Journal of the Indian Society of Soil Science, Vol. 60, No. 3, pp 218-224 (2012)

Performance of different Sources of Sulphur on the Yield and Quality of Rapeseed (*Brassica campestris* L.)

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Field experiments were conducted during the winter seasons of 2006–2007 and 2007–2008 in an Aeric Endoaquept (pH 6.67) to study the performance of different sources of sulphur (S) on the yield and quality of rapeseed cultivar B-9. There were three sources of S namely, single superphosphate (SSP), elemental S and S-52, which were applied for growing rapeseed. The 0.15% $CaCl_2$ extractable-S content in the soil and total S content in the dry matter of rapeseed decreased up to 97 days of crop growth. The highest S content in the soil was recorded with the application of 30 kg S ha^{-1} as SSP throughout the crop growth which resulted in 151, 46.4, 59.8 and 48.8% increase over control, elemental S @ 30 kg ha^{-1}, 1% S-52 and 2% S-52, respectively. The highest seed and stover yield was 910 and 4380 kg ha^{-1}, respectively in the treatment T_3 (30 kg S ha^{-1} as SSP), resulting in a 41.9 and 18.9% increase in the yield over that of the control during both the years. The mean oil content, crude protein and soluble protein 40.1, 30.5 and 28.8% were highest, respectively, in the treatment T_3. The highest benefit-cost ratio was 1.77 with the foliar application of 1% S-52.

Key words: Rapeseed, sulphur sources, sulphur content, yield

Sulphur improves the quality of food crops, particularly of oilseeds. It plays an important role in the formation of S-containing amino acids like cystine (27% S), cysteine (26% S), methionine (21% S), which act as building blocks in the synthesis of proteins. More than 99% of S in rapeseed is bound in proteins and glucosinolates (Schnug *et al.* 1990). Further, S is a constituent of oil in oilseed crops. It has a role to play in increasing chlorophyll formation and aiding photosynthesis (Marschner 1986). Sulphur also plays a role in the activation of enzymes, nucleic acids and forms a part of biotin and thiamine (Coleman 1966). Sulphur is very important for oilseeds as the volatile di- and poly-sulphide compounds help to increase the pungency of the vegetable oils (Tandon 1995).

Sulphur deficiency symptoms are becoming widespread throughout the world, especially in India. In agricultural systems with low S inputs, soil organic matter is a major source of S and the transformations between organic and inorganic S pools are important for the supply of S to plants. Introduction of high yielding varieties and subsequent use of high analysis S-free fertilizers under intensive cropping systems have resulted in increased incidences of S deficiencies. Sulphur fertilizers are most commonly available as either soluble sulphate or elemental forms (S°). Elemental S is totally unavailable to plants. Elemental S must be oxidized by soil microbes to SO_4-S before it becomes available to crops. Thus, it takes considerably more time for S° to become available, compared to soluble sulphate forms of fertilizer. The rate of conversion from S° to plant available SO_4-S mainly depends on the particle size to which the product degrades and the method of application (Boswell and Friesen 1993). Since production has to be sustained, there is a need to not only increase the fertilizer S taken up by the crops, but also to develop technologies for the efficient use of the available S-containing materials along with NPK fertilizers.

Sulphur application either to the soil or as foliar spray increases the yield of crops and also enhances the quality of crops particularly of oilseeds crops. Keeping these in view, the present investigation was

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undertaken to study the performance of different sources of sulphur on maintenance of S in soils in relation to yield and quality of rapeseed.

