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Residual effect of Udaipur rock phosphate sources, incubation methods and FYM on soil fertility in wheat-maize sequence

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ABSTRACT

A field experiment was carried out during two consecutive years, 1999-2000 and 2000-2001 on clay-loam soils of Udaipur to investigate the residual effect of incubated sources of Udaipur rock phosphate and FYM on soil in wheat-maize cropping sequence. Twenty six treatments were evaluated, *viz*., 3 sources of Udaipur rock phosphate (URP18%, 31% and 34%), 4 incubation methods (no incubation, incubation with phosphate solubilizing bacteria, incubation with farmyard manure and incubation with farmyard manure + phosphate solubilizing bacteria) and 2 farmyard manure levels (0 and 10 t ha^{-1}) along with 2 checks (40 and 60 kg P_2O_5 ha^{-1} through DAP). Phosphorus application at increasing levels from 40 to 60 kg P_2O_5 ha^{-1} through DAP enhanced available P content in soil after harvest of wheat. Increasesing levels of phosphorus through DAP had no residual effect on bulk density and available N content in soil. Phosphorus status of soil was higher with DAP than URP after harvest of wheat, but after harvest of succeeding maize both the sources were at par. Application of phosphorus through URP reduced bulk density of soil after harvest of crops. More available P in soil was recorded under high grade URP (31% and 34%) than low grade URP (18%). Better availability of P in soil was recorded in URP incubated with FYM and FYM+PSB treatments. FYM application at 10 t ha^{-1} reduced bulk density and increased available N and P contents in soil after wheat and succeeding maize. Incubated high grade Udaipur rock phosphate may be a viable source of phosphorus in wheat-maize cropping sequence and have equal residual effect to that of water soluble P sources.

I. INTRODUCTION

Phosphorus is one of the major nutrients required by the plants and its availability limits the crop yield. Rational fertilization, particularly for phosphorus, is one of the most important measures to improve crop yield and it is one of the main limiting factors for crop production (Xu Tang *et al*., 2008). Due to intensive cultivation and adoption of HYV's, India has to import large quantities of phosphatic fertilizers. The total reserves of phosphate rock of all categories and grade of our country is only 145 m tonnes (Prasad, 2002). Rajasthan has reserve of 79 m tonnes of phosphate rock. Out of this, 14.68 m tonnes is of high grade (30-34%) and 51.81 m tonnes is of low grade having about 15-20% P_2O_5 (Shaktawat *et al*., 2004). Though the direct use of low grade rock phosphate as 'P' has been attempted by many scientists in neutral and alkaline soils, but the success of this is yet to be established. Good residual effects of high grade rock phosphate were reported by Beri *et al*. (2004) in rice- wheat and soybean - mustard cropping systems by Shaktawat and Sharma (2001). The uptake of phosphorus from soils by crops, however, is low compared to nitrogen and potassium. The necessity for high fertilizer dosage when relatively small quantities of phosphorus are being removed from soil indicates that much of the added phosphorus remains in soil whether in fixed or available form. Majumdar *et al.* (2007) recorded significant improvement in available P, organic P and total P in soil with application of phosphorus at 60 kg P_2O_5 ha^{-1} to soybean through SSP, RP and SSP+RP (1:1). The present investigation was carried out to investigate the residual effect of incubated sources of Udaipur rock

phosphate and FYM after harvest of crops in wheat-maize cropping sequence in south Rajasthan.

2. MATERIALS AND METHODS

The field experiment was conducted during the winter (*rabi*) and rainy (*kharif*) seasons of 1999-2000 and 2000-2001, respectively at Rajasthan College of Agriculture, Udaipur. The soil of experimental field was clay-loam in texture. The experimental soil had available N 261.5 kg ha^{-1}, available P 19.2 kg ha^{-1}, available K 327.0 kg ha^{-1} and Calcium Carbonate (%) 3.45 with soil pH 7.9 in the year 1999-2000. In the second year (2000-2001), it had available N 280.7 kg ha^{-1}, available P 18.8 kg ha^{-1}, available K 305.4 kg ha^{-1} and Calcium Carbonate (%) 3.60 with soil pH 7.8. In each year, separate field was chosen for experiment. Twenty six treatments were evaluated, *viz.*, 3 sources of Udaipur rock phosphate (URP18%, 31% and 34%), 4 incubation methods (no incubation, incubation with PSB, incubation with FYM and incubation with FYM+PSB) and 2 farmyard manure levels (0 and 10 t ha^{-1}) along with 2 checks (40 and 60 kg P_2O_5 ha^{-1} through DAP). These 26 treatment combinations [(3x4x2) +2] were replicated 4 times in randomized block design. The gross and net plot size for each treatment was 6 m x 3.6 m and 5 m x 2.7 m, respectively.

