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Effect of Phosphorus, Sulphur and PSB on Yield of Indian Mustard (*Brassica juncea* L.) and Available Macronutrients in Soil

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An experiment was conducted to study the effect of different levels of phosphorus (0, 30, 40 and 50 kg P_2O_5 ha^{-1}), sulphur (0, 30, 40 and 50 kg S ha^{-1}) and two level of seed inoculation with phosphate solubilizing bacteria (PSB) on yield of mustard and available macronutrients in soil. Results showed that grain yield was significantly increased by the application of phosphorus, sulphur and PSB. The maximum yield was obtained with conjoint use of phosphorus @ 50 kg P_2O_5 ha^{-1} and sulphur @ 50 kg S ha^{-1} along with PSB. The post-harvest soil samples after harvest of mustard showed a slight decrease in pH and EC and increase in organic carbon, available nitrogen, phosphorus, potassium and sulphur due to application of phosphorus, sulphur and PSB either alone or in combination.

Key words: Phosphorus, sulphur, PSB, mustard, yield, available nutrients

Rapeseed and mustard (*Brassica juncea* L.) are the major *rabi* oilseed in India and stand next to groundnut in the oilseed economy. Rapeseed and mustard are the most important edible oils of northern and eastern parts of India. The role of phosphorus (P) is critical in plant metabolism which plays an important role in energy transfer, respiration and photosynthesis. It is a key structural component of nucleic acids, co-enzymes, phosphoproteins and phospholipids. Phosphorus fertilization is a major input in crop production (Blackshaw *et al.* 2004). It participates in metabolic activities as a constituent of nucleoprotein and nucleotides and also plays a key role in the formation of energy rich bond like adenosine diphosphate (ADP) and adenosine triphosphate (ATP). Favorable response of mustard to applied P was reported by Gangwal *et al*. (2011) and Solanki *et al*. (2016). In areas where mustard is traditionally grown without P, poor growth and low yields are common features. Further, it improves seed size, stimulates proper seed filling and increases oil content. Rapeseed and mustard crop belongs to cruciferae family which preferentially need sulphur (S) for their growth and development. Sulphur is called as the fourth major essential element for plant. Sulphur plays a multiple role for better productivity as well as quality of oilseeds (Biswas *et al*. 1995). Each unit of fertilizer S generates 3-5 units of edible oil. It is the major constituent of important amino acids like cystin, cysteine and methionine and helps in the formation of chlorophyll. Sulphur application also has marked effect on soil properties and is used as soil amendment such as gypsum and pyrite to improve the availability of other nutrients in soil. Between the two common sources of S, gypsum is available in India and is a cheaper source of S which may be used for oilseed crops. Rathore *et al*. (2015) reported the highest seed and oil yield in mustard (*Brassica juncea*) cv. Kranti, Varuna and Rohini with 20 kg S ha^{-1} applied through gypsum. Biofertilizers are known to play a vital role in soil fertility and crop productivity and considered as eco-friendly which can reduce the cost of chemical fertilizers to substantial amount. They supplement chemical fertilizers towards meeting the integrated nutrient demand of the crops. Phosphate solubilizing bacteria (PSB) promote seed germination and initial vigour of the plants by producing growth promoting substances. Application of PSB results in increased mineral and water uptake, root development, vegetative growth and nitrogen (N) fixation (Gangwal *et al*. 2011). Therefore, present study was taken up to study the combined effect of P, S and PSB on yield of mustard crop and soil properties.

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Table 1. Initial soil properties of the experimental site

Soil parameters	Value
Sand (%)	59.7
Silt (%)	21.0
Clay (%)	19.3
Textural class	Sandy loam
Bulk density (Mg m^{-3})	1.37
Particle density (Mg m^{-3})	2.64
Porosity (%)	46.5
Soil pH (1:2:: soil:water)	8.10
EC (dS m^{-1})	0.79
Organic carbon (g kg^{-1})	4.6
Available N (kg ha^{-1})	241
Available P_2O_5 (kg ha^{-1})	27.6
Available K_2O (kg ha^{-1})	329
Available S (kg ha^{-1})	8.57

Materials and Methods

A field experiment was conducted at Agronomy Instructional Farm, Krishi Vigyan Kendra, Chittorgarh, MPUAT, Udaipur, Rajasthan during *rabi* season of 2012-13 and 2013-14. The surface soil samples (0-15 cm) were collected from the experimental site and analyzed for physicochemical properties as outline by Jackson (1973) and presented in table 1.

