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Integrated phosphorus management in pigeonpea (*Cajanus cajan*) – wheat (*Triticum aestivum*) cropping system

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ABSTRACT

A field experiment was conducted during 2005-06 and 2006-2007 at New Delhi in the rainy (*kharif*) and winter (*rabi*) seasons on sandy-loam soil to assess the effect of sources and levels of phosphorus on pigeonpea [*Cajanus cajan* (L.) Millsp.] – wheat (*Triticum aestivum* L. emend. Fiori & Paol.) cropping system. Results revealed that application of P to pigeonpea at 34.4 kg/ha through single superphosphate + phosphorus-solubilizing bacteria (PSB) recorded higher mean yield attributes and grain yield (1.49 t/ha) of pigeonpea and yield attributes and yield (4.49 t/ha) of wheat over no P and 17.2 kg P/ha through single superphosphate alone or rock-phosphate + PSB. Direct application of P to wheat up to 34.4 kg P/ha improved the mean yield attributes and grain yield (4.53 t/ha). The mean increase in wheat-grain yield due to P fertilization was 10.26 and 7.31% compared with that in the control and 17.2 kg P/ha respectively. The system productivity (pigeonpea-equivalent yield) was the highest when pigeonpea and wheat received 34.4 kg P/ha through pressmud + PSB (4.06 t/ha) and 34.4 kg P/ha (3.99 t/ha) respectively. Application of 34.4 kg P/ha through single superphosphate with or without PSB or pressmud + PSB to pigeonpea recorded significantly higher P uptake by the system over rock-phosphate + PSB. The P balance in the soil increased with increase in P fertilization to the system.

Key words: Pigeonpea, Phosphorus, Phosphorus-solubilizing bacteria, Pressmud, Rock phosphate, Wheat

Diversification of rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L. emend. Fiori & Paol.) system in Indo-Gangetic plains has led to identification of several pulse and oilseed crops as potential substitutes of rice. The substitution of rice with legumes like pigeonpea was more promising owing to improved productivity of the succeeding wheat (Singh *et al*., 2006). The introduction of short-duration varieties of pigeonpea and late-sown varieties of wheat has made pigeonpea - wheat sequence more feasible and acceptable to farmers in the wheat belt of north India, especially in areas with assured irrigation owing to residual effect of N and enhanced availability of P (Shivran and Ahlawat, 2000). Both pigeonpea and wheat crops respond favourably to phosphorus application. Since a major part of P remains unutilized by the first crop, its application is invariably reflected in the succeeding crops. Studies on legume-wheat cropping system have shown that where the legume crop removed less of the applied P, yield of the succeeding crop increased. Application of P in wheat reduced the soil-available N status, but substantially increased the soil P after harvest due to greater uptake of N by the crop along with P (Singh and Rai, 2003). An attempt was therefore made to evaluate the direct and residual effects of phosphorus in pigeonpea - wheat cropping system.

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MATERIALS AND METHODS

The field experiment was carried out at Indian Agricultural Research Institute, New Delhi during the rainy and winter seasons of 2005-06 and 2006-07 at a new site each year. The soil was sandy loam with pH 7.8 and 8.1(1:2.5 soil to water), organic C 0.36 and 0.38%, available N 160.6 and 164.8 kg/ha, and available P 12.9 and 13.3 kg/ha at the beginning of the experiment in 0-30 cm soil layer in 2005–06 and 2006–07 respectively. The total rainfall received during the experimental period was 578.3 mm in 2005-06 and 629.5 mm in 2006-07. There were nine integrated phosphorus treatments through combination of sources (single superphosphate, rock-phosphate, pressmud) and levels (17.2 and 34.4 kg/ha) of P to pigeonpea with and without PSB along with absolute control, laid out in randomized block design. During *rabi*, the experiment was laid out in split-plot design with P applied to pigeonpea in the main plots and P applied directly to the succeeding wheat in the subplots. The treatments were replicated thrice. The recommended dose of N @ 25 kg/ha to pigeonpea and 120 kg/ha to wheat was applied through urea. Phosphorus was applied as per treatment. Single superphosphate was placed 3-5 cm below the seed with the help of metallic tube attached to plough. Rock phosphate and pressmud were applied and mixed with the soil in advance, 15 days before sowing. The amount of sulphur through single superphosphate was balanced in all the plots. The phosphate-solubilizing bacterial culture (PSB) 'Microphos' containing inoculum of *Pseudomonas striata* (Chester) was used to inoculate pigeonpea seeds. Pigeonpea cv 'Pusa 992' was sown on 14 June and 19 June in 60 cm x 20 cm geometry and harvested on 25 November and 20 November in 2005 and 2006 respectively. Wheat cv 'HD 2824' was sown after pigeonpea on 5 December and 2 December respectively. Other management practices were adopted as per recommendations of the crops under irrigated conditions. The soil was analysed after pigeonpea and wheat for change in nutrient status from the initial levels. The productivity of the system was measured by computing the pigeonpea-equivalent yield on the basis of market price of these two crops. The nutrient uptake by the crops was obtained as the product of concentration of nutrient and yield.