Three grades of Udaipur rock phosphate were used for the experiment. Low grade (18%) and high grade (31% and 34%) rock phosphates were ground. Ground rock phosphates were sieved to get size of 150 micron for low grade and 74 micron for high grade before incubation. The chemical composition of low and high grade Udaipur rock phosphates is given in Table 1. These sources of rock phosphates were incubated with FYM (1:3 W/W) and PSB culture (0.3%) alone and in combination, keeping control as a check. The composition of FYM on oven dry basis is given in Table 2. Before incubation a fixed quantity of soil at 300 kg ha^{-1} of respective field was added to the rock phosphate. The URP was incubated for 21days in gunny bags with continuous aeration and wetting before use. *Bacillus subtilis* var. phosphaticum was used for incubation.

The rainfall received during wheat growth period in the years 1999-2000 and 2000-2001 was 0.6 mm and nil, respectively. The maize crop received total rainfall of 452.9 and 537.6 mm during its growth period in the year 2000 and 2001, respectively. However, the distribution of rainfall varied in both the years. All the treatments and 45 kg N ha^{-1} through urea were applied at a depth of 5 cm below the seed with the help of *kudali* at the time of sowing of wheat crop. The wheat variety "Raj- 3077" was sown on December 4, 1999 in first year and on December 7, 2000 in second year. The remaining dose of nitrogen at 45 kg ha^{-1} was top-dressed at the time of I^{st} irrigation through urea. The succeeding maize variety "Mahi Kanchan" was sown on July 6, 2000 in first year and on June 28, 2001 in second year in the same plots of wheat. Being a residual experiment, no phosphatic fertilizer was applied in succeeding maize crop. A uniform dose of 60 kg N ha^{-1} was applied in three splits at sowing, knee high stage and silking stage of maize crop. The wheat crop was harvested on April 8, 2000 in first year and April 10, 2001 in the second year. The succeeding maize crop was harvested on October 7, 2000 in first year and October 1, 2001 in the second year. To find out residual effect of treatments, bulk density, available nitrogen and available phosphorus were estimated in soil samples after harvest of wheat and succeeding maize.

Table: 1
Chemical composition of low and high grade Udaipur rock phosphates

S. No	Parameter	URP (18%)	URP (31%)	URP (34%)
1	P_2O_5 (%)	17.8	31.3	33.8
2	CaO (%)	42.7	46.0	46.0
3	MgO (%)	9.2	1.4	1.92
4	R_2O_3 *(%)	1.14	1.6	1.55
5	L.O.I.** (%)	22.4	5.5	4.02
6	AI ***(%)	1.94	-	-
7	Particle size	150 micron	74 micron	74 micron

* R_2O_3-Fe_2O_3 + Al_2O_3+ Cr_2O_3 + other oxides
** L.O.I.- Loss on ignition
*** AI - Acid insoluble

Table: 2
The composition of FYM on oven dry basis

Parameter	Year	
	1999-2000	2000-2001
Dry Matter (%)	56.0	53.0
N (%)	0.54	0.48
P_2O_5 (%)	0.24	0.26
K_2O (%)	0.53	0.54

Bulk Density

Soil samples were taken from experimental field before treatment application and after harvest of the wheat and succeeding maize from individual treatment plot at four points with the help of core sampler. The soil samples of individual treatment plots were thoroughly mixed and

homogeneous sample was prepared for individual treatment plot. The bulk density was determined by method of Piper, 1950 and expressed in mg m^{-3}.

