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Effect of different sources of phosphorus on summer mungbean (*Vigna radiata*) in alkaline soil of Delhi

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ABSTRACT

The field experiments were conducted at the Indian Agricultural Research Institute, New Delhi for 3 years from 2002 to 2004 to study the effects of incorporation of 6 tonnes/ha of residue of wheat crop on the efficiency of diammonium phosphate (DAP) and Mussoorie rock phosphate plus inoculation of phosphorus-solubilizing bacteria (MRP + PSB) on summer mungbean var. 'PS 16'. Application DAP @ 17.5 and 35 kg P/ha significantly increased seed yield over control by 16–34 and 39–49%, respectively, P uptake by 18–26 and 35–44%, respectively, gross returns by 13–25 and 32–41%, respectively and net return of mungbean by 23–288 and 87–278%, respectively, whereas application MRP + PSB @ 17.5, 35 and 52.5 kg P/ha increased seed yield over control by 9–17, 24–31 and 40–70%, respectively, P uptake by 7–16, 23–35 and 38–51%, respectively, gross returns by 8–13, 18–28 and 37–56%, respectively and net returns of mungbean by 14–138, 43–146 and 85–678%, respectively. Thus, MRP + PSB at 35 and 52.5 kg/ha was at par with DAP at 17.5 and 35 kg/ha, respectively in terms of seed yield, P uptake and gross and net returns of mungbean. Agronomic efficiency ranged between 5.3 and 10.1 kg seed/kg P for DAP and between 3.1 and 6.3 kg seed/kg P for MRP + PSB. Similarly, apparent recovery of MRP + PSB was lower (3.4–7.0%) than that of DAP (7.0–10.2%). However, incorporation of residue of preceding wheat crop significantly increased the efficiency of MRP + PSB and thus MRP + PSB along with residue incorporation can be used for P fertilization in mungbean crop.

Key words: Agronomic efficiency, Apparent recovery, Available P, Balance sheet, Gross and net income, Phosphorus-solubilizing bacteria, Seed yield

During last two decades commencing from 1995–96 the production of cereals has increased from 168 to 202 million tonnes, whereas the production of pulses remained static at 14 + 2 million tonnes in the country. This resulted in a drastic reduction in per capita pulse availability from 45 g in 1995–96 to 35 g in 2006–07 (FAI 2007). This has accentuated the problem of protein malnutrition in the country where majority of its population is vegetarian. Hence, there is an urgent need to increase pulse production in the country. Mungbean (*Vigna radiata* L) is an important pulse crop in India. Being a photo-insensitive and short-duration crop, it can be grown during summer. However, its productivity is generally low ranging from 0.5 to 0.8 tonnes/ha (Sharma and Prasad 2001). The productivity averaged over 10 years has shown only a marginal increase (Ali *et al.* 2002). One of several reasons of lower yield of summer mungbean is that it is generally grown on residual fertility. The P contents in most Indian soils, on the other hand, are low. Motsara (2002) reported that 60% soils are low to medium in available P content. Added inorganic P as water-soluble phosphate fertilizers undergoes complex exchanges between various soil pools This is especially true in the tropics where many soils have extremely high P-fixation capacity. Consequently, large amounts of fertilizer P are needed to attain reasonable crop yields. In India, the price of fertilizer P is the highest; the cost of 1 kg P varies from Rs 34.4 through DAP to Rs 38.9–39.5 through single super phosphate as against Rs 10.5 for 1 kg N through urea and Rs 8.4 for 1 kg K through muriate of potash (FAI 2007). Because of high cost, small and marginal farmers in India generally skip P fertilization. The N:P consumption ratio in India is 2.6:1 (FAI 2007) as against the desirable ratio of 2:1 for sustainable crop production (Tiwari 2002). The high cost of phosphorus in India is because bulk of the phosphate rock for making phosphate fertilizers is imported. However, there are substantial deposits of low-grade rock phosphate in India, which can partly meet the crop demands for phosphorus. One such deposit is Mussoorie rock phosphate (MRP). Attempts have been made in the past to use finely ground MRP directly on soil of *p*H 7 and above with the help of pyrites and phosphate-solubilizing micro-

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organisms (Sharma and Prasad 2003). The present investigation was undertaken to study the effect of crop residue incorporation on the relative efficiency of diammonium phosphate and MRP at varying rates of application on productivity and economics of mungbean and P balance in soil.

