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Response of Sulphur Nutrition and Mulching on Indian mustard (*Brassica napes* L.)

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Authors' contributions

This work was carried out in collaboration between all authors. Authors SJ and TN designed the study and performed the statistical analysis. Authors DK and SK wrote the first draft of the manuscript. Authors TN and DK managed the analyses of the study. Authors SK and DK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Field experiment was conducted to study the effect of sulphur nutrition and mulching on Indian mustard (*Brassica napes* L.) at Rajeev Gandhi South Campus (Banaras Hindu University), Mirzapur, Uttar Pradesh during rainy season of 2013. Three levels of sulphur 20 kg ha^{-1} S (S_1), 40 kg ha^{-1} S (S_2), 60 kg ha^{-1} S (S_3) and five levels of mulching, Zero mulch (M_0), paddy straw @ 4 t ha^{-1} (M_1), wheat straw @ 6 t ha^{-1} (M_2), legume straw @ 5 t ha^{-1} (M_3), and green weed mulch @ 12 t ha^{-1} (M_4) were included in the experiments. Variety named 'PT-303' was selected for experimental study which was suitable for soils of Vindhyan region. Results showed that, plant height (98.9 cm), plant dry weight (32.1 g), length of siliquae (6.20 cm), seed siliquae^{-1} (16.5), test weight (3.07 gm) were recorded highest in $S_2 \times M_1$ treatment combination as well as changes in soil physical, and chemical properties. Significantly the highest results were recorded in S_2 (S_{40} kg ha^{-1}) along with M_1

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paddy straw @ 4 ha^{-1} ($S_2 \times M_1$) in growth as well as yield attributing characters of Indian Mustard. In terms of nutrient uptake highest nitrogen as well as sulphur uptake noticed in S_2M_1. Soil samples collected after harvesting of mustard crop showed the highest nitrogen 223.90 N kg ha^{-1}, phosphorus 26.90 kg ha^{-1}, organic carbon 0.410% and water holding capacity 43.60% in S_2M_3 treatment combination. The combined application of 40 kg ha^{-1} with paddy straw was superior all over the treatments combinations.

Keywords: Sulphur; Indian mustard; mulch; physico-chemical properties.

1. INTRODUCTION

Rapeseeds mustard is an important oilseed crop which ranks third in vegetable oils after soybean and palm while second in oilseed proteins production after soybean in the world [1]. Annual production of rapeseed-mustard in India was about 8.02 mt covering an area of about 6.40 mha with a total productivity of 12.62 q ha^{-1} [2,3]. It is estimated that 58 mt of oilseeds will be required by the year 2020, wherein the share of rapeseed-mustard will be around 24.2 mt [4]. During the last seven years, there has been a considerable increase in productivity from 1750 kg ha^{-1} in 2006-07 to 1850 kg ha^{-1} in 2012-13 and production has also increased from 46.27 m t in 2006-07 to 63.09 m t in the 2012-13 [5]. Rapeseed-mustard crops in India are grown in diverse agro climatic conditions ranging from north eastern/north western hills to down south under irrigated/rainfed, timely/late sown, saline soils and mixed cropping. Indian mustard accounts for about 75-80 % of the 6.6 m ha under these crops in the country during 2013-14 crop seasons. Global production of rapeseed was about 71.09 mt in 2013-14 as edible vegetable oil only soybean and palm oil production exceeded that of oilseed rape [2,6]. Uttar Pradesh is prominent in rapeseed and mustard in the country and its stands next only to Rajasthan in both area and production. However, the productivity of rapeseed and mustard in U.P. (831 kg ha^{-1}) is much below than national (1075.4 kg ha^{-1}) and world average (1635.5 kg ha^{-1}). The basic factors behind this phenomenal low productivity are non-availability of high yielding problem specific varieties, sub-optimal and imbalanced use of fertilizers, lack of irrigation facilities, attack of pests and diseases.

Since fertilizers are most expensive inputs, imperative to optimize their use with rational approach with aim to have greater efficiency of applied fertilizers. Rapeseed and mustard stand next to groundnut in the oilseed economy [7].Various nutrients and micronutrients are required for oilseed production, but the nutrient that plays a multiple role in providing nutrition to oilseed crops, particularly those belonging to *Cruciferae* family is sulphur [8]. Each unit of fertilizer sulphur generates 3-5 units of edible oil, a commodity needed by every family. Sulphur can be called as fourth major element of the plant because it is a constituent of three amino acids and helps in the formation of chlorophyll and synthesis of oils [9]. Sulphur application also has marked effect on soil properties and is used assoil amendment to improve the availability of other nutrients in soil [10]. It’s a cheapest of the four major plant nutrients today. Between the two common sources of sulphur, a relatively large deposit of gypsum are available in India are the cheap source of sulphur, hence could be better source of sulphur for oilseed crops [11]. The highest seed and oil yield in mustard (*Brassica juncea*) viz. Kranti, Varuna and Rohini was obtained by applying Sulphur 20 kg ha^{-1} [12]. In Rainfed farming, judicious use of water is essential for increasing area under crop production with limited water supply. Therefore, uses of moisture conservation measures are essential under such situation is preferred. Mulching has been advocated as an effective means for conserving soil moisture as insulating barrier which checks evaporation from soil surface and protecting the roots of the plants from heat, cold or drought or to keep fruit clean. It checks evaporation and modifies the soil and air microclimate in which a plant is growing. This may include temperature moderation, salinity and weed control. It exerts decisive effects on earliness, yield and quality of the crop.

