was calculated and expressed in centimeters (cm).

Number of leaves plant^{-1}:

The number of leaves plant^{-1} was counted from 35 randomly selected plants in each plot at four critical growth stages: branching (30 DAS), pre-flowering (45 DAS), siliqua/pod formation (65 DAS), and silique development/ripening (90 DAS). The mean number of leaves was calculated and expressed as leaves plant^{-1}.

Leaf area Index:

Leaf area index (LAI) was determined at 60 days after sowing (DAS) using 35 randomly selected plants from each plot. LAI was calculated using the following formula, and the mean value for each plot was computed.

$$LAI = \frac{\text{Total leaf area } (m^2)}{\text{ground area } (m^2)}$$

Number of branching:

The number of primary and secondary branches was counted on 35 randomly selected plants from each plot at 90 days after sowing (DAS). The mean number of branches was calculated and expressed as branches plant^{-1}.

Dry matter accumulation:

Dry matter accumulation was determined by randomly collecting 25 plants from each plot at 35 days after sowing (at mustard greens). The samples were dried in a hot air oven at 45°C overnight. The mean dry matter accumulation was calculated and expressed as g plant^{-1}.

Number of silique:

The number of silique was counted on 35 randomly selected plants from each plot at 90 days after sowing (DAS). The mean number of silique was calculated and expressed as silique plant^{-1}.

Statistical analysis:

The mean values, column charts and line charts were analyzed using Microsoft Excel (Version 2010). Statistical analyses, including analysis of variance, post hoc tests and correlation analyses, were performed using Daniel's XL Toolbox software (Version 5.09).

Table 3: Effect of sulphur (S) on plant height (cm) at different growth stages of mustard crop.

Treatments	Different growth stages			
	30 DAS	45 DAS	65 DAS	90 DAS
00.0 kg S ha^{-1} (Control)	15.71	90.90	111.39	128.21
10.0 kg S ha^{-1}	15.90	101.40	130.16*	147.95*
20.0 kg S ha^{-1}	16.72	124.63	150.04*	167.06*
30.0 kg S ha^{-1}	18.75	139.77*	177.05*	191.42*
40.0 kg S ha^{-1}	17.50	131.51*	160.18*	176.93*
50.0 kg S ha^{-1}	18.14	122.24	148.55*	164.62*

*Significant at $p \leq 0.05$; S mean sulphur; DAS mean days after sowing

Table 4: Effect of sulphur (S) on number of leaves plant^{-1} at different growth stages of mustard crop.

Treatments	Different growth stages			
	30 DAS	45 DAS	65 DAS	90 DAS
00.0 kg S ha^{-1} (Control)	5.84	11.99	15.97	18.82
10.0 kg S ha^{-1}	6.02	12.86	18.56	22.62
20.0 kg S ha^{-1}	6.13	13.21	19.95	25.69
30.0 kg S ha^{-1}	7.20	17.13*	23.53	28.96*
40.0 kg S ha^{-1}	6.85	15.38	22.06	26.85
50.0 kg S ha^{-1}	6.49	14.72	20.06	25.93

*Significant at $p \leq 0.05$; S mean sulphur; DAS mean days after sowing

Results and Discussions

Plant height and branches plant^{-1}

The experimental data (Table 3) showed that the application of 30 kg S ha^{-1} resulted in the greatest plant height at all growth stages (30, 45, 65 and 90 DAS), followed by 40 kg S ha^{-1}. Both sulphur treatments were significantly superior to the control (no sulphur application) at 45, 65 and 90 DAS. In both treatments (30 and 40 kg S ha^{-1}), plant height increased by approximately 54% and 45%, 59% and 44%, and 49% and 38% over the control at 45, 65 and 90 DAS, respectively (Fig. 2).

Increasing doses of sulphur resulted in an increase in both primary and secondary branches of mustard, as also reported by Verma *et al.*, (2018). In the present study, the highest number of both primary and secondary branches was recorded with 30 kg S ha^{-1}, followed by 40 and 50 kg S ha^{-1} (Table 5). All three sulphur treatments were significantly superior to the control (without sulphur application). In three treatments (30, 40 and 50 kg S ha^{-1}), the number of primary and secondary branches plant^{-1} increased by approximately 46%, 44%, and 24%, and 55%, 48%, and 45% over the control, respectively (Fig. 4).

The increase in plant height and branching may be attributed to enhanced cell division, elongation, and expansion, as well as increased chlorophyll synthesis under adequate sulphur nutrition. Sulphur plays a vital role in meristematic tissue activity and shoots development, thereby promoting greater plant height and branching. In addition, improved root development under sulphur application may have enhanced the uptake of other essential nutrients, resulting in increased vegetative growth and taller plants. These findings are in agreement with the results reported by Alam *et al.*, 2014 and Begum *et al.*, 2012. Similarly, previous studies by Anupma, 2024, Kumar *et al.*, 2018, Verma *et al.*, 2018, and Singh and Singh, 2017 reported that sulphur application enhanced plant metabolic functions, including enzyme activation and protein synthesis, thereby contributing to increased plant height.

