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

UMMED SINGH[1] AND I. P. S. AHLAWAT*

Division of Agronomy, Indian Agricultural Research Institute, New Delhi 110 012

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ABSTRACT

A field experiment was conducted at New Delhi during 2002–03 and 2003–04 on sandy-loam soil with 10 kg available P/ha to optimize the P requirement in pigeonpea [*Cajanus cajan* (L.) Millsp.]-wheat [*Triticum aestivum* L. emend. Fiori & Paol.] cropping system. This study revealed that 17.2 kg P/ha to pigeonpea recorded higher mean growth (plant height, 158.7 cm; branches/plant, 22.9 leaf-area index, 2.20), yield attributes (pods/plant, 194.5; grains/pod, 4.45; 1,000-grain weight, 74.45 g) and grain yield (2.05 Mg/ha) over no P and phosphate-solubilizing bacteria (PSB) alone. Application of 17.2 kg P/ha to the preceding pigeonpea also increased the mean growth (plant height, 72.7 cm; tillers/m row length, 101.1; LAI, 3.11) and yield attributes (spikes/m row, 91.8; grains/spike, 33.4), and also grain yield of the succeeding wheat (4.55 Mg/ha) compared with no P to pigeonpea Besides residual P, direct application of P to wheat up to 17.2 kg P/ha + PSB also increased the mean growth yield attributes and grain yield (4.85 Mg/ha) of wheat. Residual as well as direct-applied P up to 17.2 kg/P ha + PSB increased the total productivity of the cropping system in terms of pigeonpea-equivalent yield (residual, 4.48 Mg/ha; direct, 4.37 Mg/ha) over the preceding P levels. The cropping system removed the highest mean total P (26.8 kg/ha) when both the crops received 34.4 kg P/ha. The soil available P status after the cropping cycle improved over the initial status (10 kg/ha) with increasing rates of P application up to 34.4 kg/ha (18.8 kg/ha). However, negative balance of soil P (8.8 kg/ha) was noticed in the plots receiving no P.

Key words: Phosphorus, Phosphate-solubilizing bacteria, Pigeonpea, Wheat

The development of short-duration cultivars of pigeonpea [*Cajanus cajan* (L.) Millsp.] and late-sown cultivars of wheat (*Triticum aestivum* L. emend. Fiori & Paol.) in the last 2-3 decades has made pigeonpea-wheat sequence more feasible and acceptable to farmers in the wheat belt of northern India, especially in areas with assured irrigation. The benefit of P management based on cropping system is that it enables the distribution of P among the component crops according to their responsiveness and aims at taking residual effect into account at the time of making recommendations to the farmers. The P-fertilizer recommendations for individual crops of pigeonpea and wheat are already available. But these recommendations do not take into account the utilization of P by the preceding crops and the P applied to them in sequence. As only a limited part of the applied P (15-20%) is utilized by a crop, the P requirement of the succeeding crop may be modified by the residual P. Phosphate fertilization of legumes during rainy season is known to increase the available P status of the soil and results in higher yield of the succeeding wheat crop (Prasad *et al.*, 1998). Studies on legume and wheat cropping system have shown that where the legume crop removed less amount of the applied P, yield of the succeeding crop increased (Mahajan and Khanna, 1968). An experiment was therefore conducted to optimize the phosphorus needs in pigeonpea-wheat sequence.

MATERIALS AND METHODS

A field experiment was conducted at New Delhi during the winter and rainy seasons of 2002-03 and 2003-04. The soil was sandy loam with pH (1:2.5 soil: H_2O) nearly neutral (7.8 and 8.1), having low organic carbon (0.37 and 0.39%), available N (163 and 167 kg/ha) and available P (10 kg/ha in both seasons) at 0-30 cm soil depth in the respective growing seasons. The experiment was laid out in split-plot design replicated thrice, with five levels of P, viz control, phosphate-solubilizing bacteria (PSB), 17.2 kg

***Corresponding author :** (E-mail : ahlawat47@hotmail.com)

Present address:[1]Regional Research Station and Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology, Wadura (Sopore), Jammu & Kashmir 193 201