Nitrogen and Phosphorus Analysis

Soil samples were drawn from each experimental plot up to 15 cm depth after harvest of wheat and succeeding maize. These were sun dried, ground to pass through 2 mm sieve and analyzed for available N and P as per the alkaline $KMnO_4$ method (Subbiah and Asija, 1956) and Olsen's method (Olsen *et al*., 1954).

Statistical Analysis

The data for individual year were subjected to analyses in randomized block design as described by Cochran and Cox (1967) and also pooled.

3. RESULTS AND DISCUSSION

Levels of Phosphorus (DAP)

The results of investigation revealed that increasing levels of phosphorous from 40 to 60 P_2O_5 ha^{-1} to wheat crop had significant effect on available P content in soil after harvest of wheat, but the increasing levels of P had equal residual effect on available P in the soil after succeeding maize (Table 3 and 4). This might be due to that wheat and maize crops absorbed considerable quantity of phosphorus from soil with increasing levels of phosphorus (Table 6). Mahala *et al*. (2006) and Mamata *et al*. (2007) also reported higher P content in soil after harvest of crops with higher doses of P-I fertilizers. Further, increasing levels of phosphorus didn't influence the bulk density and available nitrogen content in soil after harvest of wheat and succeeding maize.

DAP vs. URP

After harvest of wheat, P content in soil was higher under DAP treatment as compared to URP treatments, whereas available P content in soil at harvest of succeeding maize under URP treatment was to the same magnitude to that of DAP (check). These results are in conformity with Rana *et al*. (2004) and they reported that available soil P status increased as a result of continuous application of soluble P whereas residual P from rock phosphates

Table: 3
Effect of Udaipur rock phosphate sources, incubation methods and FYM on bulk density, available N and P status of soil after harvest of wheat

Treatments	Bulk density(mg m^{-3})			Available N (kg ha^{-1})			Available P (kg ha^{-1})		
	1999-2000	2000-2001	Pooled	1999-2000	2000-2001	Pooled	1999-2000	2000-2001	Pooled
DAP (Check) (P_2O_5 kg ha^{-1})									
40	1.375	1.363	1.369	274.93	257.90	266.42	24.80	22.65	23.73
60	1.380	1.365	1.373	275.13	258.90	267.02	27.18	24.85	26.02
'F' test	NS	NS	NS	NS	NS	NS	*	*	*
DAP (Check) vs. URP treatments									
Check (DAP)	1.378	1.364	1.371	275.03	258.40	266.72	25.99	23.75	24.87
URP treatments	1.346	1.335	1.341	277.17	264.41	270.79	24.47	22.78	23.63
'F' test	*	*	*	NS	NS	NS	*	*	*S
URP sources (60 kg P_2O_5 ha^{-1})									
URP (18%)	1.347	1.334	1.341	277.14	264.88	271.01	23.34	21.92	22.63
URP (31%)	1.344	1.334	1.339	277.17	263.68	270.43	24.79	23.06	23.93
URP (34%)	1.348	1.338	1.343	277.19	264.67	270.93	25.27	23.35	24.31
CD(P=0.05)	NS	NS	NS	NS	NS	NS	0.66	0.46	0.46
Incubation methods									
No incubation	1.348	1.339	1.344	276.93	263.95	270.44	23.70	22.45	23.08
Incubation with FYM	1.342	1.332	1.337	277.27	264.31	270.79	24.97	23.01	23.99
Incubation with PSB	1.351	1.337	1.344	276.78	264.91	270.85	23.98	22.51	23.25
Incubation with FYM+PSB	1.345	1.332	1.339	277.70	264.46	271.08	25.23	23.15	24.19
CD(P=0.05)	NS	NS	NS	NS	NS	NS	0.76	0.54	0.58
FYM (t ha^{-1})									
0	1.362	1.349	1.356	272.69	258.88	265.79	22.44	20.71	21.57
10	1.331	1.321	1.326	281.65	269.94	275.76	26.49	24.86	25.68
CD(P=0.05)	0.014	0.014	0.012	5.32	5.40	5.39	0.54	0.38	0.40

* = Significant at 5% level of significance
NS = Non-significant

Table: 4
Effect of Udaipur rock phosphate sources, incubation methods and FYM on bulk density, available N and P status of soil after harvest of maize

