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Phosphate rock dissolution and P uptake by Soybean (*Glycine max*)

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Abstract

Dissolution pattern of five Phosphate Rocks (PRs) in two selected soils of Karnataka namely, soils from Mudigere (Fine Kaolinitic Kandic Paleustalf) and from Doddaballapura (Fine mixed Typic Ustropepts) was monitored using 0.5 M NaOH as extractant. The PRs used were Gafsaphos, 60 mesh (GP1), Gafsaphos, 100 mesh (GP2), North Carolina Rock Phosphate, 80 mesh (NCRP), Maton Rock Phosphate, 100 mesh (MTRP), Mussoorie Rock Phosphate, 100 mesh (MRP) and Udaipur Rock Phosphate, 100 mesh (URP). Laboratory incubation running for 90 days was used for the dissolution study whereas green house study was employed to test the efficiency of different PRs in terms of biomass accumulation. The results showed higher dissolution of imported rocks compared to indigenous rocks. In general, the dissolution rate increased upto 30th day and very gradually declined further. Gafsaphos, 100 mesh registered higher per cent dissolution than Gafsaphos, 60 mesh in both the soils. The biomass of 45 day old soybean plants grown in green house with different PRs positively followed the trend of PR dissolution. Hence, among PRs, GP2 registered highest biomass followed by NCRP and GP1. Highest concentration of P in soybean plants was noticed with GP2 followed by NCRP and GP1. However, NCRP recorded highest P use efficiency followed by GP2 and GP1.

Additional keywords: Karnataka soils, phosphorus use efficiency.

Introduction

Direct methods for measuring the dissolution of phosphate rock in soil have invariably been based on the inorganic P fractionation procedure of Chang and Jackson (1957), or one of its many modifications. Thus, increases in Fe-P and Al-P fractions in a soil to which a PR is added are considered to provide an estimate of P that has dissolved from the PR, whereas increases in Ca-P are considered to indicate unreacted PR (Chu *et al.* 1962). These chemical fractionation procedures are very time consuming.

Single extraction with NaOH is used as a direct estimate of PR dissolution in soil without requiring a more elaborate fractionation scheme (Mackay *et al.* 1986). Minerals of the apatite group do not dissolve to any significant extent in this reagent (Chang and Jackson 1957), any increase in NaOH-extractable P in a soil to which a PR is added should provide an estimate of the amount of P dissolved from the PR. In the present investigation, NaOH extraction is employed to compare the dissolution of imported and indigenous PRs in two selected soils of Karnataka.

Materials and methods

Representative soil samples (0-15 cm depth) collected from coffee growing area of Mudigere and from grape growing area of Doddaballapura were used for the dissolution study using incubation technique. The basic chemical properties of the soils like pH and EC were estimated by standard procedures (Jackson 1973). The OC was estimated by wet oxidation method (Piper 1966). Available P was estimated by estracting with Bray 1 extractant and analysed by chlorostannous molybdate method (Jackson 1973). Exchangeable Ca by versenate titration (Hesse 1971) and exchangeable Al by extraction with 1 M KCl and estimated by aluminon method (Barnhisel and Bertsch 1982). Calcium exchange capacity was determined by equilibrating the soil with 0.025 M $CaCl_2$ and subsequently extracting the soil with 0.1 M KNO_3 (Mackay *et al.* 1986) and sesquioxides were determined by the method of Piper (1966). The physical and chemical properties of the soils are given in Table 1.

Table 1. Physical and chemical properties of the soils

Properties	Mudigere Soil	Doddaballapura soil
Coarse sand (%)	63.50	58.25
Fine sand (%)	10.50	26.20
Silt (%)	10.00	2.53
Clay (%)	14.00	12.00
Textural classification	Loamy sand	Loamy sand
pH (1:2.5)	5.50	6.50
Electrical conductivity (dS m^{-1} at 25°C)	0.13	0.08
Organic carbon (%)	2.62	0.65
Cation exchangeable capacity (c mol(+) kg^{-1})	16.91	5.58
Available P (kg ha^{-1})	13.61	16.47
Calcium exchangeable capacity (cmol(+) kg^{-1})	6.80	4.0
P sorption index	63.05	32.20
Exchangeable calcium (cmol(+) kg^{-1})	3.53	1.25
Exchangeable Al (ppm)	3.20	2.40
Ca saturation (%)	20.87	22.40
Al saturation (%)	32.29	43.01
Sesquioxides (%)	3.6	2.00

