Indian Journal of Agronomy **54**(1): 42–46 (March 2009)

Effect of rates and sources of phosphorus on productivity and economics of rice (*Oryza sativa*) as influenced by crop-residue incorporation

S. N. SHARMA*, R. PRASAD, Y.S. SHIVAY, M.K. DWIVEDI, SANDEEP KUMAR AND D. KUMAR

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

Received: April 2008

ABSTRACT

A field experiment was conducted at New Delhi for 3 years during rainy season (*kharif*) of 2001 to 2003 to study the effect of crop-residue incorporation on the relative efficiency of di-ammonium phosphate (DAP) and Mussoorie rock phosphate (MRP) in rice (*Oryza sativa* L.). Phosphorus application generally increased the growth and yield parameters, yields as well as gross and net returns of rice. The increase of these parameters was however significant when the rate of P application was increased from 0 to 35 kg P/ha. At 35 kg P/ha MRP in conjunction with phosphate solubilizing bacteria (PSB) was statistically on a par with DAP, increasing the grain yield by 10-17%, P uptake by 26-54%, available P content in soil by 12-99% and net profit by 15-37% over the control. Agronomic efficiency and apparent recovery of DAP were higher than those of MRP at 17.5 kg P/ha, but on a par with those at 35 kg P/ha. Crop-residue incorporation had no significant effect on grain yield but it significantly increased the apparent recovery of applied P and available P content of soil. Thus, the combined application of MRP, PSB and crop residue proved a good practice that can be used as P fertilizer for rice.

Key words: Agronomic efficiency, Diammonium phosphate, Gross and net returns, Mussoorie rock phosphate, Phosphorus-solubilizing bacteria, Yield

One reason of lower yield of rice (*Oryza sativa* L.) is lower P content in the Indian soil. Motsara (2002) reported that 60% soils are low to medium in available P. Added inorganic P as water soluble phosphate fertilizer undergoes complex exchanges between various soil-P 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 Indian context the price of fertilizer-P is the highest amongst the major nutrients. The current cost of 1 kg P varies from Rs 34.4 through diammonium phosphate (DAP) to Rs 38.9–59.5 through single superphosphate compared with Rs 10.5 for 1 kg N through urea and Rs 8.4 for 1 kg K through muriate of potash. These prices are excluding the Government-subsidy component. Owing to the high cost of fertilizer P, the small and marginal farmers in India generally skip P application. The N: P consumption ratio in India is 2.6:1 (FAI. New Delhi, 2006) compared with the desirable ratio of 2:1 for sustainable crop production (Tiwari, 2002). Further, the reason for high cost of phosphorus in India is mainly that the 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 of phosphorus. One such deposit is Mussoorie rock phosphate (MRP). Attempts have been made in the past to use finely ground MRP directly into the soil of pH 7.0 and above with the help of phosphate-solubilizing micro-organisms (Bojinova *et al.*, 1997; He *et al.*, 2002) and pyrites (Sharma and Prasad, 1996). Singh *et al.* (1988) reported that under waterlogged condition the crop residues increase the availability of P through the mechanism of chelating and favourable changes in soil pH. The present investigation was therefore undertaken to study the effect of crop residue on the efficiency of DAP and MRP at varying rates of application on the growth, yield and economics of rice and available P content of soil.

***Corresponding author** (Email: snsharma_agro@yahoo.com)

MATERIALS AND METHODS

A field experiment was conducted during rainy season (*kharif*) of 2001 to 2003 at the Research Farm of Indian Agricultural Research Institute, New Delhi (280 38' N latitude, 770 11' E longitude and 228.6 m above mean sea-level). The soil was sandy clay-loam, having 52.5% sand, 21.0% silt and 26.5% clay. It contained 12.0 t/ha organic C, 1.3 t/ha Kjeldahl N, 16.0 kg/ha 0.5 M NaHCO3-extractable P and 500 kg/ha 1 N NH4OAc-extractable K, and had pH 8.3 at the beginning of the experiment.

