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Phosphorus and Sulphur Nutrition with P-Solubilizing Bacterial Inoculation Enhanced the Quality and Yield of Soybean (Cultivar JS-335)

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Field experiment was conducted to assess the response of soybean (cultivar JS-335) to phosphorus and sulphur nutrition with phosphorus solubilizing bacterial inoculation on yield and quality of grain. The results of two years studies revealed that yield attributes, seed and straw yield were increased with the application of sulphur and phosphorus with phosphorus solublizing bacterial inoculation than without phosphorus solublizing bacteria. However, application of 40 kg/ha significantly influenced the yield attributes and yield over its preceding doses. Numbers of pods per plant, seeds per pod, seed index, seed, straw and biological yield were also significantly increased by 40 kg P_2O_5/ha with phosphorus solubilizing bacterial inoculation over its lower levels. Hence, it is apparent that soybean production may be enhanced by the application of sulphur at 40 kg /ha and phosphorus at 40 kg P_2O_5/ha with phosphorus solubilizing bacterial inoculation.

Key word: Phosphorus, Sulphur, Soybean, Phosphobacteria.

Soybean [*Glycine max* (L.) Merrill] is a miracle crop of the world due to excellent nutritional quality, as it stands surrogate for nutritional security for large section of vegetarian people. In India, Rajasthan stands second in the area and production. In spite of its high yield potential (4.5 t ha^{-1}), soybean productivity is much less in India (0.95 t ha^{-1}) than the world average of 2.3 t ha^{-1} (FAI, 2006). It is a highly nutrient exhaustive as well as oil seeded legume requires higher amount of nutrients particularly P and S for its higher productivity. Phosphorus is an important constituent of major biological products in plants itself and plays a key role in the balance nutrition of the crops. Phosphate nutrition to the soybean results in an exhaustive rooting better. However, the importance of microbial inoculation in soil nutrients cycling and their role in plant nutrition has been realized for a long time. Recently attempts have been made to identify specialized group of soil microorganisms that will allow plant to absorb P from sources that are otherwise less available *viz*; mineral rocks, phosphate rock (Srivastava and Ahlawat, 1995). Phosphorus solublizing bacteria become a source of P to plants upon its release from their cells. The phosphorus solublizing bacteria reduce the P fertilizer application by 50 % without any significant reduction of crop yield (Jilani *et al*., 2007; Yazdani *et al.,* 2009). It infers that phosphorus solublizing bacterial inoculants hold great prospects for sustaining crop production with optimized P fertilization. Among the soil bacterial communities, phosphate solubilization is the result of combined effect of pH decrease and organic acids production (Fankem *et al.,* 2006). The use of P - solubilizing bacteria enhanced the availability of phosphorus in soil and its uptake by plants (De and Singh, 2010). Symbiotic relationship between phosphorus solublizing bacteria and plants is synergistic in nature as bacteria provide soluble phosphate and plants supply carbon compounds (mainly sugars), that can be metabolized for bacterial growth (Pérez *et al*., 2007). Sulphur is best known for its role in the formation of sulphur containing amino acids, synthesis of proteins, vitamins, chlorophyll and oil in oilseeds. Sulphur promotes nodulation in legumes and produces bold seed in oilseed. Therefore, the present study was undertaken to evaluate the effect of phosphorus and sulphur nutrition with and without phosphorus solublizing bacterial inoculation on production potential and quality of soybean.

Materials and Methods

The field experiment were carried at Agricultural Research Station, Kota, Rajasthan, India during *Kharif* 2007 and 2008 to assess the effect of phosphorus and sulphur nutrition with phosphorus solubilizing bacterial (PSB) inoculation on

