Journal of the Indian Society of Soil Science, Vol. 60, No. 2, pp 138-144 (2012)

Rock Phosphate-enriched Pressmud Compost: Direct Effect in Pearl Millet (*Pennisetum glaucum* L.) and Residual Effect in Mustard (*Brassica juncea*) in a Typic Haplustept

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Rock phosphate-enriched pressmud compost (RPEPMC) was prepared by composting fresh pressmud and rock phosphate mixture in the ratio of 20:1 (w:w basis) in cylindrical plastic container with a composite microbial culture at 0.1% (w:w) level. A field experiment was conducted during rainy season (*kharif*) followed by winter (*rabi*) season of 2006-07 to evaluate the RPEPMC as partial substitute of fertilizer phosphorus (P) in terms of direct and residual P uptake and P use efficiency (PUE) by crops to study the changes in available P at 60 days after sowing (DAS) as well as after harvest of both the crops and various inorganic P fractions in soil after cropping. Results showed that pearl millet responded up to 26.1 kg ha^{-1} of P application. Application of diammonium phosphate (DAP) proved superior to RPEPMC with respect to grain and stover yield, P derived from P sources, total P uptake and PUE by pearl millet at 34.8 kg P ha^{-1} level. Among the various ratios of RPEPMC and DAP (3:1, 1:1 and 1:3) tried at 34.8 kg P ha^{-1} level, the 1:3 ratio showed best performance followed by 1:1 and 3:1 ratios. Phosphorus applied to pearl millet had considerable residual effect on succeeding mustard, the effect being more pronounced at higher levels of P application. The residual effect of P applied at 34.8 kg P ha^{-1} through RPEPMC and DAP produced 74.3 and 59.6% relative grain yield and 74.6 and 56.2% relative total P uptake, respectively at maturity against fresh application of 34.8 kg P ha^{-1} through DAP in mustard. The relative total P uptake by mustard at 34.8 kg P ha^{-1} through the three ratios was in the order of 3:1>1:1>1:3. Residual effect of RPEPMC and DAP in combination applied at 34.8 kg P ha^{-1} in a 3:1 ratio showed higher available P at 60 DAS as well as after harvest of mustard. Moreover, the application of RPEPMC in soils of medium available P status (Typic Haplustepts) in pearl millet-mustard sequence replaced about half to two-third of P requirement of crops from fertilizer with no appreciable change in soil P fertility.

Key words: Rock phosphate-enriched pressmud compost, P use efficiency, pearl millet, mustard, available P, inorganic P fractions, correlation matrix

Phosphorus (P) is the second most limiting nutrient after nitrogen in majority of soils for crop production. The deficiency of P is widespread in most of the regions of the world as well as in the soils of the Indo-Gangetic Plains, and its application is crucial to improve productivity of the cropping system (Yadvinder-Singh and Bijay-Singh 2001). Nevertheless, in most situations, P balance is negative even with the recommended rate of P fertilizer use (Yadvinder-Singh *et al*. 2000). Therefore, optimum use of P is crucial for long-term sustainability of the cropping system. In view of the inherent P deficiency of soil, farmers depend mostly on chemical fertilizers to meet high P demand of crops. In India the cost of applying conventional water soluble P fertilizer is high because of high manufacturing cost involved in importing high-grade rock phosphate (RP) and sulphur. It is estimated that about 300 million tonnes (Mt) of RP deposits are available in India (TIFAC 2011) and only a fraction of it (about 25%) meets the specification of the fertilizer industry because of low P content (low-grade). Most of the

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rock phosphates are reasonably suitable for direct use in acid soils, but have not given satisfactory results in neutral to alkaline soils (Narayanasamy and Biswas 1998). This urgently calls for an improvement in the effectiveness of RP and efficient utilization of P by the crops in neutral and alkaline soils. So the vast potential of this native RP can be exploited in order to reduce the dependence of farmers entirely on water soluble P-fertilizer. Composting of organic wastes with rock phosphate has been reported to enhance the dissolution of RP and thus enrichment of P can be achieved (Biswas and Narayanasamy 2006). Efforts have been made to improve the agronomic effectiveness of low-grade RP by preparing rock phosphate enriched compost (Mishra *et al*. 1982) or inoculating it with phosphate solubilizing microorganisms (Kapoor *et al*. 1983).

