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Saturation, Labile Pools, Distribution Coefficients for Soil Phosphorus on Sanborn Field and other Missouri Soils

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ABSTRACT

A study was made on the soil phosphorus levels of selected plots from Sanborn Field and other Missouri soils in relation to the fertilizer treatments, cropping systems and natural phosphorus levels. The results showed that plots 9, 13, 17, 38 and 5 were not saturated with phosphorus while the soils of plots 2, 10, 20 and the soils of Sarpy, Beulah and Sharkey series were saturated. Soil phosphorus found in the labile pools, as shown by distribution coefficients and Brays reagent was related to the treatment and management of crops on Sanborn Field and the natural phosphorus level of Missouri soils.

INTRODUCTION

Many parameters for evaluating soil phosphorus in relation to crop growth have been devised since the beginning of modern agriculture. Most of these parameters have shown a close relationship with crop growth in limited geographic soil areas. Success has not been complete because uptake from the soil depends on several factors: the amount of total available phosphorus, the concentration of P in the soil solution, the diffusion rate of P in the soil and many biological factors.

The amount of available nutrients in the soil is sometimes referred to as the labile pool. Bowman *et al.* (4) reported that the labile phosphorus in soil, determined by the isotopic exchange method, gave the highest correlation with total phosphorus uptake by crops, as compared with Olsen, Colwell and resin-P determinations, reported by Beckwith (3).

Many acceptable methods have been devised for determining and calculating usable pools of phosphorus, and phosphorus concentration in the soil solution and relating these determinations to phosphorus fertilizer required for adequate plant growth. (2, 3, 6, 8, 10, 13, 14).

The objective of this study was to relate long time fertilizer soil treatments on some Sanborn Field plots and some high phosphorus Missouri soils to the phosphorus saturation of soils, the distribution coefficient (intensity factor) (Kd) and the size of the usable labile phosphorus pool.

MATERIALS AND METHODS

Nine soil samples of Mexico silt loam (udollic Ochraqualf) were taken from the plots in Sanborn Field at the University of Missouri-Columbia. Sanborn Field was established in 1888. Two samples, Sharkey clay (vertic Haplaquept) and Beulah loamy fine sand (typic Dystrochrept), derived from Mississippi River alluvium, and one sample of Sarpy loamy fine sand (typic Udipsamment), derived from Missouri River alluvium, were used for comparison as soils more than adequately supplied with "available P" as estimated by Bray No. 2. Some chemical properties of the soils and treatment pertaining to Sanborn Field is given in Table 1.

The pH of the soils was determined by mixing 10 g of soil with 20 ml of 0.01 M $CaCl_2$ solution (12). Isotopic exchange was carried out in duplicate on 10 g of soil by shaking with 20 ml of 0.005 N citric acid solution containing P^{32} for 24 hours. After the soil mixture was shaken in an end-over-end shaker at room temperature, the samples centrifuged, the clear supernatent liquid was removed. The radioactivity of P^{32} in the supernatent was determined by liquid scintillation counting, with a gel mixture of Triton X-100, toluene, PPO and POPOP. The radioactivity of the samples and the control solution was measured with a Packard Model 3003 Tri-Carb Scintillation Counter. The concentration of the non-radioactive phosphorus was determined by the ascorbic acid method with a Beckman DB Spectrophotometer (11). The labile pool phosphorus (LPp) and the distribution coefficient of phosphorus (Kd) of each soil were calculated from the values obtained by spectro-photometric analysis and isotopic measurements (5,11).

$$\text{Lpp} = \frac{\text{Concentration of P in solution (ppm)}}{\text{Radioactivity of } P^{32} \text{ in solution}} \times \frac{\text{Volume of solution (ml)} \times 100}{\text{Air dry weight of soils (g)}}$$

$$\text{Kd} = \frac{\text{Radioactivity of } P^{32} \text{ in solid phase (cpm)}}{\text{Radioactivity of } P^{32} \text{ in solution (cpm)}} \times \frac{\text{Volume of solution (ml)}}{\text{Air dry weight of soil (g)}}$$

The extractable phosphorus was determined by Bray No. 2 reagent. Two g of soil with 20 ml of Bray 2 extractant were shaken for 5 minutes. The amount of phosphorus in the extract was determined by the ascorbic acid method. Phosphorus sorption and the phosphorus fertilizer requirement were measured using the method developed by Ozanne and Shaw (7, 8, 14). Two g of air dry soil were introduced into equal weight certrifuge tubes with 20 ml of 0.01M CaC1 solution containing 0 to 40 ppm of phosphorus. The triplicated mixtures were shaken for 17 hours on the end-over-end shaker and centrifuged for 10 minutes at 2,000 rpm. After the concentration of phosphorus in the supernatant was determined, the amount of phosphorus absorbed in the supernatent was determined, the amount of phosphorus absorbed by the soil and Langmuir phosphorus maxima were calculated (13).

