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ORIGINAL ARTICLE

Relative efficiency of diammonium phosphate and mussoorie rock phosphate on productivity and phosphorus balance in a rice–rapeseed–mungbean cropping system

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Abstract The field experiments were conducted at the Indian Agricultural Research Institute, New Delhi, India for 3 years from 2001–2002 to 2003–2004 to study the relative efficiency of diammonium phosphate (DAP) and Mussoorie rock phosphate along with phosphorus solubilizing bacteria inoculation (MRP + PSB) at different rates of application on productivity and phosphorus balance in a rice-rapeseed-mungbean cropping system. Phosphorus application significantly increased the productivity of rice-rapeseed-mungbean cropping system and resulted in an increase in 0.5 M $NaHCO_3$ extractable P content in soil. The relative agronomic effectiveness (RAE) of MRP + PSB in relation to DAP as judged by the total productivity was 53–65% in the first cycle but reached 69–106% in the third cycle of the cropping system. The P balance (application—crop removal) was generally more positive for MRP + PSB than DAP and the highest P balance was recorded with an application of 52.5 kg P ha^{-1} as MRP + PSB, resulted in highest 0.5 M $NaHCO_3$ extractable P content in soil. The present study, thus, shows that MRP + PSB could be usefully employed as an alternative to DAP in long term in the rice–rapeseed–mungbean cropping system.

Keywords Available P · CO_2 evolution · Diammonium phosphate · Mussoorie rock phosphate · Phosphorus balance · Phosphorus solubilizing bacteria · Productivity · Relative agronomic effectiveness

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Introduction

The rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping systems (RWCS) occupy about 28.8 million hectares (m ha) in Asia's five countries, namely, India, Pakistan, Nepal, Bangladesh and China (Prasad 2005). These countries are not just any five of the more than 200 countries of the world; they represent 43% of the world population on 20% of the world's arable land (Singh and Paroda 1994). Taking these five countries together RWCS cover 28% of the total rice area and 35% of the total wheat area in the world. In India RWCS occupy 12 m ha and contributes about 31% of the total food grain production (Kumar et al. 1998). Similarly in China RWCS occupy about 13 m ha (Jiaguo 2000) and contribute about 25% of the total cereal production in the country (Lianzheng and Yixian 1994). Thus, RWCS are of considerable significance in meeting Asia's food requirements.

However, practice of following a cereal–cereal cropping system on the same piece of land over years has led to soil fertility deterioration and questions are being raised on its sustainability (Duxbury et al. 2000; Ladha et al. 2000; Prasad 2005). Efforts were therefore made to find out alternate cropping systems. Rice–rapeseed (*Brassica compestris*)–mungbean (*Vigna radiata*) cropping system was found to be more remunerative and soil recuperative cropping system for north western India (Sharma and Sharma 2004). However, the inputs for this newly evolved cropping system are to be standardized for its long-term sustainability. Phosphorus (P) is a limiting plant nutrient in Indian agriculture and 60% soils are low to medium in available P (Motsara 2002). Added inorganic P as water-soluble phosphate fertilizers undergoes complex exchanges between various soil P pools (Stevenson 1986). This is, especially true in the tropics where many soils have extremely high P fixation capacity (Sanchez and Uehara 1980). 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_2O_5 varies from US $ 0.34 through DAP to US $ 0.38–0.57 through single super phosphate as against US $ 0.22 for 1 kg N through urea and US $ 0.16 for 1 kg K_2O through muriate of potash (FAI 2006). Because of high cost, small and marginal farmers in India generally skip P fertilization. The high cost of P 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 P. One such deposit is Mussoorie rock phosphate (MRP). Attempts have been made in the past to use finely ground MRP directly in soil of pH 7 and above with the help of phosphate solubilizing micro-organisms (PSB/PSM) which have the capability to convert plant unavailable P appetites to plant available phosphate forms (Cosgrove 1977; Illmer and Schinner 1992; Sharma et al. 1983; Sharma and Prasad 1996; Sharma and Prasad 2003).