MATERIALS AND METHODS

The field experiments were conducted during the summer (April–June) of 2002–04 at the Indian Agricultural Research Institute, New Delhi (28°38′ N latitude, 77°11′ E longitude and 228.6 m above msl). The soil of the experimental field was a sandy clay loam (typical Ustochrept), having 52.5% sand, 21.0% silt and 26.5% clay. It contained 12.0 tonnes/ha organic C, 1.3 tonnes/ha Kjeldahl N, 16.0 kg/ha 0.5 *M* $NaHCO_3$ extractable P and 500 kg/ha 1 *N* NH4OAC extractable K and had a *p*H of 8.3 (1:2.5 soil: water ratio) at the start of experiment.

The experiments were laid out in a split-plot design with 6 replications. The treatments consisted of 2 crop residue management practices (no residue incorporation and residue incorporation @ 7 tonnes/ha) in main plots and 6 phosphorus treatments [control, 17.5 kg P/ha as diammonium phosphate (DAP), 17.5 kg P/ha as Mussoorie rock phosphate (MRP), 35 kg P/ha as DAP, 35 kg P/ha as MRP and 52.5 kg P/ha as MRP] in sub-plots. The 6 tonnes/ha rate of residue incorporation was fixed on the assumption that average crop of wheat produces about 6 tonnes/ha straw. The treatments were continued throughout the study (3 years) in the same plots. The main plot size was 25 m × 23 m and sub-plot size was 7.5 m × 7.0 m.

Immediately after the harvest of the winter (*rabi*) season wheat crop, the field was irrigated and when soil was workable the residue of preceding wheat was uniformly spread over soil surface in residue incorporation treatment. The residue was incorporated by harrowing and disking of the field. The residue contained 0.50–0.53% N, 0.05–0.06% P and 1.6–1.7% K and thus incorporation of residue resulted in addition of 30–32 kg N, 3.0–3.6 kg P and 96–102 kg K/ha/year. Mungbean variety 'PS 16' was seeded at a uniform row spacing of 30 cm with a seed rate of 20 kg/ha in the second week of April. Commercial grade granulated DAP containing 18% N and 20% P was used in DAP-treated plots. The treatment of 35 kg P/ha as DAP resulted in the application of 31.5 kg N/ha. Hence, a basal dose of 31.5 kg N/ha as urea in control and MRP treatments and of 15.75 kg N/ha as urea in the treatment of 17.5 kg P/ha P was applied with P application. All the fertilizers were broadcast before sowing. In MRP treated plots MRP containing 7.86% P was used. Of the total P in MRP 12% was soluble in neutral ammonium citrate. MRP-plots were inoculated with phosphorus-solubilizing bacteria (PSB) using *Pseudomonas striata* and hence the treatment is designated as MRP + PSB. For inoculation with PSB, the slurry was prepared by dissolving 200 g brown sugar in 250 ml water and then warming it for 15 min. at 40°C. The slurry thus prepared was diluted 10 times with water and a packet of PSB culture obtained from the Microbiology Division, Indian Agricultural Research Institute, New Delhi was added to diluted slurry. Inoculation was done by mixing the seeds with culture slurry. The seeds were then dried in shade for 4 hr and sown. The crop received 3 irrigations of 10 cm depth, first at 20 days after sowing (DAS), second after 35 DAS and third at 50 DAS. The crop was harvested in 2 pickings, first after 50–55 DAS and second after 70–75 DAS and seed weight of 2 pickings was recorded. The seed yield was adjusted at 14% moisture. After second picking plants were harvested and their fresh weight was recorded. A plant sample was drawn from each plot for moisture determination and straw yield was adjusted at oven dry basis.

The agronomic efficiency (AE) of P sources was calculated by using following expression:

$$AE = \frac{Y_t - Y_c}{Pa}$$

where, AE is the agronomic efficiency in kg seed/kg P applied, Yt is the seed yield in applied plot in kg/ha, Yc is the seed yield in control plot in kg/ha and Pa is the P applied in kg/ha.

The apparent recovery (AR) of P was computed using following expression:

$$AR\ (\%) = \frac{P_t - P_c}{Pa} \times 100$$

where, AR is the agronomic efficiency in percentage, Pt is the amount of P taken up from P applied plot in kg/ha, Pc is the amount of P taken up from control plot in kg/ha and Pa is the amount of P applied in kg/ha.