Materials and Methods

Field experiments were conducted at the farmer's field in Adhata village, Amdanga block, North 24 Parganas (22^0 39′ N, 88^0 54′ E, 8.35 m above mean sea level), West Bengal, during the dry season of 2006–2007 and 2007–2008 with rapeseed (*Brassica campestris* L.) (cv. B-9) in an Inceptisol. The seeding was done during the winter period in the month of November 2006 and harvested in March 2007. Again the seeding and harvesting was followed in the second year 2007-2008. The chemical properties of the experimental soil were: pH 6.67, organic C 7.6 g kg^{-1}, cation exchange capacity 12.5 cmol(p^+) kg^{-1}, available N 318 kg ha^{-1}, available P 15 kg ha^{-1}, available K 156 kg ha^{-1} and sulphate-S 17.6 kg ha^{-1}. Organic carbon was determined by the Walkley and Black (1934) method; available N by $KMnO_4$-oxidizable N (Subbiah and Asija 1956); available P by Olsen reagent (Olsen *et al*. 1954); available K by extraction with 1*N* ammonium acetate of pH 7.0 (Jackson 1973) and sulphate S by extraction with 0.15% $CaCl_2$ (Bardsley and Lancaster 1960).

The treatments comprised of control (T_1), elemental S at 30 kg ha^{-1} (T_2), S at 30 kg ha^{-1} as single superphosphate (T_3), 1% S-52 as foliar application (T_4) and 2% S-52 as foliar application (T_5). The experiments were laid out in a randomized block design (RBD) and the respective treatments were applied to each plot. Each treatment was replicated three times. A basal dose of P and K was applied at 50 kg ha^{-1} each and N was applied at 100 kg ha^{-1} in two splits, *i.e.* 50 kg N ha^{-1} at basal and 50 kg N ha^{-1} at grand growth period to all the treatments. The N, P and K were applied in the form of urea, diammonium phosphate and muriate of potash (potassium chloride). The S-52 is a S-containing fertilizer in liquid form containing 52% S, was supplied by M/S Total Agri Care Concern Pvt Ltd, Kolkata, for the investigation. The S-52 was sprayed three times at 20 days of crop growth, vegetative growth stage (35 days after sowing [DAS]) and preflowering stage (50 DAS). Elemental S and single superphosphate were broadcasted followed by incorporation 15 days before sowing of rapeseed in the respective treatments. Rapeseed was sown at a row spacing of 20 cm with a grain density of 0.8 g m^{-2}. The experiment was laid out with a number of sub plots measuring of 20 m^2 (5 m × 4 m) surrounded by borders of 0.30 m width with sufficient height to check the mixing of different treatment materials as buffer zone. The crop was grown up to maturity stage.

Plant samples were collected at an interval of 17 DAS from 5-6 randomly selected locations in each plot up to 97 days of crop growth and again at harvest. Plant samples were harvested at the ground level randomly from 50-cm row length. The harvested samples were washed following standard procedures and dried in hot air oven at 65 ± 5 °C. Whole shoot (leaf and stem) was analyzed for S content in dry matter up to 97 days of crop growth, while at harvest the seed and stover were separately analyzed for S content. Dried and ground plant sample (1 g) were digested with diacid mixture (HNO_3: $HClO_4$: 9:4) and total S was determined turbidimetrically (Chesnin and Yien 1951). Another portion of ground oven-dried plant samples were digested separately with concentrated H_2SO_4 for determination of total N (Jackson 1973) following macro-Kjeldahl method.

Net plots of 20 m^2 were harvested for grain yield and after threshing, the seeds were cleaned, sun-dried and their weights recorded. The oil content of rapeseed was determined by Soxhlet's ether extraction method (AOAC 1975) and the oil yield was expressed as kg ha^{-1}. Crude protein content was obtained by multiplying the nitrogen content with a constant factor of 6.25, and was expressed as kg ha^{-1}. The soluble protein was determined by the Lowry's method (Lowry *et al*. 1951). The data were statistically analyzed using the analysis of variance (ANOVA) technique as applicable to randomized block design (Gomez and Gomez 1984). The significance of the treatment effects was determined using the F-Test; to determine the significance of the difference between the means of the two treatments least significant differences (LSD) were estimated at the 5% probability level, and Duncan's Multiple Range Test was used.