Thus the present investigation was undertaken to study the relative efficiency of DAP and MRP (with PSB) at varying rate of application on productivity and P balance in a rice–rapeseed–mungbean cropping system. This information is currently not available on this pertinent aspect.

Materials and methods

Site and Soil

The field experiments were conducted during three Indian crop years (July–June) from 2001–2002 to 2003–2004 at the Indian Agricultural Research Institute, New Delhi, India (28° 38′ N latitude, 77° 11′ E longitude and 228.6 m above mean sea level). The soil of the experimental field was a sandy clay loam, having 52.5% sand, 21.0% silt and 26.5% clay. It contained 12 Mg ha^{-1} organic C, 1.3 Mg ha^{-1} Kjeldahl N, 14 kg ha^{-1} 0.5 M $NaHCO_3$ extractable P and 500 kg ha^{-1} 1 N NH_4OAC extractable K and had a pH of 8.3 at the start of experiment.

Rice–rapeseed–mungbean cropping system

This is a three crops a year intensive cropping system. Rice was grown from mid July to first week of November, rapeseed from the second week of November to the second week of March and mungbean from the third week of March to the last week of June each year.

Experimental design and treatments

The experiments were laid out with six treatments in a randomized block design with six replications. The treatments consisted of control, 17.5 kg P ha^{-1} as DAP or MRP + PSB, 35 kg P ha^{-1} as DAP or MRP + PSB and 52.5 kg P ha^{-1} as MRP + PSB. These treatments were applied to each crop of the rice-rapeseed–mungbean cropping system each year. The study was continued for 3 years. The plot size was 7.5 m × 7.0 m.

Phosphorus fertilizers

Commercial grade granulated DAP containing 18% N and 20% P and MRP containing 8.3% P were used. Of the total P in MRP 12% was soluble in neutral ammonium citrate. MRP plots were inoculated with phosphates solubilizing bacteria (PSB) *Pseudomonas striata*. For inoculation with PSB, a 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 ten 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 in rice crop was done by dipping the roots of the seedlings in PSB culture slurry, while inoculation in rapeseed and mungbean was done by dipping the seeds in culture slurry. The seeds were then dried in shade for 24 h before sowing.

Field techniques

The cropping system was started in July each year. The experimental field was flooded with water and puddled with a tractor drawn off-set disc harrow. A basal dose of 33 kg K ha^{-1} as muriate of potash, 4.5 kg ha^{-1} zinc as zinc sulphate heptahydrate and P as per treatments was applied at final puddling. Nitrogen (N) at 120 kg N ha^{-1} as urea was applied in two splits; half dose at 10 days after transplanting (DAT) and the rest at 30 DAT. In plots receiving DAP, the amount of N applied through DAP was taken into account while making N application in rice as well as in other crops of the cropping system. Two to three seedlings of 21–25 days of age $hill^{-1}$ of rice (variety 'Pusa Basmati 1') were transplanted in mid-July at a spacing of 20 cm × 10 cm. Rice was harvested in the first week of November each year.

After the rice harvest the land was prepared by disking and leveling. Rapeseed (variety 'Pusa Bold') was sown during the second week of November. The crop received 40 kg N ha^{-1} as urea, P as per treatment, 33 kg K ha^{-1} as muriate of potash at sowing and 40 kg N ha^{-1} as urea at 40 days after sowing. The rapeseed was harvested in the second week of March each year.

Immediately after the harvest of the rapeseed, the field was irrigated and at optimum soil moisture level it was disked and leveled. Mungbean variety 'PS 16' was seeded at a uniform row spacing of 30 cm in the third week of March each year. The crop received a basal dose of 20 kg N ha^{-1} as urea and P as per treatment. No K was applied to this crop. The crop was harvested in the last week of June every year of the experimentation.