Gross income of different treatments was calculated using following expression:

$$GI = Yi \times Pc$$

where, GI is the gross income in Rs/ha, Yi is the grain yield of the treatment I and Pc is the procurement price of mungbean. Cost of cultivation of mungbean was calculated on the basis of prevailing rates of inputs in the market during the study and then the cost of cultivation was averaged over 3 years. The net income of treatment I was obtained by subtracting the cost of cultivation of treatment I from gross income of treatment I.

The seed and straw samples were analyzed for total P as per procedure described by Prasad *et al*. (2006). After 3 years of study, soil samples were drawn from 0 to 25 cm depth in each plot and analyzed for 0.5 M NaHCO3 extractable P. Data of each character were subjected to analysis of variance using 'F' test and mean separation was done by Least Significant Difference (LSD) at 5% error probability (Gomez and Gomez 1984). A best fit linear (Yi = A0 + bi Xi) or quadratic ($Yi = A0 + bi\ Xi + ciXi^2$) response equation was

fitted between rates of P and seed yield of mungbean

where, 'Yi' is the mean yield with source I, 'Xi' is the rate of P application, 'bi' is the linear co-efficient, ci is the quadratic co-efficient of the response equation with source I and 'A0 'is the intercept at X = 0 kg P/ha. The values of co-efficient of determination (R^2) were also estimated each year and are given in Fig 1.

RESULTS AND DISCUSSION

Seed yield

Seed yield of mungbean ranged from 0.47 to 0.74 tonnes/ha in control plots and from 0.55 to 1.10 tonnes/ha in P applied plots (Table 1). In 2002 seed yield of mungbean increased significantly when rate of P application was increased from 0 to 52.5 kg P/ha as MRP + PSB, whereas in 2003 and 2004 mungbean seed yield increased with increasing level of P up to 35 kg P/ha as DAP and 52.5 kg P/ha as MRP + PSB. However, the differences between 17.5 and 35 kg/ha as MRP + PSB in 2003 and between 35 and 52.5 kg/ha as MRP + PSB in 2004 were not significant. The PSB inoculation might have made the MRP more soluble as indicated by available P content in soil (Table 5). He *et al*. (2002) also reported that PSB can make native and less soluble P as in MRP more readily available to the crops.

Residue incorporation had no significant effect on seed yield of mungbean in first year, whereas in second and third years residue incorporation significantly increased the seed yield of mungbean over control. Interaction effect between phosphorus and crop residue was significant in all the 3 years of study. In 2002, P application had no significant effect on seed yield without residue incorporation, whereas with residue incorporation MRP + PSB at 52.5 kg P/ha significantly increased the seed yield of mungbean over control. During 2003, without residue incorporation DAP at 17.5 kg P/ha failed to show its significant effect on seed yield, whereas with residue incorporation 17.5 kg P/ha as DAP significantly increased the seed yield of mungbean. Similarly, in 2004 both DAP and MRP + PSB at 17.5 kg P/ha increased the mungbean seed yield only when residue was incorporated.

The response of mungbean to DAP was quadratic in the first year and linear in the second and third years irrespective to residue management practice (Fig 1). This shows that response to DAP increased with time. Response to MRP + PSB was linear irrespective to residue management practice in all the 3 years of study.

Straw yield

Straw yield of mungbean ranged from 3.85 to 4.95 tonnes/ha in control plots and from 4.16 to 5.78 tonnes/ha in P applied plots (Table 1). Phosphorus application had no

Table 1 Effect of rates and sources of phosphorus on seed and straw yields (tonnes/ha) of mungbean as influenced by residue incorporation

