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Residual effect of different sources and levels of sulphur on growth, yield attributes and yield of mustard (*Brassica* spp.)

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Abstract

A field experiment was conducted during the Rabi seasons of 2021–22 and 2022–23 at the Instructional-cum-Research Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, to study the residual effect of different sources and levels of sulphur applied to the preceding rice crop on growth, yield attributes and yield of succeeding mustard (*Brassica* spp.). The experiment was laid out in a split-plot design with three replications, comprising nine main-plot treatments representing the residual effect of different sulphur sources and levels applied to the preceding rice crop and three sub-plot fertilizer levels, viz. no RDF, 50% RDF and 100% RDF applied to mustard. The mustard variety Chhattisgarh Sarson was grown by direct sowing at a spacing of 45 × 10 cm. The recommended fertilizer dose for mustard was 100:80:40 kg N: P₂O₅: K₂O ha⁻¹, and no sulphur was directly applied to the succeeding mustard crop. The soil was Kanhar, characterized by low organic carbon, low available nitrogen and sulphur, medium available phosphorus and high available potassium, with neutral soil reaction (pH approximately 7.1). The residual sulphur treatments significantly influenced the growth, yield attributes and seed yield of mustard. Among the residual treatments, T₈, comprising 40 kg S ha⁻¹ through ammonium sulphate in the preceding rice crop, generally recorded the highest values of growth and yield attributes and the highest mean seed yield (16.53 q ha⁻¹) and stover yield (40.07 q ha⁻¹). T₇, comprising 30 kg S ha⁻¹ through ammonium sulphate, generally followed T₈, while T₅, comprising 40 kg S ha⁻¹ through elemental sulphur, was another comparatively superior treatment. The absolute control (T₉) generally recorded the lowest values, with a mean seed yield of 12.71 q ha⁻¹. Direct application of fertilizer to mustard also improved growth and yield, with 100% RDF generally recording the highest values followed by 50% RDF and no RDF. The interaction between residual sulphur treatments and fertilizer levels was significant for selected parameters, number of siliqua plant⁻¹, siliqua length and test weight. The results demonstrated that sulphur applied to the preceding rice crop exerted a measurable residual effect on the succeeding mustard crop and that this residual benefit was further supported by adequate fertilizer nutrition in mustard.

Keywords: Residual sulphur, mustard, *Brassica* spp., ammonium sulphate, elemental sulphur, fertilizer levels, seed yield

1. Introduction

Mustard (*Brassica* spp.) is an important oilseed crop cultivated widely during the *rabi* season and contributes substantially to edible oil production. Sustaining productivity of mustard under intensive cropping systems requires efficient management of plant nutrients. Among the essential nutrients, sulphur has particular importance in oilseed crops because of its role in plant growth, protein synthesis and reproductive development. Adequate sulphur availability is therefore important for obtaining optimum growth, yield attributes and seed yield.

Continuous cultivation and intensive fertilizer use may alter the availability of secondary nutrients in soil. Sulphur removed by crops can contribute to depletion of available sulphur, particularly in soils having initially low sulphur status. The residual availability of sulphur applied to one crop may, therefore, become important for the succeeding crop in a cropping sequence.

The residual effect of sulphur is influenced by its source and level of application. Elemental sulphur undergoes oxidation in soil before becoming available to plants, while ammonium sulphate supplies sulphur in a comparatively readily available form along with nitrogen.

Consequently, the amount and source of sulphur applied to a preceding crop may influence the quantity of sulphur remaining in the soil and its availability to the succeeding crop.

Mustard has a relatively high nutrient requirement and is considered responsive to balanced nutrient management. In a rice–mustard cropping sequence, sulphur applied to the preceding rice crop may provide a residual nutrient contribution to the succeeding mustard crop. However, the magnitude of this residual effect may also depend on the fertilizer supply to mustard itself. Therefore, the present investigation was undertaken to study the residual effect of different sources and levels of sulphur on growth, yield attributes and yield of mustard (*Brassica spp.*).

2. Materials and Methods

2.1 Experimental site

A field experiment was conducted during the rabi seasons of 2021–22 and 2022–23 at the Instructional-cum-research farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh,

India.

The mustard crop was grown as the succeeding crop after rice to evaluate the residual effect of different sulphur treatments imposed on the preceding rice crop.

The experimental soil was Kanhar soil, characterized by low organic carbon, low available nitrogen, medium available phosphorus, high available potassium and low available sulphur. The soil reaction was neutral, with a pH of 7.1.

2.2 Experimental design and treatment structure

The experiment was laid out in a split-plot design with three replications. The experiment comprised nine main-plot treatments representing the residual effect of sulphur management treatments applied to the preceding rice crop and three sub-plot fertilizer levels applied directly to the succeeding mustard crop. The gross plot size was 2.25 m × 5.5 m.