Soil sampling and chemical analysis

At the harvest of each crop of the system, grain and straw samples were drawn from each plot and analysed for total P as per procedure described by Prasad et al. (2006). After completion of each 1 year cycle of the system, soil samples (0–20 cm depth) for each plot were collected and analysed for 0.5 M $NaHCO_3$ extractable P. Further, at the end of 3 cycles of rice–rapeseed–mungbean cropping system the soil samples (0–20 cm) were also analysed for the population of PSB and CO_2 evolution from soil as per procedure described by Subba Rao (1977).

Rice equivalents

The productivity of different cropping systems can not be compared on the basis of grain yields *per se* because the crops differ in the value of their economic produce. Therefore, rice equivalents of different crops were calculated using the following expression:

$$\text{Rice equivalents } (\text{Mg ha}^{-1}) = \text{Yca} \times \text{Pca}/\text{Pcr}$$

where Yca is the economic yield of crop 'a' (other than rice) in Mg ha^{-1}, Pca is the unit price of the economic produce of the crop 'a' and Pcr is the unit price of rice grain.

Statistical analysis

Data collected 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). Relative agronomic effectiveness (RAE) of MRP + PSB in relation to DAP was calculated using the following expression as suggested by Sharma et al. (1983):

$$\text{RAE}(\%) = \frac{\text{YMRP} + \text{PSB} - \text{Ycontrol}}{\text{YDAP} - \text{YC}} \times 100$$

where YMRP + PSB is the grain yield with MRP + PSB, Ycontrol is the grain yield for the control (no phosphorus) plots and YDAP is the grain yield with DAP. The RAE values of MRP + PSB were calculated at each of two rates (17.5 and 35 kg P ha^{-1}) separately.

Results and discussion

Grain/seed yield and rice equivalents

Rice: P application increased rice yield in all the 3 years of study (Table 1). In the first year MRP + PSB at

Table 1 Effect of rates and sources of phosphorus on grain/seed yield of rice–rapeseed–mungbean cropping system

Sources of P	Rates of P (kg P ha^{-1})	Grain/seed yield (mg ha^{-1})			
		Rice	Rapeseed	Mungbean	Total rice equivalents
2001–2002					
–	0	5.8	1.4	0.5	9.3
DAP	17.5	6.3	1.9	0.6	11.2
MRP + PSB	17.5	6.0	1.8	0.5	10.3
DAP	35.0	6.5	2.0	0.6	11.6
MRP + PSB	35.0	6.3	1.8	0.6	10.8
MRP + PSB	52.5	6.4	2.1	0.8	11.8
LSD ($P = 0.05$)		0.55	0.46	0.20	0.70
2002–2003					
–	0	4.9	1.2	0.7	8.4
DAP	17.5	5.1	1.7	0.9	10.0
MRP + PSB	17.5	4.9	1.4	0.8	9.0
DAP	35.0	5.7	1.7	1.1	11.0
MRP + PSB	35.0	5.1	1.5	0.9	9.6
MRP + PSB	52.5	5.4	1.6	1.1	10.5
LSD ($P = 0.05$)		0.58	0.31	0.30	0.60
2003–2004					
–	0	4.9	1.7	0.6	9.2
DAP	17.5	5.7	2.0	0.7	10.8
MRP + PSB	17.5	5.6	1.9	0.6	10.3
DAP	35.0	5.8	2.0	0.8	10.9
MRP + PSB	35.0	5.9	2.0	0.7	11.0
MRP + PSB	52.5	6.2	2.1	0.7	11.4
LSD ($P = 0.05$)		0.47	0.30	0.12	0.80

52.5 kg P ha^{-1} was at par with 35 kg P ha^{-1} as DAP and significantly increased the grain yield of rice over control. In the second year a significant increase in rice yield was obtained only with 35 kg P ha^{-1} as DAP. In the third year MRP + PSB and DAP at 17.5 kg P ha^{-1} were at par and significantly increased the rice yield over control. There was an additional increase in rice grain yield when the level of P application was raised from 17.5 to 52.5 kg P ha^{-1} as MRP + PSB. During the first and second years, soil might have absorbed tightly almost all of the dissolved P from fertilizers applied at lower rate with very little increase in soil solution P as indicated from data presented in Table 4. This resulted in very little increase in rice yields. At higher levels of P application as the solution P increased above the threshold concentration for net P uptake by plants, crop yield increased steeply as reported by Rajan (1973) and Fox et al. (1986).