Treatment	2002			2003			2004		
	NR	RI	Mean	NR	RI	Mean	NR	RI	Mean
Seed yield									
Control	0.48	0.47	0.47	0.72	0.76	0.74	0.60	0.64	0.62
DAP at 17.5 kg P/ha	0.59	0.64	0.62	0.80	0.91	0.86	0.66	0.80	0.73
MRP + PSB at 17.5 kg P/ha	0.51	0.59	0.55	0.77	0.85	0.81	0.64	0.77	0.71
DAP at 35.0 kg P/ha	0.64	0.68	0.66	0.94	1.25	1.10	0.77	0.95	0.86
MRP + PSB at 35.5 kg P/ha	0.53	0.64	0.59	0.83	1.01	0.92	0.74	0.87	0.81
MRP + PSB at 52.5 kg P/ha	0.75	0.84	0.80	0.90	1.25	1.08	0.76	0.98	0.87
Mean	0.58	0.64		0.83	1.00		0.69	0.84	
CD (*P*=0.05)									
Phosphorus (P)		0.22			0.07			0.09	
Residue (R)		NS			0.07			0.08	
P × R		0.31			0.10			0.12	
Straw yield									
Control	3.95	4.50	4.22	4.76	4.95	4.95	3.85	4.09	3.97
DAP at 17.5 kg P/ha	4.62	51.80	4.56	5.19	5.30	4.93	4.37	4.64	4.72
MRP + PSB at 17.5 kg P/ha	4.30	5.17	4.82	4.91	5.13	5.11	4.16	4.53	4.35
DAP at 35.0 kg P/ha	4.43	5.33	4.65	5.40	5.52	5.00	4.77	4.95	5.12
MRP + PSB at 35.5 kg P/ha	4.40	5.33	4.89	5.22	5.58	5.40	4.61	4.65	4.63
MRP + PSB at 52.5 kg P/ha	48.5	56.30	4.94	5.65	5.78	5.38	5.22	4.85	4.47
Mean	4.58	4.78			5.19	5.13	4.81	4.60	
CD (*P*=0.05)									
Phosphorus (P)		NS			0.68			0.61	
Residue (R)		NS			NS			NS	
P × R		NS			NS			NS	

NR, No residue; RI, residue incorporation; NS, non-significant

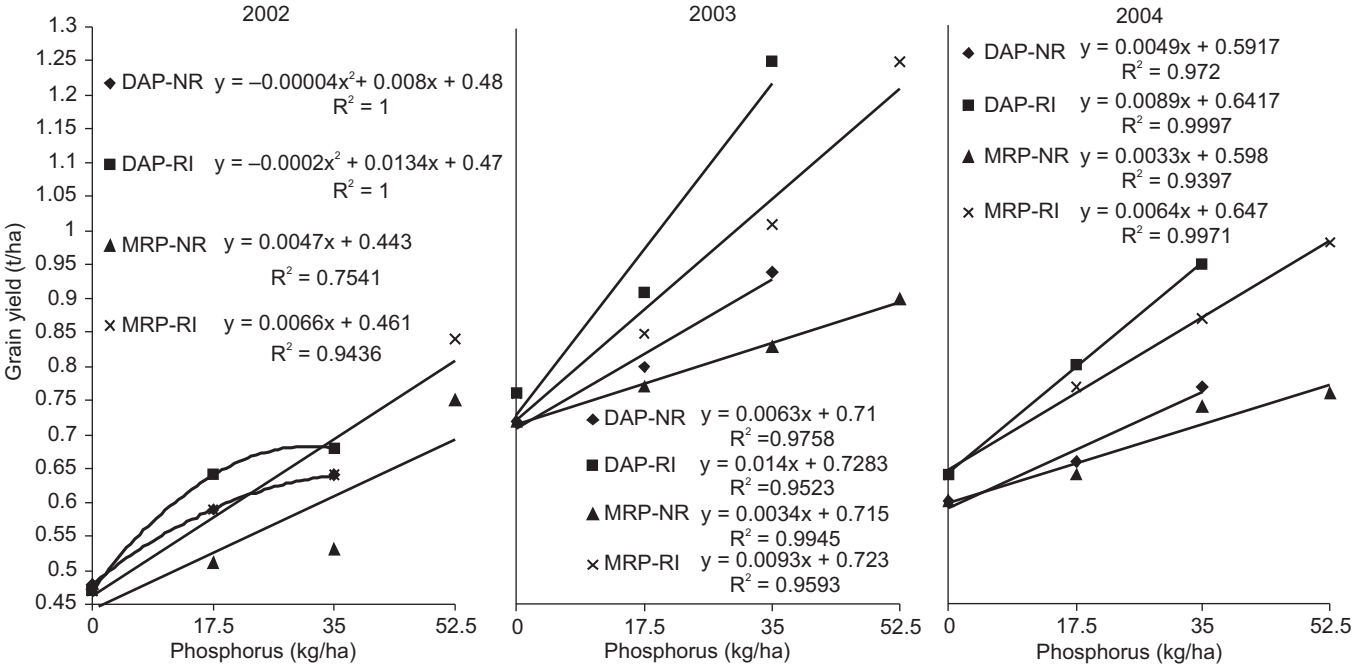


Fig 1 Effects of rates and sources of phosphorus on seed yield (tonnes/ha) of mungbean as influenced by residue incorporation

