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Research Communication

Influence of phosphorus and biofertilizers on symbiotic parameters, productivity and profitability of soybean (*Glycine max*)

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ABSTRACT

A field study was carried out during the rainy (*kharif*) season of 2019 at the Regional Research Station, Punjab Agricultural University, Ludhiana and Faridkot, Punjab, to study the effect of phosphorus levels and biofertilizers on the symbiotic parameters, productivity, and profitability of soybean [*Glycine max* (L.) Merr.]. The experiment comprised 4 phosphorus levels (0, 17, 26 and 35 kg P/ha) and 4 biofertilizer treatments [uninoculated control, *Bradyrhizobium*, Phosphate-solubilizing bacteria (PSB) and *Bradyrhizobium* + PSB]. Total 16 treatment combinations were laid out in a factorial randomized complete-block design, replicated 3 times. Application of 35 kg P/ha recorded the highest symbiotic parameters, growth and yield attributes and seed yield of 2 and 1.84 t/ha at Ludhiana and Faridkot, respectively, which were significantly higher than the control and 17 kg P/ha but statistically at par with 26 kg P/ha at both the locations. However, the highest production efficiency (14.62 and 13.50 kg/ha/day at Ludhiana and Faridkot, respectively) was recorded with application of 35 kg P/ha, being statistically at par with 26 kg P/ha. The highest monetary efficiency (302 and 277 ₹/ha/day at Ludhiana and Faridkot, respectively) was obtained with the application of 35 kg P/ha which were at par with 26 and 17 kg P/ha at Ludhiana, while with 26 kg P/ha at Faridkot. Inoculation with *Bradyrhizobium* + PSB and sole inoculation of PSB were at par with each other and both proved superior to uninoculated control for growth and yield attributes, seed yield and monetary efficiency.

Key words: Biofertilizers, Phosphorus, Seed yield, Soybean, Symbiotic parameters

Soybean [*Glycine max* (L.) Merrill] is an important oilseed and legume crop grown across the world. Soybean production supports the livelihood of a large number of people associated with cultivation, trading, processing, industrial usages, value-addition, and export of soybean and its products, in India and overseas (Dass *et al*., 2016; Dass *et al*., 2019).

As a legume crop, it fixes 61–337 kg N/ha symbiotically (Salvagiotti *et al.,* 2008) and also adds 1–1.5 t/ha N-rich leaf-litter (Dass *et al.,* 2016; Dass and Bhattacharyya, 2017; Rajanna *et al*., 2022), thus enhances the soil fertility. It is a fast-growing crop that has high nutritional requirements than any other legume crop. Fertilizers are needed to complete the high nutritional requirement of soybean but their continuous and imbalance use causes deterioration of soil health. Phosphorus (P) deficiency is the major constraint in pulse production, since it affects growth, nodule development, N-fixation, root development and improvement of crop quality. The low availability of native soil phosphorus coupled with poor utilization of available P causes a decline in the fertility rate of the soil. However, microbial biomass assimilates P and prevents its adsorption and fixation. More than 60% of phosphatic fertilizers become unavailable after a very short time of application due to its fixation in the form of diphosphate and triphosphate (Jain and Trivedi, 2005). This fixed pool of phosphorus can be made available to plants by using phosphate-solubilizing bacteria (PSB). The PSB (*Pseudomonas* sp. and *Bacillus* sp.) secrete organic acids, which lower *p*H and dissociate phosphorus which is fixed in the form of calcium phosphate and increases P availability in the soil (Kumawat *et al*., 2022). Soil or seed inoculated with these *Rhizobium* strains lead to an increase in the nutrient acquisition and seed yield of legumes. Plant-growth promoting rhizobacteria (PGPR) along with *Bradyrhizobium* can improve growth and nodulation properties in soybean significantly than uninoculated control (Virk *et al.,* 2018). Integrated nutrient management is a better option in production

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technology to sustain soil fertility and crop productivity.

