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RESEARCH

Effect of Different Doses of Sulfur on Growth and Yield of Rapeseed (*Brassica campestris* var. Lumle Tori)

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Abstract

Sulfur plays an important role in the growth and yield of rapeseed plants. A field experiment was conducted in a randomized complete block design with seven levels of sulfur (60 kg/ha, 50 kg/ha, 40 kg/ha, 30 kg/ha, 20 kg/ha, 10 kg/ha, and 0 kg/ha in three replicates) to evaluate the effect of different doses of sulfur on the growth and yield of rapeseed (*Brassica campestris* var. Lumle Tori) in Khairahani, Chitwan. Plant height, number of branches per plant, number of pods per plant, pod length, grain per pod, pod weight, fresh weight, dry weight, stover weight, harvest index, and grain yield were recorded. Significant differences were observed in plant height, yield-related traits, and grain yield. The results showed significant differences between the growth and yield-related traits of the different treatments. Plant height and number of branches increased with increasing sulfur dose, reaching a maximum of 60 kg/ha. The maximum number of pods per plant was observed at 20 kg/ha, and the maximum pod length and grain per pod were observed at 60 kg/ha. Grain yield and harvest index were maximum at 20 kg/ha. The results showed that the maximum grain yield could be obtained by applying 20 kg/ha of sulfur. These findings provide valuable guidance for optimizing agricultural practices to meet the increasing global demand for oilseeds.

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Statement of Sustainability: This study highlights the importance of sulfur use in increasing rapeseed growth rate and yield, thereby promoting nutritional diversity, food security, and sustainable agricultural practices. By identifying optimal sulfur levels, the research improves resource efficiency, soil health, climate resilience, and local economies. This information paves the way for informed decisions to promote sustainable, productive, and environmentally responsible agricultural systems that are aligned with broader global sustainability goals.

1. Introduction

Rapeseed (*Brassica campestris* var. Lumle tori) is an important global oilseed crop, known for its oil-rich seeds containing approximately 43% oil and 19% protein (Poisson et al., 2019). Cultivated in the Terai and mid-hills of Nepal, it thrives in cool winter months with high humidity of around 90% for optimal growth and yield. However, excessive moisture, such as from water logging, can adversely affect plant growth. Rapeseed oil is the third most consumed vegetable oil in the world after soybean and palm oil, contributing to approximately 13% of the global oil supply (Raman et al., 2019). Rapeseed is extensively grown in Nepal and contributes to the agricultural economy. Rapeseed is rich in essential fats, proteins, and vitamins, which distinguishes it from the traditional Nepalese diet based on cereals and pulses (Chaudhary, 2001). Rapeseed oil is exceptional for its balanced (1:2) omega-3 to omega-6 ratio, making it a desirable food source. It is also rich in vitamin E, which is important for skin and eye health.

Sulfur, an important macronutrient, is essential for the synthesis of chlorophyll, glucosides, and glucosinolates, the activation of enzymes, and sulfhydryl (SH-) bonds that give oilseeds their pungent flavor (Kumar et al., 2018). Sulfur deficiency mostly results in a decrease in nitrogen uptake, which in turn has a significant impact on yield components and ultimately reduces seed yield (Fismes et al., 2000; Jan et al., 2008; Brennan and Bolland, 2008). Rapeseed has a high sulfur requirement due to its unique growth requirements compared to other crops (Zhao et al., 1997). Despite its global importance, rapeseed yields in Nepal lag due to factors such as soil nutrient imbalance and biological stress (Bhatta et al., 2019). Poor fertilization practices and nutrient depletion due to continuous cultivation affect soil quality, resulting in reduced oilseed quality and yield. Severe sulfur deficiency can eventually lead to reduced growth, especially in terms of reduced shoot-to-root ratio (Hawkesford and DeKok, 2006). Sulfur deficiency further exacerbates these problems by affecting amino acid accumulation and nitrogen uptake, ultimately inhibiting growth, and leading to reduced oilseed yields (De Pascale et al., 2008; Abdallah et al., 2010; D'Hooghe et al., 2013).

With the growing demand for oilseeds, it is important to improve their yield. Improvements in technology and inputs are needed because of the limited expansion of arable land. The efficient use of sulfur in canola makes it an ideal target for yield improvement (Hedge et al., 2009). Optimized sulfur application can lead to improved growth, alleviate nutrient deficiencies, and contribute to the overall goals of oilseed production. The specific objectives of the study include investigating the effects of different sulfur doses on rapeseed growth and productivity and identifying the most effective sulfur dose for maximizing yield and yield-related traits. This research aims to bridge the productivity gap and contribute to the sustainable cultivation of rapeseed in Nepal's agricultural landscape.