2. MATERIALS AND METHODS

Field experiment was carried out at the Agricultural Research Farm of the Rajeev Gandhi South Campus (Banaras Hindu University) Barkachha, Mirzapur (U.P.) during rainy season of 2013. The campus is situated in Vindhyan region of district Mirzapur (25°10′ N latitude, 82º37′ E longitude and altitude of 147 m MSL). This region comes under agro-climatic zone III A (semi-arid eastern plain zone) with invariably poor fertility status. Annual rainfall of locality was 209 mm in 2010, of which nearly 90% is contributed by South West monsoon between July and September. Recommended variety "PT-303" was selected for present investigation. Three levels of sulphur, 20 kg ha^{-1} S (S_1), 40 kg ha^{-1} S (S_2), 60 kg ha^{-1} S (S_3) and five levels of mulching, i.e., No mulch (M_0), paddy straw @ 4 tons ha^{-1} (M_1), wheat straw @ 6 t ha^{-1} (M_2), legume straw @ 5 t ha^{-1} (M_3), and green weed mulch @ 12 t ha^{-1} (M_4) were included in the experiments. The experiment was carried out in split plot design with three replications.Statistical analysis was done by Analysis of Variance (ANOVA) of factorial randomized block design and means were tested for significance at $P \leq 0.05$.Soil samples were collected at depth of 0-15 cm and were brought into laboratory, dried in shade at room temperature and processed to pass through 2-mm sieve. Water holding capacity of the soil samples was determined by Keen-Roczkowski box as described [13], pH and EC in a 1:2.5 soil: water mixture [14], organic carbon by a modified Walkley-Black method [14], mineralizable N by potassium permanganate method [15], available P by [16], available K in soil with flame photometer [17] and available sulphur by the turbid metric method [18]. Results were as follows,

Table 1. Physico-chemical properties of experimental plot

Particulars	Description
Physical constants-	
(a) Bulk density (Mg m^{-3})	1.45
(b) Particle density (Mg m^{-3})	2.65
(c) Maximum water holding capacity (%)	31.12
(d) Soil texture	Sandy loam
Chemical Properties-	
(a) pH	5.8
(b) EC (dSm^{-1}) at 25°C	0.12
(c) Organic carbon (%)	0.36
Nutritional Properties-	
(a) Available N (kg ha^{-1})	210.33
(b) Available P_2O_5 (kg ha^{-1})	21.26
(c) Exchangeable K_2O (kg ha^{-1})	218.22
(d) Available SO_4^2(kg ha^{-1})	16.54

3. RESULTS AND DISCUSSION

Growth attributes traits shows significantly highest plant height at 60 days after sowing and at harvest stage was observed by application of 40 kg ha^{-1}sulphur (S_2) over 20 kg ha^{-1} S (S_1). Whereas in case of different mulch levels, the highest plant height recorded under paddy straw @ 4 t ha^{-1} (M_1) 83.8 cm followed by legume straw @ 5 t ha^{-1} (M_3) 83.1 cm at 60 days after sowing, (98.2 cm) and (95.1 cm) respectively at harvesting stages. Interaction between sulphur levels and mulching for plant height was found significant at each levels of treatment combinations. Highest plant height recorded in 40 kg ha^{-1}.

S (S_2) x paddy straw @ 4 t ha^{-1} (M_1) and found significantly superior over rest of treatments (Table 2). These results are in close conformity [19,20]. A number of workers [21,22,23] have also reported same increase in plant height with an increase in rate of sulphur application. In Plant dry weight, effect of sulphur level and mulching treatments was significant. Data shows that highest plant dry weight recorded under 40 kg ha^{-1} S (S_2) 17.5 cm at 60 days after sowing and 28.5 cm at harvesting stage. Plant dry weight $plant^{-1}$ was significantly influenced by different moisture conservation treatments. Highest plant dry weight recorded under paddy straw @ 4 tons ha^{-1} (M_1) 18.8 g at 60 days after sowing and 30.9 g at harvest stages (Table 3). The interaction between sulphur level and mulching for plant dry weight was also found significantly superior over rest of other interaction levels at 60 days after sowing and at harvest (Table 3). The chloroplast protein synthesis is stimulated by availability of sulphur to plant and higher synthesis of chloroplast results in better photosynthetic efficiency and ultimately improved dry matter production. An increase in dry matter accumulation was reported in mustard due to sulphur fertilization [21,22,24] as well as an increasing trend of plant dry weight with application of sulphur 40 kg ha^{-1} was also noticed [25].