Mustard cultivar Bio-902 was grown with four levels of P (0, 30, 40 and 50 kg P_2O_5 ha^{-1}), four levels of S (0, 30, 40 and 50 kg S ha^{-1}) and two levels of PSB seed inoculation (without and with inoculation) during both the years. Irrigation scheduling, fertilizer application and intercultural operations were followed as per normal agronomic practices. The experiment was laid out in factorial randomized block design with 32 treatments and three replications. Required quantities of P and S were applied through diammonium phosphate (DAP) and gypsum, respectively. The crop was fertilized with recommended dose of N (60 kg N ha^{-1}) through DAP and urea. Half dose of N and full doses of P and S were applied as basal and remaining half dose of N was applied as top dressing at 30 days after sowing. The pure and freshly prepared strains of PSB inoculants were used for seed treatment uniformly before sowing as per treatments. All the cultural practices were followed as per general recommendations. Grain yield was recorded at harvest for all the treatments. Surface soil samples were collected and analyzed for pH, electrical conductivity (EC), organic carbon (OC) and available N, P, K and S as per standard methods (Jackson 1973).

Results and Discussion

Yield of mustard crop

There was significant effect of different P levels on seed and stover yield up to 40 kg P_2O_5 ha^{-1} (Table 2). Application of 30, 40 and 50 kg P_2O_5 ha^{-1} increased the seed and stover yield over control by 13.9, 30.7 and 33.2 per cent in seed and 13.8, 31.8 and 35.6 per cent in stover yield, respectively. The highest mean seed and stover yield (19.7 and 50.4 q ha^{-1}) and net

Table 2. Effect of phosphorus, sulphur and PSB on seed and stover yield of mustard

Treatments	Seed yield (q ha^{-1})			Stover yield (q ha^{-1})		
	2012-13	2013-14	Pooled	2012-13	2013-14	Pooled
Phosphorus levels (P_2O_5 kg ha^{-1})						
0	14.7	14.9	14.8	36.4	38.0	37.2
30	16.7	17.0	16.8	41.5	43.1	42.3
40	19.3	19.4	19.3	48.2	49.8	49.0
50	19.6	19.9	19.7	49.8	51.1	50.4
S.Em.±	0.30	0.26	0.20	0.81	0.79	0.56
CD (P= 0.05)	0.84	0.74	0.55	2.28	2.23	1.58
Sulphur levels (S kg ha^{-1})						
0	15.0	15.2	15.1	38.9	40.5	39.7
30	17.4	17.6	17.5	43.3	45.0	44.1
40	18.6	18.8	18.7	46.3	47.6	47.0
50	19.2	19.5	19.3	47.3	48.9	48.1
S.Em.±	0.30	0.26	0.20	0.81	0.79	0.56
CD (P=0.05)	0.84	0.74	0.55	2.28	2.23	1.58
PSB inoculation						
Without inoculation	17.2	17.3	17.2	41.9	43.0	42.5
With inoculation	18.0	18.2	18.1	46.0	48.0	47.0
S.Em.±	0.21	0.19	0.14	0.57	0.56	0.40
CD (P= 0.05)	0.59	0.52	0.39	1.61	1.58	1.12

returns (Rs.38531 ha^{-1}) was recorded at 50 kg P_2O_5 ha^{-1} and benefit: cost ratio (1.86) was recorded at 40 kg P_2O_5 ha^{-1}. The beneficial effect of P on yield attributing characters could be ascribed to crop growth and more flowering and pod setting as P stimulates the flowering and seed formation (Yawalkar *et al*. 1996) and also producing bold sized seeds with more accumulation of photosynthates. Moreover, cumulative effect on improvement in all growth and yield attributing characters under P application might have contributed to the increase in seed yield. These findings are in accordance with those reported earlier by Patel (2000), Lanjewar and Selukar *et al*. (2005), Gangwal *et al*. (2011) and Solanki *et al.* (2016).

The average seed yield had significant effect due to application of S (Table 2). The yield increased progressively and significantly with each successive doses of S. The pooled seed yield was 15.1 q ha^{-1} with no-S application which increased to 17.5, 18.7 and 19.3 q ha^{-1} with application of 30, 40 and 50 kg S ha^{-1}, respectively. Similarly, stover yield increased from 39.7 to 44.1, 47.0 and 48.1 q ha^{-1} in 30, 40 and 50 kg S ha^{-1}, respectively. Thus, the difference in yield resulting from S application was significant. Similar results were reported by Raj *et al.* (1998). Inoculation of seeds with PSB also increased seed (18.1 q ha^{-1}) and stover yield (47.0 q ha^{-1}) compared to without inoculation. Similar results were reported by Gangwal *et al*. (2011) and Solanki *et al* (2016).