RESULTS AND DISCUSSION

Phosphorus that disappeared from solution was assumed to have been sorbed. These values are shown in Figure 1. The optimum phosphorus concentration in the soil solution for good plant growth may vary with plant species and the soil moisture content (1). A concentration of 0.2 ppm has been suggested as one at which most plants will attain maximum growth (3).

A value of 0.3 ppm was used as a standard value for establishing fertilizer rate for wheat (13). For this study, the phosphorus status and the fertilizer requirement of each soil was evaluated using 0.3 ppm as a critical concentration in the equilibrated solution. The soil of plots 17, 9, 13, 19, 38 and 5 from Sanborn Field sorbed 123, 115, 82, 55, 47 and 40 ug P/g soil, respectively. Phosphorus should be applied to these soils for maximum plant growth.

The other soils studied were sufficiently phosphorus saturated so that P in solution exceeded 0.3 ppm. These would not require further phosphorus fertilization for growth of even the more demanding crops (3, 7, 8). The phosphorus requirements of plots 9, 13 and 17 were higher than the other soils because these plots had not been previously fertilized. Although the P sorption isotherm method has failed sometimes to evaluate the P supplying capabilities of widely differing soils (1), generally it agreed well with plant accumulation of P (3).

The labile pool is defined as the sum of P in the soil solution and the amount of P on the soil exchanger when the soil is equilibrated with 0.005 N citric acid solution. The labile pool was determined by isotopic exchange. The available P was that amount as extracted by Bray No. 2 solution. The distribution coefficient and the phosphorus absorption maxima are given in Table 2. The relationships were sought among the four factors investigated. Consistent trends were not observed among the amounts of P sorbed and the quantity found in the labile pools. In most instances, the labile P was well correlated with the amount extracted with Bray No. 2 (Fig. 2). The magnitude of P adsorption maxima decreased with increasing percentage of sand in the soils.

The intensity factor of soil P was investigated and given in Table 3. The distribution coefficient, Kd, may be regarded as a practical measure of the relative bonding of ions to the soil (15). The apparent intensity factor, Kd(9), will change with the amount of P in the labile pool, the adsorption properties of the soil colloid and the kinds of phosphorus in the soil. The 0.005 N citric acid P and the amount of P found in the 0.01 M $CaC1_2$ were both increased when fertilizer phosphorus was added to the soil. With the exception of the Beulah soil, the phosphorus in 0.005 N citric acid was closely related to the labile pool P.

The Sanborn Field samples showed a P sorption maximum in the range of 249-377 mg/kg. The differences can be related to the O.M. depletion. Table 4 shows untreated plots 9, 13 and 17 to have a P sorption maximum of 357 mg/kg. The average value for the treated plots was 287 mg/kg. The average 0.M.% for treated plots was 1.6% as compared to 2.5% for the untreated plots. The higher than expected P sorption maximum shown by plot 19 is possibly a result of a change in distribution caused by removing grass hay.

Sanborn Field plots were excellent for evaluating the effects of fertilizer treatments on the amounts and kinds of phosphorus remaining in the soil. The plots are of less value for comparing soil test P to crop yields, since the nitrogen treatments were not uniform. A relationship was observed between the grain yields of wheat and the labile P of plots 9, 5, 2 and 10 (Fig. 3). The distribution coefficient Kd and the yield of wheat also showed reasonable relationship.

SUMMARY

Soils sampled from Sanborn Field, and the alluvial land associated with the Mississippi and Missouri Rivers, were studied in relation to the amount of P extracted by Bray's reagent, the size of the labile pool, the amounts soluble in 0.005 N citric acid, the phosphorus adsorption capacity as measured with 0.01 M $CaCl_2$ and the distribution coefficient. The phosphorus adsorption capacity was decreased, the phosphorus saturation and the labile pool increased when lime, P fertilizer and manure were applied to the soil.