Yield attributing traits shows length of siliquae $plant^{-1}$ has increased significantly with increasing levels of sulphur up to 40 kg ha^{-1} and highest length of siliquae $plant^{-1}$ was recorded under 40 kg sulphur ha^{-1}. In moisture conserving practice highest length of siliquae $plant^{-1}$ was recorded under paddy straw @ 4 tons ha^{-1} (M_1) followed by legume straw @ 5 t ha^{-1} (M_3) as lowest length of siliquae $plant^{-1}$ was recorded under No mulch (M_0) followed by green weed mulch @ 12 t ha^{-1} (M_4) (Table 4). The highest length of siliquae $plant^{-1}$ was recorded in 40 kg ha^{-1} S (S_2) x paddy straw @ 4 tons ha^{-1} (M_1) and interaction was found significantly superior through at harvest stage. In number of seed siliquae^{-1} the highest were recorded at 40 kg ha^{-1} S (S_2). Increasing rate of sulphur significantly reduces the number of seeds siliquae^{-1}. Moisture conserving practice data indicates maximum seeds siliquae^{-1} which was recorded under paddy straw @ 4 tons ha^{-1} (M_1) followed by legume straw @ 5 t ha^{-1} (M_3) and minimum seeds siliquae^{-1} were recorded under No mulch (M_0) followed by green weed mulch @ 12 t ha^{-1} (M_4). Interaction between sulphur level and mulching for number of seeds siliquae^{-1} was found significantly superior in 40 kg ha^{-1} S (S_2) x paddy straw @ 4 tons ha^{-1} (M_1) over all other interaction levels at 60 days after sowing. Sulphur fertilization with 40 kg ha^{-1} was more efficient than 60 kg S ha^{-1} in increasing the seed yield which might be supplemented with increased number of seeds siliquae^{-1} [26]. 1000-grain weight showed significantly highest test weight observed by application of 40 kg ha^{-1} sulphur (S_2) over 20 kg ha^{-1} S (S_1). Whereas in case of different mulch levels, highest test weight was recorded under paddy straw @ 4 tons ha^{-1} (M_1) 2.99 g followed by legume straw @ 5 t ha^{-1} (M_3) 2.82 g during investigation (Table 4). The interaction between sulphur levels and mulching for plant height found also significant. The significantly highest test weight was observed by 40 kg ha^{-1} S (S_2) x paddy straw @ 4 tons ha^{-1} (M_1) 3.07 g and was found significantly superior over rest of levels. Increase in test weight with an increase in the rate of sulphur application has also been reported [27]. The number of siliquae plant^{-1} increased significantly with increasing levels of sulphur up to 40 kg ha^{-1}. Data indicated that considerably highest number of siliquae plant^{-1} was recorded under 40 kg ha^{-1} S (S_2). These results are in conformity [28,29,30]. The highest number of siliquae plant^{-1} was recorded by 40 kg ha^{-1} S (S_2) x paddy straw @ 4 tons ha^{-1} (M_1) and was found significantly superior over all other interaction levels.

Table 2. Interaction between sulphur level and mulching on plant height

Treatments	Plant height (cm)							
	60 days after sowing				At harvest			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
M_0	68.8	69.9	69.6	69.4	80.1	95.3	81.1	85.5
M_1	83.4	85.2	82.8	83.8	97.3	98.9	98.5	98.2
M_2	81.0	81.1	81.8	81.3	92.6	93.9	93.1	93.2
M_3	82.1	83.8	83.3	83.1	95.3	93.9	96.1	95.1
M_4	66.9	79.4	81.6	76.0	91.9	92.5	92.5	92.3
Mean	76.4	79.9	79.8		91.4	94.9	92.3	
SEm (±)				0.94				1.57
CD (*p*=0.05)				2.73				4.59

Table 3. Interaction between sulphur level and mulching on dry matter accumulation

Treatments	Dry matter accumulation plant^{-1} (cm)							
	60 days after sowing				At harvest			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
M_0	13.9	14.0	13.8	13.9	23.9	23.6	24.0	23.8
M_1	16.3	20.4	19.6	18.8	29.7	32.1	30.8	30.9
M_2	15.0	17.6	16.4	16.3	27.2	28.9	28.9	28.4
M_3	15.1	18.4	18.4	17.3	28.5	30.8	29.6	29.6
M_4	14.0	17.2	16.1	15.8	26.8	27.3	28.1	27.4
Mean	14.9	17.5	16.9		27.2	28.5	28.3	
SEm (±)				0.28				0.38
CD (*p*=0.05)				0.81				1.11

Table 4. Sulphur level and mulching on length of siliquae plant^{-1}(cm), Number of seed siliquae^{-1}, Test weight (g), Seed yield (kg), Straw yield (kg), Harvest index (%) and Number of siliquae plant^{-1}

Treatment	Length of siliquae plant^{-1}	Seed siliquae^{-1}	Test weight (g)	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index	Number of siliquae plant^{-1}
Nutrient application							
S_1	4.5	14.3	2.51	1035	2921	26.16	104.4
S_2	4.9	15.8	2.65	1219	3050	28.55	108.3
S_3	4.6	14.8	2.62	1246	3011	29.28	104.8
CD (p=0.05)	0.24	0.76	0.03	82	17	1.40	2.70
SEm±	0.06	0.19	0.01	21	4	0.36	0.69
Mulches							
M_0	4.0	14.0	1.96	1074	2863	27.27	90.0
M_1	5.4	16.2	2.99	1249	3177	27.86	122.2
M_2	4.6	14.8	2.74	1173	2881	28.84	106.5
M_3	4.9	15.7	2.82	1201	3192	27.61	113.3
M_4	4.5	14.2	2.46	1136	2858	28.39	97.3
CD (p=0.05)	0.30	0.88	0.03	28	66	0.57	2.74
SEm±	0.10	0.30	0.01	10	23	0.19	0.94