2. Materials and Methods

2.1. Study Area and Agroclimatic Conditions

This study was conducted at IAAS Rampur Campus Agricultural Research Field in Khairahani-6, Chitwan, Nepal from December to March 2022. The coordinates of the site were 27.59 °N latitude and 84.7 °E longitude, and it was located 180 m above sea level in the Terai region. The experimental site had a climate with high humidity and warm temperatures and experienced distinct rainy seasons with an annual mean temperature of 26.92 ºC and 232.58 mm of annual rainfall.

2.2. Design of Experiment and Treatment Details

The experiment followed a randomized complete block design (RCBD) with seven sulfur treatment levels and three replications. Each plot was 3 × 2 m, with a total of 21 plots. Lumle tori was used as the cultivar in this study. The treatments used in the experiments were T1 (60 kg S/ha), T2 (50 kg S/ha), T3 (40 kg S/ha), T4 (30 kg S/ha), T5 (20 kg S/ha), T6 (10 kg S/ha), T7 (0 kg S/ha). Figure 1 shows experimental pictures of the rapeseed plant.

Figure 1. Experimental field layout with 21 plots, each containing 7 treatments and 3 replications featuring rapeseed plant growth.

2.3. Land Preparation and Agronomic Practices

The field underwent two rounds of plowing with a tractor-powered plow, followed by cross-harrowing and plowing. Previous crop residues and weeds were removed, and the soil was leveled. Organic manure (6 t/ha) and fertilizers were applied evenly. Di-ammonium Phosphate (DAP), urea, and muriate of potash (MoP) were applied at recommended rates. Seeds were treated with Bavistin before planting. The seed was sown at 6.5 kg/ha with a row spacing of 30 cm and a planting distance of 10 cm. Thinning was done 25 days after sowing (DAS) to achieve optimum plant spacing. For insect control, Imidacloprid 17.8% SL (@1 mL/L water) was sprayed to reduce aphid infestation. Harvest was at 95 DAS followed by thorough threshing.

2.4. Observation of Crop Parameter

Five randomly selected plants per plot were observed for various parameters. Plant height was measured at 30 DAS and 15-day intervals thereafter, and averages were calculated. Effective branches were determined by counting on days 45 and 60 and then converted to averages. The number of pods per plant was recorded at days 45 and 60 and the corresponding averages were calculated at harvest. Pod length was measured at 60, and 70 DAS, during harvest using a measuring scale and then averaged. Grains per pod were determined by counting the sampled plants and determining the mean grain weight. The fresh samples were weighed using a balance. After drying for several days, the dry weight was determined. Stover weight was determined after threshing the plants from each plot. Grain yield was obtained from the entire plot area, adjusted to a moisture content of 9%, and then converted to tons per hectare using the formula presented by Mulvaney et al. (2020).

$$\text{Grain yield at 9\% moisture} = \frac{(100\text{-Moisture Content}) \times \text{Plot Yield (kg)} \times 10000\ m^2}{(100\text{-}9) \times \text{Net Plot Area } (m^2)}$$

The harvest index, which measures the proportion of grain yield to total biological yield, was calculated using the formula presented by Imran et al. (2021):

$$\text{Harvest Index (HI)} = \frac{\text{Grain yield}}{\text{Biological Yield}} \times 100$$

2.5. Statistical Analysis

R-Studio (RStudio, Inc., USA) and Microsoft Excel (Microsoft Corp., USA) were used for data analysis. Statistical analysis was performed using analysis of variance (ANOVA) to determine significant differences between data points. Duncan's Multiple Range Test (DMRT) was used for comparison.

3. Results and Discussion

3.1. Effect on Plant Height of Rapeseed

Sulfur plays an important role in the growth of rapeseed. The application of different doses of sulfur significantly increased plant height (Table 1). The highest plant height was obtained in treatment T1 (20.3 cm) 30 days after sowing (DAS), followed by treatments T4 (18.9 cm) and T2 (18.62 cm). In contrast, the lowest plant height was recorded in T7 (16.97 cm). Similarly, at 45 DAS, the greatest plant height was observed in T1 (54.27 cm), followed by T2 (53.89 cm) and T6 (53.25 cm). Conversely, the shortest plant height (48.44 cm) was observed in treatment T7. After 60 days, the maximum plant height was observed in treatment T2 (74.54 cm), followed by T1 (73.43 cm) and T3 (73.35 cm). In contrast, the control group (T7) had a minimum plant height of 68.35 cm, followed by T5 (70.75 cm).