Main-plot treatments: residual sulphur management

Treatment	Description
T ₁	100% P ₂ O ₅ through DAP + 76.53% N through urea
T ₂	100% P ₂ O ₅ through SSP + 100% N through urea
T ₃	100% P ₂ O ₅ through DAP + 76.53% N through urea + 20 kg S ha ⁻¹ through elemental sulphur
T ₄	100% P ₂ O ₅ through DAP + 76.53% N through urea + 30 kg S ha ⁻¹ through elemental sulphur
T ₅	100% P ₂ O ₅ through DAP + 76.53% N through urea + 40 kg S ha ⁻¹ through elemental sulphur
T ₆	100% P ₂ O ₅ through DAP + 59.03% N through urea + 20 kg S ha ⁻¹ through ammonium sulphate
T ₇	100% P ₂ O ₅ through DAP + 50.28% N through urea + 30 kg S ha ⁻¹ through ammonium sulphate
T ₈	100% P ₂ O ₅ through DAP + 41.53% N through urea + 40 kg S ha ⁻¹ through ammonium sulphate
T ₉	Absolute control

These treatments were applied to the preceding rice crop, and their residual effects were evaluated in the succeeding mustard crop.

Sub-plot fertilizer treatments

The succeeding mustard crop received three fertilizer levels:

- F₁: No RDF
- F₂: 50% RDF
- F₃: 100% RDF

The recommended fertilizer dose for mustard was 100:80:40 kg N:P₂O₅:K₂O ha⁻¹.

No sulphur was directly applied to mustard.

2.3 Crop establishment

The mustard variety Chhattisgarh Sarson was used. The crop was established by direct sowing in lines at a spacing of 45 × 10 cm during the rabi seasons of 2021–22 and 2022–23.

2.4 Fertilizer management

The recommended fertilizer dose for mustard was 100:80:40 kg N: P₂O₅: K₂O ha⁻¹. Fertilizers were applied according to the three sub-plot fertilizer treatments, viz. no RDF, 50% RDF and 100% RDF.

No additional sulphur was applied directly to mustard. Thus, the sulphur response observed in mustard was considered to represent the residual effect of sulphur applied to the preceding rice crop.

2.5 Observations recorded

Observations were recorded on plant growth, yield attributes and yield of mustard.

Growth observations

- Plant population (no. m⁻²)

- Plant height (cm)
- Number of branches plant⁻¹
- Dry matter accumulation (g plant⁻¹)

Yield attributes

- Number of siliquae plant⁻¹
- Number of seeds siliqua⁻¹
- Silique length (cm)
- Test weight (g)

Yield observations

- Seed yield (q ha⁻¹)
- Stover yield (q ha⁻¹)
- Harvest index (%)

Observations were recorded during both experimental years and mean values were calculated for interpretation.

2.6 Statistical analysis

The experimental data were statistically analysed according to the procedure appropriate for a split-plot design with three replications. The effects of residual sulphur treatments, fertilizer levels and their interaction were evaluated at the 5% probability level. Where applicable, critical differences were used for comparison of treatment means.

3. Results and Discussion

3.1 Growth parameters

3.1.1 Plant Population

Plant population (no. m⁻²) of mustard influenced by the residual sulphur treatments was non-significant. Among the residual treatments, T₈ recorded the highest mean plant population at harvest (26.77), followed by T₇ (26.76), whereas T₉ recorded the lowest (25.03). Among fertilizer levels, F₃ recorded the highest

mean plant population (26.42), followed by F_2 and F_1 . The relatively higher plant population under the superior treatments may be attributed to better nutrient availability and crop establishment.

3.1.2 Plant height

Plant height increased progressively with crop growth and was favourably influenced by the residual sulphur treatments. T_8 recorded the highest mean plant height at later stages, reaching 173.39 cm at harvest, followed by T_7 (166.50 cm), whereas T_9 (absolute control) recorded the lowest (145.56 cm). Among fertilizer levels, F_3 (100% RDF) recorded the highest plant height (171 cm) followed by F_2 (163.54 cm) and F_1 (143.07 cm). The improvement may be attributed to better nutrient availability and utilization in the succeeding mustard crop. Similar improvement in plant height is reported by Tarafdar *et al.* (2019) [7]

3.1.3 Number of branches plant⁻¹

The number of branches plant⁻¹ increased with crop growth. T_8 recorded the highest mean values, particularly at 60 DAS (5.56) and 90 DAS (11.70), whereas T_9 recorded the lowest. Similarly, F_3 recorded the highest number of branches, followed by F_2 and F_1 . The greater branching under residual sulphur and adequate fertilizer supply indicates improved vegetative development. The results are in agreement with the findings of Singh (2017) [6].