This study revealed the following items of importance:

1. The soil found on plots 17, 9, 13, 38 and 5 were not saturated with phosphorus, while the soils of plots 2, 10, 20, and the Sarpy, Beulah and Sharkey series were saturated.
2. A high Kd (low intensity) for P was found on soils 9, 17 and Missouri River Sarpy soil. A low Kd was found for the Beulah and Sharkey soils. The low Kd observed on plot 10 might be a result of manure treatments.
3. Untreated plots 9, 13 and 17 showed a low level for labile pool phosphorus. The amounts of extractable phosphorus were also found to be low. It is of interest to note that plot 10 which has been treated with manure and cropped to continuous wheat has the highest labile pool, it is higher than the soils of the rivers. Plot 38 which was treated with annual amounts of manure for 25 years, then treated with P_2O_5 in amounts equal to 12 lbs annually for 75 years, reveals a low level in the labile pool. This indicates that the annual additions of 12 lbs of P_2O_5 will not increase phosphorus levels when the soil is being cropped.
4. The amount of phosphorus extracted with Brays No. 2 reagent correlated with the size of the labile pool for all soils with the exception of Sarpy and Beulah. This observation supports the suggestion that extractable phosphorus will result in a reliable value for the size of the labile pool for all soils except those which contain apatite.

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Table 1. Chemical properties of some Missouri soils and the treatments of Sanborn Field plots.

Soils	pH[x]	Bray 2	OM	Sum. CEC[xx] Me/100 g	Materials applied	Amount of P^2O^5 Estimated	Cropping System
Sanborn Field		P ppm	%			lbs/A	
2	5.9	96	2.0	14.8	CaMg lime, phosphate KC1 according to soil test, and N	2292	Continuous Wheat
5	5.5	65	2.5	14.2	3 tons manure annually	1215	Continuous Wheat
9	4.6	16	1.5	13.8	No treatment		Continuous Wheat
10	5.4	143	2.5	13.6	6 tons manure annually	2430	Continuous Wheat
13	4.8	8	2.0	10.2	No treatment		Continuous Corn
17	4.7	13	1.5	15.7	No treatment		Continuous Corn
19	5.5	42	3.0	13.6	8 tons manure on corn 5 tons manure on wheat	860	Corn-oats-wheat clover-tim.-tim.
20	6.6	148	2.3	11.8	CaMg-lime rock phosphate KC1 and N according to test	2292	Corn-oats-wheat clover-tim.-tim.
38	6.5	33	2.5	13.9	Lime 200 lbs of 4-12-4 on corn and wheat	1326	Corn-oats-wheat clover
Sarpy	7.7	93	0.2	6.0	———	———	———
Beulah	6.5	54	1.1	3.2	———	———	———
Sharkey	5.6	176	1.3	19.8	———	———	———

Table 2. Labile pools, distribution coefficients and adsorption of phosphorus.

Soils	Brays No. 2	LP P	%		P max.
Sanborn Field	ppm P	ppm	Kd	OM	ug/g
2	96	66	178	2.0	274
5	65	44	239	2.5	321
9	16	20	292	1.5	377
10	143	121	152	2.5	309
13	8	12	169	2.0	318
17	13	16	268	1.5	376
19	42	24	202	3.0	310
20	148	83	198	2.3	248
38	33	19	173	2.5	264
Sarpy	93	15	215	0.2	50
Beulah	54	24	3	1.1	trace
Sharkey	176	103	33	1.3	trace

Table 3. Distribution coefficients concentration of phosphorus in various extracts.

Soils	Kd	0.005 N Citric Acid P	0.01M $CaCl_2$ P	Radioactivity of P remaining in solution
Sanborn Field		ppm	ppm	%
2	176	.367	.102	1.11
5	239	.183	.056	.83
9	292	.068	.011	.68
10	152	.787	.281	1.30
13	169	.068	.021	1.17
17	268	.060	.008	.74
19	202	.117	.026	.98
20	198	.415	.097	1.00
38	173	.110	.021	1.14
Sarpy	215	.070	.005	.92
Beulah	3	5.060	.131	42.24
Sharkey	33	2.930	.450	5.67

Table 4. Labile pools, sorption max. phosphorus saturation soluble phosphorus and treatments of soil.