Treatment	Bulk density(mg m^{-3})			Available N (kg ha^{-1})			Available P (kg ha^{-1})		
	1999-2000	2000-2001	Pooled	1999-2000	2000-2001	Pooled	1999-2000	2000-2001	Pooled
DAP (Check) (P_2O_5 kg ha^{-1})									
40	1.382	1.360	1.371	268.38	253.45	260.92	19.03	18.00	18.52
60	1.383	1.360	1.372	270.13	253.60	261.87	19.75	18.95	19.35
'F' test	NS	NS	NS	NS	NS	NS	NS	NS	NS
DAP (Check) vs. URP treatments									
DAP (Check)	1.382	1.360	1.371	269.25	253.53	261.39	19.39	18.48	18.94
URP treatments	1.363	1.347	1.355	268.60	256.80	262.70	19.18	17.96	18.57
'F' test	*	*	*	NS	NS	NS	NS	NS	NS
URP sources (60 kg P_2O_5 ha^{-1})									
URP (18%)	1.361	1.345	1.353	268.83	256.39	262.61	18.58	17.61	18.10
URP (31%)	1.364	1.348	1.356	268.48	256.30	262.39	19.51	18.11	18.81
URP (34%)	1.363	1.347	1.356	268.50	257.70	263.10	19.46	18.18	18.82
CD(P=0.05)	NS	NS	NS	NS	NS	NS	0.47	0.48	0.44
Incubation methods									
No incubation	1.363	1.349	1.356	268.65	257.47	263.06	18.57	17.54	18.06
Incubation with FYM	1.360	1.345	1.353	268.70	254.30	261.50	19.47	18.17	18.82
Incubation with PSB	1.367	1.351	1.359	267.99	257.78	262.89	18.86	17.78	18.32
Incubation with FYM+PSB	1.361	1.342	1.352	268.08	257.64	262.86	19.83	18.37	19.10
CD(P=0.05)	NS	0.007	NS	NS	NS		0.54	0.55	0.52
FYM (t ha^{-1})									
0	1.375	1.358	1.367	265.73	254.14	259.94	17.92	16.52	17.22
10	1.350	1.335	1.343	271.48	259.46	265.47	20.44	19.41	19.93
CD(P=0.05)	0.014	0.005	0.005	5.48	5.12	5.27	0.38	0.39	0.37

* = Significant at 5% level of significance
NS = Non-significant

decreased with successive crops. URP reduced the bulk density of soil after harvest of wheat and succeeding maize, but didn't influence N content in soil. These results are in conformity with Meena (2003) in alkaline calcareous soil of south Rajasthan.

URP Sources

Better availability of available P in soil after harvest of wheat and succeeding maize was recorded under high grade URP (31% and 34%) as compared to low grade URP (Table 3 and 4). URP (34%) and URP (31%) recorded 7.42 and 5.74% higher available P in soil after harvest of wheat over URP (18%), respectively. After harvest of succeeding maize URP (34%) and URP (31%) recorded 3.98 and 3.92% higher available P in soil over URP (18%), respectively. Highest available P content in soil after harvest of wheat and succeeding maize was observed with URP (34%). This might be due to the fact that low grade URP has higher content of dolomite, which neutralized the acid produced during incubation of URP with organic matter. Whereas, high grade URP has an advantage of not having carbonate gangue, which helps in bringing P into available form (Rana, 2004). Sources of URP had no effect on bulk density and available nitrogen content in soil after harvest of wheat and succeeding maize.

