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Research Paper

Effect of levels and time of sulphur application on growth, yield and quality of soybean (*Glycine max*)

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ABSTRACT

A field experiment was carried out during the rainy season of 2009 and 2010 at IARI, New Delhi, to study the performance of soybean [*Glycine max* (*L.*) *Merr*.] as influenced by different levels (0, 15, 30 and 45 kg/ha) and time of sulphur application [Basal, flowering and split (50% basal and 50% flowering)]. The growth parameters were variably influenced by the sulphur management. Branches/plant, leaf-area index and number of nodules were higher with higher levels of sulphur application. Among the treatments, split application of 45 kg sulphur as 50% basal and 50% at flowering recorded highest values of branches/plant, leaf-area index and nodules/plant over the other shown treatments. The physiological indices like mean crop growth and mean relative growth rate higher number of recorded variable response to sulphur management. Seed yield was the highest, being 35.77% with split application of 45 kg sulphur as 50% basal and 50% at flowering (1.90 t/ha) over the control (1.40 t/ha). The stover yield was highest with basal application of 45 kg sulphur. The quality parameters like protein content and oil content in seed recorded the highest values with split application of 45 kg sulphur as 50% basal and 50% at flowering.

Key words : Growth parameters, Quality, S levels, Split application, Soybean, Time of application

Soybean area and production have been increasing tremendously in the last 4 decades, from a meagre few thousand hectares in seventies to nearly 10.69 million ha in 2012, with a production of 12.68 mt with an average productivity of 1,185 kg/ha (SOPA, 2013). Sulphur being an important nutrient responsible for synthesis of several amino acids and fatty acids in oilseed crops, is seldom given due recognition in the nutrient management. Over the years, the intensive agriculture with no addition of sulphur has caused its decline in the soil. The problem has been further compounded by the use of high-analysis fertilizers lacking sulphur and discontinuation of application of organic sources of nutrients like farmyard manure. There is a need for laying emphasis on alleviating the sulphur deficiency in soil and increasing the efficiency of applied sulphur. It calls for study on important aspects of sulphur management with reference to the amount of sulphur required by the crop, method of sulphur application and time of sulphur fertilization to the crop.

The systematic sulphur management with due regards for the right quantity, time of application with reference to crop requirement and physiology has been observed to record higher growth, increased physiological indices, yield and increased sulphur efficiency. Further it has also resulted in complementary effect on use efficiency of other macro-as well as micro-nutrients. The impact of sulphur management has been found to be complementary on the nodulation in soybean leading to nitrogen economy and higher monetary returns (Sharma *et al.*, 2004; Shivakumar *et al.*, 2009). Since most of the soils in the soybean-growing areas are deficient in the available sulphur, there is a need for systematic study on the sulphur nutrition aiming at increasing the productivity of soybean and higher sulphur-use efficiency.

MATERIALS AND METHODS

A field experiment was carried out during the rainy season of 2009 and 2010 at the research farm of Indian Agricultural Research Institute, New Delhi, (28° 40'N, 77° 12'E, 228.6 m above the mean sea-level). The mean annual rainfall of Delhi is 650 mm and of which more than 80%

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is generally received during the south–west monsoon season (July–September), with mean annual evaporation of 850 mm. The soil was sandy loam, low in available N (266.4), medium in available P (8.0 kg/ha) and K (153 kg/ha) and low in available S (9.5 ppm). The soil was slightly saline in nature with pH 7.8. The treatments consisted 9 combinations of 3 levels of sulphur, viz. 15, 30 and 45 kg S/ha, and 3 times of application, viz. 100% as basal, 100% at flowering and split application with 50% at sowing and 50% at flowering along with one absolute control, totaling to 10 treatments. The gypsum was used as source of sulphur. Ten treatments were tried in randomized block design, replicated thrice.

The crop was sown during the first week of August in 2009 and the second week of July in 2010 with the onset of monsoon and raised as per the recommended package of practices with 35 kg N, 75 kg P_2O_5 and 40 kg K_2O/ha. Soybean variety 'DS 9712' was used as test crop variety and raised with a seed rate of 75 kg/ha. There was a significant difference in the rainfall received during the individual years. In 2009, a total 490 mm spread over fewer rainy days was received while in 2010, a total 750 mm of well-distributed rainfall was received during the cropping season. In 2009, crop experienced a drought like situation in the initial weeks of establishment needing several gap fillings. All the growth parameters were recorded at regular interval, while yield parameters and yield were recorded at harvest. The observations recorded on different parameters were statistically analyzed as per the analysis of variance (ANOVA) for randomized block design at 0.05 probability.