3.1.4 Dry matter accumulation

Dry matter accumulation increased markedly with crop age. T_8 recorded the highest mean dry matter accumulation at, with 51.04 g plant⁻¹ at 60 DAS, 70.56 g plant⁻¹ at 90 DAS and 74.26 g plant⁻¹ at harvest, followed by T_7 , whereas T_9 recorded the lowest values. F_3 also recorded the highest dry matter accumulation (74.49 g plant⁻¹ at harvest). The response indicates a favourable residual effect of sulphur on biomass production. Similar findings also reported by Chandel *et al.* (2002) [2].

3.2 Yield attributes

3.2.1 Number of siliquae plant⁻¹

Residual sulphur significantly influenced siliquae production. T_8 recorded the highest mean number of siliquae plant⁻¹ (146.39), followed by T_7 (141.78) and T_5 (139.11), whereas T_9 recorded the lowest (125.28). Among fertilizer levels, F_3 recorded the highest value (145.79), followed by F_2 and F_1 . Greater siliquae production under T_8 may be associated with better vegetative growth and reproductive development. The results are in agreement with the findings of Rao and Shaktawat (2000) [4].

3.2.2 Number of seeds siliqua⁻¹

The number of seeds siliqua⁻¹ was highest under T_8 (15.69), followed by T_7 (14.96) and T_5 (14.62), while T_9 recorded the lowest (12.32). F_3 recorded the highest mean value (15.24) compared with F_2 (14.14) and F_1 (12.49). Improved sulphur

nutrition may have favoured reproductive development and seed formation. Similar findings also reported by Rao and Shaktawat (2000) [4].

3.2.3 Siliqua length

Siliqua length was highest under T_8 (5.08 cm), followed by T_7 (4.82 cm) and T_5 (4.66 cm), whereas T_9 recorded the lowest (3.74 cm). Fertilizer application also increased siliqua length, with F_3 recording 5.08 cm, followed by F_2 (4.39 cm) and F_1 (3.56 cm). The significant interaction between residual treatment and fertilizer level indicates that siliqua development was influenced by their combined effect. Rao and Shaktawat (2000) [4] Tarafdar *et al.* (2019) [7] are on the same opinion.

3.2.4 Test weight

The residual sulphur treatments significantly affected test weight. T_8 recorded the highest mean value (5.03 g), followed by T_7 (4.96 g) and T_5 (4.91 g), whereas T_9 recorded the lowest (3.89 g). F_3 recorded the highest value (5.01 g), followed by F_2 (4.36 g) and F_1 (3.94 g). The higher seed weight under T_8 indicates improved seed development under favourable residual nutrient availability. Similar findings also reported by Rao and Shaktawat (2000) [4] Tarafdar *et al.* (2019) [7].

3.3 Yield

3.3.1 Seed yield

Seed yield was significantly influenced by the residual sulphur treatments. T_8 recorded the highest mean seed yield (16.53 q ha⁻¹), followed by T_7 (16.00 q ha⁻¹) and T_5 (15.59 q ha⁻¹), whereas T_9 recorded the lowest (12.71 q ha⁻¹). T_8 and T_7 were statistically at par. The higher seed yield under T_8 may be attributed to its favourable effect on plant growth, siliquae production, seeds siliqua⁻¹ and test weight. The results are in agreement with the findings of Tarafdar *et al.* (2019) [7] Singh *et al.* (2008) [5].

3.3.2 Stover yield

Stover yield followed a similar trend. T_8 recorded the highest mean stover yield (40.07 q ha⁻¹), followed by T_7 (38.31 q ha⁻¹) and T_5 (37.53 q ha⁻¹), whereas T_9 recorded the lowest (29.65 q ha⁻¹). The greater stover production was consistent with the higher vegetative growth and dry matter accumulation under the superior residual sulphur treatments. Singh (2017) [6] is on the same opinion.

3.3.3 Harvest Index

Harvest index was not significantly influenced by residual sulphur treatment. Numerically, T_8 recorded the highest mean harvest index (30.34%), followed by T_5 (30.13%), whereas the differences among treatments were relatively small. Thus, the residual sulphur effect was expressed more strongly through seed and stover production than through harvest index.

