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ADSORPTION AND DESORPTION OF PHOSPHATE BY SOILS

KEY WORDS: adsorption, desorption, added phosphate, hyperbola-like curve

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ABSTRACT

Added P adsorbed, expressed as a percentage of total added P, was closely and inversely related to added P subsequently desorbed, expressed as a percentage of added P adsorbed. This relationship was not linear but followed a hyperbola-like curve. For the limiting cases where adsorption was 0% and 100%, desorption was 100% and 0%, respectively. If desorption is the mechanism limiting the release of P into the soil solution for plant utilization, then the well-established relationship between P adsorbed in the laboratory and the recovery of fertilizer P under field conditions is accounted for.

INTRODUCTION

Soils of high "phosphate-fixing capacity" are soils in which the growing crop recovers only a small proportion of added fertilizer phosphate. These soils usually adsorb large amounts of P when shaken with P-containing solutions in the laboratory.[1] The fact that soil P cannot be utilized by plants until the phosphate has passed into the soil solution by a desorption step[2] suggests that soils which adsorb P most readily, release it by desorption least readily. In this paper the relationship between

the adsorption of added P and the amount of P released in a subsequent desorption step is considered.

MATERIALS

The fifteen Brazilian samples (Table 1) are representative of a large area of the state of Rio Grande do Sul. In each case the upper 25cm of the profile was sampled. Two A1 horizons and a C horizon of three contrasting soils from the United States, and A1 horizons of soils from Afghanistan, Iraq, New Zealand, and Australia were analyzed for comparison with the samples from Brazil. The samples were air dried and passed through a 2-mm sieve. Free iron oxide content and pH (Table 1) were determined because these properties are important factors in phosphate adsorption.

METHODS

Free iron oxides were determined by treatment with citrate-dithionite-bicarbonate and Fe in the extracts was determined by the orthophenanthroline method[3]. Soil pH was measured with a glass electrode using a 1:2 soil-water ratio.

For adsorption studies, 1-g samples of air-dried soil were transferred into a 100-ml polypropylene centrifuge tube and 50ml of 0.1M NaCl containing either 10 or 25 μg P/ml as KH_2PO_4 was added. The tubes were agitated on a wrist-action shaker for 24 hours at 25°C, centrifuged, and an aliquot of the supernatant taken for the colorimetric determination of inorganic P[4]. Following removal of the supernatant, the tubes were weighed to determine the volume of solution entrapped in the residue. An appropriate volume of 0.1M NaCl was added to bring the total volume to 50 ml; the 24-hour extraction, recovery of the supernatant, and the colorimetric determination of inorganic P in the desorption extract were

TABLE 1

Location, pH, and Free Iron Oxide Content of Soils

No.	Soil	Parent Material	Location	pH	Free Fe_2O_3 %
1	Sao Sepé	Sch.*	Brazil	4.7	3.7
2	Cambaí	Sch.	Brazil	5.1	2.3
3	Alta das Canas	Sa., Si.	Brazil	4.3	2.2
4	Sao Gabriel	Sh.	Brazil	5.2	0.5
5	Nova Prata+	Ba.	Brazil	3.8	7.3
6	Passo Fundo	Ba.	Brazil	3.9	2.4
7	Passo Fundo	Ba.	Brazil	3.8	7.8
8	Durox	Ba.	Brazil	3.7	13.2
9	Veranopolis+	Ba.	Brazil	3.8	4.6
10	Passo Fundo	Ba.	Brazil	4.3	11.6
11	Julio de Castilhos	Ba.	Brazil	3.8	3.9
12	Santa Maria	Sh.	Brazil	4.3	0.5
13	Cruz Alta	Sa., Ba.	Brazil	3.7	7.0
14	Santo Angelo	Ba.	Brazil	3.9	14.6
15	Bom Retiro	Sa.	Brazil	3.8	0.7
16	Antigo IIIC	Drift	WI, U.S.A.	5.0	0.7
17	Clyman	Loess	WI, U.S.A.	4.8	0.7
18	Plainfield	Eolian sand	WI, U.S.A.	4.8	0.5
19	Shisham Bagh	Calc. Alluv.	Afghanistan	7.5	0.1
20	Falluja	Calc. Alluv.	Iraq	7.7	1.3
21	Franz Josef, Stage 1	Mica-Sch.	New Zealand	7.9	0.1
22	Motuiti	Eolian sand	New Zealand	6.3	0.4
23	Foxton	Eolian sand	New Zealand	5.4	0.6
24	Koputaroa	Eolian sand	New Zealand	4.6	1.0
25	Corangamite	Ba.	Australia	4.9	8.7

* Sch. = schist; Sa. = sandstone; Si. = siltstone; Sh. = shale; Ba = basalt; Calc. Alluv = calcareous alluvium; Lac. Silt = lacustrine silt.

\+ Soil name unknown; site name given.

then carried out as above. In calculating the amount of P released from the sediment during the desorption step, the amount of P in the entrapped solution following centrifugation after the adsorption step was subtracted. The amount of P adsorbed is expressed as a percentage of the total added P, and the amount desorbed as a percentage of the amount adsorbed.