Incubation Methods

Availability of soil phosphorus after harvest of wheat and succeeding maize was higher under FYM and FYM+PSB incubation method treatments over no incubation and PSB incubation method. Highest available P in soil after harvest of wheat and succeeding maize was recorded with FYM+PSB followed by FYM in both years. Incubation of URP with FYM and FYM+PSB recorded 3.94 and 4.81% higher available P content in soil over no incubation, respectively after harvest of wheat. After harvest of maize corresponding increases were 4.21 and 5.76% over no incubation, respectively. The possible reason for this might be that during incubation period FYM produced organic acids which solubilize phosphorus from URP. The activity of PSB increased in presence of FYM, which in turn solubilize unavailable phosphorus from URP

Table: 5
Interactive effect of URP sources and FYM on P availability in soil after harvest of maize (2001)

FYM (t ha^{-1})	URP sources		
	URP (18%)	URP (31%)	URP (34%)
0	19.46	21.09	21.56
10	24.39	25.04	25.15
CD (P = 0.05)		0.660	

to available form. The inoculation of compost with PSB, increase the efficiency of compost in terms of P dissolution and release of soluble P from rock phosphates (Biswas and Narayanasamy, 2002). FYM also acts as chelating agent and increased CEC of soil, which might have restricted the conversion of available phosphorus to di and tri-calcium phosphate in soil and increase available P and viable counts of phosphate solubilizers in soil (Qureshi *et al*., 2005).

FYM

Application of FYM @ 10 t ha^{-1} to wheat had significant effect in reducing bulk density and increasing available N and P content in soil after harvest of wheat and succeeding maize. FYM increased N and P content in soil by 3.75 and 19.05% over no FYM, respectively after harvest of wheat. After succeeding maize, corresponding increases were 2.13 and 15.74% over no FYM, respectively. It is well established fact that organic matter solubilizes applied nutrients as a result of enhanced activity of soil microbes, which in turn, increase availability of nutrient in soil. FYM have positive residual effect on the available N and P in soil (Mahala *et al.*, 2006).

Interactive Effect of URP Sources and FYM

Interactive effect of FYM and URP sources significantly enhanced available P status of soil after harvest of succeeding maize during 2001. All the three sources of URP significantly increased P content of soil alongwith FYM. Application of URP (34%) and URP (31%) proved superior over URP (18%) without FYM, while along with FYM, URP (18%) and URP (31%) were equally effective and URP (34%) proved superior over URP (18%).

4. CONCLUSIONS

On the basis of experiment conducted, it may be inferred that the amount of available P from rock phosphate could be increased by incubation with PSB and FYM. The

Table: 6
Effect of Udaipur rock phosphate sources, incubation methods and FYM on total P uptake

Treatment	P - uptake by wheat (kg ha^{-1})			P - uptake by maize (kg ha^{-1})		
	1999-2000	2000-2001	Mean	1999-2000	2000-2001	Mean
DAP (Check)(P_2O_5 kg ha^{-1})						
40	30.81	28.07	29.44	20.79	23.20	22.00
60	34.65	32.63	33.64	22.22	24.50	23.36
'F' test	NS	*		NS	NS	
DAP (Check) vs. URP treatments						
Check (DAP)	32.73	30.55	31.54	21.51	23.85	23.68
URP treatments	31.88	29.21	30.55	22.11	25.74	23.93
'F' test	NS	NS		NS	NS	
URP sources (60 kg P_2O_5 ha^{-1})						
URP (18%)	29.91	26.94	28.43	20.58	23.99	22.29
URP (31%)	32.59	30.18	31.39	22.52	26.15	24.34
URP (34%)	33.13	30.50	31.82	23.24	27.08	25.16
CD(P=0.05)	1.46	1.48		1.33	1.42	
Incubation methods						
No incubation	27.73	25.55	26.64	21.58	25.29	23.44
Incubation with FYM	33.57	30.71	32.14	22.21	25.82	24.02
Incubation with PSB	31.26	27.79	29.53	22.02	25.52	23.77
Incubation with FYM+PSB	34.95	32.77	33.86	22.64	26.33	24.49
CD(P=0.05)	1.69	1.70		NS	NS	
FYM (t ha^{-1})						
0	28.43	25.00	26.72	20.39	23.66	21.99
10	35.33	33.42	34.38	23.90	27.82	25.86
CD(P=0.05)	1.19	1.20		1.09	1.16	

* = Significant at 5% level of significance
NS = Non-significant

application of organic manure could be successfully used for increasing P availability from rock phosphate. URP may be a viable source of phosphorus in wheat-maize cropping sequence and have equal residual effect to that of water soluble P fertilizers.

