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Response of soybean (*Glycine max*) to different sources and levels of sulphur application

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ABSTRACT

Sulphur (S) is an important nutrient element for increasing soybean [*Glycine max* (L.) Merrill.] yield and oil content. The present study was conducted for three years to evaluate the effect of four levels of S (0, 20, 30 and 40 kg S/ha) applied through three different S sources (single super phosphate: SSP), gypsum and bentonite-S). Soybean responded to S application and its yield increased significantly up to 30 kg S/ha through different S sources. Across the S levels, the improvement in seed yield under SSP, gypsum and bentonite-S ranged from 0.257, 0.253 and 0.280 t/ha over the control. Application of sulphur has a positive effect on S concentration and total S uptake by the crop. All the three sources of S recorded equivalent effect on soybean at 30 kg S/ha. From the above, it may be concluded that application of 30 kg S/ha has maximized the productivity of soybean under sulphur deficient soils. The returns per rupee spent values increased with an increase in S application from 20 to 30 kg S/ha, indicating higher returns from these levels per unit of money spent on sulphur. Sulphur applied through SSP, gypsum and bentonite was equally efficient in meeting the S requirement of soybean under S deficient soils.

Keywords: Bentonite-S, Gypsum, Soybean, SSP, Sulphur, Yield

Soybean [*Glycine max* (L.) Merrill.] popularly known as Golden Bean, is an important leguminous crop, rich in protein (40-42%), oil content (18-20%) and has the high economic potential to be used in food industries worldwide. India has 11.3 million ha under soybean and produces 13.8 million tonnes of soybean seeds (Anonymous 2019). However, soybean could not yield its potential unless provided required nutrient inputs to produce sufficient biomass (Singh *et al.* 2018). Among the various nutrients required for optimum growth of soybean, sulphur (S) is the most important secondary nutrient for which soybean response most. Sulphur is a constituent of three amino acids, *i.e.* cystine, cysteine and methionine and plays an important role in the nutrition of oilseeds (Parmar *et al.* 2018). The S requirement of oilseed crops is higher than cereal crops, where S uptake in oilseeds ranged from 5–20 kg/t (Dhageet *et al.* 2014). A recent analysis of Indian soils revealed an average deficiency level of 28.5% for S (Shukla and Behera 2019). According to Brar *et al.* (2013), the S deficiency in soils of 9 districts in Punjab ranged from 6.0–48.8 per cent. Increased preference for Di-ammonium phosphate as a source of N and P over SSP may not be adequate for S oilseeds.

The response of soybean to applied S varied with soil types, sources, management practices and crops. Soybean crop may need more S than it is being supplied through the recommended doses of P through SSP in S deficient soil, which may not be economically viable. There are now many other S fertilizers available, but the comparative response of various S sources on oilseeds and cereal crops has been studied by a few workers (Brar *et al.* 2013, Brar *et al*. 2015, Saini *et al*. 2016). Therefore, assessment of S requirement of crops based on S fertilizers and their relative efficiencies is needed to optimize the S nutrition of soybean for maximum yield. The present study aimed at evaluating the efficacy of different S fertilizers to meet the S requirement of soybean. The economics of S management through different fertilizer in soybean was also studied.

MATERIALS AND METHODS

Location and climate: A field experiment was conducted during 2015–17 at the Research Farm of Department of Soil Science, Punjab Agricultural University, Ludhiana Punjab, India. The region belongs to C_4 climate characterized by sub-tropical, semi-arid type of climate.

Site characterization: The bulk soil samples (0-15 cm depth) were collected from the field before the commencement of the experiment (2015) and tested for

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important soil properties using the standard procedures. The experimental soils were normal in reaction (pH: 7.56), electrical conductivity (0.15 dS/m), low in soil organic carbon (0.38%), low in available N (123.8 kg/ha), high in available P (28.3 kg/ha), low in available K (119.2 kg/ha) and S (14.0 kg/ha).

Experimental details: The experiment was conducted in 2015, 2016 and 2017 in a randomized complete block design with three replications in the plots measuring 60 m^2 (12 m × 5 m). The treatments comprised control (without S), SSP-S_{20}, SSP-S_{30}, SSP-S_{40}, Gypsum-S_{20}, Gypsum-S_{30}, Gypsum-S_{40}, Bentonite-S_{20}, Bentonite-S_{30}, and Bentonite-S_{40}. Nitrogen (31 kg/ha) and P (26 kg/ha) was applied to soybean following the recommendation of Punjab Agricultural University, Ludhiana, under irrigated conditions. Most of the time, the canal water was used as a source of irrigation water.