significant effect on straw yield of mungbean in first year, whereas in second year MRP + PSB at 52.5 kg P/ha significantly increased straw yield of mungbean over control. During third year DAP and MRP + PSB at 35 kg P/ha were at par and significantly increased straw yield of mungbean over control. Lower effects of P application on straw yield as compared to P effects on seed yield were due to the fact that P application generally increases weight of grain/seed and thus results in higher effect on grain/seed yields. Straw yield of mungbean was not significantly affected by residue incorporation. The interaction between residue incorporation and phosphorus application was also not significant.

Phosphorus uptake

Mungbean removed 6.5–9.1 kg P/ha from control plots and 7.1–13.4 kg P/ha from P applied plots (Table 2). The P concentration ranged from 0.316 to 0.378% in seed and 0.083 to 0.160 in straw. Phosphorus application significantly increased P uptake of mungbean in all the 3 years of study. During the first year P uptake of mungbean increased significantly when the rate of P application was increased from 0 to 52.5 kg P/ha as MRP + PSB. During the second year MRP + PSB at 35 kg P/ha was at par with 17.5 kg P/ha as DAP and significantly increased P uptake of mungbean over control. Similarly, MRP + PSB at 52.5 kg P/ha was at par with 35 kg P/ha as DAP and significantly increased P uptake of mungbean over their lower levels. During the third year, application of 17.5 kg P/ha either through DAP or MRP + PSB significantly increased P uptake of mungbean over control. Further, increase in the rate of P application from

Table 2 Effect of rates and sources of phosphorus on P uptake (kg/ha) of mungbean as influenced by residue incorporation

Treatment	2002			2003			2004		
	NR	RI	Mean	NR	RI	Mean	NR	RI	Mean
Control	6.5	7.3	6.9	8.4	9.1	8.7	6.9	7.6	7.2
DAP at 17.5 kg P/ha	8.0	9.4	8.7	10.0	10.6	10.3	8.2	9.5	8.8
MRP + PSB at 17.5 kg P/ha	7.1	8.9	8.0	8.8	9.9	9.3	7.6	9.1	8.3
DAP at 35.0 kg P/ha	8.2	10.5	9.3	10.6	13.1	11.8	9.4	11.5	10.4
MRP + PSB at 35.5 kg P/ha	7.6	10.0	8.8	9.7	11.8	10.7	8.9	10.5	9.7
MRP + PSB at 52.5 kg P/ha	9.2	11.6	10.4	10.6	13.4	12.0	9.7	11.5	10.7
Mean	7.8	9.6		9.7	11.3		8.4	9.9	
CD (*P*=0.05)									
Phosphorus (P)		2.9			0.8			1.0	
Residue (R)		NS			0.9			1.2	
P × R		4.1			1.2			1.4	

NR, No residue; RI, residue incorporation; NS, non-significant

17.5 to 35 kg P/ha either through DAP or MRP + PSB also resulted a significant increase in P uptake of mungbean over 17.5 kg P/ha. An additional increase in the level of MRP + PSB from 35 to 52.5 kg P/ha did not result in a significant increase in P uptake of mungbean. These results show that effects of P application on P uptake were higher than on seed and straw yields because of a positive effect of P application on P concentrations in seed and straw of mungbean.

Phosphorus balance of 3 years

Without P application mungbean resulted in a negative balance of 21 kg P/ha in 3 years (Table 3). Application of 52.5, 105 and 157.5 kg P/ha in 3 years, on the other hand, resulted in a positive balance of 26–28, 75–77 and 126 kg P/ha, respectively in 3 years of study. Application of MRP + PSB had higher positive effect on P balance than DAP due to less removal of P by the crop in MRP + PSB-treated plots. Incorporation of crop residue also resulted in a positive effect on P balance in 3 years of study.