REFERENCES

Beri, V., Sidhu, B.S. and Rupela, O.P. 2004. Evaluation of value added rice straw manure prepared from rock phosphate and rice straw in relation to nitrogen and phosphorus substitution in rice-wheat system. In: *Phosphate Rich Organic Manure.(*Shaktawat, M.S., Aery, N.C., Mohan Singh, Swami, B.N. and Katewa, M.K., Eds.), Himanshu Publications, Udaipur. pp. 39-50.

Biswas, D.R. and Narayanasamy, G. 2002. Mobilization of phosphorus from rock phosphate through composting using crop residue. *Fert. News*, 47:53-56.

Cocharan, W.G. and Cox, G.M. 1967. Experimental design. II Ed. John Willey and sons Inc., New York. pp. 95-147.

Majumdar, B., Venkatesh, M.S., Kailash Kumar and Patiram. 2007. Effect of rock phosphate, superphosphate and their mixtures with FYM on soybean and soil-P pools in a Typic Hapludalf of Meghalaya. *J. Indian Soc. Soil Sci.,* 55(2):167-174.

Mahala, H.L., Shaktawat, M.S. and Shivran, R.K. 2006. Direct and residual effects of sources and levels of phosphorus and farmyard manure in maize (*Zea mays*)-mustard (*Brassica juncea*) cropping sequence. *Indian J. Agron.,* 51(1):10-13.

Mamata Begum, Narayanasamy, G., Rai, R.K. and Biswas, D.R. 2007. Influence of integrated nutrient management on nitrogen and phosphorus in soil under wheat-mungbean-maize cropping system. *J. Indian Soc. Soil Sci.,* 55(2):175-183.

Meena, B.S. 2003. Effect of phosphorus sources, solubilizers and bio-regulators on productivity of pigeonpea (*Cajanus cajan*). Ph.D. Thesis, MPUAT, Udaipur. pp. 40-83.

Olsen, S.R., Cole, C.S., Watanable, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA, Washington, D.C. Circ. No. 939.

Piper, C.S. 1950. Soil and plant analysis. Interscience Publishers Inc. New York. pp. 110-111.

Prasad, Murari. 2002. Rock phosphate deposits in Madhya Pradesh-Present status and future prospects. *Fert. News* . 47(2) : 25-31.

Qureshi, A.A., Narayanasamy, G., Chhonkar, P.K. and Balasundaram, V.R. 2005. Direct and residual effect of phosphate rocks in presence of phosphate solubilizers and FYM on the available P, organic carbon and viable counts of phosphate solubilizers in soil after soybean, mustard and wheat crops. *J. Indian Soc. Soil Sci.,* 53(1): 97-100.

Rana, U.V.S. 2004. Production of phosphate rich organic manure (PROM) from press mud and distillery waste. In: *Phosphate Rich Organic Manure. (*Shaktawat, M.S., Aery, N.C., Mohan Singh, Swami, B.N. and Katewa, M.K., Eds.), Himanshu Publications, Udaipur. pp. 51-59.

Rana, N.K., Prasad, J. and Sarkar, A.K. 2004. Residual effect of single large application of rock phosphate on crop yields in acidic soil. *J. Res.*, Birsa Agricultural University. 16(1): 31-37.

Shaktawat, M.S. and Sharma, D.D. 2001. Effect of rock phosphate applied along with FYM and PSB on production of soybean-mustard cropping system in calcareous soils. In: Proceedings of PROM Review-2002 held at RSMML, Udaipur, December 4, 2001. pp. 7-14.

Shaktawat, M.S., Sharma, D.D. and Mehta, Y.K. 2004. Rock phosphate applied alongwith acidulants under soybean-mustard cropping system in alkaline soils. In: *Phosphate Rich Organic Manure. (*Shaktawat, M.S., Aery, N.C., Mohan Singh, Swami, B.N. and Katewa, M.K., Eds.), Himanshu Publications, Udaipur, pp. 23-38.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.,* 25(8): 259-260.

Xu Tang, Jumei Li, Yibing Ma, Xiying Hao, Xiuying Li. 2008. Phosphorus efficiency in long-term (15 years) wheat-maize cropping systems with various soil and climate conditions. *Field Crop Res.,* 108(3): 231-237.