Rapeseed: In the first and second year of the study a significant increase in the seed yield of rapeseed was recorded with 17.5 kg P ha^{-1} as DAP or 52.5 kg P ha^{-1} as MRP + PSB, whereas in the third year application of 35 kg P ha^{-1} as MRP + PSB also significantly increased the seed yield of rapeseed (Table 1). Further increase in the rate of MRP + PSB from 35 to 52.5 kg P ha^{-1} and of DAP from 17.5 to 35 kg P ha^{-1} did not result in an additional increase in the rapeseed yield.

Mungbeen: Seed yield of mungbean increased significantly when the rate of P application was increased from 0 to 52.5 kg P ha^{-1} as MRP + PSB in the first year, whereas in the second year MRP + PSB at 52.5 kg ha^{-1} was at par with 35 kg P ha^{-1} as

DAP and significantly increased mungbean yield over control (Table 1). In the third year only DAP at 35 kg P ha^{-1} increased seed yield of mungbean over control.

Total productivity of the system: Total productivity of the system was evaluated in terms of rice equivalents (Table 1). At 17.5 kg P ha^{-1} MRP + PSB significantly increased value of rice equivalents over control and DAP over MRP + PSB in the first 2 years, whereas in the third year MRP + PSB and DAP at 17.5 kg P ha^{-1} were at par and resulted in a significant increase in total rice equivalents of the cropping system over control. The value of rice equivalents further increased when the rate of MRP + PSB was increased from 17.5 to 52.5 kg P ha^{-1}.

Mean data over the 3 years indicated that MRP + PSB at 35 kg P ha^{-1} was at par with DAP at 17.5 kg P ha^{-1} and MRP + PSB at 52.5 kg P ha^{-1} was at par with DAP at 35 kg ha^{-1} (Fig. 1). Frederick et al. (1992) also reported that the average agronomic efficiency of Kodjari-rock phosphate ranged from 35 to 80% in the field in Burkina Faso with an average of 48%.

Relative agronomic effectiveness of MRP + PSB

Rice: Data presented in Table 2 show that MRP + PSB was 0–87% as effective as DAP at 17.5 kg ha^{-1}, whereas at 35 kg ha^{-1} it was 25–111% as effective as DAP. The higher values were observed in the third year of study. This would be expected since the continuous application of MRP + PSB led to higher 0.5 M $NaHCO_3$ extractable P content in soil (Table 5). In rice the RAE value for MRP + PSB was 71% in the first year and 111% in the third year. Higher RAE values for MRP + PSB in the present study were due to the inoculation of PSB in the plots receiving MRP. The advantage of PSB in increasing plant available