Table 1: Plant population of mustard as influenced by different treatments

Treatment	Plant population (no. m ⁻²)					
	30 DAS			At harvest		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Residual effect of S managements on succeeding crop						
T_1 : 100% P_2O_5 (D) + 76.53% N (U)	35.45	35.27	35.36	25.70	25.58	25.64
T_2 : 100% P_2O_5 (S) + 100% N (U)	35.74	35.54	35.64	25.99	25.85	25.92
T_3 : 100% P_2O_5 (D) + 76.53% N (U) + 20 kg S ha ⁻¹ (ES)	36.29	36.15	36.22	26.54	26.46	26.50
T_4 : 100% P_2O_5 (D) + 76.53% N (U) + 30 kg S ha ⁻¹ (ES)	37.16	37.06	37.11	27.41	27.37	27.39
T_5 : 100% P_2O_5 (D) + 76.53% N (U) + 40 kg S ha ⁻¹ (ES)	37.23	37.11	37.17	27.48	27.42	27.45
T_6 : 100% P_2O_5 (D) + 59.03% N (U) + 20 kg S ha ⁻¹ (AS)	35.97	35.71	35.84	26.22	26.02	26.12

T ₇ : 100% P ₂ O ₅ (D) + 50.28% N (U) + 30 kg S ha ⁻¹ (AS)	36.64	36.32	36.48	26.89	26.63	26.76
T ₈ : 100% P ₂ O ₅ (D) + 41.53% N (U) + 40 kg S ha ⁻¹ (AS)	36.66	36.31	36.49	26.91	26.62	26.77
T ₉ : Absolute control	34.99	34.52	34.76	25.23	24.83	25.03
SEm±	2.18	3.14	2.66	3.21	3.14	3.17
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Fertilizer levels						
F ₁ : Control	36.21	35.99	36.10	26.45	26.30	26.38
F ₂ : 50% RDF	36.24	36.00	36.12	26.49	26.31	26.40
F ₃ : 100% RDF	36.27	36.01	36.14	26.52	26.32	26.42
SEm±	1.26	1.86	1.56	1.85	1.86	1.86
CD (P=0.05)	NS	NS	NS	NS	NS	NS
SEm±	3.78	5.59	4.68	5.56	5.59	5.57
Interaction (RxF)	NS	NS	NS	NS	NS	NS

*D = DAP, U = Urea, S = SSP, ES = Elemental sulphur & AS = Ammonium sulphate

Table 2: Plant height of mustard at 30 DAS and 60 DAS as influenced by different treatments

Treatment	Plant height (cm)					
	30 DAS			60 DAS		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Residual effect of S managements on succeeding crop						
T ₁ : 100% P ₂ O ₅ (D) + 76.53% N (U)	17.41	17.25	17.33	110.73	106.93	108.83
T ₂ : 100% P ₂ O ₅ (S) + 100% N (U)	18.62	18.44	18.53	112.00	110.10	111.05
T ₃ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 20 kg S ha ⁻¹ (ES)	19.44	19.22	19.33	112.53	110.42	111.47
T ₄ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 30 kg S ha ⁻¹ (ES)	20.01	19.82	19.92	115.40	115.01	115.20
T ₅ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 40 kg S ha ⁻¹ (ES)	20.09	20.01	20.05	117.15	115.71	116.43
T ₆ : 100% P ₂ O ₅ (D) + 59.03% N (U) + 20 kg S ha ⁻¹ (AS)	19.77	19.43	19.60	112.64	111.35	112.00
T ₇ : 100% P ₂ O ₅ (D) + 50.28% N (U) + 30 kg S ha ⁻¹ (AS)	21.02	20.79	20.90	119.80	118.61	119.21
T ₈ : 100% P ₂ O ₅ (D) + 41.53% N (U) + 40 kg S ha ⁻¹ (AS)	22.10	21.84	21.97	122.22	120.61	121.42
T ₉ : Absolute control	15.37	15.10	15.23	104.47	101.44	103.53
SEm±	1.36	1.37	1.35	2.82	2.45	2.47
CD (P=0.05)	NS	NS	NS	8.46	7.35	7.41
Fertilizer levels						
F ₁ : Control	18.32	17.99	18.16	107.47	106.92	107.20
F ₂ : 50% RDF	19.26	19.10	19.18	114.41	112.00	113.20
F ₃ : 100% RDF	20.36	20.20	20.28	120.43	117.80	119.31
SEm±	0.72	0.73	0.73	1.16	1.25	1.04
CD (P=0.05)	NS	NS	NS	3.32	3.57	2.99
SEm±	2.17	2.19	2.18	3.47	3.74	3.07
Interaction (RxF)	NS	NS	NS	NS	NS	NS

*D = DAP, U = Urea, S = SSP, ES = Elemental sulphur & AS = Ammonium sulphate

Table 3: Plant height of mustard at 90 DAS and at harvest as influenced by different treatments