The experiment was laid out in split-plot design with six replications. The treatments consisted of two practices of crop-residue management (residue removed and residue incorporation) in main plots and six phosphorus treatments [The 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 subplots. The residue of preceding wheat was added @ 6 t/ha a weak before rice transplanting. It contained 0.50-0.53% N, 0.05-0.06% P and 1.6-1.7% K, and thus the incorporation of residue resulted in addition of 30–32 kg N, 3.0–3.6 kg P and 96–102 kg K/ha/yr. The treatments were continued throughout the study (3 years) in the same plots. The main plot size was 25 m x 23 m and subplot size was 7.5 m x 7.0 m.

The MRP plots were inoculated with phosphates-solubilizing bacterium (PSB), *Pseudomonas striata*. For inoculation with PSB, the slurry was prepared by dissolving 200 g brown sugar in 250 ml water and then warmed for 15 min. at 40^0C. This slurry 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 the diluted slurry. Inoculation was done by dipping the roots of the rice seedlings in PSB culture slurry before transplanting.

The field was flooded with water and puddled with a tractor-drawn offset disc harrow. A basal dose of 30 kg K/ha as muriate of potash, 20 kg/ha zinc sulphate heptahydrate and P as per treatments was applied at final puddling. Nitrogen @ 120 kg N/ha as urea was applied in two splits, half at 10 days after transplanting (DAT) and the rest at 30 DAT. The amount of N applied as DAP was taken into consideration while calculated the amount of urea applied at 60 kg N/ha at 10 DAT. Rice (‘Pusa Basmati 1’) was transplanted in mid-July with 21-25 days old seedlings @ 2–3/hill, at a spacing of 20 cm x 10 cm. Rice was harvested in the first week of November. At maturity 10 hills were randomly selected in each plot. The height of longest tiller of the hill was measured and the total tillers of selected 10 hills were counted. Similarly, 10 panicles from each plot were selected randomly and their length was measured and the number of grains was counted. The average values of these characters are presented in Table 1. The rice-grain yield was recorded at 14% moisture and straw yield at oven-dry basis. Gross income of different treatment was calculated using the following expression: GI = Yi x PC, where GI is the gross income in rupees per ha; Yi is the grain yield of the treatment I; and PC is the procurement price of rice grain. The cost of cultivation of rice was calculated on the basis of prevailing rates of inputs in the market during the experimentation period and then the cost of cultivation was averaged over 3 years.

RESULTS AND DISCUSSION

Growth and yield

Phosphorus application significantly increased the plant height, number of grains/panicle number of tillers/hill and panicle length (Table 1). The plant height increase significantly when the rate of P application was increased from 0 to 35 kg P/ha either as DAP or MRP. The number of tillers/hill increased significantly with the application of DAP @ 35 kg P/ha and MRP @ 52.5 kg p/ha length increased significantly when the rate of P application was

Table 1. Effect of rates and sources of phosphorus on growth, yield attributes (mean), yield and economics (mean) of rice

Treatments	Plant height (cm)	Tillers/ m^2	Panicle length (cm)	Grains/ panicle	Grain yield (t/ha)			Straw yield (t/ha)			Mean economics ($x\ 10^3$ Rs/ha)	
					2001	2002	2003	2001	2002	2003	Cost of cultivation	Net returns
Phosphorus (kg/ha)												
Control	98.9	547.0	25.5	86.4	5.76	4.73	4.92	7.03	6.82	7.70	25.7	17.1
17.5 as DAP	100.4	600.0	26.0	92.6	6.14	5.07	5.57	7.92	7.27	8.44	26.5	20.2
17.5 as MRP	100.1	575.0	25.9	90.3	6.02	4.84	5.36	7.23	7.02	8.10	26.2	18.8
35.0 as DAP	101.6	632.0	27.0	99.4	6.33	5.37	5.69	7.67	7.57	8.55	27.2	21.1
17.5 as MRP	101.2	598.0	26.6	94.7	6.34	5.23	5.73	7.50	7.41	8.38	26.7	21.5
52.5 as MRP	101.0	648.0	27.3	98.3	6.64	5.34	5.92	8.28	7.50	8.61	27.4	21.8
SEm$\pm$	0.83	22.0	0.23	2.4	0.17	0.14	0.21	0.22	0.23	0.29	1.28	1.79
CD (P=0.05)	2.03	61.0	0.66	5.3	0.48	0.38	0.61	0.63	0.64	0.83	3.62	5.06
Residue												
N residue (NR)	100.9	581.7	26.2	92.8	6.12	5.00	5.46	7.55	7.12	8.11	25.2	20.9
Residue incorporation	101.3	618.3	26.5	95.5	6.29	5.20	5.61	7.66	7.14	8.48	28.1	19.3
SEm$\pm$	0.60	15.8	0.2	1.8	0.16	0.06	0.12	0.16	0.17	0.12	0.6	1.0
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	2.0	NS