P/ha, 17.2 kg P/ha + PSB and 34.4 kg P/ha applied to each pigeonpea and wheat in the cropping system. A common uniform dose of 31 kg N/ha through urea was given to pigeonpea after adjusting the N applied through diammonium phosphate (DAP). Similarly, a uniform dose of 120 kg N/ha through urea was given to wheat in two splits, half at sowing and the remaining half at 21 days after sowing, after adjusting the N supplied from DAP. The entire dose of P as per treatment was applied through DAP at sowing in both the crops. The seeds of pigeonpea and wheat were inoculated by phosphate-solubilizing bacterial culture containing inoculums of *Pseudomonas striata* as per treatment. Pigeonpea cultivar 'Pusa 855' and wheat cultivar 'HD 2285' were used in this study. Pigeonpea was sown in rows 50 cm apart on 5 July 2002 and 28 June 2003. An intra-row spacing of 20 cm was maintained. Wheat was sown in rows 25 cm apart on 2 December 2002 and 29 November 2003, using 125 kg seed/ha. The weeds were controlled by pre-emergence spray of pendimethalin @ 1.0 kg/ha in pigeonpea, and post-emergence spray of isoproturon @ 1.0 kg/ha in wheat. However, herbicide application in both the crops was also supplemented with one hand weeding at 30 days in pigeonpea and 45 days in wheat. The pigeonpea-equivalent yield was computed by converting the wheat yield to pigeonpea yield, based on their market prices.

RESULTS AND DISCUSSION

Effect of P on pigeonpea

Phosphorus application up to 17.2 kg P/ha improved the plant-growth attributes in terms of plant height, branching and leaf-area index (LAI)] of pigeonpea (Table 1). However, LAI showed marked improvement with 34.4 kg P/ha over 17.2 kg P/ha in 2003, but the difference between 17.2 kg P/ha + PSB and 34.4 kg P/ha was not perceptible. PSB alone also improved the plant growth. P fertilization up to 17.2 kg P/ha significantly increased the yield components, viz. pods/plant, grains/ pod and 1,000-seed weight, and seed yield of pigeonpea (Tables 1, 3) in both the seasons. PSB inoculation of seeds also increased the yield attributes and yield of pigeonpea. However in 2002 the higher rate of 34.4 kg P/ha recorded higher yield over that of 17.2 kg P/ha but similar to 17.2 kg P/ha + PSB. Over the seasons, PSB alone increased the grain yield of pigeonpea by 14.7 per cent, whereas 17.2 kg P/ha with and withtout PSB and 34.4 kg P/ha recorded 31.5-38.9% increase in yield. In general, the increase in yield with P treatment was greater in 2002.

Phosphorus plays a very important role of symbiotic nitrogen fixation in legumes, where it acts as a source of energy. In this investigation the overall improvement in crop growth of pigeonpea with P application was on account of its pivotal role in early formation of roots, their proliferation, photosynthesis, energy-transfer reactions, increased microbial activity in root nodules and symbiotic biological N-fixation process, as also reported by Tisdale *et al.* (1995). The beneficial effect of PSB alone in pigeonpea could be ascribed to solubilization of native phosphorus through excretion of glutamic, succinic, lactic, oxalic, fumaric acids etc. (Subba Rao, 1986).The improvement in growth of pigeonpea due to favourable influence of P led to efficient and greater partitioning of metabolites and adequate translocation of photosynthates and nutrients to the develop reproductive structure (Tisdale *et al.*, 1995). Shivran and Ahlawat (2000) also observed improved yield attributes in pigeonpea with P application. The improvement in yield attributes and yield of pigeonpea by PSB inoculation alone might be owing to its positive effect on growth (as stated earlier), which in turn resulted in the development of higher yield attributes and finally increased grain yield (Gaur, 1985; Shivran *et al.*, 2000). The response of pigeonpea to a particular dose of P (17.2 kg P/ha with and without PSB in the present case) was a reflection of its status in the soil, and also other soil characteristics influencing the P-fixation capacity of the soil. The experimental soil was low in available P.