Effect of different treatments on properties of soil

The different treatments of P, S and PSB inoculation tended to have a marked effect on the properties of soil after the crop harvest.

Soil pH: The soil pH after crop harvest was in the order of $P_0 > P_{30} > P_{40} > P_{50}$ and $S_0 > S_{30} > S_{40} > S_{50}$ (Table 3). The soil pH tended to decrease with the progressive increase in added P and S fertilizers, but the difference was slightly conspicuous. Minimum pH of the soil after the crop harvest was recorded in 50 kg S ha^{-1}. The pooled data revealed that treatment with PSB resulted in significantly lower pH (7.71) than without PSB (7.85).

Electrical conductivity: There was no significant effect of P levels on the EC after the crop harvest; however, there was significant effect of S levels on the EC in soil after the crop harvest. The EC of soil was however, significantly reduced (0.30 dS m^{-1}) by S application @ 50 kg ha^{-1}. The EC in plots inoculated with biofertilizer (PSB) recorded the average value of 0.41 dS m^{-1} at 25 °C that was significantly lower than uninoculated plots (0.43 dS m^{-1}).

Organic carbon: The OC in soil at harvest increased significantly with P and S application over control (Table 3). Similarly, seeds inoculated with PSB improved the OC content in soil. The OC content in soil inoculated with PSB increased the average OC content in soil (5.0 g kg^{-1}) which was significantly higher than uninoculated plots (4.5 g kg^{-1}).

Table 3. Effect of phosphorus, sulphur and PSB on pH, electrical conductivity and organic carbon in soil after harvest of mustard

Treatments	pH			Electrical conductivity (dS m^{-1})			Organic carbon (g kg^{-1})		
	2012-13	2013-14	Pooled	2012-13	2013-14	Pooled	2012-13	2013-14	Pooled
Phosphorus levels (P_2O_5 kg ha^{-1})									
0	7.82	7.78	7.80	0.44	0.42	0.43	4.9	4.5	4.7
30	7.81	7.77	7.79	0.44	0.41	0.43	4.9	4.7	4.8
40	7.80	7.75	7.77	0.43	0.39	0.42	4.9	4.6	4.8
50	7.79	7.73	7.76	0.43	0.39	0.41	5.0	4.7	4.8
S.Em.±	0.01	0.01	0.01	0.01	0.05	0.01	0.04	0.04	0.03
CD (P=0.05)	0.02	0.02	0.02	0.02	0.01	0.01	0.11	0.12	0.08
Sulphur levels (S kg ha^{-1})									
0	7.94	7.88	7.91	0.55	0.53	0.54	4.8	4.5	4.7
30	7.87	7.78	7.83	0.47	0.43	0.45	4.9	4.6	4.7
40	7.72	7.71	7.72	0.40	0.36	0.38	4.9	4.7	4.8
50	7.68	7.66	7.67	0.32	0.28	0.30	5.0	4.7	4.8
S.Em.±	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.04	0.03
CD (P=0.05)	0.02	0.02	0.02	0.02	0.01	0.01	0.11	0.12	0.08
PSB inoculation									
Without inoculation	7.86	7.83	7.85	0.44	0.41	0.43	4.8	4.2	4.5
With inoculation	7.75	7.68	7.71	0.43	0.39	0.41	4.9	5.0	5.0
S.Em.±	0.01	0.01	0.00	0.01	0.01	0.01	0.03	0.03	0.02
CD (P=0.05)	0.02	0.02	0.01	0.01	0.01	0.01	0.08	0.09	0.06

Table 4. Effect of phosphorus, sulphur and PSB on available nitrogen, phosphorus, potassium and sulphur in soil after harvest of mustard