Treatment	Plant height (cm)					
	90 DAS			At harvest		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Residual effect of S managements on succeeding crop						
T ₁ : 100% P ₂ O ₅ (D) + 76.53% N (U)	145.56	142.22	143.89	151.11	149.44	150.28
T ₂ : 100% P ₂ O ₅ (S) + 100% N (U)	148.89	146.67	147.78	153.33	152.22	152.78
T ₃ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 20 kg S ha ⁻¹ (ES)	150.36	147.59	148.97	158.02	155.78	156.90
T ₄ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 30 kg S ha ⁻¹ (ES)	154.63	156.11	155.37	164.44	161.44	162.94
T ₅ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 40 kg S ha ⁻¹ (ES)	156.80	156.22	156.51	165.56	161.78	163.67
T ₆ : 100% P ₂ O ₅ (D) + 59.03% N (U) + 20 kg S ha ⁻¹ (AS)	150.40	148.62	149.51	161.27	160.38	160.82
T ₇ : 100% P ₂ O ₅ (D) + 50.28% N (U) + 30 kg S ha ⁻¹ (AS)	160.69	157.30	158.99	168.33	164.67	166.50
T ₈ : 100% P ₂ O ₅ (D) + 41.53% N (U) + 40 kg S ha ⁻¹ (AS)	167.36	163.41	165.38	174.50	172.28	173.39
T ₉ : Absolute control	142.22	140.00	141.11	146.67	144.44	145.56
SEm±	4.63	4.88	4.72	3.48	2.57	2.89
CD (P=0.05)	13.88	14.63	14.15	10.42	7.72	8.66
Fertilizer levels						
F ₁ : Control	141.03	140.09	140.56	144.70	141.44	143.07
F ₂ : 50% RDF	155.03	151.40	153.21	164.31	162.76	163.54
F ₃ : 100% RDF	162.91	161.23	162.07	172.06	169.94	171.00
SEm±	2.19	2.23	2.18	1.87	1.74	1.72
CD (P=0.05)	6.28	6.38	6.24	5.35	4.98	4.92
SEm±	6.57	6.68	6.53	5.60	5.21	5.15
Interaction (RxF)	NS	NS	NS	NS	NS	NS

*D = DAP, U = Urea, S = SSP, ES = Elemental sulphur & AS = Ammonium sulphate

Table 4: Number of branches plant⁻¹ of mustard as influenced by different treatments

Treatment	Number of branches plant ⁻¹								
	60 DAS			90 DAS			At harvest		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Residual effect of S managements on succeeding crop									
T ₁ : 100% P ₂ O ₅ (D) + 76.53% N (U)	4.85	4.92	4.89	9.47	9.41	9.44	9.54	9.64	9.59
T ₂ : 100% P ₂ O ₅ (S) + 100% N (U)	4.88	4.99	4.94	9.69	9.62	9.66	9.72	9.88	9.80
T ₃ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 20 kg S ha ⁻¹ (ES)	4.91	5.05	4.98	10.05	9.98	10.02	10.09	10.16	10.12
T ₄ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 30 kg S ha ⁻¹ (ES)	5.08	5.22	5.15	10.66	10.60	10.63	10.71	10.82	10.77
T ₅ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 40 kg S ha ⁻¹ (ES)	5.11	5.23	5.17	11.03	10.97	11.00	11.08	11.18	11.13
T ₆ : 100% P ₂ O ₅ (D) + 59.03% N (U) + 20 kg S ha ⁻¹ (AS)	4.94	5.08	5.01	10.37	10.32	10.34	10.32	10.51	10.42
T ₇ : 100% P ₂ O ₅ (D) + 50.28% N (U) + 30 kg S ha ⁻¹ (AS)	5.20	5.27	5.24	11.46	11.19	11.32	11.28	11.38	11.33
T ₈ : 100% P ₂ O ₅ (D) + 41.53% N (U) + 40 kg S ha ⁻¹ (AS)	5.41	5.71	5.56	11.72	11.68	11.70	11.78	11.95	11.86
T ₉ : Absolute control	4.56	4.61	4.59	9.08	9.03	9.17	9.10	9.17	9.12
SEm±	0.15	0.17	0.15	0.39	0.39	0.39	0.48	0.45	0.46
CD (P=0.05)	0.45	0.51	0.45	1.17	1.18	1.16	1.44	1.34	1.39
Fertilizer levels									
F ₁ : Control	4.61	4.63	4.58	9.13	9.03	9.19	9.10	9.19	9.14
F ₂ : 50% RDF	4.97	5.10	5.04	10.48	10.41	10.33	10.50	10.65	10.46
F ₃ : 100% RDF	5.39	5.63	5.55	11.56	11.50	11.57	11.61	11.73	11.78
SEm±	0.13	0.14	0.13	0.18	0.18	0.18	0.24	0.25	0.25
CD (P=0.05)	0.38	0.39	0.36	0.52	0.51	0.51	0.70	0.72	0.70
SEm±	0.40	0.41	0.38	0.55	0.53	0.54	0.73	0.75	0.74
Interaction (RxF)	NS	NS	NS	NS	NS	NS	NS	NS	NS