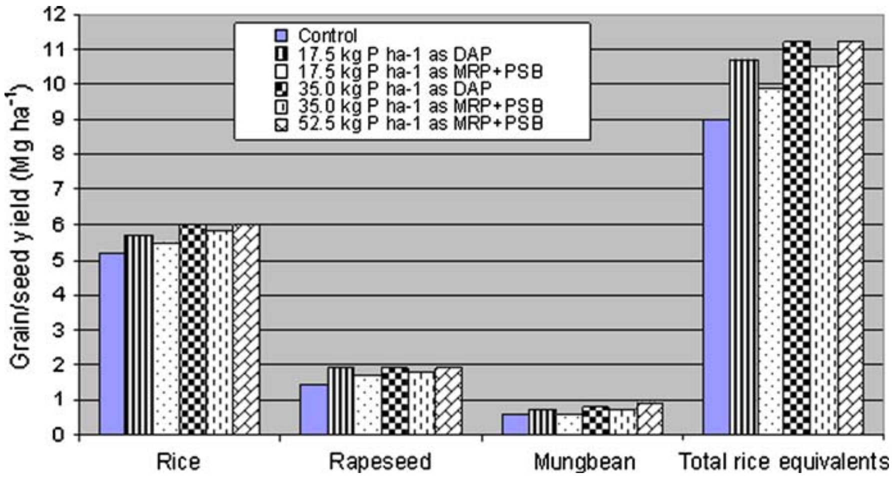

Fig. 1 Effect of rates and sources of phosphorous on grain/seed yeild of different crops and total rice equivalents of the cropping system (Mean over 3 years)

Table 2 Relative agronomic effectiveness (%) of MRP + PSB in relation to DAP

Rates of P (kg P ha^{-1})	Rice	Rapeseed	Mungbean	Rice + rapeseed + mungbeen
2001–2002				
17.5	40.0	80.0	0	52.6
35.0	71.4	66.7	100.0	65.2
2002–2003				
17.5	0	40.0	50.0	37.5
35.0	25.0	60.0	50.0	46.1
2003–2004				
17.5	87.5	66.7	0	68.7
35.0	111.1	100.0	50.0	105.9

P was also reported by several other workers (Kuccy et al. 1989; Gaur 1990; Bojinova et al. 1997; He et al. 2002). A very low value of 25% in the second year is difficult to explain.

Rapeseed: The RAE values for MRP + PSB ranged from 40 to 80% at 17.5 kg P ha^{-1} and from 60 to 100% at 35 at kg P ha^{-1}, again higher values were observed in the third year of study. A number of other workers (Jones 1998; Clien 2003; Clien et al. 2003) reported that plants species like rapeseed have the ability to secrete organic acids that results in an enhanced dissolution of rock phosphate even on alkaline soils. In the present study also RAE values for MRP + PSB for rapeseed were the highest among the three crops grown in the cropping system.

Mungbean: The RAE value for MRP + PSB ranged from 0 to 50% at 17.5 kg P ha^{-1} and from 50 to 100% at 35 at kg P ha^{-1}. Habib et al. (1999) had also reported a RAE value of 55% for Syrian rock phosphate (12.2% total P and 2.0% citrate soluble P) on a soil of pH 7.7. In several other studies (Mathur et al. 1979; Govil and Prasad 1974; Maloth and Prasad 1976; Babare et al. 1997; Bolan et al. 1990; Casanova 1995; Dahanayake et al. 1995; Rajan et al. 1996) also the amount of doses of ground rock phosphate required were two to three times of that needed as single super phosphate or triple super phosphate. However, in some trials even on alkaline soils MRP was found as good as single super phosphate (PPCL 1983; Rangaswamy and Arunachalam 1983; Loganathan et al. 1994).

Cropping system as a whole: MRP + PSB was 37–69% as effective as DAP at 17.5 kg ha^{-1}, whereas at 35 kg ha^{-1} it was 46–106% as effective as DAP. Thus, in the final year MRP + PSB was slight better than DAP, suggesting that in the long run continued application of MRP + PSB could be as good a source of P as DAP for the rice–rapeseed–mungbean cropping system. These values are much more than those reported by Mathur et al. (1979) and Maloth and Prasad (1976) and show a definite advantage of using PSB with MRP. Phosphorus solubilizing bacteria, *Pseudomonas striata* has been reported to solubilize inorganic forms of P. This is achieved by excreting organic acids that dissolve phosphoric minerals and/or chelate cationic partners of the P ion directly, releasing P into solution (Halder et al. 1990; Gaur 1990; Allan and Killorn 1996; Bojinova et al. 1997; He et al. 2002).