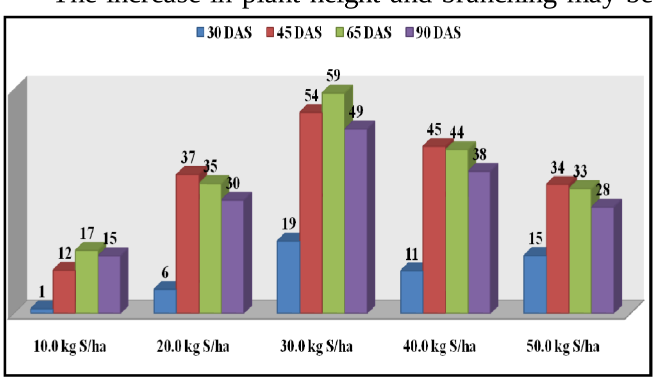


Fig. 2: Percent (%) Response on plant height through different levels of sulphur fertilizations over the control (without sulphur).

Number of leaves plant^{-1} and Leaf area index (LAI)

The experimental data (Table 4) indicated that the application of 30 kg S ha^{-1} produced the highest number of leaves plant^{-1} at all growth stages (30, 45, 65 and 90 DAS). This sulphur treatment was significantly superior to the control (no sulphur application) at 45 and 85 DAS. Compared with the control, the treatments with 30 kg S ha^{-1} increased the number of leaves plant^{-1} by approximately 43% at 45 DAS and 54% at 90 DAS,

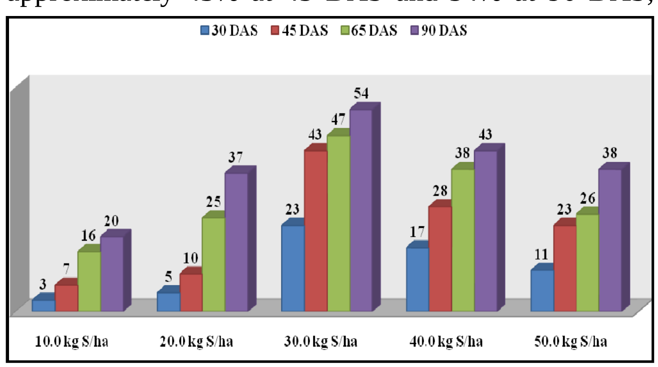


Fig. 3: Percent (%) Response on number of leaves plant^{-1} at different levels of sulphur fertilizations over the control (without sulphur).

Table 5: Effect of sulphur (S) on LAI, branches plant^{-1}, dry matter accumulation plant^{-1} and siliques/pods plant^{-1} of mustard crop.

Treatment	LAI	NPB	NSB	DMA	NSP
T_1: 00.0 kg S ha^{-1}	2.81	4.55	12.88	1.87	144.00
T_2: 10.0 kg S ha^{-1}	3.13	4.74	15.43	2.14	173.67
T_3: 20.0 kg S ha^{-1}	3.51	5.75	17.68	2.81	195.50
T_4: 30.0 kg S ha^{-1}	4.12*	6.65*	20.00*	3.45	220.83*
T_5: 40.0 kg S ha^{-1}	3.87*	6.56*	19.12*	3.13	207.17*
T_6: 50.0 kg S ha^{-1}	3.67*	5.66*	18.68*	2.98	193.00*

LAI; Leaf area Index at 60 DAS; NPB: No. of primary branches plant^{-1} at 90 DAS; NSB: No. of secondary branches plant^{-1} at 90 DAS; DMA: Dry matter accumulation (g plant^{-1}) at 35 DAS; NSP: No. of siliques/pods plant^{-1} at 90 DAS

***Significant at $p \leq 0.05$; S mean sulphur; DAS mean days after sowing**

respectively (Fig. 3).

Sulphur fertilization increased the number of leaves plant^{-1}, which ultimately resulted in a higher leaf area index (LAI). These findings are in close agreement with those reported by Piri and Sharma (2006), Dongarkar *et al.*, (2005) and Verma *et al.*, (2018). In the present study, the highest LAI (4.12) was recorded with 30 kg S ha^{-1}, followed by 40 kg S ha^{-1} (3.87) and 50 kg S ha^{-1} (3.67), while the lowest LAI (2.81) was observed in the control treatment at 60 DAS (Table 5). All three sulphur treatments were significantly superior to the control. At 60 DAS, the leaf area index (LAI) increased by 47%, 38%, and 31% over the control for the treatments of 30, 40, and 50 kg S ha^{-1}, respectively (Fig. 4).