RESULTS AND DISCUSSION

Growth parameters

The growth parameters viz. number of branches, leaf-area index (LAI), number of nodules and their biomass increased with higher levels during early stage of crop growth when applied as basal, whereas in later stages split application of 45 kg sulphur as 50% basal and 50% at flowering recorded highest values (Table 1). Management factors like spacing and plant nutrition can affect the number and distribution of branches in soybean. Sulphur plays an important role in vegetative growth and its deficiency at this stage causes severe reduction in biomass production and reduction in number of branches/plant. Mohanti *et al.* (2004) and Jamal *et al.* (2005) reported similar results. The leaf-area index was highest (3.85) at 60 days with application of 45 kg S/ha split as 50% as basal and 50% flowering over the other treatments (Table 1). The results confirm the findings of Hemantaranjan and Trivedi (1997), and Ganeshamurthy and Reddy (2000).

The sulphur nutrition treatments did not show significant effect on mean crop-growth rate (CGR) during 30–60 days and 60–90 days (Table 1). The control with no sulphur application recorded the lowest mean CGR among the treatments. The mean relative growth rate (RGR) shown variable response to sulphur management treatments at different stages of crop growth. Between 30 and 60 days after sowing, the application of 45 kg S/ha at flowering recorded significantly higher mean RGR, while at all other stages in both the years of experimentation, the mean RGR was not influenced significantly by any of the treatments and all treatments were found at par with each other. Between 30–60 days after sowing, application of 45 kg S/ha as basal showed its greater utility ensuring the timely availability of sulphur; however at later stages, perhaps indicating that the basal application of sulphur too made available sulphur continuously during the growing season commensurating with the crop demand. Jamal *et al.* (2005) reported positive correlation between different growth indices and observed that the leaf area index, leaf-area duration, crop-growth rate and biomass production increased with increasing sulphur doses.

The number of nodules increased between 45 and 60 days substantially (Table 1). At 45 days, the highest number of nodules/plant were observed with application of 45 kg S/ha as basal, while at 60 days the highest number of nodules/plant were observed with split application of 45 kg S/ha as 50% basal and 50% at flowering. The control with no-sulphur application recorded the lowest number of nodules at all the stages. The higher dose of 45 kg S/ha basal recorded higher nodulation at 45 days, while the application of 45 kg S/ha, split as 50% basal and 50% at flowering, made its impact on the nodulation recording-more number of nodules/plant at 60 days after sowing, indicating the beneficial effect of split application of sulphur on the nodulation in soybean. But on the contrary, the application of 45 kg S/ha split as 50% basal and 50% at flowering recorded higher biomass, indicating that during well-spread rains and unstressed crop, application of sulphur as basal dose alone could increase the nodule biomass. Sharma *et al*. (2004) reported similar positive effect of sulphur on nodulation.

Yield parameters

The application of 45 kg S/ha split as 50% basal and 50% at flowering recorded significantly higher values of all these yield parameters, viz. pods/plant, seeds/pod and seed index (Table 2). It was closely followed by application of 30 kg S/ha split as 50% basal and 50% at flowering. The application of 45 kg S/ha as a basal and application of 30 kg S/ha split as 50% basal and 50% at flowering were at par with application of 45 kg S/ha split as 50% basal and 50% flowering with regards to number of seeds/pod. Similar trend was also observed in seed index. The lowest yield parameters were noted in the control with no sulphur. Pods/plant, seeds/ pod and seed index were the highest with 45 kg S/ha split as 50% basal and 50% at flowering. As most of the yield parameters are greatly influenced by the availability of sulphur, they could get sufficient amount of sulphur in this treatment as the sulphur replenishment was coinciding with the switching over of crop from vegetative to reproductive phase leading to improved yield parameters. Further, as the demand for sulphur by the soybean is higher, its application at flowering might have helped to absorb more sulphur leading to improved performance of all the yield parameters. Similar observations were also been made by Tomar *et al*. (2004) and Vijayapriya *et al.* (2005). Irrespective of the climatic conditions prevailed in the first and second year, the split application could easily make sufficient quantity of sulphur available and thus improved the yield parameters.

Yield and harvest index

The seed yield of soybean was significantly higher with 45 kg S/ha split as 50% basal and 50% at flowering (Table 2), closely followed by 45 kg S/ha basal and application of 45 kg S/ha at flowering. The increasing levels of sulphur applied as basal, at flowering or split as 50% basal and 50% at flowering recorded increasing seed yield. The present trend may be attributed to the higher quantity of sulphur applied in split coinciding with the crop demand.