RESULTS AND DISCUSSION

At the 25 μg added P/ml level the proportion of added P adsorbed by the soils ranged from 85% for the strongly weathered Durox soil from Brazil to 0% for the very weakly weathered Shisham Bagh soil from Afghanistan (Fig. 1).

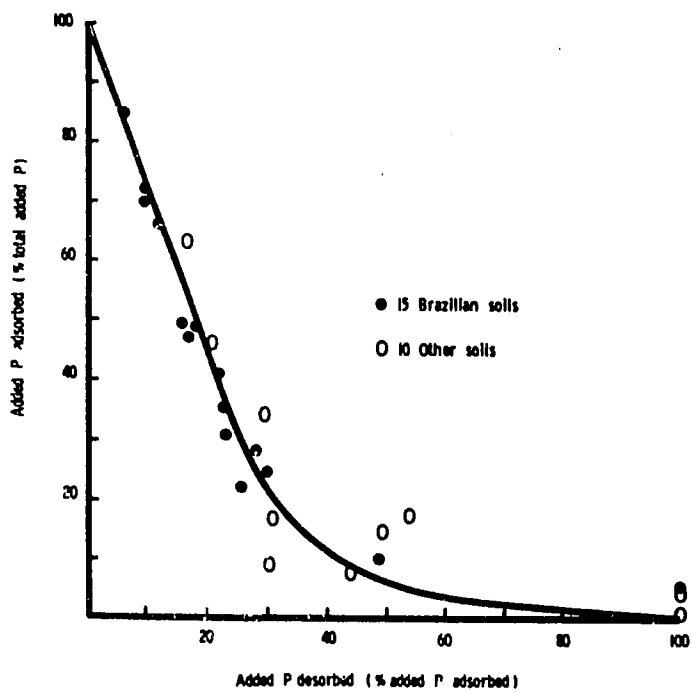

Fig. 1

Adsorption in relation to desorption of added inorganic P (1250 μg) in a 0.1M NaCl system.

In general, P adsorption was related to the free iron oxide content of the soils although variations in the crystallinity of the iron oxides apparently complicate this relationship.

Soils which adsorbed a high proportion of added P during the adsorption step desorbed a low proportion of adsorbed P in the subsequent desorption step, and vice-versa. For example, only 6% of the

adsorbed P was desorbed from the Durox soil (85% adsorption) whereas 100% of the adsorbed P was desorbed from the Bom Retiro soil (6% adsorption). It is apparent (Fig. 1) that the relationship between added P adsorbed (expressed as a percentage of total added P) and added P desorbed (expressed as a percentage of added P adsorbed) is not linear. A curve, however, not unlike a hyperbola in shape, can be drawn through the data points (Fig. 1). The extrapolated curve appears to pass through the point ($x = 0$, $y = 100$). Furthermore, this curve appears to pass through ($x = 100$, $y = 0$) although experimental error in the determination of y is large in this region of the curve.

A curve passing through ($x = 0$, $y = 100$) and ($x = 100$, $y = 0$) arises if, at the end of both the adsorption and desorption steps:

$$\frac{\text{added P on the solid phase}}{\text{added P in solution}} = K$$

then, at the end of the adsorption step

$$\frac{\text{P adsorbed as \% total added P}}{\text{total added P}} = \frac{100K}{1 + K} = y$$

also at the end of the desorption step

$$\frac{\text{P desorbed as \% added P adsorbed during the adsorption step}}{\text{P adsorbed during the adsorption step}} = \frac{100}{1 + K} = x$$

therefore $y = Kx$ and $K = \frac{100-x}{x}$, giving $y = 100-x$.

If this relation holds, then for a sample adsorbing 100% of the added P, the proportion of adsorbed P subsequently desorbed would be 0%, and vice-versa. The relationship between y and x according to this model, however, is linear, and not a hyperbola-like curve as in Fig. 1.

Data obtained with the same adsorption-desorption procedure using the same soils but an added P level of 10 μg P/ml fitted a curve very similar in shape to that in Fig. 1. This was the case even though the proportion of added P adsorbed was higher at the lower initial level of added P and the extent of desorption correspondingly lower.

It is well established that the recovery of added fertilizer P is inversely related to the ability of the soil to adsorb this P against removal by growing plants. Because the adsorption and desorption of added P under our experimental conditions are inversely related, it may be anticipated that soils which adsorb or "fix" fertilizer P most readily under field conditions will release this P least readily into the soil solution.

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Supplement to manuscript "Adsorption and desorption of phosphate by soils" by J. K. Syers, J. T. Murdock, and J. D. H. Williams.

Adsorption and desorption of added inorganic P (500 μg/g soil) in a 0.1M NaCl system.

No.	Soil	Added P adsorbed as % of total added P	Added P desorbed as % of added P adsorbed
1	São Sepé	58	13
2	Cambai	55	22
3	Alta das Canas	46	22
4	São Gabriel	19	32
5	Nova Prata	92	3
6	Passo Fundo I	80	8
7	Passo Fundo II	87	2
8	Durox	98	1
9	Veranopolis	90	4
10	Passo Fundo III	74	10
11	Julio de Castilhos	78	8
12	Santa Maria	51	16
13	Cruz Alta	81	6
14	Santo Angelo	94	3
15	Bom Retiro	12	100