Phosphorus uptake

Rice: P application significantly increased P uptake by rice in all the 3 years of study (Table 3). During the first year 35 kg P ha^{-1} as MRP + PSB was at par with 17.5 kg P ha^{-1} as DAP and significantly increased P uptake by rice over control. The 52.5 kg P ha^{-1} of MRP + PSB was significantly superior to 17.5 kg P ha^{-1} of same source. During the second year P uptake of rice increased significantly when rate of P application was increased from 0 to 35 kg P ha^{-1} either as DAP or MRP + PSB. Further, increase in the rate of P application from 35 to 52.5 kg P ha^{-1} as MRP + PSB 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^{-1} either through DAP or MRP + PSB significantly increased P uptake by rice over control. Further increase in the rate of DAP from 17.5 to 35 kg P ha^{-1} did not increase P uptake over 17.5 kg P ha^{-1}, whereas in case of MRP + PSB, 52.5 kg P ha^{-1} was significantly superior to 17.5 kg P ha^{-1} in respect of P uptake by rice.

Rapeseed: MRP + PSB at 35 kg P ha^{-1} was at par with 17.5 kg P ha^{-1} as DAP and significantly increased P uptake over control in all the 3 years of study; during the first year application of 17.5 kg P ha^{-1} as MRP + PSB also increased P uptake of rice over control. Further increase in the level of DAP from 17.5 to 35 kg P ha^{-1} resulted in an additional increase in P uptake of rapeseed in the first 2 years, whereas an increase in level of MRP + PSB from 17.5 to 35 kg P ha^{-1} increased P uptake significantly in all the 3 years of study. Further, increase in the rate of MRP + PSB from 35 to 52.5 kg P ha^{-1} also increased P uptake in the first year of study, however, 52.5 kg P ha^{-1} as MRP + PSB was at par with 35 kg P ha^{-1} as DAP.

Mungbean: MRP + PSB at 35 kg P ha^{-1} was at par with 17.5 kg P ha^{-1} as DAP and significantly increased P uptake of mungbean over control in all the 3 years of study. Similarly MRP + PSB at 52.5 kg P ha^{-1} was at par with 35 kg P ha^{-1} as DAP and significantly increased P uptake by mungbean over their lower levels in the last 2 years, whereas in the first year 52.5 kg P ha^{-1} of MRP + PSB was significantly superior to 35 kg P ha^{-1} of DAP.

Total P uptake of the system: MRP + PSB at 17.5 kg P ha^{-1} significantly increased P uptake over

Table 3 Effect of rates and sources of phosphorus on P uptake (kg ha^{-1}) by different crops of rice–rapeseed–mungbean cropping system

Sources of P	Rate of P (kg ha^{-1})	Rice	Rapeseed	Mungbean	Total
2001–2002					
–	0	17.5	11.2	6.5	35.2
DAP	17.5	19.7	16.2	8.1	43.9
MRP + PSB	17.5	19.1	13.8	7.4	40.3
DAP	35.0	19.8	19.2	8.4	74.4
MRP + PSB	35.0	20.4	16.1	7.7	44.2
MRP + PSB	52.5	21.6	18.6	9.6	49.8
LSD ($P = 0.05$)		1.7	1.5	0.9	2.3
2002–2003					
–		16.2	11.0	8.6	35.8
DAP	17.5	17.4	14.9	10.2	42.5
MRP + PSB	17.5	16.6	12.3	9.4	38.3
DAP	35.0	19.6	18.0	12.0	49.9
MRP +PSB	35.0	19.3	13.8	10.8	43.9
MRP + PSB	52.5	20.5	14.8	12.0	47.3
LSD ($P = 0.05$)		1.3	1.3	0.8	2.9
2003–2004					
–		16.8	11.1	7.0	34.9
DAP	17.5	20.1	14.5	8.1	42.7
MRP + PSB	17.5	19.2	12.6	7.8	39.6
DAP	35.0	20.5	15.4	9.6	45.5
MRP + PSB	35.0	20.1	14.5	8.9	43.5
MRP + PSB	52.5	21.3	15.4	9.6	46.3
LSD ($P = 0.05$)		1.7	1.5	0.9	3.1