RESULTS AND DISCUSSION

Effect of P on pigeonpea

Phosphorus application had significant influence on yield attributes, viz. number of pod/plant, number of grain/pod and 1,000-grain weight over no P (Table 1). Application of P at 34.4 kg P/ha through single superphosphate with or without PSB or pressmud + PSB or 17.2 kg P/ha through pressmud + PSB, being at par, recorded significantly higher number of pod/plant, number of grain/pod and 1,000-grain weight over no P and 17.2 kg P/ha through single superphosphate alone or rock-phosphate + PSB. Further, application of 17.2 kg P/ha through single superphosphate + PSB or pressmud + PSB, being on a par, with 34.4 kg P/ha through single superphosphate alone or rock-phosphate + PSB recorded significantly more number of pod/plant, number of grain/pod and 1,000-grain weight compared with no P and 17.2 kg P/ha through rock phosphate + PSB. The higher value for yield attributes may be due to the effect of P on root development, energy transformation and metabolic processes of plant, which resulted in greater translocation of photosynthates towards the sink development (Singh and Ahlawat, 2007).

Significant improvement in grain yield of pigeonpea was recorded due to P application (Table 1). In 2005 all the sources of P at both the rates (17.2 and 34.4 kg P/ha) recorded statistically similar yields, but all of them were significantly higher than the control. In 2006 the application of 34.4 kg P/ha through single superphosphate + PSB being on a par with pressmud + PSB recorded the highest grain yield and improved the grain yield over the control and 17.2 kg P/ha through single superphosphate alone or

Table 1. Effect of sources and level of P on yield attributes of pigeonpea and their direct and residual effect on yield attributes of wheat (mean data of 2 seasons)

Treatment	Pigeonpea					Wheat					Pigeonpea equivalent yield (t/ha)	
	Pods/ plant	Grains/ pod	1,000 grain weight (g)	Seed yield (t/ha)		Spikes/m row	Grains/ spike	1,000-grain weight (g)	Grain yield (t/ha)			
				2005	2006				2005-06	2006-07	2005-06	2006-07
P-level (kg/ha) and source to pigeonpea												
Control	78.6	2.35	59.97	1.25	1.08	94.7	38.58	39.75	4.13	4.16	3.46	3.59
17.2, SSP	102.9	2.88	66.48	1.51	1.32	101.2	41.15	40.99	4.20	4.32	3.76	3.93
17.2, SSP + PSB	104.8	2.94	67.22	1.55	1.36	102.1	41.60	41.10	4.23	4.34	3.81	3.98
34.4, SSP	113.7	3.23	70.34	1.56	1.40	109.7	45.55	42.23	4.38	4.51	3.90	4.12
34.4, SSP + PSB	115.3	3.28	71.11	1.57	1.41	111.3	45.91	42.39	4.42	4.55	3.94	4.15
17.2, RP + PSB	94.1	2.78	65.07	1.48	1.25	100.9	41.36	40.88	4.26	4.25	3.76	3.81
34.4, RP + PSB	103.9	2.92	66.79	1.51	1.33	110.7	45.92	42.17	4.47	4.38	3.91	3.97
17.2, PM + PSB	110.5	3.11	69.18	1.55	1.39	101.9	41.55	41.16	4.22	4.33	3.82	4.00
34.4, PM + PSB	114.7	3.26	70.87	1.56	1.41	112.2	46.78	42.62	4.47	4.58	3.96	4.17
SEm±	3.3	0.11	1.18	0.06	0.03	1.4	0.80	0.31	0.04	0.06	0.06	0.04
CD (P=0.05)	9.9	0.33	3.55	0.17	0.08	4.3	2.40	0.92	0.13	0.19	0.19	0.13
P to wheat (kg/ha)												
0						95.1	40.20	40.12	4.06	4.15	3.68	3.83
17.2						106.2	43.15	41.69	4.39	4.42	3.86	3.99
34.4						113.7	46.12	42.63	4.48	4.57	3.90	4.08
SEm±						0.7	0.31	0.22	0.03	0.03	0.02	0.02
CD (P=0.05)						1.9	0.89	0.63	0.08	0.10	0.04	0.05