increased from 0 to 35 kg P/ha as DAP. MRP was effective @ 35 and 52.5 kg/ha. The number of grains/panicle increased significantly with the application of 17.5 kg P/ha as DAP or 35.0 kg P/ha as MRP. Further increase in rate of P application to 35 kg P/ha as DAP also significantly increased the number of grains/panicle. Incorporation of residue had no significant effect on growth and yield-at-tributing characters of rice.

The grain yield of rice increased significantly when the rate of P application was increased from 0 to 35 kg P/ha either as DAP or MRP during 2001 and 2002, whereas during 2003 DAP at 17.5 kg P/ha also significantly increased it over the control (Table 1). Further increase in the rate of DAP from 17.5 to 35 kg P/ha in 2003 and of MRP from 35 to 52.5 kg P/ha during all the 3 years did not result in additional increase in grain yield of rice. Taking cognizance of the fact that PSB can make native and less-soluble P as in MRP more readily available to the crops (Bojinova *et al.*, 1997; He *et al.*, 2002), the present study was made with the combined application of PSB and MRP and the results show that MRP and DAP were on a par at 35 kg P/ha but not at 17.5 kg P/ha. Its reason is that MRP at lower rate might have not released sufficient quantity of available P to meet the P requirement of crop. The increase in yield attributes due to MRP application was also significant only at higher rate of P application.

Application of 17.5 and 35 kg P/ha as DAP significantly increased the straw yield of rice in the first and last 2 years respectively whereas MRP significantly increased it over the control only at 52.5 kg P/ha, which was similar to that obtained with DAP at 35 kg P/ha (Table 1). Similar trend was observed in plant height and number of tillers/m^2 (Table 1). Thus an increase in plant height and number of tillers/m^2 led to a significant increase in straw yield of rice with 35 kg P/ha as DAP or 52.5 kg P/ha as MRP.

Incorporation of crop residue had no significant effect on the grain yield of rice, but increased the efficiency of MRP. At 17.5, 35 and 52.5 kg P/ha without residue incorporation, MRP increased the grain yield of rice over the control by 8.7, 16.8 and 18.2% respectively, whereas with residue incorporation, MRP at 17.5, 35 and 52.5 kg P/ha increased it by 9.4, 16.8 and 22%, respectively. The response equations worked out separately for DAP and MRP with and without residue incorporation revealed that the response of rice to DAP was quadratic without residue incorporation and linear with residue incorporation during the first 2 years and vice-versa in the third year. The response of rice to MRP was linear irrespective of residue-management practices in all the 3 years of study.

Incorporation of crop residue had no significant effect on straw yield of rice; however, residue incorporation significantly increased the efficiency of MRP. For example in 2001 MRP @ 35 and 52.5 kg P/ha increased the straw yield over the control by 4 and 15%, respectively without residue incorporation compared with 10 and 21%, respectively with residue incorporation. Similar trends were obtained during 2002 (Table 2). However, in 2003 the interaction between phosphorus and residue was not significant.

P uptake

Phosphorus application significantly increased the P uptake by rice in all the 3 years of study (Table 3). During the first year 35 kg P/ha as MRP was on a par with 17.5 kg P/ha as DAP, which significantly increased P uptake by rice over the control. P @ 52.5 kg/ha as MRP was significantly superior to that @ 17.5 kg/ha. During the second year P uptake of rice increased significantly when the rate of P application was increased from 0 to 35 kg P/ha either as DAP or MRP. Further increase in its rate from 35 to 52.5 kg P/ha as MRP did not result in an additional increase in the amount of P uptake by rice. During the third year application of 17.5 kg P/ha either through DAP or MRP significantly increased the P uptake by rice over the control. Further increases in the rate of DAP from 17.5 to 35 kg P/ha did not increase the P uptake over 17.5 kg P/ha, but MRP @ 52.5 kg P/ha proved significantly superior

Table 2. Interaction effect of phosphorus (rates and sources) and residue management practices on grain and straw yield of rice.