Results and Discussion

Sulphur Content in Soil and Plant

The amount of 0.15% $CaCl_2$ extractable S content was decreased with the progress of crop growth irrespective of different treatments in both years up to 97 days (Fig. 1). The S content of soil significantly increased over control with the application of S at different sources throughout the crop growth period. The magnitude of such increase, however, varied between the treatments, being highest in T_3 where 30 kg S was applied as basal through single superphosphate, followed by T_2 receiving 30 kg S as basal through elemental S. There was no significant difference be-

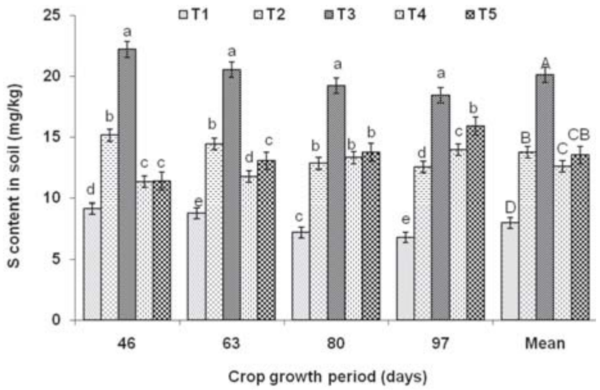

Fig. 1. Effect of different sources of S on S content in the rhizosphere soil of rapeseed. Means followed by the same letter are not significantly different at the 0.05 level of probability by Duncan's Multiple Range Test (DMRT). Bars are ±SE of the mean.

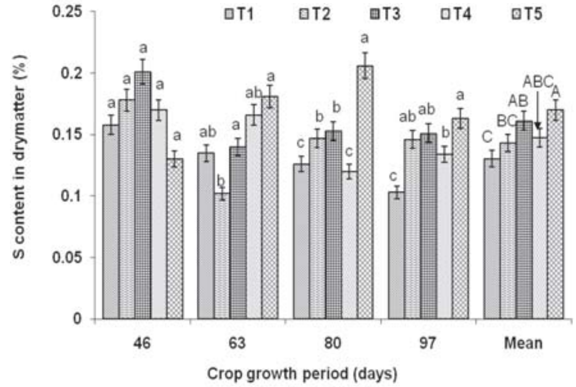

Fig. 2. Effect of different sources of S on S content in the dry matter of rapeseed. Means followed by the same letter are not significantly different at the 0.05 level of probability by Duncan's Multiple Range Test (DMRT). Bars are ±SE of the mean

tween the treatments T_4 and T_5, and maintained lowest available S compared to T_2 and T_3 in the soil, which might be due to the variation in application modes of S as foliar spray. The highest content of S maintained in the treatment T_3 might be explained due to its greater solubility of S as SSP and availability to the plants compared to S applied as elemental S which needs time to be converted to the plant available forms. Singh *et al*. (1995) observed that ammonium sulphate exhibited the highest S content and elemental S recorded the lowest S in the soil which is in conformity with the findings of the present study.% increase in S content over control in soil due to the application of different sources of S was highest (139.4%) in the treatment T_3 followed by T_2 (72.2%) where S was applied in the form of SSP and elemental S, respectively during both years.

The S content in the dry matter of rapeseed (Fig. 2) consistently decreased with the progress of crop growth irrespective of treatments in both the years. There was no significant difference among the treatments in the initial period of crop growth; however, at the later stage the results showed significant differences. Among various treatments, the mean content of S in the plant was highest (0.17%) in the treatment T_5 where S-52 at 2% was applied as a foliar spray and was significantly higher than the treatments T_1 and T_2 and was at par with T_3 and T_4. However, the greater absorption of S due to foliar application of S-52 at 2% might be explained by quick absorption of S within the plant body compared to S applied to the soil as basal. With regards to the% increase of S content over control, it was found that the treatment T_5 recorded highest (30.3%) followed by T_3 (23.7%), T_4 (12.9%) and T_2 (9.7%) treatments. The lowest S content in T_2 might be due to the use of elemental S as source which is less soluble and also more time is required for the conversion into plant usable SO_4^{2-}–S form. Janzen and Bettany (1984) reported that the higher S applications relative to N availability caused excessive accumulation of S in the plant tissue of rapeseed. Bose *et al*. (2009) observed that the higher level of elemental S at 60 kg ha^{-1} was better than S at 30 kg ha^{-1} on the S content of rapeseed at different stages of crop growth.