rock phosphate + PSB, and 34.4 kg P/ha through rock phosphate + PSB. Application of 17.2 kg P/ha through single superphosphate + PSB or pressmud + PSB registered higher grain than over no P and 17.2 kg P/ha through rock phosphate + PSB. The yield increment due to 34.4 kg P/ha through single superphosphate + PSB and pressmud + PSB was 25.5 and 24.9% in 2005, and 30.3 and 29.9% in 2006 respectively compared with no P. The increase in grain yield by P fertilization was largely due to improved yield attributes. Jat *et al.* (2004) and Singh and Ahlawat (2007) also reported similar increase in yields by application of P.

Residual effect of P on wheat

In wheat, the residual effect of P applied to pigeonpea in respect of number of spike/m row, number of grain/spike and 1,000-grain weight was noticed in all the P treatments over the control (Table 1). Significantly higher residual effect of P applied to pigeonpea was recorded with the application of 34.4 kg P/ha through single superphosphate with or without PSB or pressmud + PSB or rock phosphate + PSB through higher number of spike/m row, number of grain/spike and 1,000-grain weight in wheat over 17.2 kg P/ha through single superphosphate with or without PSB or pressmud + PSB or rock phosphate + PSB.

The residual effect of P applied to pigeonpea was noticed at 34.4 kg P/ha in wheat (Table 1). Application of 17.2 kg P/ha irrespective of the sources to the preceding pigeonpea failed to record the increase in grain yield of wheat over the control. Application of 34.4 kg P/ha through single superphosphate + PSB or pressmud + PSB to pigeonpea recorded similar grain yield of wheat, but significantly greater than no P and 17.2 kg P/ha through single superphosphate with or without PSB or rock phosphate + PSB or pressmud + PSB to pigeonpea in both the years. The increase in yield due to application of 34.4 kg P/ha through single superphosphate, single superphosphate + PSB, rock-phosphate + PSB and pressmud + PSB was 5.92, 6.97, 8.20 and 8.13% in 2005-06, and 8.44, 9.35, 5.26 and 10.12% in 2006-07 respectively over no P. The increased vigour and growth owing to residual P led to better development of yield attributes, which in turn increased the yield of wheat. Shivran *et al.* (2000) and Singh and Ahlawat (2006) also reported responses of wheat to the carry-over effect of P applied to the preceding crops.

Direct effect of P on wheat

Application of 34.4 kg P/ha to wheat significantly increased the number of spike/m row, number of grain/spike and 1,000-grain weight over no P and 17.2 kg P/ha to wheat (Table 1). Further, application of 17.2 kg P/ha also recorded significantly more number of spike/m row, num-

Table 2. Total P uptake (kg/ha) by pigeonpea-wheat sequence and post-harvest status of available P and net change in soil as influenced by P application