Seed yield shows effect of sulphur level and mulching treatments was significant. Application of 60 kg S ha^{-1} (S_3) recorded significantly higher yield than 20 kg S ha^{-1} (S_1) and 40 kg S ha^{-1} (S_2), which in turn, gave significantly higher seed yield than no irrigation (Table 4). The seed yield of mustard increased with the successive increase in the level of applied sulphur. Application of 40 kg S ha^{-1} and 60 kg S ha^{-1} increased seed yield of mustard over the 20 kg S ha^{-1} by 17 and 20%, respectively (Table 4). Similarly, in moisture conserving practices, highest grain yield recorded in paddy straw @ 4 tons ha^{-1} (M_1) but also significantly at par with wheat straw @ 6 t ha^{-1} (M_2) and legume straw @ 5 t ha^{-1} (M_3). The interaction between sulphur level and mulching indicated that grain yield was found significantly superior in 60 kg ha^{-1} S (S_3) x paddy straw @ 4 tons ha^{-1} (M_1) also superior over rest of the interaction levels (Table 5). In straw yield application of sulphur @ 40 kg ha^{-1} (S_2) enhanced straw yield significantly over 20 kg ha^{-1} S (S_1) and 60 kg ha^{-1} S (S_3). The highest straw yield was obtained at 40 kg ha^{-1} S (S_2) 3050.2 kg ha^{-1} followed by 60 kg ha^{-1} S (S_3) 3011.2 kg ha^{-1}. Among the different mulches, highest straw yield was recorded under legume straw @ 5 t ha^{-1} (M_3) 3192.4 kg ha^{-1} followed by paddy straw @ 4 tons ha^{-1} (M_1) 3177.1 kg ha^{-1} and showed at par results to each other (Table 4). The interaction effect of sulphur level and mulching treatments on straw yield was significant. The highest straw yield was recorded by 60 kg ha^{-1} S (S_3) x legume straw @ 5 t ha^{-1} (M_3) 3290.4 kg ha^{-1} which was found significantly superior over rest of the treatments (Table 5). Similar results were also reported [19]. Harvest index showed effect of sulphur level and mulching treatments which was significant (Table 4). Application of 60 kg sulphur was recorded better result but also at par with application of 40 kg S ha^{-1}. Moisture conserving practices showed significant response. Data indicates highest harvest index recorded under wheat straw @ 6 t ha^{-1} (M_2) followed by green weed mulch @ 12 t ha^{-1} (M_4) also at par results to each other. Lowest harvest index recorded under No mulch (M_0) followed by green weed mulch @ 12 t ha^{-1} (M_4). Interaction between sulphur level and mulching for harvest index found significant at each levels of treatment combinations (Table 6). The higher harvest index with sulphur application may be due to higher increase in seed yield. These results were in conformity with [31].

Nitrogen uptake (kg ha^{-1}) in grain and straw significantly highest nitrogen uptake by rapeseed under 40 kg ha^{-1} S (S_2) and 60 kg ha^{-1} S (S_3) and found at par results (Table 7). Lowest nitrogen uptake by 20 kg ha^{-1} S (S_1) is recorded in the grain and straw. In moisture conserving practices paddy straw @ 4 tons ha^{-1} (M_1) showed significantly highest nitrogen uptake in grain and straw. Legume straw @ 5 t ha^{-1} (M_3) followed by wheat straw @ 6 t ha^{-1} (M_2) showed higher nitrogen uptake in the grain and straw. Interaction between sulphur level and mulching for nitrogen uptake was found 40 kg ha^{-1} S (S_2) x paddy straw @ 4 tons ha^{-1} (M_1) and was found significantly superior over all other interaction levels in the grain and straw (Table 8).

Table 5. Interaction between sulphur level and mulching on seed yield (kg), straw yield (kg)

Treatments	Seed yield (kg)				Straw yield (kg)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
M_0	1025.2	1070.7	1126.4	1074.1	2855.2	2858.9	2873.9	2862.7
M_1	1131.3	1307.4	1307.8	1248.8	3074.6	3319.7	3137.0	3177.1
M_2	982.5	1260.2	1275.4	1172.7	2820.3	2944.1	2877.5	2880.7
M_3	1058.2	1264.0	1280.0	1200.7	3013.2	3273.7	3290.4	3192.4
M_4	978.4	1190.8	1239.3	1136.2	2841.4	2855.0	2877.1	2857.8
Mean	1035.12	1218.62	1245.78		2920.94	3050.28	3011.18	
SEm (±)				16.49				39.04
CD (p=0.05)				48.14				113.96