Nitrogen Content in Soil and Plant

Available N in the soil initially increased significantly up to 80 days of crop growth irrespective of source of S and a higher content of N being maintained with the treatment T_1 when no sulphur was applied (Fig. 3). Maintenance of greater N in the soil in the treatment T_1 (control) might be due to the relatively lower rate of absorption of N by the plants as evident from the total N content of the plant. Jain *et al*. (1984) reported that the uptake of N by different crops in the absence of S application decreased due to lower rate of absorption of N. The results further revealed that the available N in the soil recorded a gradual decrease with the progress of crop growth. The magnitude of decrease in the N content in all the treatments supplied with S was relatively higher compared to control (T_1).

The N content in the plant decreased with the progress of crop growth irrespective of treatments (Fig. 4). However, the magnitude of such a decrease varied with the treatments, N content being highest (2.35%) with the application of elemental S at 30 kg

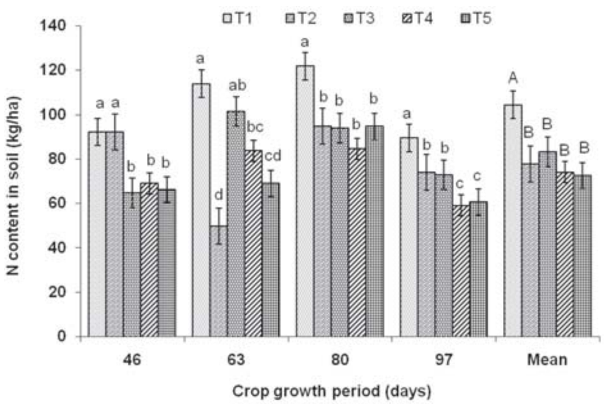

Fig. 3. Effect of different sources of S on N content in the rhizosphere soil of rapeseed. Means followed by the same letter are not significantly different at the 0.05 level of probability by Duncan's Multiple Range Test (DMRT). Bars are ±SE of the mean.

ha^{-1} up to 63 days of crop growth, and the lowest (1.27%) with the foliar application of 2% S-52 at 97 days of crop growth. However, the mean N-content was highest (2.3%) in T_4 where 1% S-52 had been applied as foliar spray resulting in 9.75% increase over control. The results of the present investigations are in agreement with the findings of Bose *et al*. (2009) who reported that the maximum N content in the dry matter of rapeseed were 2.47 and 2.41% with the application of 0.15% S as nitrosulf and 60 kg elemental S ha^{-1}, respectively. Habtegebrial and Singh (2006) observed that the nitrogen content of shoots of the *tef* crop was significantly increased with S application ($P < 0.05$), with strong positive interactions both in the split and whole applications.

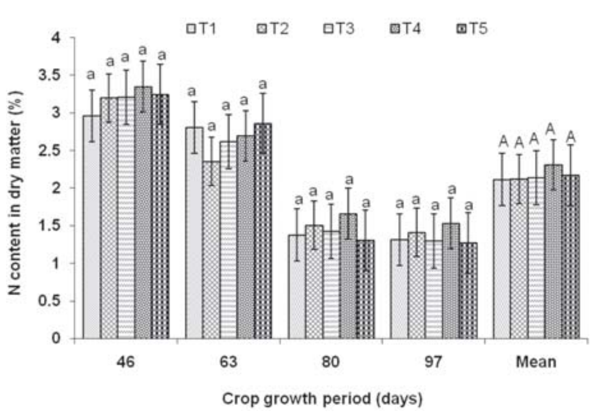

Fig. 4. Effect of different sources of S on N content in the dry matter of rapeseed. Means followed by the same letter are not significantly different at the 0.05 level of probability by Duncan's Multiple Range Test (DMRT). Bars are ±SE of the mean.