In present day agriculture, the recycling of agricultural and industrial wastes is of prime importance not only because it adds much needed organic matter but also supplements sufficient amount of nutrients to the soil. The nutrient potential of all biological and industrial wastes has been estimated at about 19.11 Mt in India (Yadvinder-Singh and Bijay-Singh 2003). India is the second largest sugar-producing country in the world, and sugar industries discharge about 5, 45 and 7.5 Mt annually of pressmud (PM), bagasse and molasses, respectively, as wastes (Satisha and Devarajan 2007). In this respect, PM, a by-product of sugar industries could be a cheap alternative to modify the RP. Therefore, it can be used as a composting material for preparation of rock phosphate-enriched pressmud compost (RPEPMC) to use as an alternative to diammonium phosphate (DAP) for integrated P nutrition of crops.

The optimization of P levels of different sources while applying in combination assumes significance from the standpoint of economics of nutrient use. The P removal by first crop rarely exceeds 15-20% of added P and therefore its application to main crop will leave residual benefits for succeeding crop. Thus, assessment of residual P utilization by succeeding crop(s) in a cropping sequence is necessary for efficient use of P fertilizers. Hence, the contribution of P from these sources towards total P uptake by crops needs to be quantified. As growing of pearl millet followed by mustard is a common practice in semi-arid region, the present research was formulated to achieve two objectives (i) to assess RPEPMC as a partial substitute of fertilizer P in terms of its P utilization efficiency by crops, and (ii) to study the changes in various P fractions in soil after pearl millet-wheat cropping sequence due to its addition.

Materials and Methods

The RPEPMC was prepared by composting fresh PM (collected from Daurala Sugar Works, Daurala, Meerut, Uttar Pradesh) having total P_2O_5 2.11%, citrate-soluble P_2O_5 0.10%, water-soluble P_2O_5 0.08%, organic carbon 32.64% and nitrogen 1.20% and RP (collected in powdered form from Rajasthan State Mines and Minerals Ltd., Udiapur, Rajasthan) having total P_2O_5 19.98% and citrate-soluble P_2O_5 0.06% and mixed in the ratio of 20:1 (w:w basis) in cylindrical plastic container (150 L capacity). After 2 days a composite microbial culture consisting of *Pseudomonas* spp., *Aspergillus* spp., *Streptomycetes* spp., *Penicillium* spp. and *Trichoderma* spp. at 0.1% (w:w) level was added and thoroughly mixed to ensure complete contact with the decomposing materials. Turning was done at weekly intervals to provide adequate aeration. Moisture content at 60-70% was maintained throughout the composting period. Composting was continued till the C:N ratio reached to a value between 10:1 to 15:1 (after 120 days of composting). The final composition of RPEMC, which was used for field experiment, had 70% moisture, 1.40% N, 2.47% total P, 0.96% citrate-soluble P and 0.21% water-soluble P.