Table 6. Interaction between sulphur level and mulching on harvest index (%)

Treatments	Harvest index (%)			
	S_1	S_2	S_3	Mean
M_0	26.4	27.2	28.2	27.3
M_1	26.9	28.3	28.4	27.9
M_2	25.8	30.0	30.7	28.8
M_3	26.0	27.8	29.0	27.6
M_4	25.6	29.4	30.1	28.4
Mean	26.14	28.54	29.28	
SEm (±)				0.34
CD (p=0.05)				0.98

Table 7. Nutrient uptake in the grain and straw of rapeseed

Treatment	Nitrogen uptake (Kg ha^{-1})		Sulphur uptake (Kg ha^{-1})	
	Grain	Straw	Grain	Straw
Nutrient application				
S_1	24.70	18.18	6.47	5.08
S_2	31.82	20.66	7.86	5.98
S_3	32.27	20.62	8.10	6.03
CD (p=0.05)	2.21	0.76	0.57	0.36
SEm±	0.56	0.19	0.15	0.09
Mulches				
M_0	23.73	8.87	6.52	4.20
M_1	34.10	24.93	8.38	7.57
M_2	30.10	21.31	7.52	5.38
M_3	31.83	23.72	7.81	6.37
M_4	28.21	20.25	7.16	4.99
CD (p=0.05)	0.836	1.00	0.30	0.54
SEm±	0.286	0.34	0.10	0.19

Supreme sulphur uptake by 40 kg ha^{-1} S (S_2) and 60 kg ha^{-1} S (S_3) in the grain and straw of rapeseed. Both the treatments showed at par results. Significantly lowest sulphur uptake was recorded under 20 kg ha^{-1} S (S_1) in the grain and straw (Table 7). In moisture conservation practices highest sulphur uptake was recorded under paddy straw @ 4 tons ha^{-1} (M_1) followed by legume straw @ 5 t ha^{-1} (M_3). Significantly lowest sulphur uptake in the grain was recorded under no mulch. The highest sulphur uptake was recorded by 40 kg ha^{-1} S (S_2) x paddy straw @ 4 tons ha^{-1} (M_1) and interaction was found significantly superior in the grain and straw (Table 9).

Significantly highest oil content was recorded in 40 kg ha^{-1} S (S_2) and 60 kg ha^{-1} S (S_3) in rapeseed. Lowest oil content was recorded in 20 kg ha^{-1} S (S_1). Moisture conservation practices data indicates that significantly highest oil content in rapeseed was recorded in paddy straw

@ 4 tons ha^{-1} (M_1) followed by legume straw @ 5 t ha^{-1} (M_3). Lowest oil content in rapeseed was recorded under No mulch (M_0) and green weed mulch @ 12 t ha^{-1} (M_4) and both the treatment showed at par results (Table 10). Interaction between sulphur level and mulching for oil content in the grain was found highest in the treatment of 40 kg ha^{-1} S (S_2) x paddy straw @ 4 tons ha^{-1} (M_1) and was found significantly superior over all other interaction levels (Table 11).

Table 8. Interaction between sulphur level and mulching on nitrogen uptake grain (kg ha^{-1}), nitrogen uptake straw (kg ha^{-1})

Sulphur x mulching	Nitrogen uptake grain (kg ha^{-1})				Nitrogen uptake straw (kg ha^{-1})			
	S_1	**S_2**	**S_3**	**Mean**	**S_1**	**S_2**	**S_3**	**Mean**
M_0	22.62	23.70	24.90	23.74	8.8	8.9	8.9	8.9
M_1	28.96	37.09	36.26	34.11	22.2	26.0	26.5	24.9
M_2	23.38	33.38	33.55	30.10	19.4	22.4	22.2	21.3
M_3	25.88	34.89	34.73	31.84	21.6	25.1	24.5	23.7
M_4	22.67	30.05	31.93	28.21	18.9	20.8	21.0	20.2
Mean	24.702	31.822	32.274	29.6	18.18	20.64	20.62	19.8
SEm (±)				0.50				0.59
CD (p=0.05)				1.45				1.73

Table 9. Interaction between sulphur level and mulching on sulphur uptake grain (kg ha^{-1}), sulphur uptake straw (kg ha^{-1})

Sulphur x mulching	Sulphur uptake grain (kg ha^{-1})				Sulphur uptake straw (kg ha^{-1})			
	S_1	**S_2**	**S_3**	**Mean**	**S_1**	**S_2**	**S_3**	**Mean**
M_0	6.2	6.5	6.8	6.5	4.0	4.2	4.4	4.2
M_1	7.4	8.8	8.9	8.4	6.1	8.3	8.3	7.6
M_2	6.1	8.1	8.4	7.5	4.9	5.6	5.7	5.4
M_3	6.7	8.3	8.4	7.8	5.7	6.9	6.5	6.4
M_4	6.0	7.5	8.0	7.2	4.7	4.9	5.3	5.0
Mean	6.48	7.84	8.1	7.48	5.08	5.98	6.04	5.72
SEm (±)				0.18				0.32
CD (p=0.05)				0.53				0.94

Table 10. Effect of sulphur levels and various types of mulches on quality parameters of rapeseed crop