Yield and Quality Attributes

Application of different sources of S significantly influenced the yield and quality attributes of rapeseed (Table 1). The seed yield was significantly higher with the application of SSP (T_3) than elemental S and S-52. However, application of 30 kg S ha^{-1} as SSP resulted in 16.3, 10.4 and 9.9% increase in seed yield over that of corresponding applications of elemental S, 1% S-52 and 2% S-52, respectively during both the years. Foliar applications of both levels of S-52 had no significant variation. The highest seed yield was 908 kg ha^{-1} in the treatment T_3 and resulted in 41.9% increase over control yield during both years. Raj and Karwasra (1994) reported that the grain yield of *toria* increased significantly with increased doses of S up to 45 mg kg^{-1}, above which it decreased significantly. Further, they observed that the SSP was the best source of S in increasing the grain yield. The stover yield was significantly higher with the application of SSP compared to other sources of S. The increase in the stover yield due to the application of 30 kg S ha^{-1} as SSP was 11.3, 10.1 and 4.5% over that of elemental S at 30 kg ha^{-1}, 1% S-52 and 2% S-52, respectively. The results of the present investigations are in agreement with the findings of Misra (2003).

The oil content, crude protein and soluble protein were significantly influenced by the different sources of S (Table 2). The oil content was significantly better with the application of SSP compared to other two sources of S. The highest oil content was 41.5% in the treatment T_3 and resulted in 8.3, 6.4 and 2% increase over that with elemental S at 30 kg ha^{-1}, 1% S-52 and 2% S-52, respectively. Naik and Rao (2004) recorded highest oil content of 40.8% in the sunflower following application of 40 kg S ha^{-1} as pyrite + farmyard manure. The crude protein was significantly higher with the application of SSP compared to other two sources of S. However, there is no significant difference in crude protein content among the elemental S at 30 kg ha^{-1}, 1% S-52 and 2% S-52. Further, application of S at 30 kg ha^{-1} as SSP recorded highest crude protein content of 25.4% and resulted in 14.3% increase over control during both the years. The results of the present investigation find support from Kumawat *et al*. (2004) who observed a significant increase in oil and protein content of mustard seed up to 60 kg S ha^{-1} and the maximum oil and protein content were 39.0 and 20.2%, respectively. The increase in seed protein content of *Brassica napus* with the application of S could be due to the fact that N is an integral part of protein and the protein of rapeseed contains relatively large quantities of the S

Table 1. Effect of different sources of sulphur on the yield of rape (*Brassica campestris* L.)

Treatment	Seed yield (kg ha^{-1})			Stover yield (kg ha^{-1})		
	2006-07	2007-08	Pooled	2006-07	2007-08	Pooled
T_1: Control (No S)	648^d	632^d	640^d	3727^c	3645^c	3686^d
T_2: Elemental S 30 kg ha^{-1}	778^c	784^c	781^c	3903^c	3974^b	3939^c
T_3: 30 kg S ha^{-1} as SSP	895^a	921^a	908^a	4333^a	4435^a	4384^a
T_4: 1% S-52	821^b	823^b	822^b	3943^{bc}	4015^b	3979^c
T_5: 2% S-52	825^b	826^b	826^b	4173^{ab}	4212^{ab}	4193^b

†Within a column, means followed by the same letter are not significantly different at the 0.05 level of probability by Duncan's Multiple Range Test (DMRT).

Table 2. Effect of different sources of sulphur on oil, crude and soluble protein contents in rape (*Brassica campestris* L.)