A field experiment was conducted to evaluate the direct and residual effect of RPEPMC during *kharif* 2006 followed by *rabi* 2006-07 at the research farm of Indian Agricultural Research Institute, New Delhi. The soil comes under Meharuli series, member of coarse loamy, non-acid mixed hyperthermic family of Typic Haplustepts. The physicochemical properties of the experimental soil as determined by standard procedures were as follows: texture sandy loam; pH (1:2, soil:water) 7.8; EC (1:2, soil:water) 0.32 dS m^{-1}; organic C 0.39%; CEC 10.87 cmol (p^+) kg^{-1}; exchangeable Ca 9.14 cmol (p^+) kg^{-1}; Fe-P + Al-P 91.5 mg kg^{-1}; Ca-P 204.8 mg kg^{-1} and available N, P and K 100, 7.1 and 105 mg kg^{-1} soil, respectively. The treatments consisted of two sources of P *viz*., RPEPMC and DAP. Four P levels through DAP (8.7, 17.4, 26.1 and 34.8 kg P ha^{-1}), three ratios of RPEPMC and DAP @ 34.8 kg P ha^{-1} level (3:1, 1:1 and 1:3 on P basis) and two controls (control-1 as absolute control and control-2, which was supplied with fresh DAP @ 34.8 kg P ha^{-1}) in *rabi* season. These treatments were laid out in a randomized block design with three replications. The treatments were T_1- absolute control in pearl millet and in mustard; T_2-DAP @ 8.7 kg P ha^{-1} in pearl millet and residual in mustard; T_3-DAP @ 17.4 kg P ha^{-1} in pearl millet and residual in mustard; T_4-DAP @ 26.1 kg P ha^{-1} in pearl millet and residual in mustard; T_5-DAP @ 34.8

kg P ha^{-1} in pearl millet and residual in mustard; T_6-RPEPMC @ 34.8 kg P ha^{-1} in pearl millet and residual in mustard; T_7-RPEPMC @ 26.1 kg P ha^{-1} + DAP @ 8.7 kg P ha^{-1} in pearl millet and residual in mustard; T_8-RPEPMC @ 17.4 kg P ha^{-1} + DAP @ 17.4 kg P ha^{-1} in pearl millet and residual in mustard; T_9-RPEPMC @ 8.7 kg P ha^{-1} + DAP @ 26.1 kg P ha^{-1} in pearl millet and residual in mustard; and T_{10}-Fresh DAP @ 34.4 kg P ha^{-1} in mustard. Pearl millet variety 'Pusa Hybrid 605' was sown in third week of July 2006 and harvested in third week of October 2006. The RPEPMC and DAP were applied basally as per the treatments and raked to mix the fertilizer materials with soil. The recommended dose of K @ 46 kg ha^{-1} and half dose of N @ 50 kg ha^{-1} were applied after balancing the N content of DAP and RPEPMC. The remaining half dose of N was applied at the time of flowering. In the succeeding mustard crop (Pusa Bold), N @ 100 kg ha^{-1} and K @ 38 kg ha^{-1} were applied as per recommended doses with no P application except in control-2 treatment of pearl millet. In this treatment DAP @ 34.8 kg P ha^{-1} was applied to compare the residual effect of different levels of RPEPMC and DAP and the different combinations as applied (@ 34.8 kg P ha^{-1}) in pearl millet and mustard crops.

The surface soil samples (0-15 cm depth) from each plot were collected at 60 DAS and after the harvest of pearl millet and mustard crops for the determination of Olsen-P and exchangeable Ca. Total organic C and total N in compost was determined by wet oxidation method (Snyder and Trofymow 1984) and micro-Kjeldahl method, respectively. Total P content in compost was determined by acid digestion followed by colorimetric estimation of P by vanado-molybdate-phosphoric yellow colour method. Water-soluble P and citrate-soluble P in compost were determined as per the procedure outlined by Fertiliser (Control) Order (1985). Available P and exchangeable Ca in soil were estimated by standardized methodology followed by Olsen *et al.* (1954) and Jackson (1973), respectively. Inorganic P fractions (Al-P, Fe-P and Ca-P) in soil were determined as per the procedure outlined by Olsen and Sommers (1982). The P content in plant samples was determined by di-acid mixture digestion followed by colorimetric method as in case of total P in compost. Phosphorus uptake and P use efficiency in pearl millet and mustard were calculated as follows:

Computation of P uptake and P use efficiency (PUE) in pearl millet

P uptake in control = P uptake from soil

P uptake from fertilizer (any level) = P uptake from fertilizer treated soil - P uptake from soil

P uptake from compost (any level) = (P uptake from compost and fertilizer mixture) - (P uptake from soil + P uptake from fertilizer)

$$\text{P use efficiency} = \left(\frac{\text{P uptake from source}}{\text{P applied}}\right) \times 100$$

Computation of P uptake and P use efficiency (PUE) in mustard

P uptake in control = P uptake from soil

Residual P uptake from fertilizer (any level) = P uptake from fertilizer treated soil - P uptake from soil

Residual P uptake from compost (any level) = (P uptake from compost and fertilizer mixture) - (P uptake from soil + P uptake from fertilizer)

$$\text{Residual P use efficiency} = \left(\frac{\text{Residual P uptake from source}}{\text{P applied to previous crop}}\right) \times 100$$

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).