The economic optimum dose of P was 29.3 and 27.8 kg/ha, yielding 2.12 and 2.22 tonnes/ha with a response of

Table 1. Effect of phosphorus on growth and yield attributes of pigeonpea

Treatment (kg P/ha)	Plant height (cm)		Branches/plant		Leaf-area index (90 DAS)		Pods/plant		Seed/pod		1,000-Seed weight (g)	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Control	123.8	132.3	14.8	16.3	1.52	1.71	151.2	157.1	2.4	2.6	58.5	62.6
PSB	142.1	146.5	18.2	20.2	1.83	1.92	174.9	176.3	3.1	3.4	66.4	69.1
$P_{17.2}$	157.5	159.9	21.6	24.3	2.18	2.21	193.4	195.6	4.3	4.6	73.6	75.3
$P_{17.2}$ + PSB	161.2	163.5	23.3	25.2	2.32	2.38	196.3	198.4	4.6	4.8	73.6	76.4
$P_{34.4}$	166.7	169.4	23.9	26.1	2.41	2.44	199.2	200.3	4.7	4.9	74.8	77.6
CD (P=0.05)	12.8	13.0	2.5	3.5	0.25	0.18	16.0	17.5	0.5	0.4	7.0	5.9

DAS = Days after sowing

0.64 and 0.58 tonnes/ha respectively. Each kg of P gave a response of 21.5 and 20.4 kg grain in 2002 and 2003 respectively.

Residual effect of P on wheat

The residual effect of P was evident on growth and yield attributes as well as yield of wheat in both the years. Application of 17.2 kg P/ha to the preceding pigeonpea significantly increased the growth (plant height, tillers/m row and LAI) and yield attributes (spikes/m row and grains/spike), as well as the yield of succeeding wheat over no phosphorus and PSB alone (Tables 2 and 3). PSB alone could not affect the grain yield of succeeding wheat crop, but the residual effect of 17.2 kg P/ha with and without PSB and 34.4 kg P/ha was quite pronounced, and resulted in 8.5-15.0 higher yield.

The soil-available P status showed marked improvement with each increment of applied P up to 34 kg residual P/ha (Table 3). The improvement in soil-available P by residual P from pigeonpea after wheat harvest was because the P applied to pigeonpea was not even fully utilized by both the crops of the cropping system. On the contrary, a decline in soil-available P over its initial status was observed where pigeonpea did not receive P. It was owing to removal of P by both the crops without its addition in the soil. The PSB alone also could sustain the P status of the soil even after wheat harvest, because of its ability to solubilize the native P.

Direct effect of P on wheat

The direct application of P to wheat at 17.2 kg/ha + PSB, being on a par with that of 34.4 kg/ha, significantly increased the growth (plant height, tillers/m row length and LAI), yield attributes (spikes/m row and grains/spike) and yield of wheat compared with lower levels (Tables 2 and 3). Although PSB inoculation alone in wheat gave minor increases (3.9% in 2002-03 and 5.0% in 2003-04) in grain yields, these were statistically significant. Over the seasons, application of 17.2 kg P/ha to wheat increased the grain yield by 13.8 per cent, which further increased to 20.4% with addition of PSB inoculation to the same rate of P. However, further increases in P rate to 34.4 kg P/ha did not give additional increase over 17.2 kg P/ha + PSB. The increases in grain yields with P treatments were, in general, higher in 2003-04.

The improvement in growth, yield attributes and grain yield of wheat with direct application of P was due to continued and balanced supply of this nutrient. The greater availability of P and its active involvement in shoot and root growth led to better plant growth, which later translated into higher yield attributes and yield of wheat. The response of wheat in terms of improved yield at-

Table 2. Direct and residual effects of phosphorus on growth and yield attributes of wheat

Treatment	Plant height (cm)		Tillers / m row		Leaf-area index		Spikes/m row		Grains/spike		1,000-grain weight (g)	
	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04
P to pigeonpea (kg P/ha)												
Control	66.3	64.2	90.6	88.9	2.88	2.70	83.8	82.4	30.6	29.5	42.8	43.4
PSB	71.2	69.3	97.2	95.8	3.03	2.88	86.5	85.1	31.9	30.8	43.1	43.9
$P_{17.2}$	73.7	71.8	102.1	100.1	3.20	3.03	92.5	91.1	33.9	32.9	43.5	44.6
$P_{17.2}$ + PSB	76.9	74.9	106.3	104.9	3.28	3.16	96.8	95.4	35.5	34.4	44.7	45.1
$P_{34.4}$	78.1	76.1	107.8	105.7	3.41	3.19	98.2	97.4	36.0	34.9	44.9	45.4
CD (P=0.05)	5.5	5.4	7.5	7.1	0.24	0.22	7.2	7.1	2.2	2.2	NS	NS
P to wheat (kg P/ha)												
Control	64.9	63.2	89.4	87.9	2.81	2.66	72.8	71.4	32.5	26.3	42.4	42.9
PSB	69.2	67.4	95.3	93.9	3.01	2.85	79.8	78.4	33.0	28.3	42.8	43.7
$P_{17.2}$	73.9	72.0	101.8	100.1	3.19	3.02	93.2	91.8	36.1	33.0	43.7	44.9
$P_{17.2}$ + PSB	78.7	76.6	108.4	106.6	3.38	3.20	103.1	102.5	38.6	37.0	44.8	45.3
$P_{34.4}$	79.3	77.2	109.2	107.4	3.41	3.23	108.7	107.3	39.8	37.9	45.3	45.6
CD (P=0.05)	4.2	4.1	5.7	5.6	0.18	0.17	5.7	5.0	1.8	1.7	NS	NS