Treatment	Oil content (%)			Crude protein (%)			Soluble protein (%)		
	2006-07	2007-08	pooled	2006-07	2007-08	pooled	2006-07	2007-08	pooled
T_1: Control (No S)	*37.37^c	37.47^d	37.42^d	28.18^b	28.04^c	28.11^c	26.92^b	26.64^b	26.78^b
	**(36.80)	(37.00)	(36.90)	(22.31)	(22.15)	(22.23)	(20.54)	(20.11)	(20.33)
T_2: Elemental S 30 kg ha^{-1}	37.98^b	38.70^c	38.34^c	28.59^b	29.00^b	28.80^b	27.74^{ab}	28.32^a	28.03^a
	(37.56)	(39.12)	(38.34)	(22.89)	(23.54)	(23.22)	(21.65)	(22.46)	(22.06)
T_3: 30 kg S ha^{-1} as SSP	39.76^a	40.51^a	40.14^a	29.99^a	30.52^a	30.26^a	28.51^a	29.00^a	28.75^a
	(40.87)	(42.23)	(41.55)	(24.97)	(25.84)	(25.41)	(22.78)	(23.54)	(23.16)
T_4: 1% S-52	38.17^b	39.17^b	38.67^c	28.38^b	28.73^b	28.56^b	27.63^{ab}	28.18^a	27.90^a
	(38.21)	(39.87)	(39.04)	(22.64)	(23.14)	(22.89)	(21.47)	(22.31)	(21.89)
T_5: 2% S-52	39.17^a	40.24^a	39.71^b	28.45^b	29.20^b	28.83^b	28.32^{ab}	28.72^a	28.52^a
	(39.87)	(41.67)	(40.77)	(22.67)	(23.81)	(23.24)	(22.47)	(23.14)	(22.81)

*Transformed values Arc $\sin^{-1}\sqrt{\text{per cent}}$, **Original values

†Within a column, means followed by the same letter are not significantly different at the 0.05 level of probability by Duncan's Multiple Range Test (DMRT).

containing amino acids like methionine and cystine (Ahamad *et al*. 2007). The soluble protein content was significantly higher with the application of different sources of S over that of control. Dwivedi and Bapat (1998) observed that the protein synthesis in soybean grain was suppressed at low levels of S with a concomitant increase in the deposition of undesirable non-protein nitrogenous compounds. Furthermore, when soils are not sufficient in S, the synthesis of S containing amino acids is hampered, causing an adverse effect on the grain and oil yield of rapeseed.

Principal Component Analysis

The principal component analysis (PCA) study on S content in the soil explained 90.2% of the total variance 47.6% of total variance was explained for S content in the plant when only first component was considered. Further, 49.7 and 65.7% of total variance were explained by first component due to PCA in case of soil N and plant N content, respectively. The PC-plant-N, PC-soil-N, PC-soil-S, PC-plant-S, are variables representing regression factor scores of first component for accumulating variations expressed by four different days of observations of plant N, soil N, plant S and soil S, respectively acting as independent variables for regression.

Stover and seed yield (Table 3) are explained by PC-soil-S (regression factor score of first component) significantly following stepwise technique of multiple regression. The PC-soil-S actually represents the contribution of soils at each day of study and so measurement of soil S at each day is ultimately a significant predictor to predict the stover yield and seed yield. While studying crude protein, the PC-soil-S is the only important predictor and resulted in significant regression at 1% level of significance. Inclusion of PC-plant S with PC-soil-S will further explain the dependable variables of oil content and soluble protein as revealed by stepwise regression. However, PC-soil-S represents higher contribution to plant-S measured during 50 days onwards.

Economic analysis

Highest benefit-cost (B:C) ratio of 1.77 was obtained with the foliar application of 1% S-52 (Table 4). With regards to the basal application of S, application of SSP at 30 kg S ha^{-1} gave better B:C ratio (1.31) compared with elemental S (0.05). Among fo-

Table 3. Principal component analysis (regression results)