Treatments	Grain yield (t/ha)		Straw yield (t/ha)			
	2003		2001		2002	
	NR	R1	NR	RI	NR	RI
Phosphorus						
Control	4.83	5.01	7.01	7.04	9.75	6.89
17.5 as DAP	5.60	5.55	7.64	8.20	7.20	7.34
17.5 as MRP	5.25	5.48	7.18	7.27	6.90	7.15
35.0 as DAP	5.71	5.67	7.67	7.67	7.46	7.67
35.0 as MRP	5.64	5.82	7.28	7.71	7.24	7.57
52.5 as MRP	5.71	6.12	8.05	8.50	7.17	7.82
SEm±	0.29		0.31		0.32	
CD (P=0.05)	0.86		0.89		0.91	

to 17.5 kg P/ha in P uptake by rice. The effect of P application was higher on P uptake of rice than those on grain and straw yields owing to the positive effect of P application on P concentrations in grain and straw of rice.

Agronomic efficiency and apparent recovery of P

Agronomic efficiency of DAP was higher than that of MRP; however, the difference between these two sources narrowed down during the third year (2003) of the study (Table 4). An increase in the rate of P application decreased the agronomic efficiency of DAP, but increased that of rock phosphate up to 35 kg P/ha. Incorporation of crop residue also increased the agronomic efficiency of MRP except at 35 kg P/ha in 2001. Singh and Sharma (2000) also reported an increase in agronomic efficiency of nitrogen due to incorporation of residue in rice crop.

Apparent recovery of phosphorus was higher in DAP than in MRP at 17.5 kg P/ha, but the reverse position was observed at 35 kg P/ha (Table 5). This happened because the apparent recovery of DAP decreased with increase in the rate of P application, but that of MRP increased when the rate of P application increased from 17.5 to 35 kg P/ha. Further increase in the rate of P application from 35 to 52.5 kg/ha as MRP decreased the apparent recovery of P. Incorporation of crop residue increased it in both DAP as well as MRP except, DAP at 17.5 kg P/ha in 2001. Singh and Sharma (2000) also reported positive effects of residue incorporation on apparent recovery of N in rice.

Available P content in soil

Available P content in soil increased significantly with increase in the rate of both DAP and MRP (Table 5). Residue incorporation also increased the available P content in the soil in all the 3 years of study. It had adverse effect on

Table 3. Effect of rates and sources of phosphorus on P uptake (kg/ha) of rice as influenced by residue incorporation

Phosphorus	2001			2002			2003		
	NR	RI	Mean	NR	RI	Mean	NR	RI	Mean
Control	10.3	11.2	10.8	8.2	9.4	8.1	9.0	9.3	9.1
17.5 kg P/ha as DAP	13.1	13.9	13.5	10.9	12.2	11.6	11.4	12.1	11.7
17.5 kg P/ha as MRP	11.1	13.0	12.0	8.4	10.8	9.6	10.6	12.0	11.3
35 kg P/ha as DAP	12.2	15.0	13.6	10.4	12.5	11.4	11.6	13.1	12.3
35 kg P/ha as MRP	13.5	15.3	14.4	11.0	14.0	12.5	11.6	13.2	12.4
52.5 kg P/ha as MRP	13.4	16.7	15.1	10.8	14.3	12.6	12.0	13.9	12.9
Mean	12.3	14.2		10.0	11.9		11.0	12.3	
	SEm±	CD (P=0.05)		SEm±	CD (P=0.05)		SEm±	CD(P=0.05)	
Phosphorus (P)	0.86	2.43		0.84	2.37		0.90	2.54	
Residue (R)	0.53	1.85		0.28	0.98		0.30	1.05	
P x R	1.22	3.44		1.19	3.36		1.27	3.58	

NR = No residue; RI = Residue incorporation

Table 4. Effect of rates and sources of phosphorus on agronomic efficiency and apparent recovery of phosphorus in rice as influenced by residue incorporation