Agronomic efficiency

Agronomic efficiency of DAP was higher (5.3–10.1 kg grain/kg P) than that of MRP + PSB (3.1–6.3 kg grain/kg P), however the difference between 2 sources narrowed down in the third year of the study (Table 4). The agronomic efficiency of both DAP and MRP + PSB decreased with the increase in the rate of P application during the first year, whereas during the second and third years the agronomic efficiency of DAP and MRP + PSB increased with the increase in the rate of P application up to 35 kg P-/ha. Further increase in the rate of MRP + PSB resulted in an increase in agronomic efficiency in the first and second years and a decrease in third year. This is obvious in view of the fact that with continuous application of P during 2 years the response to higher dose of P decreased during the third year of study. Incorporation of crop residue also increased the agronomic efficiency of P, irrespective of source in all the 3 years of study. Singh and Sharma (2000) also reported an increase in agronomic efficiency of nitrogen due to residue incorporation in rice.

Table 3 Balance sheet of P (kg/ha) for 3 years of mungbean cultivation as influenced by rates and sources of phosphorus and residue incorporation

Treatment	P applied (A)			P removed (B)			P balance(A–B)		
	NR	RI	Mean	NR	RI	Mean	NR	RI	Mean
Control	0	3.3	1.6	21.8	24.0	22.8	(–)21.8	(–)20.7	(–)21.2
DAP at 17.5 kg P/ha	52.5	55.8	54.1	26.2	29.5	27.8	26.3	26.3	26.3
MRP + PSB at 17.5 kg P/ha	52.5	55.8	54.1	23.5	27.9	25.6	29.0	27.9	28.4
DAP at 35.0 kg P/ha	105.0	108.3	106.6	28.2	35.1	31.5	76.8	73.2	75.0
MRP + PSB at 35.5 kg P/ha	105.0	108.3	106.6	26.2	32.3	29.2	78.8	76.0	77.4
MRP + PSB at 52.5 kg P/ha	157.5	160.8	159.1	29.5	36.5	33.1	128.0	124.3	126.1
Mean	78.7	82.0		25.9	30.8		52.8	51.2	

NR, No residue; RI, residue incorporation

Table 4 Agronomic efficiency and apparent recovery of phosphorus in mungbean as influenced by residue incorporation

Treatment	2002			2003			2004		
	NR	RI	Mean	NR	RI	Mean	NR	RI	Mean
Agronomic efficiency (*kg seed/kg applied P*)									
DAP at 17.5 kg P/ha	6.3	9.7	8.0	4.6	8.6	6.6	3.4	9.1	6.3
MRP + PSB at 17.5 kg P/ha	1.7	6.9	4.3	2.8	5.1	3.9	2.3	7.4	4.9
DAP at 35.0 kg P/ha	4.6	6.0	5.3	6.3	14.0	10.1	4.8	8.8	6.8
MRP + PSB at 35.5 kg P/ha	1.4	4.8	3.1	3.1	7.1	5.1	4.0	6.6	5.3
MRP + PSB at 52.5 kg P/ha	5.1	7.0	6.1	3.4	9.3	6.3	3.0	6.5	4.7
Mean	3.8	6.9		4.0	8.8		3.5	7.7	
Apparent recovery (%)									
DAP at 17.5 kg P/ha	8.5	12.0	10.2	9.1	8.6	8.8	7.4	10.8	9.1
MRP + PSB at 17.5 kg P/ha	3.4	9.1	6.3	2.3	4.6	3.4	4.0	8.6	6.3
DAP at 35.0 kg P/ha	4.8	9.1	7.0	6.3	11.4	8.8	7.1	11.1	9.1
MRP + PSB at 35.5 kg P/ha	3.1	7.7	5.4	3.7	7.7	5.7	5.7	8.3	7.0
MRP + PSB at 52.5 kg P/ha	5.1	8.2	6.6	4.2	8.2	6.2	5.3	7.4	6.4
Mean	5.0	9.2		5.1	8.1		5.7	9.2	

NR, No residue; RI, residue incorporation

Table 5 Effect of rates and sources of phosphorus on available P content and net change in available P content over initial value (15 kg/ha) in soil after 3 years of study