Results and Discussion

Grain, Stover Yield and Harvest Index

Direct effect: Application of P sources significantly influenced the grain and stover yields of pearlmillet (Table 1). Increasing levels of P applied though DAP from 8.7 to 34.8 kg P ha^{-1} increased the grain and stover yields of pearl millet. The data indicated that 34.8 kg ha^{-1} dose of P to pearl millet applied through both RPEPMC and DAP in various ratios (except 3:1) was comparable with DAP alone at equivalent level. Harvest index of pearl millet was found to be in the following order: RPEPMC and DAP ratio of 1:3 (0.274) >1:1 ratio (0.273) > DAP 17.5 kg P ha^{-1} (0.272) >DAP 8.7 kg P ha^{-1} (0.271). This might be ascribed to better growth and development of crop under readily available P sources (DAP and 1:3 ratio of RPEPMC and DAP) at the early stage of growth.

Residual effect: An increasing trend in grain and stover yields of mustard as a result of residual effect of increasing levels of P applied through DAP to preceding pearl millet crop is discernible from the data shown in table 1. At 34.8 kg P ha^{-1} level, the residual effects in terms of grain and stover yields were higher with RPEPMC as compared to DAP. The data further showed that the different ratios of RPEPMC and DAP (3:1, 1:1 and 1:3) applied at 34.8 kg P ha^{-1} level were similar in residual effect in terms of grain and stover yields. Surendra and Sharanappa

(2000) also reported significant response of mustard crop to residual P.

Total P Uptake and P Use Efficiency

Direct effect: Data (Table 2) indicate that total P uptake followed the trend similar to grain and stover yields of pearl millet. The magnitude of increase in total P uptake varied from 26.5 to 65.2%. The performance of both 1:1 and 1:3 ratios (14.11 and 14.51 kg P ha^{-1}, respectively) was comparable to each other and both being significantly more effective than 3:1 ratio (12.65 kg P ha^{-1}). However, 1:3 ratio of RPEPMC and DAP was significantly more effective than the 3:1 ratio and comparable with DAP alone applied at the equivalent rate. The increase in total P uptake may be attributed to the proportionate increase in availability and absorption of P by pearl millet due to increasing levels of P application. The phosphorus use efficiency (PUE) increased from 22.5 to 25.5% on increasing the P level from 8.7 to 17.4 kg ha^{-1}. Further increase in the rate of P application from 17.4 to 34.8 kg ha^{-1} as DAP decreased the PUE gradually from 25.5 to 23.3% (Table 2). The performance of DAP proved superior to RPEPMC with respect to PUE in pearl millet which may be because DAP contains higher amount of a water-soluble P, while RPEPMC is an organo-mineral product with very low or traces of available P (water soluble + citrate soluble P) and slow in P release characteristics, leading to lower available P in soil at 60 days of crop growth as well as at harvest stage of pearl millet in comparison to the DAP.

Residual effect: The residual effect of increasing levels of P applied previously to pearl millet significantly increased the total P uptake by mustard (Table 2). Between the two sources of P, the performance of RPEPMC was better than that of the DAP, as judged from the higher total residual P uptake. Increased P uptake in mustard due to residual P fertilizer has also been reported by many workers

Table 1. Effect of levels and sources of P on grain yield, stover yield and harvest index by pearl millet and mustard