Yield and yield attributes: The crop was harvested at physiological maturity and the yield of seed and stover was recorded. The plant samples were collected and processed as per standard protocols. Plant samples were dried in the oven at 60±5°C and ground in a Willey grinder and digested in a di-acid mixture of HNO_3 and $HClO_4$ in the ratio (3:1) for further analysis. The S content in soybean was determined using the turbid metric method described by Chesnin and Yien (1950). The yield attributes like plant height, the number of pods per plant in soybean was recorded.

Sulphur use efficiency indices: The agronomic efficiency of applied S (AE, kg yield increase per kg S applied) and recovery efficiency of applied S (RE, %) was calculated as described by Dobermann (2007).

Statistical analysis: The data were subjected to statistical analysis using RCBD by comparing the means at 5% level of significance.

RESULTS AND DISCUSSION

Effect of rates and sources of S on soybean yield: Soybean yield was increased with the gradual increase in the level of S from 0 to 40 kg/ha. The application of S (0 to 40 kg/ha) improved seed yield of soybean by 9 to 34%, 10 to 25% and 12 to 28% during 2015, 2016 and 2017, respectively (Fig 1). Across the sources, application of 20, 30 and 40 kg S/ha recorded higher yield by 11.7, 20.1 and 31.8% (2015), 11.5, 20.5 and 23.6% (2016) and 11.3, 20.8 and 26.7% (2017), respectively, over the control. The effect of 40 kg S/ha on seed yield was more prominent in the first year of the experiment. In the second and third year of the investigation, an increase in yield was more up to 30 kg S/ha compared to control. Across the S levels, the improvement in yield under SSP, gypsum and Bentonite-S ranged from 0.257, 0.253 and 0.280 t/ha over the control. The results indicated that applying 30 kg S/ha through either source seems the optimum level of S for harvesting the maximum yield of soybean grown under S deficient soils. Similar to seed yield, stover yield also increased with the application of sulphur (Table 1).The straw yield was varied from 2.04, 1.90 and 2.27 t/ha in control to 2.67, 2.44 and 2.72 t/ha

Table 1 Effect of rate and sources of S application on stover yield, harvest index (HI), S content, S uptake, yield attributes, agronomic efficiency and apparent S recovery of soybean

Treatment	Stover yield (t/ha)				Mean HI	S content in seed#	S Content in stover#	Total S uptake#	Plant height	Pods per plant	Seeds Per pod	agronomic efficiency	apparent S recovery
	2015	2016	2017	Mean		(%)		(kg/ha)	(cm)	Number		(kg/kg)	(%)
Without S	2.04	1.90	2.27	2.07	38.9	0.338	0.112	6.75	94.7	76	2.57	-	-
SSP-S_{20}	2.21	2.18	2.47	2.28	38.9	0.346	0.137	8.14	95.5	89	2.70	7.0	7.0
SSP-S_{30}	2.42	2.26	2.57	2.42	39.6	0.358	0.142	9.09	98.8	104	2.73	9.0	7.8
SSP-S_{40}	2.65	2.36	2.69	2.57	39.5	0.367	0.155	10.09	101.3	110	2.87	8.9	8.4
Gyp-S_{20}	2.23	2.19	2.44	2.29	38.9	0.345	0.126	7.89	95.3	87	2.63	7.2	6.4
Gyp-S_{30}	2.45	2.29	2.63	2.46	39.1	0.366	0.139	9.15	96.8	97	2.77	8.6	8.2
Gyp-S_{40}	2.64	2.4	2.69	2.58	39.2	0.366	0.145	9.77	97.8	100	2.90	8.7	7.6
Bent-S_{20}	2.28	2.29	2.47	2.35	38.8	0.351	0.131	8.29	96.2	91	2.77	8.7	7.7
Bent-S_{30}	2.44	2.39	2.64	2.49	39.0	0.375	0.146	9.59	97.3	111	2.80	9.3	9.5
Bent-S_{40}	2.67	2.44	2.72	2.61	39.3	0.378	0.156	10.43	99	116	2.90	9.5	9.2
CD (5%)	0.125	0.129	0.208	0.126	1.19	0.023	0.016	0.54	NS	6.8	NS		