NS = Non-significant

Table 3. Yield of pigeonpea and wheat, total productivity of cropping system and P uptake as affected by phosphorus

Treatment	Pigeonpea yield (tonnes/ha)		Wheat yield (tonnes/ha)		Pigeonpea-equivalent yield (Mg/ha)		Total P uptake in cropping system (kg/ha)		Available soil P after cropping cycle (kg/ha)	
	2002	2003	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04
P to pigeonpea (kg P/ha)										
Control	1.48	1.65	4.24	4.16	3.58	3.77	18.1	18.9	8.7	9.6
PSB	1.71	1.88	4.32	4.34	3.85	4.09	21.0	22.2	11.3	12.8
$P_{17.2}$	1.99	2.12	4.59	4.52	4.27	4.42	23.5	24.6	13.5	15.6
$P_{17.2}$ + PSB	2.07	2.18	4.73	4.66	4.42	4.55	24.3	25.5	16.6	17.7
$P_{34.4}$	2.12	2.22	4.88	4.78	4.55	4.65	26.7	28.8	17.8	19.3
CD (P=0.05)	0.12	0.19	0.31	0.29	0.14	0.12	1.1	1.7	1.1	1.2
P to wheat (kg P/ha)										
Control			4.08	3.98	3.89	4.03	20.1	21.1	8.2	8.8
PSB			4.24	4.18	3.98	4.13	21.3	22.4	10.6	12.6
$P_{17.2}$			4.61	4.56	4.16	4.33	22.8	24.1	14.6	14.8
$P_{17.2}$ + PSB			4.88	4.82	4.29	4.46	24.3	25.8	16.4	18.7
$P_{34.4}$			4.96	4.92	4.33	4.51	25.2	26.6	18.1	20.1
CD (P=0.05)			0.14	0.10	0.10	0.09	0.6	0.7	0.8	1.0

tributes and yield by phosphorus and PSB application has also been documented by Shivran and Ahlawat (2000) and Singh and Rai (2002).

The increasing rates of P application to wheat caused corresponding improvement in soil-available P status. However, the soil-P status declined over its initial status, where the wheat crop was grown without P fertilizer (Table 3). In this investigation both the crops (pigeonpea and wheat) showed favourable response to P. Further, only a small fraction (15-20%) of applied P is usually utilized by the first crop and the left over is utilized by the subsequent crops. Hence the total productivity of the cropping system improved through the direct response of P in pigeonpea and wheat and the residual response of P in wheat. The pigeonpea-wheat cropping system removed 18-19 kg P/ha even without addition of P, which perhaps lowered the soil-P status over the initial level.

Response of wheat to residual and direct P

The wheat crop responded favourably up to direct application of 17.2 kg P/ha + PSB, where the preceding pigeonpea received no phosphorus or received PSB alone (Fig. 1). Further, there was no difference in wheat yields between 17.2 kg P/ha with and without PSB, where pigeonpea received 17.2 kg P/ha with and without PSB or 34 kg P/ha. Wheat receiving no P or PSB alone also showed favourable response to residual P up to 17.2 kg/ha + PSB, whereas it was restricted to 17.2 kg P/ha only with 17.2 kg P/ha applied to wheat. Wheat fertilized with 17.2 kg P/ha + PSB or 34.4 kg P/ha did not show any residual effect of P. It indicates that the lower two doses of P were able to meet the requirement of P in wheat. The