The sole use of biofertilizers is not enough to meet the demand of soybean but their combined use along with inorganic fertilizers not only reduces the dose of fertilizers but also helps eradicate many problems associated with the use of excessive fertilizers. The information on the optimum dose of phosphorus in combination with PSB and *Rhizobium* in soybean is meager in this region. The requirement of phosphorus in soybean is higher as compared to other legume crops. The use of PSB may reduce the dose of phosphorus by solubilizing the native phosphorus. Therefore, an experiment was conducted to study the effect of phosphorus levels and biofertilizers on the symbiotic parameters, productivity and economics of soybean.

A field study was carried out at the Punjab Agricultural University, Ludhiana (LDH) (30°54'N, 75°48'E and 247 m above the mean sea-level) and Regional Research Station, Faridkot (FDK) (30°40'N, 74°44'E and 200 m above the mean sea level), Punjab during rainy (*kharif*) season of 2019. During the crop-growing season, weekly mean maximum and minimum temperature ranged from 29.0 to 43.0°C and 16.2 to 26.1°C, respectively and weekly mean relative humidity ranged from 47 to 72% at Ludhiana, and weekly mean maximum and minimum temperature ranged from 31.3 to 38.9°C and 17.8–26.6°C, respectively, and weekly mean relative humidity ranged from 45.5 to 72% at Faridkot. A rainfall of 871.8 and 334.4 mm was received during the crop season at Ludhiana and Faridkot, respectively.

The soil of the experimental field was loamy sand at Ludhiana, while loamy at Faridkot with low and medium in organic carbon at Ludhiana and Faridkot, respectively, and low in available N (118.8 and 135.6 kg/ha) and medium in available P (14.2 and 13.5 kg/ha) at both the locations, while medium (280.0 kg/ha) and high (339.6 kg/ha) in available K at Ludhiana and Faridkot respectively. The experiment comprised 4 phosphorus levels (0, 17, 26 and 35 kg P/ha) and 4 biofertilizer treatments [uninoculated control, *Bradyrhizobium*, phosphate-solubilizing bacteria (PSB) and *Bradyrhizobium* + PSB. The 16 treatment combinations were laid out in a factorial randomized complete-block design, replicated thrice.

Soybean variety 'SL 958' was sown on 10 June 2019 and 14 June, 2019 at Ludhiana and Faridkot, respectively, using a seed rate of 75 kg/ha at 45-cm-row spacing. Soybean seed was inoculated with *Bradyrhizobium* (LSBR 3) and PSB (LSE 3) (containing 1×10^8 cells/g of carrier) as per the treatments of biofertilizers before sowing. Each culture was added @ 5 ml/kg seed to give a fine coating to an entire lot of seed. The treated seed was dried in the shade and used for sowing. Recommended nitrogen, i.e. 31.3 kg N/ha, was applied through urea (46% N) and phosphorus (P) was applied @ 0, 17, 26 and 35 kg/ha as single superphosphate (16% P_2O_5) at the time of sowing. The crop was raised according to the recommended package of practices. Harvesting was done on 27 October 2019 and 10 November 2019 at Ludhiana and Faridkot, respectively. The harvested crop was kept for sun-drying and threshing was done with the help of soybean thresher at Ludhiana and manually at Faridkot. The seed and stover yields of each plot were recorded separately.

Data on number and dry weight of nodules/plant were recorded from 5 plants at 60 DAS. Leghaemoglobin content was assessed at 60 DAS by using Drabkin's solution as per the standard procedure opined by Wilson and Reisenauer (1963). Data on plant height were recorded at harvesting from 5 random plants. Pods/plant were counted from randomly selected 10 plants/plot and number of seeds/pod was estimated by randomly selecting 10 pods from each plot. The 100-seed weight was recorded by taking 100 seeds from the produce of each plot and weight was recorded and expressed in gram. After threshing, seed yield from each net plot was weighed separately and expressed as t/ha. Stover yield was estimated by subtracting the seed yield from the biological yield from each plot. Production efficiency and monetary efficiency (Hasanain *et al.*, 2021) were calculated.