*D = DAP, U = Urea, S = SSP, ES = Elemental sulphur & AS = Ammonium sulphate

Table 5: Dry matter accumulation of mustard at 30 DAS and 60 DAS as influenced by different treatments

Treatment	Dry matter accumulation (g plant ⁻¹)					
	30 DAS			60 DAS		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Residual effect of S managements on succeeding crop						
T ₁ : 100% P ₂ O ₅ (D) + 76.53% N (U)	4.11	3.84	3.98	39.52	36.32	37.92
T ₂ : 100% P ₂ O ₅ (S) + 100% N (U)	4.28	3.87	4.08	44.11	41.58	42.85
T ₃ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 20 kg S ha ⁻¹ (ES)	4.37	4.17	4.27	44.29	44.13	44.21
T ₄ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 30 kg S ha ⁻¹ (ES)	4.66	4.55	4.60	46.74	45.33	46.04
T ₅ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 40 kg S ha ⁻¹ (ES)	4.69	4.56	4.63	48.06	45.40	46.73
T ₆ : 100% P ₂ O ₅ (D) + 59.03% N (U) + 20 kg S ha ⁻¹ (AS)	4.50	4.33	4.41	45.11	44.62	44.87
T ₇ : 100% P ₂ O ₅ (D) + 50.28% N (U) + 30 kg S ha ⁻¹ (AS)	4.80	4.79	4.80	48.19	48.66	48.42
T ₈ : 100% P ₂ O ₅ (D) + 41.53% N (U) + 40 kg S ha ⁻¹ (AS)	4.84	4.79	4.82	51.77	50.32	51.04
T ₉ : Absolute control	3.84	3.80	3.56	35.68	33.41	34.32
SEm±	0.54	0.53	0.56	1.85	1.67	1.75
CD (P=0.05)	NS	NS	NS	0.83	5.02	5.24
Fertilizer levels						
F ₁ : Control	3.90	3.97	3.94	39.09	36.14	37.62
F ₂ : 50% RDF	4.61	4.35	4.48	44.53	43.66	44.09
F ₃ : 100% RDF	4.86	4.58	4.63	50.87	50.13	50.42
SEm±	0.41	0.29	0.25	5.53	0.87	0.84
CD (P=0.05)	NS	NS	NS	2.39	2.48	2.42
SEm±	1.24	0.87	0.74	2.50	2.60	2.53
Interaction (RxF)	NS	NS	NS	NS	NS	NS

*D = DAP, U = Urea, S = SSP, ES = Elemental sulphur & AS = Ammonium sulphate

Table 6: Dry matter accumulation of mustard at 90 DAS and at harvest as influenced by different treatments

Treatment	Dry matter accumulation (g plant ⁻¹)					
	90 DAS			At harvest		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Residual effect of S managements on succeeding crop						
T ₁ : 100% P ₂ O ₅ (D) + 76.53% N (U)	53.72	51.71	52.71	57.40	55.88	56.64
T ₂ : 100% P ₂ O ₅ (S) + 100% N (U)	56.25	54.74	55.50	60.79	58.48	59.63
T ₃ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 20 kg S ha ⁻¹ (ES)	58.11	58.37	58.24	64.00	61.70	62.85
T ₄ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 30 kg S ha ⁻¹ (ES)	65.02	63.11	64.07	69.11	67.28	68.19
T ₅ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 40 kg S ha ⁻¹ (ES)	66.22	64.16	65.19	69.34	68.44	68.89
T ₆ : 100% P ₂ O ₅ (D) + 59.03% N (U) + 20 kg S ha ⁻¹ (AS)	59.41	61.09	60.25	67.78	62.45	65.12
T ₇ : 100% P ₂ O ₅ (D) + 50.28% N (U) + 30 kg S ha ⁻¹ (AS)	68.74	66.54	67.64	72.71	70.15	71.43
T ₈ : 100% P ₂ O ₅ (D) + 41.53% N (U) + 40 kg S ha ⁻¹ (AS)	71.48	69.65	70.56	75.40	73.12	74.26
T ₉ : Absolute control	45.79	43.40	44.37	48.11	47.70	48.25

SEm±	2.29	2.20	2.25	2.37	2.26	1.69
CD (P=0.05)	6.87	6.61	6.74	7.10	6.79	5.07
Fertilizer levels						
F ₁ : Control	49.52	48.04	48.78	52.17	49.92	51.04
F ₂ : 50% RDF	61.73	61.04	61.38	66.74	65.70	66.22
F ₃ : 100% RDF	70.33	68.52	69.35	75.97	72.78	74.49
SEm±	1.60	1.48	1.50	1.65	1.57	1.31
CD (P=0.05)	4.59	4.24	4.31	4.74	4.49	3.77
SEm±	4.80	4.43	4.51	4.96	4.70	3.94
Interaction (RxF)	NS	NS	NS	NS	NS	NS