Treatment	Oil content (%)	Protein content (%)
Nutrient application		
S_1	28.95	14.89
S_2	30.85	16.23
S_3	29.50	16.13
CD (P=0.05)	1.39	0.12
SEm±	0.36	0.03
Mulches		
M_0	28.20	13.81
M_1	32.21	17.02
M_2	29.44	15.96
M_3	30.60	16.50
M_4	28.38	15.45
CD (p=0.05)	0.44	0.28
SEm±	0.15	0.10

Protein content in the seeds of rapeseed was recorded in 40 kg ha^{-1} S (S_2) and 60 kg ha^{-1} S (S_3) and both the treatments showed at par results among themselves. Lowest protein content was recorded in 20 kg ha^{-1} S (S_1). Moisture conservation practice data shows that maximum protein content of rapeseed was recorded in paddy straw @ 4 tons ha^{-1} (M_1) followed by legume straw @ 5 t ha^{-1} (M_3). Minimum protein content was recorded under No mulch (M_0) followed green weed mulch @ 12 t ha^{-1} (M_4) (Table 10). Interaction between sulphur level and mulching for protein content in grain found significant at each levels of treatment combinations. The highest protein content in grain was recorded by 40 kg ha^{-1} S (S_2) x paddy straw @ 4 tons ha^{-1} (M_1) and was found significantly superior over all other interaction levels (Table 11).

Highest water holding capacity was recorded under 40 kg ha^{-1} S (S_2) followed by 60 kg ha^{-1} S (S_3).Moisture conservation practices showed highest WHC were observed by legume straw @ 5 t ha^{-1} (M_3). paddy straw @ 4 tons ha^{-1} (M_1) and wheat straw @ 6 t ha^{-1} (M_2) showed higher water holding capacity and both mulches showed at par results. Lowest water holding capacity recorded under No mulch (M_0) (Table 12). Interaction between sulphur level and mulching for water holding capacity found 60 kg ha^{-1} S (S_3) x legume straw @ 5 t ha^{-1} (M_3) and was found significantly superior over all other interaction levels. Significantly, maximum organic carbon was recorded under 40 kg ha^{-1} S (S_2). Minimum organic carbon recorded by 20 kg ha^{-1} S (S_1) followed by 60 kg ha^{-1} S (S_3) and both treatments showed at par results. In organic carbon highest value recorded under legume straw @ 5 t ha^{-1} (M_3). paddy straw @ 4 tons ha^{-1} (M_1),wheat straw @ 6 t ha^{-1} (M_2)and green weed mulch @ 12 t ha^{-1} (M_4) showed higher organic carbon, respectively and showed at par results (Table 12). Significantly lower data was recorded under No mulch (M_0). Interaction between sulphur level and mulching for organic carbon found significant at each levels of treatment combinations. The highest organic carbon was recorded by 40 kg ha^{-1} S (S_2) x legume straw @ 5 t ha^{-1} (M_3) and was significantly superior over all other interaction levels. These results are in close conformity [32,20].

Highest available nitrogen recorded in 40 kg ha^{-1} S (S_2) and 60 kg ha^{-1} S (S_3) under different sulphur levels. In moisture conservation practices paddy straw @ 4 tons ha^{-1} (M_1),wheat straw @ 6 t ha^{-1} (M_2)and legume straw @ 5 t ha^{-1} (M_3) showed highest available nitrogen, respectively and at par results among themselves (Table 12). Lowest available nitrogen recorded at No mulch (M_0) in all mulching treatments, which were significantly lower with all other treatments. Interaction between sulphur level and mulching for available nitrogen found significant at each levels of treatment combinations. Highest available nitrogen recorded by 40 kg ha^{-1} S (S_2) x legume straw @ 5 t ha^{-1} (M_3) and was found significantly superior over all other interaction levels. Data of available phosphorus showed significantly highest phosphorus availability recorded in 40 kg ha^{-1} S (S_2) followed by 60 kg ha^{-1} S (S_3) in rapeseed and lowest recorded in 20 kg ha^{-1} S (S_1). Moisture conservation practices significantly highest phosphorus availability recorded in legume straw @ 5 t ha^{-1} (M_3).

Table 11. Interaction between sulphur level and mulching for oil content (%), protein content (%)

Sulphur x mulching	Oil content (%)				Protein content (%)			
	S_1	**S_2**	**S_3**	**Mean**	**S_1**	**S_2**	**S_3**	**Mean**
M_0	30.0	27.6	26.9	28.2	13.8	13.8	13.8	13.8
M_1	30.4	34.3	32.0	32.2	16.0	17.7	17.3	17.0
M_2	27.9	30.7	29.7	29.4	14.9	16.6	16.4	16.0
M_3	29.0	32.3	30.5	30.6	15.3	17.3	17.0	16.5
M_4	27.4	29.3	28.4	28.4	14.5	15.8	16.1	15.5
Mean	28.94	30.84	29.5	29.76	14.9	16.24	16.12	15.76
SEm (±)				0.26				0.17
CD (p=0.05)				0.76				0.48