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production potential and quality of soybean. The soil of experimental site was clayey loam having slightly alkaline (pH 7.5), organic carbon (0.56%), medium with respect to available nitrogen, phosphorus and high in potassium (280.0, 23.5 and 304.0 kg ha^{-1}, respectively) and sulphur content was 8.9 mg kg^{-1} in respective years. The treatments consisting of four levels of sulphur (0, 20, 40 and 60 kg ha^{-1}), seven levels of phosphorus (0, 20 kg P_2O_5 ha^{-1}, 40 kg P_2O_5 ha^{-1} and 60 kg P_2O_5 ha^{-1}) and 20 kg P_2O_5/ha , 40 kg P_2O_5/ha and 60 kg P_2O_5 ha^{-1} with and without phosphorus bacterial inoculation were tested in a split plot design having sulphur levels in main plot treatment and phosphorus fertilization with and without phosphorus solublizing bacterial in sub-plot treatments and replicated four times. All the treatments including control were treated with *Bradyrhizobium japonicum* culture @ 500 g/75 kg seeds.The phosphorus solublizing bacterial inoculation with *Bacillus polymyxa* was followed @ 20g/kg of seed at the time of sowing of the crop as per the treatments. A promising crop variety of soybean cv. JS-335 was sown manually in furrow with maintaining the optimum plant spacing 60×10 cm. However, all the other intercultural operations were done as per need of crops. N, P and S fertilizers were applied just before the sowing according to the treatments through diammonium phosphate and elemental sulphur. Optimum plant population of 0.4 million/ha was maintained by thinning one week after germination.The observations on yield attributes such as pods per plant, seeds per plant and seed index were recorded at the time of harvest. Plants from the net plot area were harvested, tagged, bundled and dried under sun and weighed for bundle weight. Seed and stover yield were recorded after manual threshing and expressed as kg ha^{-1}.The straw yield was computed by subtracting seed yield from bundle weight. The harvest index (%) of soybean was obtained by using the formula as described by Singh and Stockopt (1971).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (Seed yield)}}{\text{Biological yield (Seed + Stover)}} \times 100$$

Oil content was determined by the soxhlets extractor using petroleum ether as extractant and finally multiplied with seed yield to convert oil yield. The protein content was determined by multiplying seed nitrogen content (%) with 6.25 (AOAC, 1960) and protein yield was worked out by multiplying the seed yield and protein content (%). Since data followed the homogeneity test, pooling was done over the seasons and mean data are given.

Results and Discussion

Yield Attributes and Yield

Application of 40 kg P_2O_5/ha with PSB inoculation significantly increased the number of pods per plant (64.27), seeds per pod (2.63) seed yield (24.53q/ ha), straw yield (37.57q/ha) and biological yield (62.09q/ha) over 40 kg P_2O_5/ha alone. The corresponding increases were to the magnitude of 7.57, 6.48, 8.68, 9.60 and 19.75 % in case of pod per plant, seeds per pod, seed yield, straw yield and biological yield respectively (Table 1). Similar finding were also reported by Tiwari *et al.* (2002). It

Table 1. Effect of sulphur and phosphorus Fertilization levels with and without PSB inoculation on yield attributing characters, yield (q/ha) and harvest index (%) of soybean (Pooled data of 2 years)

Treatment	Pods per plant	Seeds per pod	Seed index (g)	Seed yield (qha^{-1})	Straw yield (qha^{-1})	Biological yield (qha^{-1})	Harvest index (%)
Sulphur (kg/ha)							
0	47.45	2.09	9.10	16.86	27.01	43.87	38.41
20	54.57	2.34	9.57	19.71	30.66	50.36	39.12
40	61.01	2.52	9.75	22.50	34.34	56.83	39.66
60	63.06	2.55	9.80	23.59	35.57	59.15	39.92
SEm ±	1.05	0.03	0.06	0.37	0.56	0.86	0.38
CD (P=0.05)	3.12	0.10	0.18	1.10	1.66	2.56	NS
Phosphorus (P_2O_5 kg/ha) & PSB							
0	39.31	1.81	8.75	13.15	20.79	33.95	38.79
20	47.38	2.11	9.25	16.71	25.76	42.47	39.37
20 + PSB	51.65	2.27	9.42	18.36	28.84	47.19	38.83
40	59.72	2.47	9.71	22.57	34.28	56.85	39.69
40 + PSB	64.27	2.63	9.78	24.53	37.57	62.09	39.54
60	65.83	2.66	9.91	24.66	37.91	62.56	39.43
60 + PSB	67.47	2.70	10.08	24.67	38.10	62.76	39.29
SEm ±	0.94	0.03	0.06	0.37	0.70	0.96	0.48
CD (P=0.05)	2.61	0.08	0.18	1.05	1.96	2.68	NS

PSB - Phosphobacterial inoculation

is well emphasized that P played a vital role in improving nutritional status of plant though increased photosynthetic activity and N_2 fixation. These improvements suggest greater availability of nutrient and metabolites synchronized for fulfilling the demand for growth and development of each

Table 2. Interaction effect of phosphorus levels with and without PSB inoculation and sulphur levels on pooled seed yield