The reason for the increase in plant height (60 kg/ha) could be the availability of sufficient sulfur, which helps to create a more favorable environment for plant growth during the active growth periods. This leads to increased cell formation, growth, and expression in the plant body, ultimately causing plants to grow taller. Sulfur generally promotes plant growth through cell division, elongation, and expansion. This result is consistent with the findings of Nepalia (2005) and Singh and Meena (2004) in their research on mustard plants. Khatkar et al (2009) reported that higher doses of sulfur fertilization resulted in the tallest plants. This result is consistent with the findings of Nepalia (2005) and Singh and Meena (2004) in their research on mustard. Kapur et al. (2010) observed that the application of 60 kg sulfur per hectare significantly increased the height of mustard plants.

Table 1. Effect of different doses of sulfur on rapeseed plant height.

Treatment	Plant Height @ 30 DAS (cm)	Plant Height @ 45 DAS (cm)	Plant Height @ 60 DAS (cm)
T_1	20.3^{a}	54.27^{a}	73.43^{a}
T_2	18.62^{ab}	53.89^{ab}	74.54^{a}
T_3	18.36^{ab}	52.04^{ab}	73.35^{a}
T_4	18.9^{ab}	50.59^{ab}	70.77^{ab}
T_5	17.49^{ab}	50.83^{ab}	70.75^{ab}
T_6	17.44^{ab}	53.25^{ab}	73.05^{a}
T_7	16.97^{b}	48.44^{b}	68.35^{b}
Grand mean	18.29	51.9	72.036
LSD	3.16	5.66	4.369
F-test	*	*	*
CV%	9.87	6.228	3.46

Means within the column followed by the same letter(s) do not differ significantly from each other at the 5% level of significance and *, ** Significant at $p < 0.05$ and 0.01, respectively; CV = Coefficient of Variation; LSD = Least Significant Difference.

3.2. Effect on Number of Branches Per Plant of Rapeseed

The number of branches per plant showed an increasing trend with increasing sulfur levels (Table 2). At 45 days after sowing (DAS), the highest number of branches per plant was observed in treatment T1 (7.33), closely followed by T2 (7.2), both showing statistically comparable results. The lowest number of branches per plant was observed in the control group (n = 5.4). Similarly, the highest number of branches per plant at 60 DAS was observed in treatment T3 (14.80), followed by T2 (14.60) and T4 (14.33). The lowest number of branches per plant was observed in T6 (11.4), which was similar to the control group. Kapur et al. (2010) reported that the application of 60 kg/ha sulfur significantly increased the number of primary and secondary branches per plant. Sulfur is directly involved in cell growth, proliferation, elongation, and expansion, resulting in the production of more branches and plants compared to plants with deficient sulfur levels. These results were further supported by the findings of Kumar et al. (2000). Rana and Rana (2003) also observed an increase in the number of branches per plant when 60 kg/ha sulfur was applied to mustard.

3.3. Effect on Number of Pods Per Plant of Rapeseed

The number of pods per plant in rapeseed was significantly affected by sulfur application (Table 2). The maximum number of pods per plant (129.73) was observed in T5, followed by T6 (128.27) and T2 (126.87), which were all statistically similar. The lowest number of pods per plant (102.20) was observed at 60 DAS in T7. At 75 DAS, the maximum number of pods per plant was recorded in T2 (127.07), which was statistically similar to T1 and T5. The minimum number of pods per plant was observed at T7 (97.60). No significant differences in the number of pods per plant at harvest were observed among treatments. The application of 20 kg/ha of sulfur resulted in the highest number of pods per plant compared to the other treatments, indicating considerable variation among fertilizer rates (Raza et al., 2021). Amanullah et al. (2011) reported that S fertilization significantly increased the number of pods per plant compared to the control. Subhani et al. (2003) found that the number of pods per plant increased with increasing levels of S up to 40 kg/ha. The successive increase in the number of pods per plant under different doses of N and S may be due to the availability of more nutrients for proper growth of plants at different stages of rapeseed crop. These findings are in full agreement with the results reported earlier by Yasari and Patwardhan (2006).

Table 2. Effect of different doses of sulfur on branch number and pod number per plant of rapeseed.