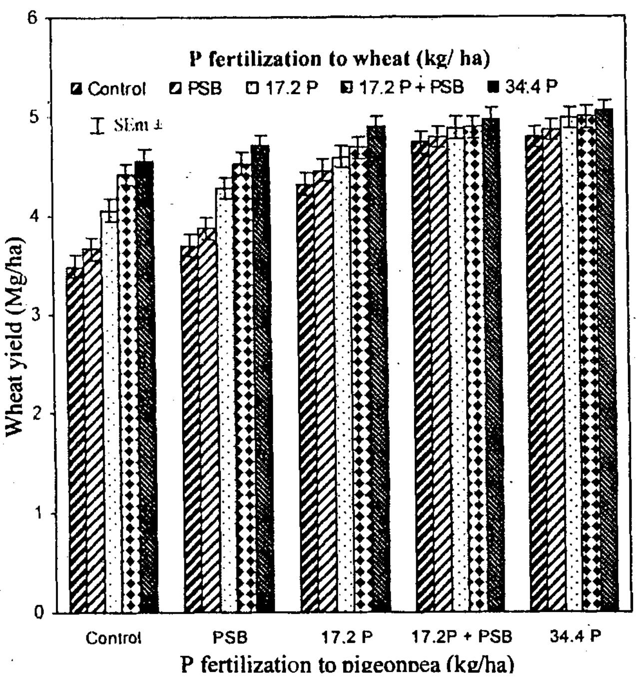

Fig. 1. Interaction effect of residual and direct-applied P on yield of wheat in pigeonpea-wheat system (mean data of 2 seasons)

residual effect of P was pronounced in wheat only where it either received no P or received suboptimum dose of P. The combinations of residual and direct-applied P @ 17.2 kg P/ha with or without PSB produced yield of wheat on a par with that of 34.4 kg P/ha applied to both the crops of the cropping system.

Effect of P on total productivity of cropping system

Phosphorus application to pigeonpea up to 17.2 kg P/ha

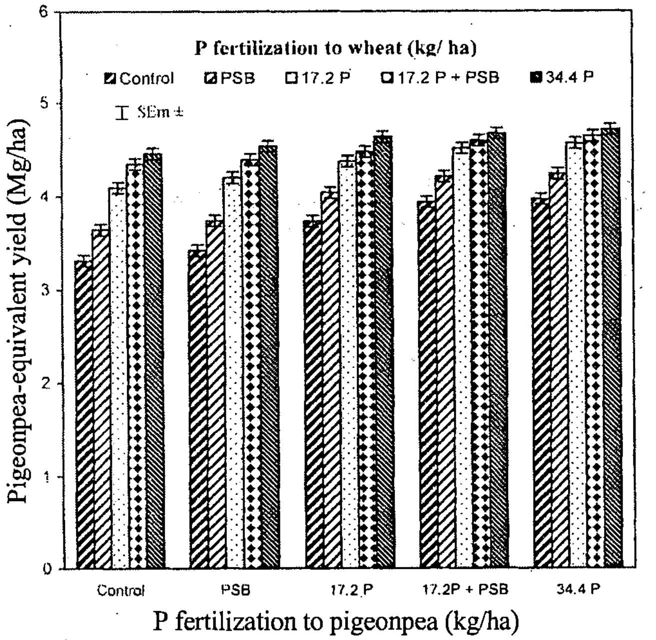

Fig. 2. Interaction effect of residual and direct-applied P on pigeonpea-equivalent yield in pigeonpea-wheat system (mean data of 2 seasons)

+ PSB markedly increased the pigeonpea-equivalent yield (PEY) over the preceding levels (Table 3). Direct application of P to wheat at 17.2 kg P/ha + PSB and 34.4 kg P/ha, both being at par, recorded significantly higher PEY over other treatments (Table 3).

The overall higher productivity of the pigeonpea-wheat cropping system in tems of PEY with P application resulted from increased economic yields of both the component crops through direct and residual effects of phosphorus. These results confirm the findings of Shivran *et al.* (2000).

The interaction effect revealed that there was marked increase in total productivity up to 17.2 kg P/ha + PSB applied to wheat, where the preceding pigeonpea received no P or received PSB alone (Fig. 2). The total productivity was similar to that with 17.2 kg P/ha with or without PSB in wheat, where pigeonpea received 17.2 kg P/ha with and without PSB or 34.4 kg P/ha. Further, wheat receiving no P recorded marked increase in total productivity, where the preceding pigeonpea received P up to 17.2 kg/ha + PSB. However, total productivity failed to increase beyond 17.2 kg P/ha applied to pigeonpea along with 17.2 kg P/ha + PSB or 34.4 kg P/ha to wheat. Application of 17.2 kg P/ha + PSB to both the crops of the sequence recorded total productivity on a par with that of 34.4 kg P/ha applied to each crop.