*D = DAP, U = Urea, S = SSP, ES = Elemental sulphur & AS = Ammonium sulphate

Table 7: Number of siliquae plant⁻¹ and number of seeds siliqua⁻¹ of mustard as influenced by different treatments

Treatment	Number of siliquae plant ⁻¹			Number of seeds siliqua ⁻¹		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Residual effect of S managements on succeeding crop						
T ₁ : 100% P ₂ O ₅ (D) + 76.53% N (U)	130.56	128.87	129.71	13.06	13.02	13.04
T ₂ : 100% P ₂ O ₅ (S) + 100% N (U)	133.89	131.67	132.78	13.21	13.18	13.19
T ₃ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 20 kg S ha ⁻¹ (ES)	135.67	132.62	134.14	13.67	13.62	13.64
T ₄ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 30 kg S ha ⁻¹ (ES)	138.78	136.57	137.67	14.33	14.10	14.22
T ₅ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 40 kg S ha ⁻¹ (ES)	140.11	138.11	139.11	14.64	14.59	14.62
T ₆ : 100% P ₂ O ₅ (D) + 59.03% N (U) + 20 kg S ha ⁻¹ (AS)	136.56	133.99	135.27	14.00	13.88	13.94
T ₇ : 100% P ₂ O ₅ (D) + 50.28% N (U) + 30 kg S ha ⁻¹ (AS)	143.33	140.22	141.78	15.00	14.91	14.96
T ₈ : 100% P ₂ O ₅ (D) + 41.53% N (U) + 40 kg S ha ⁻¹ (AS)	147.68	145.11	146.39	15.78	15.61	15.69
T ₉ : Absolute control	127.22	125.56	125.28	12.35	12.29	12.32
SEm±	3.70	3.67	3.39	0.51	0.51	0.51
CD (P=0.05)	11.11	10.99	10.18	1.53	1.52	1.52
Fertilizer levels						
F ₁ : Control	128.96	125.74	127.35	12.65	12.33	12.49
F ₂ : 50% RDF	134.93	133.54	134.23	14.18	14.11	14.14
F ₃ : 100% RDF	147.37	144.96	145.79	15.19	15.29	15.24
SEm±	3.03	3.08	3.06	0.29	0.25	0.27
CD (P=0.05)	8.70	8.83	8.77	0.83	0.71	0.76
SEm±	9.10	9.24	9.18	0.86	0.74	0.80
Interaction (RxF)	S	S	S	NS	NS	NS

*D = DAP, U = Urea, S = SSP, ES = Elemental sulphur & AS = Ammonium sulphate

Table 8: Length of siliqua and test weight of mustard as influenced by different treatments

Treatment	Length of siliqua (cm)			Test weight (g)		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Residual effect of S managements on succeeding crop						
T ₁ : 100% P ₂ O ₅ (D) + 76.53% N (U)	3.91	3.82	3.87	3.99	3.87	3.93
T ₂ : 100% P ₂ O ₅ (S) + 100% N (U)	4.00	3.97	3.99	4.07	4.01	4.04
T ₃ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 20 kg S ha ⁻¹ (ES)	4.17	4.11	4.14	4.22	4.13	4.18
T ₄ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 30 kg S ha ⁻¹ (ES)	4.70	4.43	4.57	4.60	4.51	4.56
T ₅ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 40 kg S ha ⁻¹ (ES)	4.75	4.56	4.66	4.96	4.87	4.91
T ₆ : 100% P ₂ O ₅ (D) + 59.03% N (U) + 20 kg S ha ⁻¹ (AS)	4.29	4.20	4.25	4.49	4.39	4.44
T ₇ : 100% P ₂ O ₅ (D) + 50.28% N (U) + 30 kg S ha ⁻¹ (AS)	4.88	4.77	4.82	4.99	4.92	4.96
T ₈ : 100% P ₂ O ₅ (D) + 41.53% N (U) + 40 kg S ha ⁻¹ (AS)	5.13	5.02	5.08	5.07	5.00	5.03
T ₉ : Absolute control	3.76	3.68	3.74	3.93	3.84	3.89
SEm±	0.15	0.20	0.17	0.19	0.19	0.19
CD (P=0.05)	0.45	0.59	0.52	0.57	0.57	0.57
Fertilizer levels						
F ₁ : Control	3.61	3.52	3.56	3.97	3.90	3.94
F ₂ : 50% RDF	4.46	4.32	4.39	4.43	4.30	4.36
F ₃ : 100% RDF	5.14	5.02	5.08	5.04	4.98	5.01
SEm±	0.05	0.07	0.05	0.04	0.04	0.04
CD (P=0.05)	0.13	0.21	0.15	0.10	0.10	0.10
SEm±	0.14	0.22	0.16	0.11	0.11	0.11
Interaction (RxF)	S	S	S	S	S	S