Dry matter accumulation plant^{-1}

Application of sulphur enhanced the available sulphur status of the soil, leading to higher S uptake, which in turn promoted chlorophyll synthesis and dry matter production (Jena *et al.*, 2021). In the present study, the highest dry matter accumulation was recorded with 30

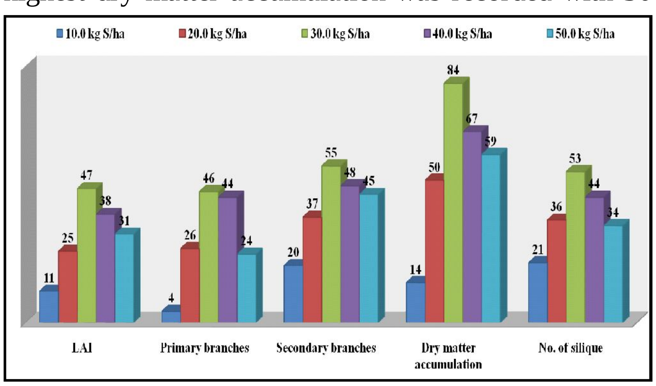


Fig. 4: Percent (%) Response on LAI, primary and secondary branches, dry matter accumulation and no. of siliques/pods at different levels of sulphur fertilizations over the control (without sulphur).

Table 6: Correlation coefficient of no. of siliques/pods plant^{-1} with plant's height, no. of leaves plant^{-1}, leaf area index (LAI), no. of branches plant^{-1}, dry matter accumulation plant^{-1}.

	(r^2)	Significant at $p \leq 0.05$
Plant's height (at 90 DAS)	0.814	Yes
Number of leaves plant^{-1} (at 90 DAS)	0.699	Yes
Leaf area Index (LAI)	0.712	Yes
Number of primary branches plant^{-1} (at 90 DAS)	0.725	Yes
Number of secondary branches plant^{-1} (at 90 DAS)	0.849	Yes
dry matter accumulation plant^{-1} [at 35 DAS (mustard greens)]	0.462	Yes

kg S ha^{-1}, followed by 40, 50 and 20 kg S ha^{-1}, while the lowest dry matter was recorded in the control (Table 5). At 35 DAS (mustard greens), the increases in dry matter accumulation over the control were 50%, 84%, 67% and 59% for 20, 30, 40 and 50 kg S ha^{-1}, respectively (Fig. 4). Sulphur (S) enhanced metabolic activities, contributing to improved overall growth and development of mustard. Improved plant nutrition increased plant height and other growth parameters, leading to greater dry matter accumulation. The rise in dry matter production may be attributed to a higher rate of protein synthesis and enhanced photosynthetic activity, resulting from increased chlorophyll synthesis due to sulphur fertilization. Similar findings have been reported by Rajput *et al.*, (2018), Tetarwal *et al.*, (2013), and Singh and Thenua (2016).

Number of silique/pod plant^{-1}

A significant effect of sulphur treatments was observed on the number of silique plant^{-1} at 90 DAS. The maximum number of silique was recorded with the application of 30 kg S ha^{-1}, which was significantly superior to the control (0.0 kg S ha^{-1}), followed by 40 and 50 kg S ha^{-1} (Table 5). At 90 DAS, the number of silique increased by 53%, 44%, and 34% over the control with the application of 30, 40, and 50 kg S ha^{-1}, respectively (Fig. 4). These results are supported by the findings of

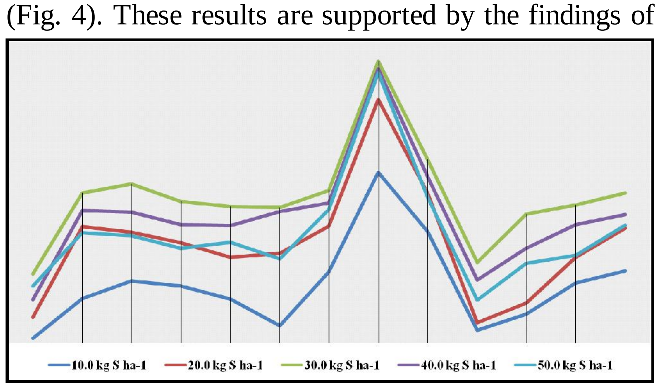


Fig. 5:

Rana *et al.*, (2020), Kumar *et al.*, (2018), Singh *et al.*, (2015), Sultana *et al.*, (2015), Tripathi *et al.*, (2010), Verma *et al.*, (2020), and Verma *et al.*, (2018).

Correlation coefficient

The number of siliques/pods plant^{-1} showed significant positive correlations with plant's height, number of leaves plant^{-1}, leaf area index (LAI), number of primary and secondary branches plant^{-1} and dry matter accumulation plant^{-1} (Table 6).

Conclusions

The present study clearly demonstrates that sulphur is a critical nutrient influencing the growth and development of mustard (*Brassica juncea* L.), particularly under Alfisol soil conditions. Application of sulphur significantly improved key growth and developmental attributes, including height of plant, number of leaves plant^{-1}, leaf area index (LAI), number of branches plant^{-1}, dry matter accumulation plant^{-1} along with number of siliques/pods plant^{-1}. Present research also evaluated that a significant positive correlations were observed between siliques/pods plant^{-1} and growth parameters. Among the six sulphur levels evaluated (0, 10, 20, 30, 40, and 60 kg S ha^{-1}), the application of 30 kg S ha^{-1} consistently resulted in superior performance across all measured parameters, indicating a strong positive response to sulphur fertilization (Fig. 5). Therefore, the findings of the present investigation suggest that application of 30 kg S ha^{-1} is optimal for mustard cultivation, as it enhances growth and development and contributes to higher yield potential.

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