Table 1. Growth parameters and nodulation of soybean as influenced by levels and time of sulphur application (pooled data of 2 years)

Treatment	Branches/ plant	LAI at 60 days	Mean CGR ($g/day/cm^2$)		Mean RGR (g/g/day)		Nodules/plant		Nodule dry weight(g/plant)	
	90 days		30–60 days	60–90 days	30–60 days	60–90 days	45 days	60 days	45 days	60 days
Control	3.1	3.07	0.39	0.20	0.052	0.010	18.8	40.3	0.48	1.40
15 kg S/ha as basal	3.3	3.23	0.45	0.20	0.050	0.009	22.1	42.1	0.51	1.52
30 kg S/ha as basal	3.5	3.40	0.47	0.29	0.048	0.012	24.0	43.4	0.54	1.59
45 kg S/ha as basal	3.5	3.65	0.53	0.37	0.050	0.013	27.6	45.2	0.58	1.68
15 kg S/ha at flowering	3.1	3.10	0.45	0.16	0.052	0.007	18.7	40.6	0.55	1.46
30 kg S/ha at flowering	3.4	3.22	0.48	0.23	0.053	0.010	20.0	41.4	0.57	1.47
45 kg S/ha at flowering	3.4	3.33	0.54	0.27	0.058	0.011	21.4	42.3	0.55	1.51
15 kg S/ha as 50% basal + 50% at flowering	3.3	3.16	0.47	0.21	0.053	0.009	21.2	41.4	0.57	1.56
30 kg S/ha as 50% basal + 50% at flowering	3.6	3.41	0.51	0.25	0.052	0.010	22.9	43.9	0.58	1.61
45 kg S/ha as 50% basal + 50% at flowering	3.9	3.85	0.57	0.31	0.051	0.011	26.3	47.4	0.62	1.76
SEm±	0.29	0.10	0.02	0.03	0.002	0.001	0.58	0.82	0.02	0.02
CD (P=0.05)	0.83	0.30	0.07	0.09	0.005	0.004	1.67	2.36	0.06	0.07

LAI, leaf-area index; days, days after sowing

Table 2. Yield attributes, seed, stover yield, harvest index, protein and oil content and their yields of soybean as influenced by levels and time of sulphur application (pooled data of 2 years)

Treatment	Pods/ plant	Seeds/ pod	Seed index (g)	Seed yield (t/ha)			Stover yield (t/ha)	Harvest index (%)	Protein (%)	Oil (%)	Protein yield (kg/ha)	Oil yield (kg/ha)
				2009	2010	Pooled						
Control	31.46	2.35	9.54	1.37	1.42	1.40	3.17	30.58	38.38	18.85	536.7	263.6
15 kg S/ha as basal	34.33	2.57	9.79	1.55	1.61	1.58	3.34	32.13	39.16	19.41	619.7	307.2
30 kg S/ha as basal	37.92	2.76	9.96	1.65	1.77	1.71	3.49	32.88	39.66	19.63	678.9	336.2
45 kg S/ha as basal	38.81	2.89	10.35	1.73	1.89	1.81	3.66	33.12	40.52	20.17	733.0	364.8
15 kg S/ha at flowering	32.91	2.48	9.99	1.48	1.60	1.54	3.33	31.60	39.03	19.35	600.9	297.7
30 kg S/ha at flowering	34.20	2.56	10.01	1.54	1.74	1.64	3.35	32.79	39.62	19.73	650.0	323.5
45 kg S/ha at flowering	37.08	2.68	10.21	1.71	1.85	1.78	3.39	34.29	40.34	20.08	717.3	357.6
15 kg S/ha as 50% basal + 50% at flowering	37.66	2.56	10.06	1.57	1.71	1.64	3.39	32.57	38.86	19.63	637.3	321.6
30 kg S/ha as 50% basal + 50% at flowering	38.22	2.82	10.04	1.62	1.84	1.73	3.49	33.13	39.86	20.05	691.3	347.2
45 kg S/ha as 50% basal + 50% at flowering	42.64	2.97	10.49	1.84	1.96	1.90	3.64	34.32	40.65	20.48	773.2	389.4
SEm±	1.22	0.06	0.08	0.027	0.023	0.033	0.05	0.56	0.21	0.18	12.87	6.91
CD (P=0.05)	3.49	0.17	0.23	0.081	0.067	0.095	0.14	1.59	0.61	0.52	36.91	19.82

By virtue of higher yield attributes with this treatment, the yield increase was obvious. Nasreen and Farid (2006) also observed increased seed yield with application of sulphur. The stover yield of soybean was significantly highest with application of 45 kg S/ha as basal or split than the other treatments (Table 2).