Treatment	Branches/Plant @ 45 DAS	Branches/Plant @ 60 DAS	Pod Plant @ 60 DAS	Pod Plant @ 75 DAS	Pod Plant @ Harvest
T_1	7.33^{a}	13.07^{ab}	125.73^{abc}	118.87^{ab}	95.67^{a}
T_2	7.2^{ab}	14.60^{a}	126.87^{ab}	127.07^{a}	110.67^{a}
T_3	6^{cd}	14.80^{a}	105.20^{bc}	105.53^{bc}	83.60^{a}
T_4	5.8^{cd}	14.33^{a}	117.67^{abc}	110.93^{bc}	84.47^{a}
T_5	5.53^{d}	13.07^{ab}	129.73^{a}	117.33^{ab}	87.93^{a}
T_6	6.47^{bc}	11.4^{b}	128.27^{ab}	98.60^{c}	98.73^{a}
T_7	5.4^{d}	12.00^{b}	102.20^{c}	97.60^{c}	84.8^{a}
Grand mean	6.247	13.32	119.381	110.847	92.26
LSD	0.79	1.79	23.57	14.28	27.207
F-test	**	**	*	**	NS
CV%	7.259	7.67	11.27	7.359	16.838

Means within the column followed by the same letter(s) do not differ significantly from each other at the 5% level of significance and *, ** Significant at $p < 0.05$ and 0.01, respectively; Coefficient of Variation; LSD = Least Significant Difference.

3.4. Effect on Pod Length of Rapeseed

The application of increasing levels of sulfur significantly increased rapeseed pod length (Table 3). The optimum pod length (5.06 cm) was observed at 60 DAS in T1, followed by T5 (4.92 cm) and T3 (4.86 cm). The lowest pod length was obtained at T6 (4.23 cm), which was similar to the control (4.24 cm). At 75 DAS, the highest pod length was obtained in T1 (5.24 cm), which was statistically similar to that in T5 (5.12 cm), and the lowest length was observed in T7 (4.60 cm). No significant differences in pod length at harvest were observed among treatments. The increase in pod length with increasing sulfur levels can be attributed to the role of sulfur in oilseed growth and development (Khalid et al., 2009). These results are also similar to the findings of Deka et al. (2018).

Table 3. Effect of different doses of sulfur on pod length, grain per pod, and pod weight of rapeseed.

Treatment	Pod Length @ 60 DAS (cm)	Pod Length @ 75 DAS (cm)	Pod Length @ Harvest (cm)	Grains/Pod
T_1	5.06^{a}	5.24^{a}	4.81^{a}	18.39^{a}
T_2	4.77^{ab}	4.78^{cd}	4.68^{a}	16.67^{bc}
T_3	4.86^{a}	4.96^{abc}	4.86^{a}	16.80^{bc}
T_4	4.47^{bc}	4.83^{bcd}	4.67^{a}	16.07^{c}
T_5	4.92^{a}	5.12^{ab}	4.67^{a}	17.53^{ab}
T_6	4.23^{c}	5.09^{abc}	4.91^{a}	16.07^{c}
T_7	4.24^{c}	4.60^{d}	4.87^{a}	16.02^{c}
Grand mean	4.649	4.946	4.78	16.79
LSD	0.36	0.32	0.67	0.96
F-test	**	*	NS	**
CV%	4.469	3.69	8.02	3.26

Means within the column followed by the same letter(s) do not differ significantly from each other at the 5% level of significance and *, ** Significant at $p < 0.05$ and 0.01, respectively; Coefficient of Variation; LSD = Least Significant Difference.

3.5. Effect on Grains Per Pod of Rapeseed

Data analysis showed that different sulfur levels significantly affected grain per pod (Table 3). The maximum number of grains per pod (18.39) was recorded in the treatment of 60 kg/ha S statistically equal to T5 (17.53). The lowest number of grains per pod was observed in T7 (control plot). Higher doses of sulfur may have a beneficial effect due to increased soil sulfur uptake, which improves sink strength and reproductive structure, which in turn increases growth metrics and yields. Significantly higher values of yield-related traits and the number of seeds per siliqua (13.83) were recorded at 60 kg S/ha (Patel et al., 2022). Amanullah et al. (2011) reported that S fertilization significantly increased the number of grains per pod as compared to the control. In another study, Subhani et al. (2003) found that the number of grains per pod increased with increasing levels of S up to 60 kg/ha.

3.6. Effect on Fresh Weight, Dry Weight, and Stover Weight of Rapeseed

Sulfur application significantly affected fresh, dry, and stover weight (Table 4). The maximum fresh, dry, and stover weights obtained in treatment T7 were 3.52 t/ha, 1.66 t/ha, and 1.42 t/ha, respectively. In this study, our stover weight results contrast with the results of Jat et al. (2003) and Piri et al. (2011). These previous studies reported an increase in mustard stover yield with increasing sulfur levels. Moreover, the observed increase in stover yield could be due to an increase in various growth parameters such as plant height, number of primary and secondary branches, and yield-attributing traits such as number of pods per plant. An increase in dry weight was possible due to the photosynthetic rate.