Treatment	Pigeonpea		Wheat		Pigeonpea - wheat sequence		Available P (kg/ha)				Net change (kg P/ha)			
							After pigeonpea		After wheat		After pigeonpea		After wheat	
	2005	2006	2005-06	2006-07	2005-06	2006-07	2005	2006	2005-06	2006-07	2005	2006	2005-06	2006-07
P-level (kg/ha) and source to pigeonpea														
Control	6.94	6.41	12.47	13.05	19.42	19.47	12.12	12.81	12.00	12.12	- 0.78	- 0.49	- 0.90	- 1.18
17.2, SSP	10.92	10.31	13.71	14.51	24.63	24.82	17.50	18.33	16.49	16.79	+ 4.60	+ 5.03	+ 3.59	+ 3.49
17.2, SSP + PSB	11.62	11.15	13.90	14.62	25.52	25.78	18.41	19.03	17.29	17.55	+ 5.51	+ 5.73	+ 4.39	+ 4.25
34.4, SSP	12.73	12.33	15.57	16.42	28.06	28.75	20.12	21.25	18.25	19.36	+ 7.22	+ 7.95	+ 5.35	+ 6.06
34.4, SSP + PSB	13.59	12.91	15.72	16.70	28.50	29.34	21.32	22.41	19.45	19.88	+ 8.42	+ 9.11	+ 6.55	+ 6.58
17.2, RP + PSB	10.55	9.25	14.02	14.37	24.57	23.62	16.70	18.16	15.20	15.81	+ 3.80	+ 4.86	+ 2.30	+ 2.51
34.4, RP + PSB	11.67	10.57	15.94	16.12	27.61	26.68	18.23	19.43	17.22	18.28	+ 5.33	+ 6.13	+ 4.32	+ 4.98
17.2, PM + PSB	12.25	11.95	13.92	14.77	26.17	26.72	17.71	18.41	16.38	16.93	+ 4.81	+ 5.11	+ 3.48	+ 3.63
34.4, PM + PSB	13.03	12.60	16.01	17.41	28.81	29.77	21.91	23.21	19.78	20.23	+ 9.01	+ 9.91	+ 6.88	+ 6.93
SEm±	0.58	0.34	0.21	0.32	0.62	0.38	0.80	0.77	0.64	0.60				
CD (P=0.05)	1.73	1.02	0.64	0.97	1.87	1.14	2.40	2.32	1.93	1.80				
P to wheat (kg/ha)														
0			13.23	13.92	24.56	24.69			12.43	12.50			- 0.51	- 0.80
17.2			14.79	15.51	26.12	26.28			17.37	18.02			+ 4.47	+ 4.72
34.4			15.74	16.67	27.08	27.34			20.92	21.80			+ 8.02	+ 8.50
SEm±			0.14	0.12	0.14	0.12			0.40	0.29				
CD (P=0.05)			0.41	0.36	0.41	0.36			1.15	0.84				

SSP = Single superphosphate, PSB = phosphorus-solubilizing bacteria, RP = rock phosphate, PM = pressmud
Initial available P (2005): 12.9 kg/ha, initial available P (2006): 13.3 kg/ha

ber of grain/spike and 1,000-grain weight in wheat over no P. The trend was similar in both the seasons. Wheat recorded the highest grain yield when P was applied directly at 34.4 kg/ha and improved the grain yield with each successive increase in the dose of P from 0 to 34.4 kg P/ha. The increase in grain yield due to application of 34.4 kg P/ha and 17.2 kg P/ha was 10.27 and 8.05% in 2005-06, and 10.25 and 6.58% in 2006-07 respectively over no P. This might be possibly due to continued and balanced supply of nutrients leading to their increased availability, and with their active involvement in shoot and root growth leading to better plant growth, which later translated into higher yield attributes and yields of wheat. Shivran and Ahlawat (2000) and Singh *et al.* (2006) also reported the responses of wheat in terms of improved yield attributes and yield due to P and PSB application.

System productivity

Application of P to pigeonpea at 34.4 kg P/ha through all sources recorded higher pigeonpea-equivalent yield (PEY) over the control (Table 1). Application of 34.4 kg P/ha through pressmud + PSB recorded higher PEY over 17.2 kg P/ha through single superphosphate alone or rock-phosphate + PSB in 2005-06. In 2006-07, 34.4 kg P/ha through single superphosphate + PSB or pressmud + PSB to pigeonpea also significantly improved the PEY over 17.2 kg P/ha through single superphosphate with or without PSB or rock phosphate + PSB or pressmud + PSB. The increase in PEY with 34.4 kg P/ha through single superphosphate + PSB or pressmud + PSB over no P was 13.68 and 14.20% in 2005-06, and 15.65 and 16.15% in 2006-07 respectively. This might be attributed to increase in economic yield of both the component crops due to residual effect of phosphorus. Shivran *et al.* (2000) and Singh and Ahlawat (2007) also reported similar results.