Phosphorus	Available P (kg/ha)			Net change(kg/ha)		
	NR	RI	Mean	NR	RI	Mean
Control	14.2	15.0	14.6	(–) 0.8	0	(–) 0.4
DAP at 17.5 kg P/ha	18.7	19.0	18.9	3.7	4.0	3.9
MRP + PSB at 17.5 kg P/ha	17.7	18.7	18.2	2.7	3.7	3.2
DAP at 35.0 kg P/ha	18.5	21.9	20.2	3.5	6.9	5.2
MRP + PSB at 35.5 kg P/ha	18.2	21.6	19.9	3.2	6.6	4.9
MRP + PSB at 52.5 kg P/ha	18.3	21.8	20.0	3.3	6.8	5.0
Mean	17.6	19.7		2.6	4.7	
CD (*P*=0.05)						
Phosphorus (P)		1.3				
Residue (R)		1.0				
P × R		1.8				

NR, No residue; RI, residue incorporation

Table 6 Effect of rates and sources of phosphorus on gross and net returns (Rs/ha) of mungbean as influenced by residue incorporation

Treatment	2002			2003			2004		
	NR	RI	Mean	NR	RI	Mean	NR	RI	Mean
Gross returns									
Control	9 350	9 300	9 325	13 270	13 875	13 572	10 925	11 645	11 285
DAP at 17.5 kg P/ha	11 160	12 190	11 675	14 480	16 250	15 365	12 085	14 320	13 202
MRP + PSB at 17.5 kg P/ha	9 625	11 515	10 570	14 050	15 355	14 702	11 680	13 815	12 747
DAP at 35.0 kg P/ha	11 815	12 785	12 300	16 690	21 613	1 9 152	13 935	16 725	15 330
MRP + PSB at 35.5 kg P/ha	10 000	12 065	11 032	15 175	17 820	16 497	13 405	15 375	14 390
MRP + PSB at 52.5 kg P/ha	13 675	15 415	14 545	16 260	21 705	18 982	13 710	17 125	15 417
Mean	10 937	12 211	14 987	17 770	12 623	14 834			
CD (*P* = 0.05)									
Phosphorus (P)		3 725			1 360			1 590	
Residue (R)		NS			1 065			1 200	
P × R		4 650			1 440			1 815	
Net returns									
Control	1 060	101	580	4 980	4 676	4 828	2 635	2 446	2 540
DAP at 17.5 kg P/ha	2 190	2 311	2 250	5 510	6 371	5 940	3 115	4 441	3 778
MRP + PSB at 17.5 kg P/ha	890	1 871	1 380	5 315	5 711	5 513	2 945	4 171	3 558
DAP at 35.0 kg P/ha	2 165	2 226	2 195	7 040	11 054	9 047	4 285	6 166	5 225
MRP + PSB at 35.5 kg P/ha	845	2 014	1 429	6 020	7 769	6 894	4 250	5 324	4 787
MRP + PSB at 52.5 kg P/ha	4 100	4 931	4 515	6 685	11 221	8 953	4 185	6 641	5 413
Mean	1 875	2 242		5 925	6 800		3 569	4 865	
CD (*P* = 0.05)									
Phosphorus (P)		662			528			488	
Residue (R)		NS			414			369	
P × R		826			559			557	

NR, No residue; RI, residue incorporation; NS, non-significant

Apparent recovery of phosphorus

Apparent recovery of phosphorus was higher in case of DAP (7.0–10.2%) than MRP (3.4–7.0%) at 17.5 as well as at 35 kg P/ha in all the 3 years of study (Table 4). The apparent recovery of P from DAP either decreased or remained same when the rate of DAP was increased from 17.5 to 35 kg P/ha, whereas the apparent recovery of P from MRP + PSB increased with increasing rate of P application up to 52.5 kg P/ha except in the third year when an increase in the rate of P application from 35 to 52.5 kg P/ha resulted in a minor reduction in apparent recovery of P from MRP + PSB. Incorporation of crop residue resulted in an increase in apparent recovery of P in case of both DAP and MRP + PSB. The positive effects of residue incorporation on apparent

recovery of N in rice were reported by Singh and Sharma (2000).