P uptake in cropping system

Phosphorus application to both pigeonpea and wheat up to 34.4 kg/ha makedly increased the total P uptake in the cropping system over the preceding levels (Table 3). However, pigeonpea receiving 17.2 kg P/ha with and without PSB did not show marked variation in total P uptake by the cropping system in both the seasons. In pigeonpea-wheat cropping system, the highest P uptake was noticed on application of the highest level of 34.4 kg P/ha owing to increased availability of both N (through BNF) and P in the legume-cereal system, resulting in profuse root and shoot growth, and activating greater absorption of P from the soil and increased biomass yields (Shivran *et al.*, 2001).

P-use efficiency

In pigeonpea the application of 17.2 kg P/ha + PSB recorded higher agronomic P-use efficiency (APUE), physiological P-use efficiency (PPUE) and apparent P recovery (APR) compared with that of 17.2 and 34.4 kg P/ha (Table 4). P-efficiency ratio (PER) and physiological efficiency index of P (PEP) declined with increase in P level. P-harvest index (PHI), however, remained unaffected by P application in pigeonpea.

In wheat the residual effect of P applied to the preceding crop of pigeonpea showed pronounced effect on P-use efficiency. Non-application to pigeonpea recorded higher APUE, PPUE, APR, PER and PEP in the succeeding wheat compared with various rates of P applied to pigeonpea, whereas PHI remained unaffected by P application (Table 4).

The direct application of 17.2 kg P/ha + PSB to wheat also recorded higher APUE and APR compared with other P treatments. Although 17.2 kg P/ha showed higher value of PPUE, the difference between the values of 17.2 kg P/ha with and without PSB was only small. The PER and PEP continued to decline with increasing rates of P up to 34.4 kg P/ha applied to wheat. PHI was not affected by P application to wheat (Table 4). As observed under residual effect of P, direct application of P to wheat also recorded decrease in P-use indices owing to relatively lower P uptake in comparison with dry-matter production and grain yield.

In our study the increase in APUE, PPUE and APR in pigeonpea with 17.2 kg P/ha + PSB compared with lower and higher levels of P could be attributed to relatively higher grain yield and P uptake by the crop. The reduction in PER and PEP with increasing levels of P might be due to relatively lower P uptake and higher dry matter and grain yield. However, the reduction in P-use indices on account of residual effect of P in wheat could be due to lower dry-matter production and grain yield and lower P uptake by the crop. Similarly, direct application of P to wheat also recorded decrease in P-use indices owing to

Table 4. P-use efficiency as influenced by P fertilization in pigeonpea-wheat cropping system

Treatment	Pigeonpea						Wheat					
	APUE	PPUE	APR	PER	PEP	PHI	APUE	PPUE	APR	PER	PEP	PHI
P to pigeonpea (kg P/ha)												
0				901.7	208.6	34.1	53.0	204.8	24.8	801.6	395.9	72.3
PSB		107.2		796.6	186.0	34.3	48.8	197.4	23.4	740.6	370.9	72.6
$P_{17.2}$	28.4	137.1	20.8	767.6	185.4	36.1	35.5	184.0	19.1	721.6	357.3	73.0
$P_{17.2}$ + PSB	32.2	143.0	23.3	747.6	184.7	36.8	20.3	121.3	15.2	732.9	354.9	73.0
$P_{34.4}$	17.6	103.5	16.8	658.5	162.3	35.6	19.5	131.9	14.5	689.9	340.2	73.7
P to wheat (kg P/ha)												
0										814.9	413.6	72.2
PSB								147.1		766.3	382.1	72.8
$P_{17.2}$							32.2	184.5	16.7	723.4	360.7	73.0
$P_{17.2}$ + PSB							47.7	176.0	26.0	705.0	338.9	73.3
$P_{34.4}$							26.3	163.9	15.5	676.9	324.2	73.5

APUE = Agronomic P-use efficiency; PPUE = physiological P-use efficiency; APR = apparent P recovery; PER = P-efficiency ratio; PEP = physiological efficiency index of P; PHI = P-harvest index

relatively lower P uptake in comparison with dry matter production and grain yield. These findings corroborate those of Batten *et al.* (1999) and Kumar and Prasad (2003).

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