3.7. Effect on Grain Yield of Rapeseed

Different levels of sulfur had a significant ($p \le 0.05$) effect on grain yield (Table 4). The highest grain yield was obtained in treatment T5 (0.265 t/ha), followed by treatment T3 (0.263 t/ha). Conversely, the lowest grain yield was recorded in treatment T7 (0.232 t/ha). Wielebski (2008) reported significantly higher yields after sulfur application at 10-30 kg/ha. The results of these experiments support the finding that the combination of sulfur and nitrogen produces maximum grain yield (Jackson, 2000; Mansoori, 2012). The influence of sulfur on productivity is mainly due to its strong effect on nitrogen metabolism. Sulfur plays an important role in nitrogen metabolism by increasing the rate at which nitrogen absorbed by plants is converted into protein. Nitrogen is the nutrient that has the greatest impact on yield, so by affecting nitrogen metabolism, sulfur directly affects seed yield (Barckzak et al., 2016). Raza et al. (2021) reported that the application of 20 kg S/ha (2.4358 t/ha) resulted in the highest grain yield. Due to the difficulty of moving sulfur from the leaves to other organs, only small amounts of the chemical can be applied to the leaves (Podlesna, 2009). According to Booth et al. (1995), only 2% of sulfate is effectively absorbed by leaves. The rest remains in the soil where it is gradually released and absorbed by the root system.

Table 4. Effect of different doses of sulfur on fresh weight, dry weight, stover weight, and yield of rapeseed.

Treatment	Fresh Weight (t/ha)	Dry Weight (t/ha)	Stover Weight (t/ha)	Grain Yield (t/ha)	Harvest Index (%)
T_1	3.06^{b}	1.43^{bc}	1.18^{b}	0.243^{b}	0.171^{ab}
T_2	2.90^{b}	1.34^{bc}	1.10^{b}	0.244^{b}	0.181^{a}
T_3	3.24^{ab}	1.52^{ab}	1.25^{ab}	0.263^{a}	0.173^{ab}
T_4	3.02^{b}	1.32^{c}	1.08^{b}	0.242^{b}	0.178^{a}
T_5	3.26^{ab}	1.36^{bc}	1.10^{b}	0.265^{a}	0.195^{a}
T_6	3.20^{ab}	1.47^{bc}	1.20^{b}	0.262^{a}	0.179^{a}
T_7	3.52^{a}	1.66^{a}	1.42^{a}	0.232^{b}	0.147^{b}
Grand mean	3.17	1.44	1.19	0.25	0.174
LSD	0.45	0.18	0.169	0.017	0.026
F-test	*	*	*	**	*
CV%	8.16	7.28	8.119	4.05	8.75

Means within the column followed by the same letter(s) do not differ significantly from each other at a 5% level of significance and *, ** Significant at $p < 0.05$ and 0.01, respectively; Coefficient of Variation; LSD = Least Significant Difference.

3.8. Effect on Harvest Index of Rapeseed

The harvest index is an important attribute in determining economy and productivity representing increased physiological capacity to mobilize photosynthesis and transfer it to economically valuable organs (Jamal et al., 2006; Malhi et al., 2007). The different levels of sulfur had non-significant variations in the harvest index of rapeseed (Table 4). The highest harvest index was obtained from T5 (0.195) followed by T2 (0.181). The lowest harvest index was observed at T7 (0.147). Amanullah et al. (2011) reported that sulfur fertilization significantly increased the harvest index as compared to the control.

4. Conclusion

This study highlights the critical role of sulfur in promoting the growth and yield of rapeseed (*Brassica napus*). The results showed that optimal sulfur application at 20 kg/ha significantly influenced several growth parameters such as plant height, number of branches, pod length, and grain per pod. As global demand for oilseeds increases, efficient use of sulfur is a key factor in achieving higher yields and overcoming nutrient-related challenges. This study provides valuable insights to guide agricultural practices aimed at maximizing rapeseed production to meet the growing global demand for edible oils and nutritional resources. In conclusion, this work highlights the significance of sulfur as a crucial element in rapeseed cultivation and provides a foundation for future studies to explore the long-term effects of sulfur application on soil health and environmental sustainability in agriculture. Overall, it suggests the importance of balanced nutrient management in achieving higher crop yields and ensuring food security.

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