*D = DAP, U = Urea, S = SSP, ES = Elemental sulphur & AS = Ammonium sulphate

Table 9: Seed yield, stover yield and harvest index of mustard as influenced by different treatments

Treatment	Seed yield (q ha ⁻¹)			Stover yield (q ha ⁻¹)			Harvest index		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Residual effect of S managements on succeeding crop									
T ₁ : 100% P ₂ O ₅ (D) + 76.53% N (U)	14.71	12.73	13.72	33.62	31.11	32.37	29.49	28.80	29.15
T ₂ : 100% P ₂ O ₅ (S) + 100% N (U)	15.01	13.09	14.05	35.22	33.65	34.44	29.32	28.72	29.02
T ₃ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 20 kg S ha ⁻¹ (ES)	15.22	13.21	14.21	37.50	34.23	35.87	29.55	29.64	29.60
T ₄ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 30 kg S ha ⁻¹ (ES)	16.24	14.13	15.18	38.15	35.62	36.89	28.83	28.81	28.82
T ₅ : 100% P ₂ O ₅ (D) + 76.53% N (U) + 40 kg S ha ⁻¹ (ES)	16.88	14.31	15.59	38.62	36.44	37.53	30.06	30.21	30.13
T ₆ : 100% P ₂ O ₅ (D) + 59.03% N (U) + 20 kg S ha ⁻¹ (AS)	15.39	14.06	14.73	37.64	34.39	36.02	27.78	29.36	28.57
T ₇ : 100% P ₂ O ₅ (D) + 50.28% N (U) + 30 kg S ha ⁻¹ (AS)	17.01	15.00	16.00	39.45	37.17	38.31	29.45	30.52	29.98
T ₈ : 100% P ₂ O ₅ (D) + 41.53% N (U) + 40 kg S ha ⁻¹ (AS)	17.32	15.74	16.53	41.36	38.78	40.07	30.02	30.66	30.34
T ₉ : Absolute control	13.64	11.78	12.71	30.62	28.43	29.65	29.10	29.41	29.15
SEm±	0.63	0.54	0.57	1.24	1.45	1.28	1.10	1.34	0.91
CD (P=0.05)	1.90	1.62	1.71	3.71	4.35	3.84	NS	NS	NS
Fertilizer levels									
F ₁ : Control	13.05	11.10	12.08	31.30	29.14	30.22	28.95	28.74	28.84
F ₂ : 50% RDF	16.22	14.47	15.35	38.77	35.79	37.28	28.72	29.59	29.16
F ₃ : 100% RDF	17.86	15.77	16.82	40.66	38.34	39.54	30.20	30.38	30.26
SEm±	0.44	0.46	0.44	0.88	0.84	0.85	0.67	0.79	0.60
CD (P=0.05)	1.26	1.33	1.26	2.52	2.40	2.44	NS	NS	NS
SEm±	1.32	1.39	1.31	2.64	2.51	2.55	2.00	2.38	1.79
Interaction (RxF)	NS	NS	NS	NS	NS	NS	NS	NS	NS

*D = DAP, U = Urea, S = SSP, ES = Elemental sulphur & AS = Ammonium sulphate

4. Conclusion

The present investigation demonstrated that different sources and levels of sulphur applied to the preceding rice crop exerted a measurable residual effect on the growth, yield attributes and productivity of succeeding mustard. Among the residual treatments, 40 kg S ha⁻¹ through ammonium sulphate (T₈) generally recorded the highest growth and yield attributes and the highest mean seed yield (16.53 q ha⁻¹) and stover yield (40.07 q ha⁻¹), while the absolute control (T₉) recorded the lowest performance. T₇, comprising 30 kg S ha⁻¹ through ammonium sulphate, generally followed T₈ and was statistically at par with T₈ for seed yield, whereas T₅, comprising 40 kg S ha⁻¹ through elemental sulphur, was another comparatively superior treatment. Direct application of fertilizer to mustard also improved crop growth, yield attributes and yield, with 100% RDF generally performing better than 50% RDF and no RDF. The residual effect was particularly evident in plant height, branching, dry matter accumulation, silique production, seeds silique⁻¹, silique length, test weight and seed yield. Therefore, under the conditions of the present investigation, application of 40 kg S ha⁻¹ through ammonium sulphate to the preceding rice crop, followed by adequate fertilizer management of the succeeding mustard crop, was the most promising nutrient-management approach for enhancing productivity of mustard in the rice–mustard cropping sequence.

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