Phosphorus (Kg P_2O ha^{-1})	Seed yield (q ha^{-1})			
	Sulphur (kg ha^{-1})			
	0	20	40	60
0	10.65	12.32	14.39	15.20
20	13.46	15.66	18.44	19.29
20 + PSB	16.29	18.84	18.70	19.59
40	17.51	20.51	25.54	26.71
40 + PSB	19.79	23.08	27.65	28.24
60	20.16	23.76	26.71	27.99
60 + PSB	20.14	23.73	26.70	28.10
P at same level of S	CD (P=0.05) 2.04			
S at same level or different levels of P	CD (P=0.05) 2.20			

PSB - Inoculated with P solubilizing bacteria

reproductive structure. Adequate supply of P helps in higher sink filling process due to its role in photosynthetic being an essential element in energy transformation process of plants. A significant increase in seed yield of soybean due to application of 40 kg P_2O_5/ha+ PSB could be ascribed to the fact that seed yield of the crop is function of several yield components which are dependent on complementary interaction between vegetative and reproductive growth of the crop. Increase in yield attributes and yield of soybean due to phosphorus fertilization in the present investigation are in close conformity with the findings of Chaturvedi *et al*., (2010). Data presented in Table 1. indicated that pods per plant seeds pod, 100 seed weight, seed, straw and biological yields was significantly enhanced by varying sulphur levels compared with control. Application of 40 kg S/ha registered significantly higher number of pods per plant (61.01), seed per pod (2.52), 100 seed weight (9.75), seed (22.50 q/ha), straw (34.34 q/ha), and biological yield
(56.83 q/ha), This increase was due to better growth of plants in terms of biomass accumulation, availability of photosynthates synchronized with the demand of growth and development of each yield components in soybean due to its indeterminate habit, vegetative and reproductive development create strong sink and both these development process compete with each other for the growth inputs namely, nutrients and metabolites. High yield are obtained by the gross contribution of yield components *viz.* pods per plant, seed per pod and individual seed weight. The observed improvement in various yield attributing characters and yields is in close conformity with the findings of Singh *et al.*

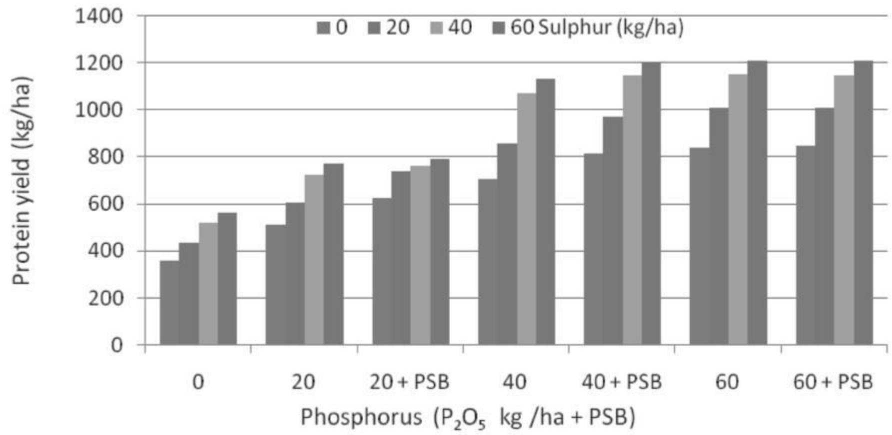

Fig.1. Interaction effect of phosphorus and sulphur fertilization with and without PSB inoculation on protein yield (kg ha^{-1}) of soybean

(2007) and Ramesh and Sammi Reddy (2004). Pooled data (Table 2) are indicative of differential response of phosphorus under various sulphur levels on seed yield. In the absence of sulphur, application of 20 kg P_2O_5 ha^{-1} with PSB significantly enhanced the seed yield over preceding P levels. Significance of 40 kg P_2O_5 ha^{-1} + PSB was also recorded under the influence of 20 and 40 kg S ha^{-1}. At higher levels of sulphur (60 kg ha^{-1}) no significant variation in yield was recorded between 40 kg P_2O_5 ha^{-1} and its combination with PSB. It is attributed to favorable environment of sulphur application in the rhizosphere by reducing soil pH leading to higher nutrient availability and uptake. Their effect was complementary to each other and synergistic up to certain levels in promoting growth of crop plant (Rennenberg and Lomoureux, 1990). Thus, cumulative influence of P with and without PSB and S application seems to have maintained balance source sink relationship through improving both the events of crop development (vegetative and generative) and ultimately resulted in increased seed yield.