Table 12. Effect of different sulphur level and mulching for available nitrogen (kg ha^{-1}), available phosphorus (kg ha^{-1}), organic carbon (%), WHC (%)

Treatment	Physio-chemical parameters					
	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	S (kg ha^{-1})	OC (%)	WHC (%)
Nutrient application						
S_1	212.09	22.12	249.13	16.73	0.48	31.12
S_2	218.57	24.35	263.73	19.21	0.36	39.84
S_3	217.21	23.10	257.93	17.81	0.38	41.79
CD (p=0.05)	0.90	0.54	4.42	0.61	0.004	0.13
SEM±	0.23	0.14	1.12	0.16	0.004	0.13
Mulches						
M_0	198.00	19.70	213.44	14.18	0.34	38.08
M_1	222.09	23.58	265.22	19.42	0.37	41.17
M_2	222.51	24.59	268.78	18.86	0.37	41.88
M_3	223.03	25.54	274.33	19.10	0.38	42.75
M_4	214.14	22.54	262.89	18.01	0.37	40.33
CD (p=0.05)	1.00	0.39	2.32	0.50	0.012	0.47
SEM±	0.34	0.14	0.79	0.17	0.004	0.16

Table 13. Interaction effect of sulphur and mulches on available nitrogen, phosphorus in post-harvest soil as affected by various treatments

Sulphur x Mulching	Available nitrogen (kg ha^{-1})				Available phosphorus (kg ha^{-1})			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
M_0	197.0	199.0	198.0	198.0	19.7	19.7	19.7	19.7
M_1	220.4	223.7	222.2	222.1	22.2	25.1	23.4	23.6
M_2	221.6	223.5	222.5	222.5	23.1	26.2	24.5	24.6
M_3	222.5	223.9	222.7	223.0	24.3	26.9	25.5	25.5
M_4	199.0	222.7	220.7	214.1	21.3	23.9	22.4	22.5
SEm (±)				0.59				0.23
CD (P=0.05)				1.73				0.68

Higher phosphorus availability was recorded in wheat straw @ 6 t ha^{-1} (M_2) followed by paddy straw @ 4 tons ha^{-1} (M_1) at harvest (Table 12). Lowest phosphorus was recorded under No mulch (M_0) in soil of rapeseed. Interaction between sulphur levels and mulching for available phosphorus found in 40 kg ha^{-1} S (S_2) x legume straw @ 5 t ha^{-1} (M_3) and was significantly superior over all other interaction levels (Table 13). Exchangeable potassium was not significant under different levels of sulphur as well as under different types of mulches also. Significantly highest sulphur availability was recorded in 40 kg ha^{-1} S (S_2) followed by 60 kg ha^{-1} S (S_2) (Table 12). Lowest availability was observed by 20 kg ha^{-1} S (S_1). Soil moisture conservation practices were not significant under different types of mulches. These results are in close conformity [32,20].

3. CONCLUSION

The application of sulphur @ 40 kg ha^{-1} with paddy straw mulch was found superior over other treatments. It was also noticed that physico-chemical properties of soil was improved due to different treatments. Considering all the parameters tested in the experiment, application of 40 kg S ha^{-1} with paddy straw mulch has significant superiority. Thus, to achieve higher yield with sustaining soil condition, application of 40 kg S ha^{-1} and paddy straw mulch for Vindhyan soil is recommended.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. USDA. Agricultural Statistics 2011. United States Department of Agriculture of United States, National Agricultural Statistics Service; 2011. Available:https://www.nass.usda.gov/Publications/Ag_Statistics/2011/