Five types of PRs were used for the experiment. They were: Gafsaphos, 60 mesh (GP1) and Gafsaphos, 100 mesh (GP2), obtained from Tunisia; North Carolina Rock Phosphate, 80 mesh (NCRP) from Texasgulf; Maton Rock Phosphate, 100 mesh (MTRP) from Hindustan Zinc Ltd., Rajasthan; Mussoorie Rock Phosphate, 100 mesh (MRP) from Pyrites and Phosphates Chemicals Ltd. (PPCL), New Delhi and Udaipur Rock Phosphate, 100 mesh (URP) from Rajasthan State Mines and Minerals Ltd (RSMML), Rajasthan. The PRs were analysed for total P (Gaur 1967), water soluble P, citrate soluble P and citrate insoluble P as given in A.O.A.C., 1980 (Table 2).

Table 2. Phosphate rocks and P forms

Phosphate Rocks	Total P (%)	Water soluble P (mg/kg)	Citrate soluble P (%)	Citrate insoluble P (%)	Total Ca (%)
GP1	13.03	5.8	2.98	10.05	29.0
GP2	13.03	7.1	2.99	10.04	29.0
NCRP	13.80	45.0	3.10	10.70	30.2
MTRP	10.07	3.5	2.30	07.77	27.0
MRP	07.95	16.6	1.89	06.04	25.0
URP	09.09	16.6	0.75	08.32	23.8

The data on dissolution were fitted in first order reaction in order to interpret the rate of dissolution

$$C = Co\ e^{-kt}$$

where C is the concentration of PR after time t, Co is the initial concentration and k the rate constant.

Phosphate rock dissolution

Two hundred gram of two mm sieved soil were transferred to clean polythene containers of 500 g capacity. The treatments consisted of six PRs and a control which consisted of only soil without PR addition. The seven treatments were replicated thrice. Phosphate rocks were applied at the rate of 500 mg P kg^{-1} of soil. Calculated amount of PRs were weighed and mixed thoroughly with the soil. The soils were brought to field capacity (0.033 MPa). The containers were kept under laboratory conditions. Incubation was carried out for 90 days.

Soil samples were drawn at 7, 15, 30, 60 and 90 days of incubation and analysed for PR dissolution by using 0.5 M NaOH. Soil samples were extracted for 16 hours with 0.5 M NaOH at a soil to solution ratio of 1:100 following a prewash with 10 mL of 1M NaCl for 1 hour to prevent the precipitation of $Ca(OH)_2$ and sorption of inorganic P (Mackay *et al.* 1986). Phosphorus in the extracts was determined colorimetrically using the phosphomolybdate method (Olsen and Sommers, 1982). The difference in P level (ΔP) between treated and control samples was used as an estimate of PR dissolution.

Green house experiment

A green house experiment was conducted using coffee growing soil from Mudigere. The test crop used was soybean var. VSL-32. Each pot received 3 kg soil. The recommended doses of N and K in the form of urea and MOP respectively were applied to each pot as per the treatments and mixed thoroughly. Phosphorus was applied at the rate of 50 kg ha^{-1} in the form of PRs. The soils were watered to field capacity and seeds were sown next day. The treatments consisted of six PRs as P source against SSP and no P treatment. The design used was RCBD with three replications. The crop was grown upto 45 days and was harvested. The biomass of shoots and roots were recorded. concentration of P in plants was estimated by wet digestion using diacid mixture and subsequent analysis by vanadomolybdate method (A.O.A.C., 1980). Phosphorus uptake in the plants was calculated by multiplying dry matter yield with P concentration and Phosphorus Use Efficiency (PUE) was obtained by dividing P uptake by P applied.

Results and discussion

Phosphate rock dissolution

The rate of PR dissolution (Kdis) was calculated for the first phase upto 30 days and overall rate constant using dissolution data from 0-90 days.

Kdis values up to 30th day are very high compared to overall Kdis values (Table 3). This is true for both the soils. The data indicate the faster dissolution up to 30 days when PRs were applied to soils.

All imported PRs recorded Kdis values ranging from 2.187 to 2.72 × 10^{-2} day^{-1} whereas indigenous PRs registered Kdis values ranging from 1.61 to 2.02 × 10^{-2} day^{-1} when reaction rate was taken into account up to 30 days for Mudigere soil. Corresponding values were 2.0 to 2.22 × 10^{-2} day^{-1} for imported P rocks and 1.55 to 1.71 × 10^{-2} day^{-1} for indigenous PRs in near neutral soil. It clearly brings out the comparative dissolution rates of two groups of PRs in two different soils.