mean of three years

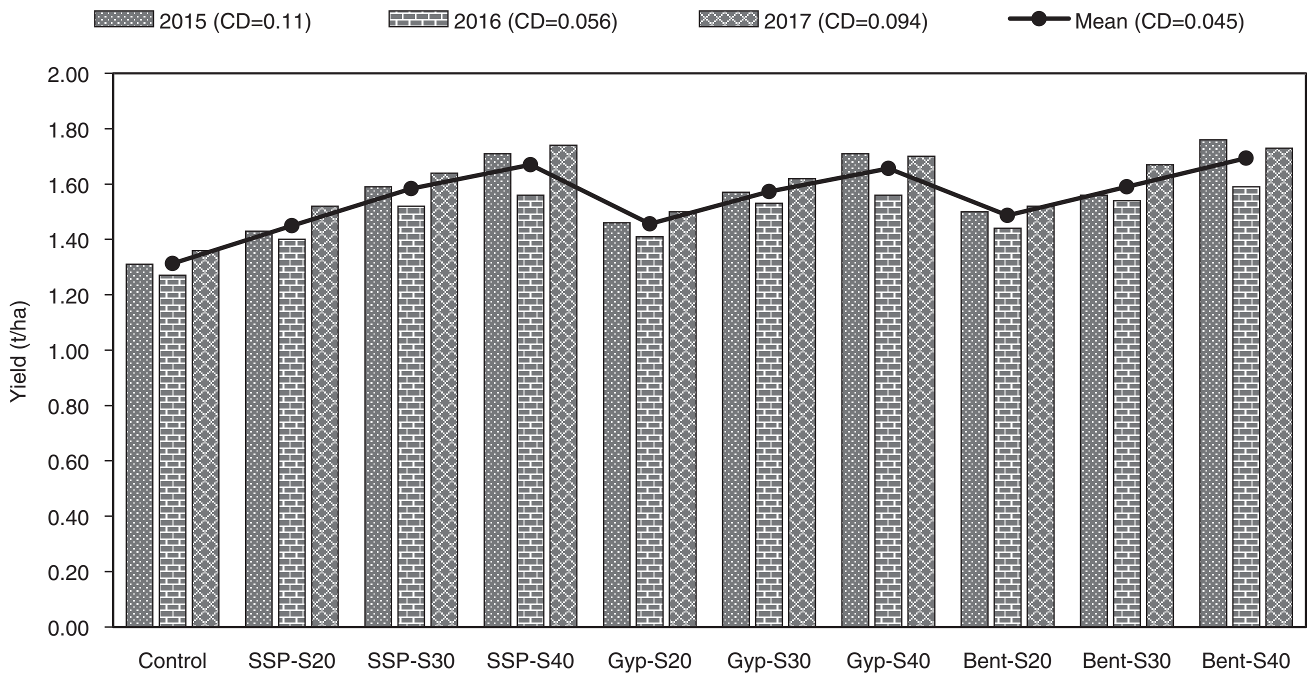

Fig 1 Effect of different sources and levels of sulphur application on seed yield of soybean (t/ha).

in Bentonite-S_{40} during 2015, 2016 and 2017 respectively. Overall, straw yield increased by 16.9% in SSP-S_{30}, 18.8% in Gypsum-S_{30} and 20.2% in Bentonite-S_{30} compared to control (without sulphur). Harvest index (HI) of soybean was influenced by S application and ranged from 38.9 to 39.6 per cent (Table 1). The highest (39.5) and lowest (38.9) HI was observed under SSP-S_{30} and control (without S), respectively.

Singh *et al.* (2018) reported that soybean seed and straw yield increased significantly up to the level of 40 kg/ha and gypsum was the most suitable source of S for soybean under mid-hill conditions in Himachal Pradesh. Sulphur fertilization improved the uptake of macro and micronutrients in oilseed crops (Singh 1999). The improvement in uptake of nutrients could be the reason for the higher yield of soybean in the present study. Moreover, S application positively affects cell division, enlargement, and elongation, resulting in faster and uniform vegetative growth of the crop (Noman *et al.* 2015). Patel *et al.* (2018) also reported a higher pod yield of groundnut crops with S fertilization. The long-term experiment data revealed that exclusion of S (NPK-S) has resulted in lower biological yield than applying a recommended optimal dose of NPK (Gupta *et al.* 2019). Application of bentonite-S and phospho-gypsum improved the seed yield of mustard by 35.7 and 15.6%, respectively, over control (Kumar *et al.* 2017). However, it was reported that the S applied through elemental sulphur and Bentonite-S has to be oxidized by a microbial process that helps solubilize the other plant nutrients, especially P, which ultimately increased yield (Katyal *et al.* 1997). Sharma and Sharma (2014) reported that the application of 20 kg S/ ha through gypsum was the optimum level of S instead of 30 kg S/ha under agro-climatic conditions of Punjab. However, Gallani *et al.* (2019) and Singh *et al.* (2017) concluded that the application of 40 kg S/ha was the optimum level of S for enhancing soybean productivity.

Effect of rate and source of S on yield attributes of soybean: Plant height under different S treatments was statistically at par. The number of pods per plant under other treatments ranged from 76–116 (Table 1). The application of S had a significant effect on the number of pods per plant compared to the control. Number of pods per plant increased from 76 in control (without S) to 104, 97 and 111 with the application of 30 kg S/ha through SSP, gypsum and bentonite-S, respectively. At an equivalent rate of different sources, the impact of S application on the number of pods per plant was statistically at par. Irrespective of the sources of S, increasing the level of S recorded a positive effect on the numbers of seeds per pod. However, the effect was statistically non-significant. These findings agree with Kumar *et al.* (2017), who reported a positive impact of S application on yield attributes of oilseed crops.