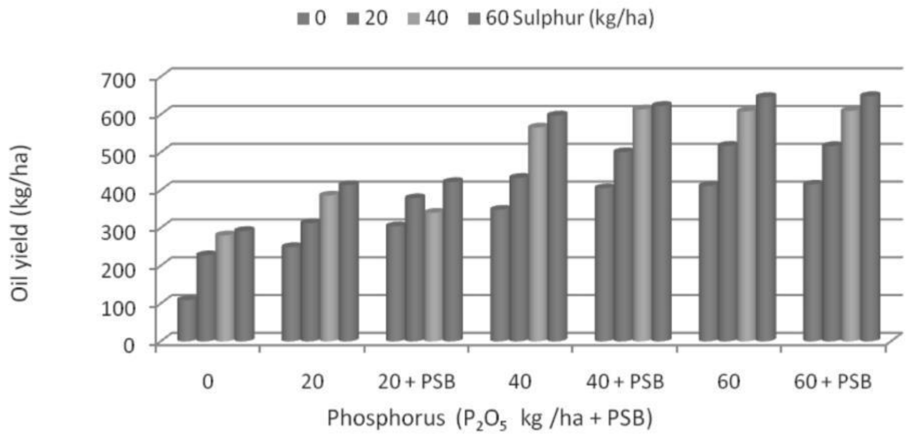

Fig. 2. Interaction effect of phosphorus and sulphur fertilization with and without PSB inoculation on oil yield (kg ha^{-1}) of soybean

Protein Yield

Irrespective of levels of sulphur, the application of increasing levels of phosphorus with inoculation increase the protein yield significantly (Fig. 1).Similarly significantly higher protein yield was recorded with increasing levels of sulphur. The overall maximum protein yield was observed under combined application of 40 kg P_2O_5+ 40 kg S ha^{-1} as compared to all other combinations of phosphorus and sulphur (1073.6 kg ha^{-1}). Both phosphorus and sulphur being the constituent of several metabolic compounds played an important role in photosynthesis, protein, carbohydrate and chlorophyll synthesis and biological energy transformation and thus influenced to plant growth. Their effect was complementary to each other and synergic upto certain levels in increasing nitrogen and protein contents of grain. These results are in close agreement with the findings of Singh *et al.* (2007).

Oil Yield

Pooled data (Fig.2) revealed that the increasing levels of sulphur significantly increased oil yield upto 40 kg P_2O_5 ha^{-1} irrespective to inoculation. However, 40 kg S ha^{-1} was significantly superior over no sulphur and 20 kg S ha^{-1}, at 20 kg P_2O_5 ha^{-1} with PSB inoculation no significance was achieved by applying 40 kg S ha^{-1} over 20 kg S ha^{-1}. Under rest of the phosphorus levels 0 to 20 and from 20 to 40 kg ha^{-1}, no significant improvement in oil yield could be observed raising S fertilization beyond 40 kg ha^{-1}. Overall superiority of 40 kg P_2O_5 ha^{-1} with PSB inoculation in combination with 40 kg S ha^{-1} could be seen from the figures (613.5 kg ha^{-1}) in respect of oil yield of soybean crop. Significant improvement in oil content of seeds with application of sulphur seems to be an account of greater availability of metabolites to seeds which intern higher conversion of these in to fatty acids or oil. Sulphur is also constituent of glutathione, a compound supposed to play vital role in plant respiration and synthesis of oil on the other hand about 30 per cent of the applied phosphorus is available to the plants and remaining gets converted in two insoluble compounds such as tricalcium phosphate and phosphate of iron aluminum and magnesium. Some heterotrophic bacteria and fungi have the ability to solubilize these compounds with their secretion of aliphatic and aromatic acids and enzymes such as phytase and phospholipases, which improve the fatty acids and increase oil content Chaturvedi *et al.* (2010).

Based on the outcome of the investigations, it could be inferred that in vertisols of humid south eastern plains of Rajasthan, the productivity of soybean could be enhanced through balanced fertilization of sulphur and phosphorus. Results showed that application of sulphur @ 40 kg/ha and phosphorus 40 kg/ha with PSB inoculation proved their superiority over other comparative levels of both the nutrients.

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