Phosphorus levels significantly influenced the number and dry weight of nodules and leghaemoglobin content at 60 DAS at Ludhiana and Faridkot (Table 1). Application of 35 kg P/ha resulted in the highest number and dry weight of nodules/plant, and the leghaemoglobin content, which was significantly higher than 17 kg P/ha and the control and statistically at par with 26 kg P/ha at the both locations. Higher number and dry weight of nodules were observed with an increase in phosphorus levels, which might be owing to an increase in the dose of phosphorus, early nitrogen fixation and better functioning of nodules. Nandini *et al.,* (2012) also reported that, application of 35 kg P/ha resulted in the highest number and dry weight of nodules over the control. Improvement in leghaemoglobin content may be owing to increased nodule number and dry weight of nodules (Table 1).

Different levels of phosphorus significantly influenced the plant height of soybean (Table 1). Application of 35 kg P/ha revealed the highest plant height at harvesting at both the locations. At Faridkot, plant height obtained at 35 kg P/ha was statistically at par with 26 kg P/ha and significantly higher than 0 and 17 kg P/ha. However, at Ludhiana, the plant height at 26 kg P/ha exhibited statistically similar results as with 17 kg P/ha and performed significantly better than unfertilized control.

The highest number of pods/plant was recorded with 35 kg P/ha, being statistically similar to 26 kg P/ha and 17 kg

Table 1. Effect of phosphorus and biofertilizers on symbiotic parameters of soybean at 60 days after sowing, plant height and yield attributes at harvesting

Treatment	Nodules/plant		Nodules dry weight (mg/plant)		Leghaemoglobin content (mg/g of fresh nodule weight)		Plant height (cm)		Pods/plant		Seeds/pod		100-seed weight (g)	
	LDH	FDK	LDH	FDK	LDH	FDK	LDH	FDK	LDH	FDK	LDH	FDK	LDH	FDK
P levels (kg/ha)														
0	45.4	35.7	102.2	68.3	3.0	2.8	80.1	77.7	58.7	61.4	2.34	2.28	9.70	9.43
17	50.5	40.9	109.9	77.4	4.8	4.1	83.2	80.5	64.9	63.5	2.66	2.69	10.41	9.86
26	52.9	44.9	113.1	89.5	5.0	4.3	84.6	83.1	67.2	65.0	2.87	2.81	10.54	10.01
35	55.5	48.1	119.2	94.7	5.4	4.4	85.8	83.3	68.4	65.9	2.99	2.90	10.62	10.12
SEm±	1.2	1.1	2.5	2.3	0.1	0.1	0.8	0.7	1.2	0.6	0.02	0.02	0.05	0.04
CD (P=0.05)	3.7	3.5	7.5	7.1	0.4	0.2	2.5	2.3	3.7	1.7	NS	NS	0.17	0.14
Biofertilizers														
Uninoculated	37.5	28.2	101.7	70.2	3.3	3.7	80.1	77.3	57.3	61.1	2.55	2.51	9.67	9.59
Bradyrhizobium	52.4	39.4	110.1	78.4	4.5	3.8	82.7	80.6	63.6	63.3	2.65	2.64	10.22	9.80
PSB	55.6	49.5	113.1	88.5	4.8	4.0	84.2	83.3	68.4	65.1	2.78	2.72	10.64	10.00
Bradyrhizobium + PSB	58.9	52.6	119.4	93.4	5.0	4.2	85.5	83.5	69.8	66.2	2.86	2.83	10.76	10.04
SEm±	1.2	1.1	2.5	2.3	0.1	0.1	0.8	0.7	1.2	0.6	0.02	0.02	0.05	0.04
CD (P=0.05)	3.7	3.5	7.5	7.1	0.4	0.2	2.5	2.3	3.7	1.7	NS	NS	0.17	0.17

LDH, Ludhiana; FDK, Faridkot

P/ha and significantly better than unfertilized control at Ludhiana. However, at Faridkot, the highest number of pods/plant was recorded at 35 kg P/ha, which was, however, statistically at par with 26 kg P/ha and significantly better than 17 kg P/ha and unfertilized control. Number of pods/plant was increased with application of phosphorus, which might be owing to improvement in growth parameters, nodulation and leghaemoglobin content (Table 1). Seeds/pod were non-significantly influenced by different levels of phosphorus and biofertilizers at both locations. Application of 35 kg P/ha resulted in the highest 100-seed weight, which gave statistically similar results as 26 kg P/ha and performed significantly better than 17 kg P/ha and unfertilized control at both the locations. Application of 75 and 60 kg P_2O_5/ha showed significantly higher 100-seed weight than the control (Jaybhay *et al.,* 2017).