Table 3. The dissolution rate (Kdis x 10^{-2} day^{-1}) of different phosphate rocks in soils

Type of PR	Mudigere soil		Doddaballapura soil	
	0-30 days	0-90 days	0-30 days	0-90 days
GP1	2.27	0.66	2.00	0.55
GP2	2.72	0.79	2.22	0.65
NCRP	2.18	0.66	2.00	0.57
MTRP	1.61	0.44	1.55	0.43
MRP	1.98	0.54	1.70	0.47
URP	2.02	0.53	1.71	0.45

The use of NaOH as an extractant is based on the assumption that the reagent does not dissolve unreacted PR and the difference in extractable P between treated and untreated sample gives an index of PR dissolution (Mackay *et al.* 1986). Moreover, NaOH has been shown to be an effective extractant of adsorbed P and non occluded Fe-P and Al-P (Williams *et al.* 1967; Syers *et al.* 1972).

Although the PR materials dissolved at different rates in two soils, in each case the reaction reached equilibrium after about 30 days. Presumably at this point, in the absence of any sinks such as plant uptake or leaching, concentrations of ions in the soil solution had increased to the point where the solubility product of the PR had been reached.

The driving force for PR dissolution are gradients in pH, pCa and $H_2PO_4^-$ activity. The solubility of PR increased with decrease in pH, decrease in activity of Ca and increase in the concentration of sink to reduce $H_2PO_4^-$ ions. It explains the higher dissolution of PRs in Mudigere soil than in Doddaballapura soil. Moreover, Mudigere soil has recorded higher P sorption index than Doddaballapura soil. P sorption capacity of soils is used as an index to identify soils where PR can be used as a P source according to Smyth and Sanchez (1981). Calcium saturation was not a major factor in this study for influencing PR dissolution since this parameter does not differ much between soils. Both exchangeable Al and per cent sesquioxides recorded higher values in Mudigere soil which are also important parameters influencing the dissolution of PR in soils.

Green house study

Shoot and root dry weight of soybean plants are given in Table 4. The efficiency of PRs was reflected both in terms of root weight and shoot weight. Total dry weight of soybean was highest with SSP even in this highly acidic soil, though the imported PRs also gave significantly higher dry matter yield over indigenous PRs. Among the PRs, GP2 resulted in highest dry matter yield which is in confirmation with PR dissolution. There seems to be a direct relationship between PR dissolution and dry matter yield. Phosphate rock was 50-55 per cent as effective as superphosphate with respect to grain and fodder production of cowpea according to Shankarmaloth and Rajendra Prasad (1976).

Table 4. Biomass of 45 day old soybean plants and available P in soil as influenced by different sources of P

Treatments	Shoot dry wt	Root dry wt	Total dry wt	Av. P. in soil
	<———	g/pot	———>	(mg/kg)
Control	1.34	0.74	2.08	2.25
GP1	3.09	1.35	4.44	4.50
GP2	5.32	1.98	5.07	5.58
NCRP	3.39	1.57	4.96	7.11
MTRP	2.30	0.94	3.23	2.43
MRP	2.33	0.99	3.32	3.42
URP	2.97	0.96	3.29	3.33
SSP	3.63	1.44	7.30	12.96
F test	*	*	*	*
CD at 5%	0.25	0.17	0.31	2.06

The highest P uptake (Table 5) was recorded in SSP treatment obviously due to higher dry matter production. All the three indigenous PRs were responsible for significantly lower P uptake than imported rocks. The P use efficiency followed the same trend as that of P uptake. Regi and Jose (1995) reported that PRs were 92.43 per cent as effective as superphosphate in increasing the total P uptake by rice. The available P status of PRs treated soils followed almost the PR dissolution pattern.

This study also indicates the possibility of using 0.5 M NaOH extractable P as an index of PR dissolution. The suitability of this extractant may have to be worked out for all types of soils where PRs are normally recommended.

Table 5. Uptake of P in 45 days old soybean plants

Treatments	P uptake (mg pot^{-1})			
	Shoot	Root	Total	PUE
Control	1.44	0.92	2.36	—
GP1	5.08	2.40	7.48	44.53
GP2	6.61	2.89	9.50	56.42
NCRP	6.01	3.01	9.02	54.34
MTRP	3.40	1.47	4.87	21.70
MRP	3.58	1.58	5.16	23.39
URP	3.46	1.43	4.89	22.83
SSP	8.69	3.41	12.10	98.50
F test	*	*	*	*
CD at 5%	0.43	0.26	0.44	5.02

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