Treatments	Available nutrients (kg ha^{-1})											
	Nitrogen			Phosphorus			Potassium			Sulphur		
	2012-13	2013-14	Pooled	2012-13	2013-14	Pooled	2012-13	2013-14	Pooled	2012-13	2013-14	Pooled
Phosphorus levels (P_2O_5 kg ha^{-1})												
0 (P_0)	247	239	243	28.4	31.8	30.1	329	332	331	11.9	12.3	12.1
30 (P_1)	255	247	251	30.5	33.8	32.1	332	335	334	13.7	13.3	13.5
40 (P_2)	257	249	253	32.8	36.7	34.8	335	337	336	14.9	14.4	14.6
50 (P_3)	260	255	257	35.7	39.1	37.4	337	340	338	15.5	15.4	15.4
S.Em.±	1.9	2.1	1.4	0.26	0.28	0.19	2.3	1.9	1.5	0.09	0.08	0.06
CD (P=0.05)	5.4	5.8	3.9	0.73	0.80	0.54	6.5	5.3	4.2	0.26	0.23	0.17
Sulphur levels (S kg ha^{-1})												
0 (S_0)	250	241	246	29.6	33.6	31.6	329	331	330	12.4	11.6	12.0
30 (S_1)	252.8	246	249	30.8	34.7	32.8	332	335	333	12.9	12.5	12.7
40 (S_2)	256.4	249	253	32.5	36.3	34.4	336	339	337	15.1	15.4	15.3
50 (S_3)	258.7	253	256	34.6	36.8	35.7	337	340	338	15.6	15.9	15.7
S.Em.±	1.92	2.1	1.4	0.26	0.28	0.19	2.3	1.9	1.5	0.09	0.08	0.06
PSB inoculation												
Without inoculation	253	246	250	31.0	34.4	32.7	333	336	334	13.7	13.4	13.6
With inoculation	256	248	252	32.7	36.3	34.5	334	336	335	14.3	14.2	14.3
S.Em.±	1.4	1.5	1.0	0.18	0.20	0.14	1.6	1.3	1.1	0.07	0.06	0.04
CD (P=0.05)	3.8	4.1	2.8	0.52	0.56	0.38	4.6	3.7	2.9	0.18	0.16	0.12

Available nitrogen: The available N in soil after the crop harvest was significantly influenced by P and S levels, the highest being obtained with 50 kg P and 50 kg S ha^{-1} (Table 4). Each successive dose of P and S resulted in significantly increase in available N up to application of 40 kg ha^{-1}. The highest N content (257 kg ha^{-1}) was recorded in 50 kg P_2O_5 ha^{-1} and 256 kg ha^{-1} was recorded in 50 kg S ha^{-1}; while the minimum available N (243 kg ha^{-1}) was obtained in control (P_0) and 246 kg ha^{-1} was in control (S_0). The seed inoculation with PSB recorded higher available N (252 kg ha^{-1}) in soil after crop harvest than without seed inoculation. It is obvious because of enhanced root residues and exudates incorporated in the soil due to seed inoculation with PSB. Similar results were reported by Gangwal *et al*. (2011).

Available phosphorus: The available P in soil after harvest of mustard is presented in table 4. The available P increased significantly with the increases in level of added P and S in soil. Maximum available P was recorded in P_{50} and S_{50} levels while minimum was in unfertilized control plot. The seed inoculation with PSB recorded higher amount of available P in soil (34.5 kg ha^{-1}) than no inoculation (32.7 kg ha^{-1}).

Available potassium: The available K in soil increased significantly by the successive dose of added P and K (Table 4). The maximum available K (338 kg ha^{-1}) was recorded at 50 P_2O_5 kg ha^{-1} level and 338 kg ha^{-1} was recorded at 50 kg S ha^{-1}; while minimum available K content (331 kg ha^{-1}) was recorded at P_0 level and (330 kg ha^{-1}) was recorded at S_0 levels. The seed inoculation with PSB recorded significantly greater amount of available K in soil after crop harvest (335 kg ha^{-1}) than uninoculated plots.

Available sulphur: The available S increased significantly by the successive dose of added P and S (Table 4). The highest levels of application of P and S resulted in significant increase in available S compared to lower levels of added P and S. The maximum available S in soil after crop harvest (15.4 kg ha^{-1}) was recorded at P_{50} level and (15.7 kg ha^{-1}) was recorded at (S_{50}) while the minimum (12.1 kg ha^{-1}) was at control (P_0) level and (12.0 kg ha^{-1}) was recorded at control (S_0). The seed inoculation with PSB recorded greater amount of available S (14.3 kg ha^{-1}) in soil after crop harvest than uninoculated control (13.6 kg ha^{-1}) (Table 4). Similar results were observed by Randhawa and Arora (1997), Patel (2000), Ghadge *et al.* (2005) and Gangwal *et al.* (2011).

Conclusions

The present study indicates that application of phosphorus and sulphur @ 40 kg ha^{-1} each along with seed inoculation with PSB biofertilizer was the best treatment compared to others and resulted in significantly higher yield of mustard. However, there is a need to verify the results in multi-location trials across the country following diverse soil and climate conditions.

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