Different levels of phosphorus significantly influenced seed and stover yields (Table 2). Application of 35 kg P/ha resulted in the highest seed and stover yields but statistically at par with 26 kg P/ha and performed significantly better than the application of 17 kg P/ha and unfertilized control at both the locations. Seed yield obtained from the application of 26 kg P/ha was statistically at par with 17 kg P/ha at Ludhiana and significantly better than 17 kg P/ha at Faridkot. However, at both the locations, it was significantly better than the unfertilized control. Application of 35 kg P/ha registered 47.9 and 49.7% higher seed yield at Ludhiana and Faridkot, respectively, over the control, which was owing to an increase in pods/plant and 100-seed weight (Table 2). Moreover, an increase in the plant height (Table 2) provided a better translocation of photosynthates to developing sink and improved symbiotic properties (Table 1) thereby provided higher yield with 26 and 35 kg P/ha. Nandini *et al.,* (2012) found that, application of 35–52 kg P/ha resulted in the highest seed yield, which was performed better than the control.

With incremental level of phosphorus, production efficiency and monetary efficiency were increased over unfertilized control (Table 2). The highest production efficiency was recorded with 35 kg P/ha which were at par with 26 kg P/ha and significantly better than application of 17 kg P/ha and unfertilized control. Application of 35 kg P/ha provided the highest monetary efficiency, at both locations. However, it was statistically at par with the application of 26 and 17 kg P/ha at Ludhiana and 26 kg P/ha at Faridkot and significantly better than unfertilized control.

Biofertilizers had a significant effect on the number and dry weight of nodules and leghaemoglobin content at 60 DAS (Table 1). The number and dry weight of nodules and leghaemoglobin content obtained from dual inoculation of *Bradyrhizobium* and PSB were the highest and statistically at par with the sole inoculation of PSB and performed

significantly better than sole inoculation of *Bradyrhizobium* and the uninoculated control. Combined application of PSB with *Rhizobium* leads to a significant increase in the number and dry weight of nodules and leghaemoglobin content as compared to uninoculated control (Jaybhay *et al.,* 2017). An increase in nodule dry weight might be owing to improved nutritional conditions by biofertilizers and an increase in number of nodules (Table 1). Since the number of nodules included both effective and ineffective nodules, there was more increase in nodule number than dry weight of nodules.

Seed inoculation with biofertilizers influenced the plant height significantly (Table 1). The highest plant height was recorded in treatment having the combined application of *Bradyrhizobium* and phosphorus-solubilizing bacteria (PSB) at both the locations. The plant height obtained with the combined application of *Bradyrhizobium* and PSB was statistically at par with the sole application of PSB and significantly better than sole inoculation of *Bradyrhizobium* and the uninoculated control.

Co-inoculation of *Bradyrhizobium* + PSB resulted in the highest number of pods/plant and 100-seed weight, which were statistically at par with sole inoculation of PSB and performed significantly better than sole inoculation of *Bradyrhizobium* and uninoculated control at both locations (Table 2). Inoculation with biofertilizers provides nutrients to plants and helps in the vigorous growth of plants. Combined application of PSB with *Rhizobium* leads to a significant increase in the number of pods than uninoculated control (Jaybhay *et al.,* 2017). Improved 100-seed weight in treatments inoculated with biofertilizers might be owing to an increase supply of assimilates towards grains through improved nutrient acquisition by roots.