Treatment	Pearl millet (direct effect)			Mustard (residual effect)		
	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index
T_1	1.50	4.08	0.269	1.58	4.73	0.251
T_2	1.81	4.96	0.267	1.76	5.32	0.248
T_3	2.28	6.11	0.272	1.94	5.87	0.248
T_4	2.53	6.80	0.271	2.08	6.30	0.248
T_5	2.73	7.48	0.267	2.22	6.72	0.248
T_6	2.33	6.37	0.267	2.38	7.37	0.244
T_7	2.35	6.45	0.267	2.29	7.10	0.244
T_8	2.65	7.03	0.273	2.29	7.08	0.244
T_9	2.69	7.15	0.274	2.24	6.95	0.244
T_{10}				2.65	8.48	0.238
LSD (P=0.05)	0.26	0.66		0.16	0.50	

Table 2. Effect of levels and sources of P on P uptake and P utilization by pearl millet and mustard

Treatment	Pearl millet (direct effect)			Mustard (residual effect)		
	P uptake (kg P ha^{-1})	P uptake from P sources (kg P ha^{-1})	P use efficiency (%)	P uptake (kg P ha^{-1})	P uptake from P sources (kg P ha^{-1})	P use efficiency (%)
T_1	7.33			11.27		
T_2	9.27	1.94	22.5	12.86	1.59	18.2
T_3	11.89	4.56	25.5	14.21	2.94	16.8
T_4	13.39	6.06	23.5	15.39	4.12	15.7
T_5	15.35	8.03	23.3	16.78	5.51	15.8
T_6	12.11	4.77	13.9	18.58	7.31	20.9
T_7	12.65	5.33	15.5	17.73	6.46	18.5
T_8	14.11	6.78	19.4	17.56	6.29	18.0
T_9	14.51	7.19	20.9	17.11	5.84	16.7
T_{10}				21.07	9.80	28.0
LSD (P=0.05)	0.86	0.89	3.02	0.88	0.75	4.55

(Surendra and Sharanappa 2000; Mahala *et al*. 2006). The residual effect between the two sources *i.e*. RPEPMC and DAP on total P uptake in mustard was much higher with RPEPMC than that with DAP (Table 2) when both the sources of P were applied at 34.8 kg P ha^{-1} level to the preceding pearl millet. The higher total P uptake in mustard due to residual effect of RPEPMC over DAP may be attributed to the fact that available P content in soil during the crop growth period was higher with RPEPMC than with DAP. Prasad (2000) also reported significant response of mustard crop to residual P. The residual effect of increasing level of P applied to preceding pearl millet through DAP led to gradual decrease in PUE (16.8 to 15.7%) by mustard. The higher PUE at lower doses may be due to the greater competition of plants for nutrients where the available P content was medium under field conditions. The RPEPMC (20.9%) proved superior to DAP (15.7%) in residual effect on PUE in mustard when both were applied to preceding pearl millet at 34.8 kg P ha^{-1} level.

Soil Available P

Direct effect: Available P in soil at two stages of crop growth *i.e*. at 60 DAS and at harvest of pearl millet as influenced by the levels and sources of P (DAP and RPEPMC) have been presented in fig. 1a. The addition of P to pearl millet increased available P in soil as judged from the higher values of Olsen-P at both the stages of crop growth in comparison to the initial Olsen-P content. Significant differences existed between the three ratios of RPEPMC and DAP combination applied at 34.8 kg P ha^{-1} level at maturity stage of pearl millet. However, at 60 DAS no significant variation was observed between 3:1 and 1:1 ratios and 1:1 and 1:3 ratios of RPEPMC and DAP combination.

Residual effect: Soil available P (Fig. 1b) at both the growth stages of mustard decreased slightly in the treatments where DAP alone was used from 8.7 to 34.8 kg P ha^{-1} to pearl millet but increased slightly in those treatments where RPEPMC alone (34.8 kg P ha^{-1}) or combination of RPEPMC and DAP in various ratios applied to pearl millet, when compared with the initial values. Further, mustard was grown as a residual crop with no fresh supply of P. The crop could make use of existing available P without supply from any source, other than soil. The RPEPMC gave maximum available P in the soil at 60 DAS as well as at harvest of mustard than DAP. This may be ascribed to the slow and gradual solubilization of P in RPEPMC. Among the various ratios of RPEPMC and DAP applied at 34.8 kg P ha^{-1} level, 3:1 ratio showed higher available P at 60 DAS and at the harvest of mustard.