2. DRMR. Vision 2050. Directorate of Rapeseed-Mustard Research (ICAR) of Sewar, Bharatpur; 2015.
Available:www.icar.org.in/Vision%202050%20DRMR%20Rajasthan.pdf
3. Sharma A, Kumar V, Singh R, Thukral AK, Bhardwaj R.. 24-epibrassinolide induces the synthesis of phytochemicals effected by imidacloprid pesticide stress in *Brassica juncea* L. Journal of Pharmacognosy and Phytochemistry. 2015b;4:60-64.
4. Bartaria AM, Shukla AK, Kaushik CD, Kumar PR, Singh NB. Major diseases of rapeseed-mustard and their management. NRC on Rapeseed-Mustard, ICAR, Sewer, Bharatpur (Rajasthan); 2001.
5. Kanwar MK, Poonam, Bhardwaj R.. Arsenic induced modulation of anti-oxidative defense system and brassinosteroids in *Brassica juncea* L. Ecotoxicology and Environmental Safety. 2015;115:119-125.
6. FAO. FAO Statistical Pocketbook 2015. Rome, FAO of UN, World Food and Agriculture; 2015.
Available:http://www.fao.org/documents/card/en/c/383d384a-28e6-47b3-a1a2-2496a9e017b2/
7. Prasad K, Chaudhary HP, Uttam SK. Effect of N, P, Sand Zn nutrition on nutrient uptake, quality and yield of rainfed Indian mustard. Indian Journal of Agricultural Sciences. 2003;47:45-50.
8. Sharma A, Kumar V, Kohli SK, Thukral AK, Bhardwaj R. Phytochemicals in *Brassica juncea* L. seedlings under imidacloprid-epibrassinolide treatment using GC-MS. Journal of Pharmacognosy and Phytochemistry. 2015a;7:708-711.
9. Yusuf M, Khan TA, Fariduddin Q. Interaction of epibrassinolide and selenium ameliorates thee excess copper in *Brassica juncea* through altered proline metabolism and antioxidants. Ecotoxicology and Environmental Safety. 2016;129:25-34.
10. Kushwaha KP, Chakravarti VK, Chaudhary HP, Uttam SK. Production potential of rainfed mustard variety 'Vaibhav' in relation to fertilization of N, P, Sand Zn in eroded alluvial soil. Progressive Research. 2006;1:37-39.
11. Ramkesh. Production potential of rainfed mustard (*Brassica juncea*) var. 'Vaibhav' in relation to fertilization of N, P, S and Zn in eroded alluvial soil. C.S.Azad University of Agriculture and Technology, Kanpur; 2000.
12. Khan N, Hussain K. Performance of mustard varieties in relation to doses of sulphur. Advances in Plant Science. 1999;12:115-118.
13. Chopra SL, Kanwar JS. Analytical agricultural chemistry, MacMillian Press, London; 1998.
14. Jackson ML. Soil chemical analysis. Printice Hall Inc. Engiewood Cliffs. N. J. U.S.A.; 1973.
15. Subbaiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soil. Curr. Sci. 1956;25:259.
16. Bray RH, Kurtz LT. Determination of total organic and available forms of phosphorus in soils. Soil Sci. 1945;59:39-45.
17. Hanway JJ, Heiden H. Soil analysis methods as used in Iowa State. College soil testing laboratory. Bulletin. 1952;57:1-131.
18. Chesnin L, Yien CH. Turbidimetric determination of available sulphur. Soil Science Society of America Proceedings 1951;15:149-151.
19. Jat BL, Jangir RP, Khangarot SS. Response of mustard varieties to different levels of sulphur in loamy sand soil. Journal of Farming Systems Research and Development. 2003;8:108-109.
20. Tetarwal JP, Ram B, Meena DS, Tomar SS. Effect of moisture conservation and sulphur sources on productivity and water use efficiency of Indian mustard (*Brassica juncea*) under rainfed conditions. Indian Journal of Agronomy. 2013;58:231-236.
21. Khanpara VD, Porwal BL, Sahu MP, Patel JC. Effect of nitrogen and sulphur on growth and yield of mustard (*Brassica juncea*). Indian Journal of Agronomy. 1993;38:266-269.
22. Tomar TS, Singh S, Kumar S, Tomar S. Response of Indian mustard to nitrogen, phosphorus and sulphur fertilization. Indian Journal Agronomy. 1997;42:148-151.
23. Rana KS, Rana DS, Kumar P. Growth and yield of turmeric (*Ercca sativa*) as affected by nitrogen and sulphur under dryland condition. Indian Journal of Agronomy. 2001;4:168-170.
24. Patel JR, Shelke VB. Effect of farmyard manure, phosphorus and sulfur on growth. Yield and quality of Indian mustard (B. juncea). Indian J. Agron. 1998;43(4):713-717
25. Karthikeyan K, Shukla LM. Effect of Boron-sulphur interaction on their uptake and quality parameters of mustard (*Brassica*

juncea L.) and sunflower (*Helianthus annuus* L.). Journal of the Indian Society of Soil Science. 2008;56: 225-230.

26. Kumar S, Verma SK, Singh TK, Singh S. Effect of nitrogen and sulphur on growth, yield and nutrient uptake by Indian mustard (*Brassica juncea*). Indian Journal of Agricultural Sciences. 2011;81:145-149.
27. Bhagat KL, Soni KC. Effect of nitrogen and sulphur on growth, seed and oil yield of mustard (*Brassica juncea*). J. Oilseeds Res. 2000;17(1):96-99.
28. Chauhan DR, Paroda S, Ram M, Paroda S, Ram M. Response of Indian mustard (*Brassica juncea* L.) to biofertilizers, sulphur and nitrogen fertilization. Indian Journal of Agronomy. 1996;41(4):620-623.
29. Rana KS, Rana DS, Gautam RC. Influence of phosphorus, sulphur and boron on growth, yield, nutrient uptake and economics of Indian mustard (*Brassica juncea*) under rainfed conditions. Indian Journal of Agronomy. 2005;50 (4):314-316.
30. Piri I, Sharma SN. Effect of levels and sources of sulphur on yield attributes, yield and quality of Indian mustard (*Brassica juncea*). Indian Journal of Agronomy. 2006;51(3):217-220.
31. Ali MH, Zaman SMH, Altaf HSM. Variation in yield, oil and protein content of rapeseed (*Brassica campestris*) in relation to levels of nitrogen, sulphur and plant density. Indian J. Agron. 1996;41(2):290- 295.
32. Ram H, Singh G, Aggarwal N. Grain yield, nutrient uptake, quality and economics of soybean (*Glycine max*) under different sulphur and boron levels in Punjab. Indian Journal of Agronomy. 2014;59:101-105.

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