control in the first and the third years of study, whereas DAP at 17.5 kg P ha^{-1} being superior to MRP + PSB at same rate, significantly increased P uptake of the system over control in all the 3 years of study. Further increase in the level of DAP from 17.5 to 35 kg P ha^{-1} also resulted in an additional increase in the amount of P removal by the system in the first 2 years of study. In case of MRP + PSB, P removal by the system increased significantly with increasing rate of P application up to 52.5 kg P ha^{-1}. However, 52.5 kg P ha^{-1} as MRP + PSB was at par with 35 kg P ha^{-1} as DAP in all the 3 years of study. Mean data over the 3 years of study indicated that MRP + PSB at 35 and 52.5 kg P ha^{-1} was at par with 17.5 and 35 kg P ha^{-1}, respectively (Fig. 2). Similar pattern was observed in productivity of the cropping system (Fig. 1).

Phosphorus balance sheet after three cycles of rice–rapeseed–mungbean cropping system

Data on P balance sheet after three cycles of rice–rapeseed–mungbean cropping system are in Table 4. P application led to a positive balance and MRP + PSB had a higher value than DAP, mainly due to higher P uptake in DAP fertilized plots (Table 3). The highest positive balance of P was recorded with MRP + PSB at 52.5 kg P ha^{-1}, the highest rate of P application. These data are well in line with the increase in 0.5 M $NaHCO_3$ extractable P in soil (Table 5).

The 0.5 M $NaHCO_3$ extractable P content in soil

Application of P as MRP + PSB or DAP increased the content of 0.5 M $NaHCO_3$ extractable P (Table 5).

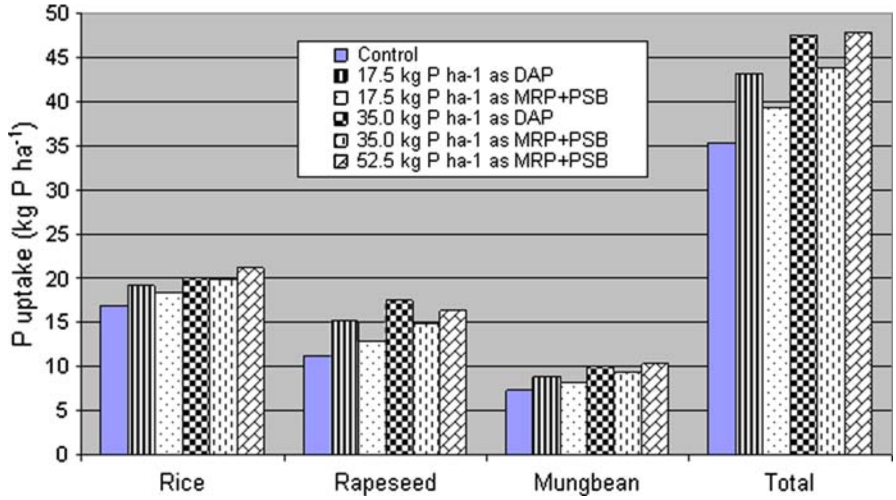

Fig. 2 Effect of rates and sources of phosphorous on P uptake by different crops (Mean over 3 years)

Table 4 Balance sheet of P after three cycles of rice–rapeseed–mungbean cropping system (RRMCS)

Sources of P	Rate of P (kg ha^{-1} $crop^{-1}$ $year^{-1}$)	Total P applied in RRMCS in 3 years (kg ha^{-1})	Total P removed by RRMCS in 3 years (kg ha^{-1})	P balance in soil (kg ha^{-1})
–	0	0	105.9	−105.9
DAP	17.5	157.5	129.2	+28.3
MRP + PSB	17.5	157.5	118.2	+39.3
DAP	35.0	315.0	142.5	+172.5
MRP + PSB	35.0	315.0	131.6	+183.4
MRP + PSB	52.5	472.5	143.4	+329.1