Inorganic P Fractions after Mustard

The levels and sources of P used for the preceding pearl millet did not cause any significant variation in Fe-P and Al-P content in soil at harvest of mustard (Fig. 1c). The values for Fe-P and Al-P fraction in soil across the P treatments ranged from 78.8 to 80.0 mg P kg^{-1} soil as against 81.5 mg P kg^{-1} soil as noticed at the commencement of experiment. However, freshly applied DAP led to significantly higher Fe-P and Al-P values than rest of the treatments. Out of the two sources at 34.8 kg P ha^{-1}

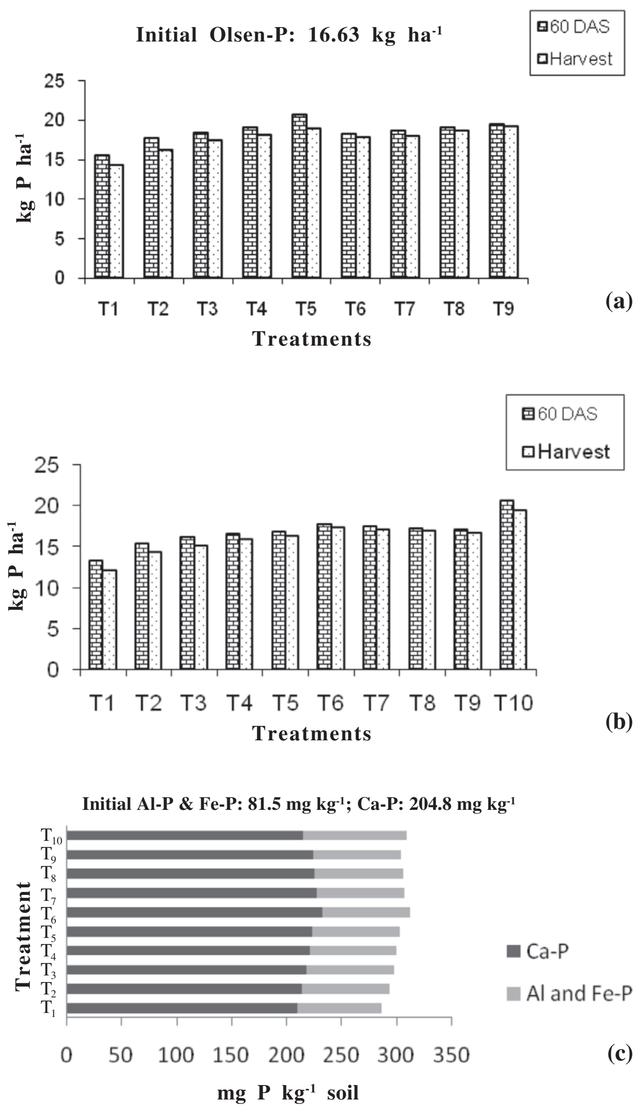

Fig.1. (a) Available P in soil at 60 DAS and at harvest of pearl millet, (b) Available P in soil at 60 DAS and at harvest of mustard, and (c) Effect of levels and sources of P applied to preceding pearl millet on inorganic P fractions after mustard

Table 3. Soil P balance after growing of pearl millet followed by mustard

Treatments	P addition (kg ha^{-1})			P removal (kg ha^{-1})			P balance
	DAP	RPEPMC	Total	Pearl millet	Mustard	Total	(kg ha^{-1})
T_1	Nil	Nil					
T_2	8.70	0.00	8.70	9.27	12.86	22.13	- 4.16
T_3	17.40	0.00	17.40	11.89	14.21	26.10	- 8.70
T_4	26.10	0.00	26.10	13.39	15.39	28.78	- 2.68
T_5	34.80	0.00	34.80	15.35	16.78	32.13	+ 2.67
T_6	0.00	34.80	34.80	12.11	18.58	30.69	+ 4.11
T_7	8.70	26.10	34.80	12.65	17.73	30.38	+ 4.42
T_8	17.40	17.40	34.80	14.11	17.56	31.67	+ 3.13
T_9	26.10	8.70	34.80	14.51	17.11	31.62	+ 3.18
T_{10}	34.80	0.00	34.80		21.07		