The harvest index of soybean was highest with split application of 45 kg S/ha as 50% basal and 50% at flowering, closely followed by 45 kg S/ha at flowering. The harvest index is an important factor indicating the conversion of photosynthates to economic yield.

Protein and oil content and their yields

The protein and oil content in seeds and their yields were significantly higher with 45 kg S/ha split as 50% basal and 50% at flowering in both the years (Table 2). Application of 45 kg S/ha as basal recorded the next best values in all these parameters. The increasing levels of sulphur at different time of application recorded increasing values. This could be probably owing to the fact that all these treatments supplied the highest level of sulphur among all the treatments. Sonune *et al*. (2001) and Gokhale *et al.* (2005) also reported similar reports of increased sulphur application increasing the protein and oil content in soybean seed. The split application of sulphur might have made it available to crop in tune with demand and thus increased its content and uptake of sulphur which ultimately resulted in the highest protein and oil content, as it is a constituent of amino acids and fatty acids. Moreover, influence of S management on oil and protein yield is the function of their content as well as seed yield.

Economics

Among the treatments, split application of 45 kg S/ha, 50% as basal and 50% at flowering recorded higher gross returns, net returns and benefit: cost ratio followed by 100% basal application of 45 kg S/ha. Shivakumar et al., (2009) and Devi *et al.* (2012) also reported similar results in soybean. The increase in gross returns, net returns and benefit: cost ratio in treatment consisting of highest dose of sulphur along with its split application at very important stages, *viz.* early growth and flowering, facilitated increased and timely availability of sulphur to soybean to match the crop requirement. Thus, it recorded good growth and yield. The monetary returns by increased yield was more than the investment made on the quantity of sulphur and its split application, resulting in higher gross returns, net returns and benefit: cost ratio.

Sulphur use indices

The pooled data for 2 years on sulphur-use indices, viz. agronomic efficiency (AE), recovery efficiency (RE) and partial factor productivity (PFP) were significantly influenced by sulphur treatments to soybean. The highest values for AE and PFPwere recorded with application of 15 kg S/ha split as 50% basal and 50% at flowering, while the lowest AE was recorded with 30 kg S/ha. As AE represents increase in seed yield per unit of nutrient application, the split application of sulphur at the lowest level resulted in maximum increase in seed yield even with nominal yield. Jat and Ahlawat, (2009) also reported similar results. Agronomic efficiency and recovery efficiency for different levels have shown variable response, whereas with respect to time of application split application of sulphur (50%

Table 3. Economics and sulphur-use indices of soybean production as influenced by levels and time of sulphur application (pooled data of 2 years)

Treatment	Gross returns (₹)	Net returns (₹)	Benefit : cost ratio	AE (kg seed increased/kg S applied)	RE (%)	PFP (kg seed/kg S)
Control	24,106	12,293	1.06	0.00	0.00	0.00
15 kg S/ha as basal	27,027	15,057	1.25	12.23	16.52	105.47
30 kg S/ha as basal	29,133	16,924	1.35	10.42	17.38	57.03
45 kg S/ha as basal	30,784	17,956	1.38	9.12	18.40	40.20
15 kg S/ha at flowering	26,395	14,021	1.15	9.34	12.45	102.58
30 kg S/ha at flowering	27,965	15,218	1.20	8.02	12.44	54.63
45 kg S/ha at flowering	30,058	16,194	1.23	8.46	14.20	39.53
15 kg S/ha as 50% basal + 50% at flowering	27,972	15,981	1.31	16.04	29.04	109.28
30 kg S/ha as 50% basal + 50% at flowering	29,510	17,079	1.35	11.14	25.90	57.76
45 kg S/ha as 50% basal + 50% at flowering	32,119	18,836	1.44	11.16	23.43	42.24
SEm±	481	468	0.04	1.73	1.59	1.27
CD (P=0.05)	1,381	1,342	0.11	4.96	4.56	3.63

AE, Agronomic efficiency; RE, recovery efficiency; PFP, partial factor productivity basal + 50% flowering) recorded highest agronomic and recovery efficiency over treatments received 100% S as a basal and 100% S at flowering.

It was concluded that owing to timely availability of sulphur through application of 45 kg S/ha split as 50% basal and 50% at flowering, the oil and protein content and their yield in soybean could be enhanced. The application of 45 kg S/ha split as 50% basal and 50% at flowering in soybean recorded the highest gross returns, net returns and benefit: cost ratio of soybean. The sulphur use indices were higher with the application of 15 kg S/ha split as 50% basal and 50% at flowering in soybean.

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