Phosphorus	2001			2002			2003		
	NR	RI	Mean	NR	RI	Mean	NR	RI	Mean
Agronomic efficiency (kg grain/kg P)									
17.5 kg P/ha as DAP	30.3	13.1	21.7	21.7	18.3	20.0	44.0	30.8	22.0
17.5 kg P/ha as MRP	10.8	19.4	15.1	2.9	9.7	6.3	24.0	26.8	25.4
35 kg P/ha as DAP	12.8	19.7	16.2	18.3	18.3	18.3	25.1	18.9	22.0
35 kg P/ha as MRP	19.4	14.0	16.7	12.0	16.8	14.4	23.1	23.1	23.1
52.5 kg P/ha as MRP	14.3	19.2	16.8	11.8	11.2	11.5	16.8	21.1	19.0
Mean	17.5	17.1		13.3	14.9		26.6	24.1	
Apparent recovery (%)									
17.5 kg P/ha as DAP	16.0	15.4	15.7	15.4	16.0	15.7	13.7	16.0	14.8
17.5 kg P/ha as MRP	4.6	10.3	7.4	2.7	8.0	5.3	9.1	15.4	12.3
35 kg P/ha as DAP	5.4	10.8	8.1	6.3	8.9	7.6	7.4	10.8	9.1
35 kg P/ha as MRP	9.1	11.7	10.4	8.0	13.1	10.5	7.4	11.1	9.3
52.5 kg P/ha as MRP	5.9	10.5	8.2	4.9	9.3	7.1	5.7	8.8	7.2
Mean	8.2	11.7		7.5	11.1		8.7	12.4	

NR = No residue; RI = Residue incorporation

Table 5. Effect of rates and sources of phosphorus on available P content (kg/ha) in soil after rice harvest

Phosphorus	2001			2002			2003		
	NR	RI	Mean	NR	RI	Mean	NR	RI	Mean
Control	14.8	16.7	15.7	14.4	15.0	14.7	11.9	12.6	12.2
17.5 kg P/ha as DAP	16.8	17.1	16.9	17.4	19.8	18.6	21.7	24.4	23.0
17.5 kg P/ha as MRP	16.6	16.9	16.8	17.0	18.1	17.5	21.2	23.9	22.0
35 kg P/ha as DAP	16.8	18.4	17.6	19.2	21.5	20.3	22.7	24.6	23.0
35 kg P/ha as MRP	17.0	18.2	17.6	19.3	20.7	19.9	22.9	25.7	24.0
52.5 kg P/ha as MRP	18.7	21.8	20.2	19.3	20.9	20.1	23.5	27.8	25.6
Mean	16.8	18.2		17.8	19.2		20.6	23.0	
	SEm±	CD (P=0.05)		SEm±	CD (P=0.05)		SEm±	CD (P=0.05)	
Phosphorus (P)	0.74	2.08		0.46	1.29		0.31	0.88	
Residue (R)	0.29	1.00		0.24	0.82		0.16	0.58	
P x R	1.04	2.94		0.65	1.83		0.44	1.24	

NR = No residue; RI = Residue incorporation

the efficiency of DAP and MRP for increasing the available P content in soil in 2001, but increased the efficiency of both in the second and third years. The reason may be that residue might have resulted in immobilization of a part of applied P and decreased the efficiency of both the sources of P. In 2002 mineralization of residue P and solubilization effect of residue on applied P might have led to positive effect of crop residue on the efficiency of both DAP and MRP. Sharma and Aggarwal (2006) reported that the solubilizing effect of crop residue was due to higher carbonic acid concentration in the residue-incorporated plots.

Economics

Cost of rice cultivation ranged from Rs 24,425 to Rs 29,240. Application of DAP at 17.5 and 35 kg P/ha increased the cost of rice by 2.8 and 5.4% respectively, whereas MRP at 17.5, 35 and 52.5 kg P/ha increased it by 2.8, 3.5 and 5.1% respectively (Table 1). Incorporation of crop residue increased the cost of rice cultivation by 11%. Application of DAP at 17.5 and 35 kg P/ha significantly increased the net returns of rice over the control, whereas MRP at 17.5 kg P/ha had no significant effect on it. At 35 kg P/ha DAP and MRP were on a par and significantly increased the net returns of rice over the control by 23 and 26% respectively. Further increase in the rate of MRP from 35 to 52.5 kg P/ha did not give additional increase in the net returns of rice. Residue incorporation reduced the net returns of rice by 8.3%.

It was concluded that MRP with PSB and crop residue can be used as P fertilizer to increase the productivity of rice and improve the P status of soil.

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