Table 4. Correlation matrix between different soil and plant parameters

Parameter	Biomass yield	Ex-Ca	Olsen-P	PUE	P uptake
			Pearl millet		
Biomass yield	1.00	NS	0.979**	NS	0.995**
Ex-Ca		1.00	NS	-0.883**	NS
Olsen-P			1.00	NS	0.972**
PUE				1.00	NS
P uptake					1.00
			Mustard		
Biomass yield	1.00	NS	0.995**	0.726*	0.999**
Ex-Ca		1.00	NS	NS	NS
Olsen-P			1.00	0.769*	0.991**
PUE				1.00	0.719*
P uptake					1.00

*Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level, NS= Not significant, PUE= Phosphorus use efficiency

level, RPEPMC recorded higher Ca-P (233.2 mg P kg^{-1}) than DAP (223.0 mg P kg^{-1}). The content of Fe-P and Al-P decreased, while Ca-P increased at the harvest of mustard in comparison to their initial values due to the fact that the experimental soil was slightly alkaline in reaction (pH 7.8). Furthermore, with the passage of time, Fe-P and Al-P tend to revert into Ca-P. Thus, all these changes eventually resulted in the accumulation of Ca-P after mustard. Under this investigation, RPEPMC-treated plots had higher Ca-P in comparison to DAP-treated plots. Phosphorus-enriched organic manure with varying P-levels also affects the transformation of P into different forms. Studies have revealed that applied phosphate transformed mostly into Ca-P followed by Fe-P, Al-P and carbonate sorbed P fractions (Murthy *et al*. 2002).

Soil P Balance

The overall P balance sheet in pearl millet – mustard cropping sequence (Table 3) showed highest net negative balance of -8.70 kg ha^{-1} with DAP 17.4 kg P ha^{-1}. The highest positive P balance was found with RPEPMC and DAP (3:1) (+4.42 kg P ha^{-1}), followed by RPEPMC 34.8 kg P ha^{-1} (+4.11 kg P ha^{-1}), RPEPMC and DAP (1:3) (+3.18 kg P ha^{-1}) and RPEPMC and DAP (1:1) (+3.13 kg P ha^{-1}).

Correlation Matrix

In case of pearl millet, the correlation matrix (Table 4) between different soil and plant parameters revealed a highly significant correlation of biomass yield with available P (r = 0.979**) and P uptake (r = 0.995**). The PUE was found to be significantly and negatively correlated with exchangeable Ca (r = -0.883**). Available P and P uptake were significantly and positively correlated (r = 0.972**). In case of mustard, the correlation matrix (Table 4) between different soil and plant parameters revealed a highly significant correlation of biomass yield with available P (r = 0.995**), PUE (r = 0.726*) and P uptake (r = 0.999**). Available P was found to be significantly and positively correlated with PUE (r = 0.769*) and P uptake (r = 0.991**). The PUE was found to be significantly and positively correlated with P uptake (r = 0.719*).

Conclusion

The present study shows that rock phosphate enriched compost can be used for P fertilization in a pearl millet-mustard cropping sequence for increased productivity and maintenance of labile soil P pools. The application of rock phosphate enriched compost in soils of medium available P status (Typic Haplustept) in pearl millet-mustard sequence meets about half to two-thirds of P requirement of crops from fertilizer with no appreciable change in soil P fertility.

Acknowledgements

The senior author is extremely grateful to the Director, Dean and Joint Director (Education), Indian Agricultural Research Institute, New Delhi for providing necessary funds in the form of Senior Research Fellowship to carry out the present study.

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Received 29 May 2010; Received in revised form 2 April 2012; Accepted 21 May 2012