Table 5 Effect of rates and sources of phosphorus on 0.5 M $NaHCO_3$ extractable P (kg ha^{-1}) content in soil after completion of a cycle of rice–rapeseed–mungbean cropping system

Sources of P	Rates of P (kg ha^{-1})	2001–2002	2002–2003	2003–2004
–	0	13.4	13.3	12.4
DAP	17.5	15.2	15.3	16.4
MRP + PSB	17.5	14.4	16.0	17.1
DAP	35.0	16.6	17.4	18.1
MRP + PSB	35.0	17.6	17.6	18.4
MRP + PSB	52.5	17.4	18.3	18.6
LSD ($P = 0.05$)		0.63	0.99	1.12

Initial value: 14 kg P ha^{-1}

Table 6 Effect of rate and source of phosphorus on phosphorus solubilizing bacteria (PSB) and CO_2 evolution from soil after completion of three cycles of rice–rapeseed–mungbean cropping system

Sources of P	Rates of P (kg ha^{-1})	PSB (cells × 10^3 g^{-1} soil)	CO_2 evolution (mg g^{-1} soil 24^{-1} h)
–	0	7.6	0.099
DAP	17.5	10.0	0.253
MRP + PSB	17.5	12.4	0.282
DAP	35.0	12.8	0.279
MRP + PSB	35.0	16.6	0.311
MRP + PSB	52.5	18.0	0.348
LSD ($P = 0.05$)		0.8	0.018

After completion of first and second cycles, the 0.5 M $NaHCO_3$ extractable P increased significantly with each successive increase in the level of MRP + PSB up to 52.5 kg ha^{-1} and of DAP up to 35 kg ha^{-1}, however, the difference between 35 and 52.5 kg P ha^{-1} as MRP + PSB was not significant after completion of first cycle of the system. The highest 0.5 M $NaHCO_3$ extractable P content was recorded with 52.5 kg P ha^{-1} as MRP + PSB. After completion of third cycle, MRP + PSB at 35 and 52.5 kg P ha^{-1} and DAP at 35 kg P ha^{-1} were at par and recorded significantly more 0.5 M $NaHCO_3$ extractable P content in soil than 17.5 kg P ha^{-1} as MRP + PSB or DAP, which in turn, recorded significantly higher 0.5 M $NaHCO_3$ extractable P content in soil than control. Ruaysoongnern and Keerati-Kasikorn (1998) also reported that higher builds up of 0.5 M $NaHCO_3$ extractable P in soil with RP is possible when very high rates of RP are applied as compared to soluble phosphate fertilizer. Saggar et al. (1992), on the other hand reported that Olsen *P* values were not significantly different with different rates of phosphate rock and suggested a mixed cation-anion resin soil test for P release from rock phosphate. However, in the present study rock phosphate was used with PSB, which solubilizes P from rock phosphate and Olsen's *P* values for MRP + PSB were similar to that observed with DAP.

Phosphate solubilizing bacteria count in soil

The number of PSB cells increased with P application and as expected at each level of P, the PSB cell count was higher in plots receiving MRP + PSB (Table 6). The highest PSB cell count was recorded with 52.5 kg P ha^{-1} as MRP + PSB.

CO_2 evolution from soil

The CO_2 evolution in soil increased significantly with increasing the rate of P application (Table 6) At each level of P the CO_2 evolution was significantly more with MRP + PSB than DAP and the highest CO_2 evolution was recorded with 52.5 kg P ha^{-1} as MRP + PSB. Increased CO_2 evolution in the plots receiving MRP + PSB may partly explain capacity of PSB to solubilize MRP P by maintaining higher carbonic acid concentration in soil solution as reported by Sharma and Aggarwal (2006).

Conclusion

The present study shows that MRP along with PSB inoculation can be used for P fertilization in a rice–rapeseed–mungbean cropping system for increased productivity, maintenance of soil P pool, higher microbial count and sustainability of the system.

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