Application of P to wheat up to 34.4 kg P/ha registered marked increase in PEY. Application of 17.2 kg P/ha applied to wheat also markedly increased the PEY over the control. The increase in PEY with 17.2 and 34.4 kg P/ha over no P was 4.7 and 6.05% in 2005-06, and 4.28 and 6.68% in 2006-07 respectively. This could be due to increased economic yield of both the crops (pigeonpea and wheat) with P application. This result is in close conformity with that of Shivran and Ahlawat (2000).

Total P uptake

In 2005, the application of 34.4 kg P/ha through single superphosphate + PSB markedly increased the total P uptake in pigeonpea over no P, 17.2 kg P/ha through single superphosphate with or without PSB and 17.2 and 34.4 kg P/ha through rock phosphate + PSB (Table 2). In 2006, the application of 34.4 kg P/ha through single superphosphate with or without PSB or pressmud + PSB, being at par, increased the total P uptake in pigeonpea over no P, 17.2 kg P/ha through single superphosphate alone and 17.2 and 34.4 kg P/ha through rock phosphate + PSB. Phosphorus application to pigeonpea at 34.4 kg P/ha through single superphosphate with or without PSB or rock phosphate + PSB or pressmud + PSB, being at par, significantly improved the total P uptake by wheat over no P and 17.2 kg P/ha through single superphosphate with or without PSB or rock phosphate + PSB or pressmud + PSB in both the years.

Pigeonpea fertilized with 34.4 kg P/ha through single superphosphate with or without PSB or pressmud + PSB, being at par, recorded higher P uptake in pigeonpea-wheat system over no P and 17.2 kg P/ha through single superphosphate with or without PSB or rock phosphate + PSB or pressmud + PSB in both the years. Phosphorus application directly to wheat at 34.4 kg P/ha increased the total P uptake in pigeonpea – wheat over no P and 17.2 kg P/ha. The increase in dry-matter yield together with higher content of P finally led to higher uptake of P in pigeonpea and wheat. The added P increased the availability of P to plants, which in turn might have resulted in profuse shoot and root growth, thereby activating greater absorption of P from the soil and improving the grain and stover or straw yields. The present trend of increased nutrient uptake is in line with those of Shivran and Ahlawat (2000) and Singh *et al.* (2006).

P balance

It was observed that soil-available P after pigeonpea markedly improved with the increase in applied P to pigeonpea crop (Table 2). Application of 34.4 kg P/ha through pressmud + PSB or single superphosphate + PSB, being at par, recorded significantly higher soil-available P after pigeonpea over no P, 17.2 kg P/ha through single superphosphate with or without PSB or rock phosphate + PSB or pressmud + PSB and 34.4 kg P/ha through rock phosphate + PSB. Negative balance of P was observed in the control plot only.

The soil available P after wheat improved significantly with successive increase in the rate of applied phosphorus within each source to pigeonpea. Application of 34.4 kg P/ha through single superphosphate + PSB or pressmud + PSB to pigeonpea, being a par, recorded higher soil-available P after wheat over no P and 17.2 kg P/ha through single superphosphate with or without PSB or rock phosphate + PSB or pressmud + PSB in both the years of study. Pigeonpea fertilized with 34.4 kg P/ha through single superphosphate alone markedly improved the available P after wheat over no P and 17.2 kg P/ha through rock phosphate in 2005-06, and no P and 17.2 kg P/ha through single superphosphate alone or rock phosphate + PSB or pressmud + PSB in 2006-07. Application of P directly to wheat at 34.4 kg/ha recorded the maximum available P in the soil after wheat, being markedly higher over the control and 17.2 kg P/ha. This could be explained in terms of poor P utilization. Moreover, since the excessive dose of fertilizer P does not result into luxury consumption, the unutilized portion goes into the soil system and becomes the unavailable fraction of soil P mainly because of its inherent chemical nature of fast fixation in the soil. Singh and Rai (2003) and Singh and Ahlawat (2007) also reported similar results. The negative balance of available P was observed in the control plot only in both the years.

Application of 34.4 kg P/ha through single superphosphate + PSB or pressmud + PSB recorded higher productivity of pigeonpea and the system as a whole. Performance of the succeeding wheat was markedly superior when pigeonpea received 34.4 kg P/ ha through single superphosphate + PSB or pressmud + PSB. Direct application of P to wheat up to 34.4 kg P/ha recorded higher productivity of wheat.

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