Co-inoculation of *Bradyrhizobium* and PSB provided the highest seed yield (20.1% and 22.4% higher at Ludhiana and Faridkot, respectively, over the control), over sole inoculation of *Bradyrhizobium*, uninoculated control and gave statistically similar results obtained with sole inoculation of PSB at both locations (Table 2). The increase in seed yield might be because of improved yield attributes (Table 2), which might have been owing to improved growth parameters and symbiotic parameters (Table 1). Higher seed yield in biofertilizer-inoculated treatments might be owing to secretion of indole acetic acid which helps in mobilization of fixed phosphorus and enhanced nutrient supply to plants and root nodulation. Jaybhay *et al.* (2017) and Virk *et al.,* (2017) also reported that, the combined application of PSB and *Bradyrhizobium* resulted in the highest seed yield over the control. Interaction effects of P levels and biofertilizers on seed yield were found to be non-significant (Table 3).

The highest production efficiency and monetary efficiency were recorded with dual inoculation of *Bradyrhizobium* and PSB which gave statistically similar results as sole inoculation of PSB and performed significantly better than sole inoculation of *Bradyrhizobium* and uninoculated control at both the locations (Table 2). This was mainly because of higher seed yield resulting from the inoculation of biofertilizers. Virk *et al.,* (2018) also found the highest returns with dual inoculation of biofertilizers.

It can be concluded that, the application of 35 kg P/ha provides the highest symbiotic parameters, yield attributes, seed yield, production efficiency and monetary efficiency at Ludhiana and Faridkot, Punjab. However, application of

Table 2. Effect of phosphorus and biofertilizers on yield, production efficiency and monetary efficiency of soybean

Treatment	Yield (t/ha)				Production efficiency (kg/ha/day)		Monetary efficiency (₹/ha/day)	
	Seed yield		Stover yield					
	LDH	FDK	LDH	FDK	LDH	FDK	LDH	FDK
P levels (kg/ha)								
0	1.35	1.23	2.62	2.36	9.88	9.01	175	161
17	1.78	1.55	3.06	2.61	12.99	11.37	268	223
26	1.90	1.76	3.22	2.86	13.93	12.85	290	267
35	2.00	1.84	3.33	2.96	14.62	13.50	302	277
SEm±	0.04	0.03	0.07	0.06	0.31	0.27	12	10
CD (P=0.05)	0.13	0.11	0.23	0.20	0.96	0.81	37	31
Biofertilizers								
Uninoculated	1.58	1.42	2.70	2.37	11.53	10.40	205	179
Bradyrhizobium	1.71	1.54	2.95	2.63	12.50	11.28	244	216
PSB	1.85	1.68	3.19	2.86	13.53	12.32	286	258
Bradyrhizobium + PSB	1.89	1.74	3.39	2.94	13.86	12.74	301	275
SEm±	0.04	0.03	0.07	0.06	0.31	0.27	12	10
CD (P=0.05)	0.13	0.11	0.23	0.20	0.96	0.81	37	31

LDH, Ludhiana; FDK, Faridkot

Table 3. Interaction effects of phosphorus and biofertilizers on seed yield of soybean at Ludhiana and Faridkot

Treatment	Seed yield (kg/ha)				
	P levels (kg/ha)				
	0	17	26	35	Mean
Biofertilizers					
			Ludhiana		
Uninoculated	1,155	1,602	1,733	1,830	1,580
Bradyrhizobium	1,281	1,774	1,868	1,955	1,713
PSB	1,464	1,863	1,993	2,090	1,853
Bradyrhizobium + PSB	1,514	1,908	2,039	2,136	1,899
Mean	1,353	1,780	1,908	2,003	
Interaction CD (P=0.05)			NS		
			Faridkot		
Uninoculated	1,069	1,379	1,582	1,670	1,425
Bradyrhizobium	1,189	1,499	1,702	1,790	1,545
PSB	1,314	1,649	1,852	1,940	1,688
Bradyrhizobium + PSB	1,371	1,706	1,909	1,997	1,745
Mean	1,235	1,558	1,761	1,849	
Interaction CD (P=0.05)			NS		

17 kg P/ha at Ludhiana and 26 kg P/ha at Faridkot along with seed inoculation with PSB alone as well as dual inoculation of *Bradyrhizobium* and PSB were found to be the most efficient for obtaining high productivity and profitability of soybean.

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