Model	Variable	Unstandardized coefficients B	Std. Error	Standardized coefficients Beta	t	Sig.
Stepwise	Dependent variable: Stover yield; Predictors: (Constant), PC soil S					
	(Constant)	40.16	0.64		62.38	0.00
	PC soil S	1.92	0.67	0.63	2.89	0.01**
	R	R^2	Adj. R^2	SE (estimate)		
	0.63	0.39	0.34	2.49		
Stepwise	Dependent variable: Seed yield; Predictors: (Constant), PC soil S					
	(Constant)	8.09	0.16		49.39	0.00
	PC soil S	0.58	0.17	0.69	3.39	0.005**
	R	R^2	Adj. R^2	SE (estimate)		
	0.69	0.47	0.43	0.64		
Stepwise	Dependent variable: Oil content; Predictors: (Constant), PC soil S, PC Plant S					
	(Constant)	39.32	0.18		216.74	0.00
	PC soil S	1.28	0.20	0.69	6.44	0.00**
	PC plant S	0.81	0.20	0.44	4.09	0.002**
	R	R^2	Adj. R^2	SE(estimate)		
	0.94	0.88	0.86	0.70		
Stepwise	Dependent variable: Crude protein; Predictors: (Constant), PC soil S					
	(Constant)	23.35	0.19		124.94	0.00
	PC soil S	1.06	0.19	0.84	5.47	0.00**
	R	R^2	Adj. R^2	SE(estimate)		
	0.84	0.70	0.67	0.72		
Stepwise	Dependent variable: Soluble protein; Predictors: (Constant), PC soil S, PC Plant S					
	(Constant)	22.15	0.16		142.02	0.00
	PC soil S	0.76	0.17	0.65	4.45	0.00**
	PC plant S	0.48	0.17	0.41	2.81	0.02*
	R	R^2	Adj. R^2	SE(estimate)		
	0.88	0.77	0.73	0.60		

PC soil S: Principal component soil S; PC plant S: Principal component plant S; *, **: Significant at $P \leq 0.05$ and $P \leq 0.01$, respectively

Table 4. Effect of different sources of S on benefit-cost ratio of rapeseed (Pooled mean of 2006-07 and 2007-08)

Treatments	Yield (kg ha^{-1})		Added yield over control (kg ha^{-1})		Value of added yield (Rs ha^{-1})	Cost of added inputs (Rs ha^{-1})	Added profit over control	Benefit cost ratio (Rs ha^{-1})
	Grain	Straw	Grain	Straw				
T_1: Control (No S)	640	3686	—	—	—	—	—	—
T_2: Elemental S 30 kg ha^{-1}	781	3939	141	253	1098.90	1049.85	49.05	0.05
T_3: 30 kg S ha^{-1} as SSP	908	4384	268	700	2305.80	999.90	1305.90	1.31
T_4: 1% S-52	822	3979	182	293	1384.65	499.95	884.70	1.77
T_5: 2% S-52	826	4193	186	507	1622.70	999.90	622.80	0.62

Variable cost: Elemental S = Rs 34.65 kg^{-1}, S-52= Rs 500 L^{-1}, Single super phosphate= Rs 4.50 kg^{-1}
Fixed Cost: Rapeseed grain = Rs 6.0 kg^{-1}, Stover = Rs 1.00 kg^{-1}, Urea = Rs 5.40 kg^{-1}, SSP = Rs 4.50 kg^{-1}, MOP = Rs 6.00 kg^{-1}, Seed cost = Rs 300 ha^{-1}, Land preparation = Rs 230 ha^{-1}, Irrigation = Rs 350 ha^{-1} $season^{-1}$, Plant protection chemicals = Rs 572 ha^{-1} $season^{-1}$, Labour = Rs 110 $labour^{-1}$.

liar application treatments, 1% S-52 was better than 2% S-52.

Conclusions

The increase in the rapeseed grain yield was recorded (highest of 19.7 and 25.8%, respectively) during 1st year and 2nd year over control with a basal application of 30 kg S ha^{-1} as SSP. Application of SSP resulted in highest S in the soils throughout the crop growth period compared to other sources of S. Furthermore, application of 2% of S-52 was best for maintenance of S content in the dry mater of rapeseed throughout the crop growth period. Among the sources of S, *i.e.* elemental S, SSP and S-52 applied to the rapeseed, the performance of SSP on yield, quality attributes and available S content of soil was better than the other sources of S. From the economic point of view, application of 1% S-52 as foliar was best for the profitability of rapeseed crop. The soil S was the most important predictor for yield and quality attributes of rapeseed.

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Received 16 March 2011; Received in revised form 1 October 2011; Accepted 21 May 2012