Available P content in soil

Application of no P to mungbean during 3 years resulted in a depletion of 20.7–21.8 kg P/ha from the soil during 3 years of study (Table 3) and made a negative change in available P content in soil over initial level, whereas application of 17.5, 35 and 52.5 kg P/ha/year resulted in a positive balance of 26.3–28.4, 75.0–77.4 and 126.0 kg P/ha, respectively during 3 years of study and this resulted in a positive change of 3.2–3.9, 4.9–5.2 and 5.0 kg P/ha, respectively in available P content in soil after 3 years of study. The available P content of soil increased significantly with increasing rate of both DAP and MRP (Table 5). Residue incorporation also increased available P content in soil in all the 3 years of study. Residue incorporation, however had an adverse effect on the efficiency of DAP and MRP for increasing available P content in soil in the first year, whereas in second and third years it increased the efficiency of both DAP and MRP. This is obvious in view of the fact that residue might have resulted in immobilization of a part of applied P and decreased the efficiency of both the sources of P. During second year mineralization of residue P and solubilization effect of residue on applied and native P might have led to positive effect of crop residue on the efficiency of both DAP and MRP. The solubilizing effect of crop residue was due to higher carbonic acid concentration in residue incorporated plots as reported by Sharma and Aggarwal (2006).

Economics

The gross returns of mungbean ranged from Rs 9 325 to 13 875 in control plots and Rs 10 570 to 19 152 in P applied plots (Table 6). During the first year the gross returns of mungbean increased significantly when the rate of P application was increased from 0 to 52.5 kg P/ha as MRP + PSB, whereas in the second and third years 35 kg P/ha as MRP + PSB was at par with 17.5 kg P/ha as DAP and significantly increased gross returns of mungbean over control. Similarly, 52.5 kg P-/ha as MRP + PSB was at par with 35 kg P-/ha as DAP and significantly increased gross returns over their lower levels.

Residue incorporation did not affect the gross returns of mungbean in the first year, whereas in the second and third years residue incorporation significantly increased gross returns of mungbean over no residue incorporation. Interaction effect between phosphorus and crop residue was significant in all the 3 years of study. In 2002, P application had no significant effect on gross income of mungbean without residue incorporation, whereas with residue incorporation MRP + PSB at 52.5 kg P/ha significantly increased the gross income of mungbean over control. During 2003–04, without residue incorporation DAP at 17.5 kg P/ha failed to show its significant effect on gross income of mungbean, whereas with residue incorporation 17.5 kg P/ha as DAP significantly increased the gross income of mungbean. Further, 52.5 kg P/ha as MRP + PSB showed its superiority over 35 kg P/ha of same source only when residue was incorporated.

Cost of cultivation of mungbean ranged from Rs 8 290 to Rs 10 480. Application of DAP at 17.5 and 35 kg P-/ha increased cost of mungbean cultivation by 7.8 and 15.5%, respectively, whereas MRP + PSB at 17.5, 35 and 52.5 kg P/ha increased cost of cultivation by 5.1, 9.8 and 14.7%, respectively. Incorporation of crop residue increased cost of rice cultivation by 10%. Application of P either as DAP or MRP + PSB resulted in higher increase in the cost of cultivation when residue was not incorporated.

The net returns of mungbean ranged from Rs 580 to 4 828 in control plots and Rs 1 380 to 9 047 in P-applied plots (Table 6). Application of P increased net returns of mungbean in all the 3 years of study. In 2002, 17.5 and 35 kg P/ha of MRP + PSB were at par and significantly increased net income of mungbean over control. Similarly, both the levels of DAP were at par and significantly increased net returns of mungbean over same levels of MRP + PSB. However MRP + PSB at 52.5 kg P/ha was significantly superior to DAP at 35 kg P/ha. During 2003–04 both the sources of P at 17.5 kg P/ha were at par and significantly increased net income of mungbean over control. At 35 kg P/ha DAP was significantly superior to MRP + PSB in 2003 but similar in 2004. These results indicate that the effect of MRP + PSB increased with time and became as effective as DAP in third year of study.

Residue incorporation resulted in a significant increase in net returns of mungbean only in the second and third years of study. Residue incorporation also had a favourable effect on response of mungbean to P in all the 3 years of study. In 2002 MRP + PSB at 17.5 and 35 kg P/ha increased the net income of mungbean over control only when residue was incorporated. Similarly, during 2003–04 both DAP and MRP + PSB at 17.5 kg P/ha increased the net income of mungbean over control only when residue was incorporated. Also application of 52.5 kg P/ha as MRP + PSB increased net returns of mungbean over 35 kg P/ha of same source with residue incorporation.

The present study shows that MRP + PSB at higher rate (35–52.5 kg P/ha) can be used for P fertilization in mungbean crop for increased productivity and higher net returns.

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