Effect of rate and source of S on concentration and uptake of sulphur by soybean: Application of S improved the mean concentration of S in both seeds and stover of soybean compared to control (Table 1). The mean concentration of S in soybean seeds and stover ranged from 0.338 and 0.112 per cent in control to 0.378 and 0.156% in Bentonite-S_{40} treatment, respectively. Equivalent rates of S application from different sources have comparable S content in both seeds and stover. The improvement in S concentration in seeds was significant up to 30 kg S/ha. However, the total S uptake increased up to the application of 40 kg S/ha (Table 1). Results revealed that the highest mean total S uptake (10.43 kg S/ha) was recorded with 40 kg S/ha through Bentonite-S_{40} and the lowest (6.75 kg S/ha) under control

Table 2 Effect of rate and source of S application on returns per rupee spent (RPRS) in soybean

Treatments	Soybean yield (t/ha)	Returnvb (₹ per ha) Yield* MSP	S Inputs (₹ per ha)	Return over variable cost	RPRS
Without S	1.31	36785	0	36785	
SSP-S_{20}	1.45	40716	600	40116	5.6
SSP-S_{30}	1.58	44366	900	43466	7.4
SSP-S_{40}	1.67	46894	1200	45694	7.4
Gyp-S_{20}	1.46	40997	313	40684	12.5
Gyp-S_{30}	1.57	44086	469	43617	14.6
Gyp-S_{40}	1.66	46613	625	45988	14.7
Bent-S_{20}	1.49	41839	689	41150	6.3
Bent-S_{30}	1.59	44647	1033	43614	6.6
Bent-S_{40}	1.69	47455	1378	46077	6.7

#MSP of Soybean= ₹ 28080 per tonne (Mean of three years MSP of soybean); *167, 250 & 333 kg SSP for 20, 30 & 40 kg S/ha (SSP @ ₹ 360 per q up to 375 kg); 125, 188 & 250 kg Gypsum for 20, 30 & 40 kg S/ha (Gypsum @ ₹ 250 per q) and 22, 33 & 44 kg Bentonite-S for 20, 30 & 40 kg S/ha (Bentonite @ ₹ 3100 per q)

(without S). Thus, total S uptake increased significantly with the increasing level of S application. These results agree with Devi *et al.* (2012), who reported that fertilizer S significantly increased the S uptake. Higher seed S content compared to stover might be due to higher accumulation of S containing organic compounds as seed storage reserves, thereby leading to an apparent depletion of S content and low uptake in straw as reported by Jadhav *et al.* (2007).

Effect of rate and source of S application on sulphur use efficiency indices: The mean agronomic efficiency ranged from 7.0 kg seeds/kg S under Gypsum-S_{20} to 9.5 kg seeds/kg Sunder Bentonite-S_{40} (Table 1). Application of S at the rate of 40 kg S/ha through SSP/gypsum/Bentonite-S recorded mean agronomic efficiency of 8.9, 8.7 and 9.5 kg seeds/kg, respectively. However, equivalent rates and sources of S had a similar effect on the mean agronomic efficiency of applied S. Overall, 30 kg S/ha had higher apparent S recovery under different S fertilizer sources except SSP-S_{30} treatment. The mean apparent S recovery was highest under 30 kg S/ha applied through Bentonite-S and lowest under 20 kg S/ha applied through gypsum.

Effect of rates and sources of S on economic return: The return per rupee spent (RPRS) was computed based on benefits from crop and the input expenses of rates and sources of S only (Table 2). In general, the RPRS values increased with an increase in S application from 20–30 kg S/ha, indicating higher returns from these levels per unit of money spent on sulphur. For example, 30 kg S/ha through each source recorded RPRS of 7.4 for SSP-S_{30}, 14.6 for Gypsum-S_{30} and 6.6 for Bentonite-S_{30}. Biswas *et al.* (2004) reported that each rupee spent on fertilizer S generated an extra benefit of ₹ 12–24 at the optimum dose (value: cost ratio) and emphasized a value: cost ratio of 2–2.5 is generally accepted to be conducive to fertilizer use. In the present study, the returns per rupee spent from fertilizer S at optimum dose ranged from ₹ 6.6–14.7. Thus, the application of S could be encouraged to harvest potential yield of soybean and additional economic benefits to the farmers in S deficient soils.

Conclusions

The results of the present study indicated that soybean grown on S deficient soils respond to S application. The application of 30 kg S/ha was an optimum dose of S required for obtaining maximum soybean production and economic returns under S deficient soils. All the tested three sources of S (gypsum, SSP and bentonite-S) were equally efficient in meeting the S requirement of soybean.

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