Plot/Soil Designation	Plot Fertilizer History (Summary)	Approximate P added over the years	P Sorption Max	Labile P Pool	P Saturation	.01 M $CaC1^2$ P	pH
		Kg/ha	Mg/kg	mg/kg	%	Mg/L	
9	None	OP	377	20	5	.011	4.6
13	None	OP	318	12	4	.021	4.8
17	None	OP	376	16	4	.008	4.7
19	Manure 2.2 tons	860	310	24	8	.026	5.5
5	Manure 3 tons	1215	321	44	14	.056	5.5
10	Manure 6 tons	2430	309	121	39	.281	5.4
38	Lime, 4-12-4	1326	264	19	7	.021	6.5
2	Lime, NPK	2292	274	66	24	.102	5.9
20	Lime, NP (Rock)K	2292	248	83	33	.097	6.6
Sarpy	Missouri River		50	15	30	.005	7.7
Beulah	Mississippi River		Neglayable	24	Excess	.131	6.5
Sharky	Mississippi River		Neglayable	103	Excess	.450	5.6

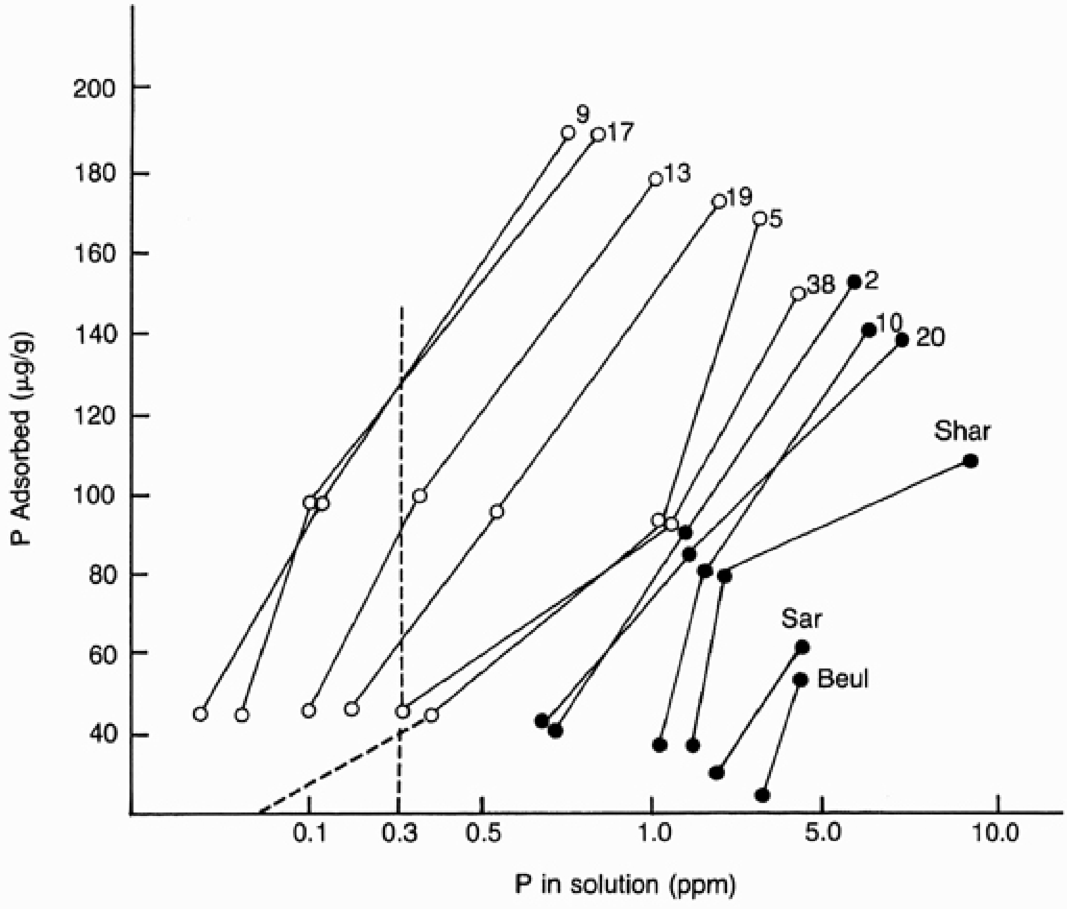

Figure 1. Phosphate adsorption, with various equilibrium concentration of P, by some Missouri soils.

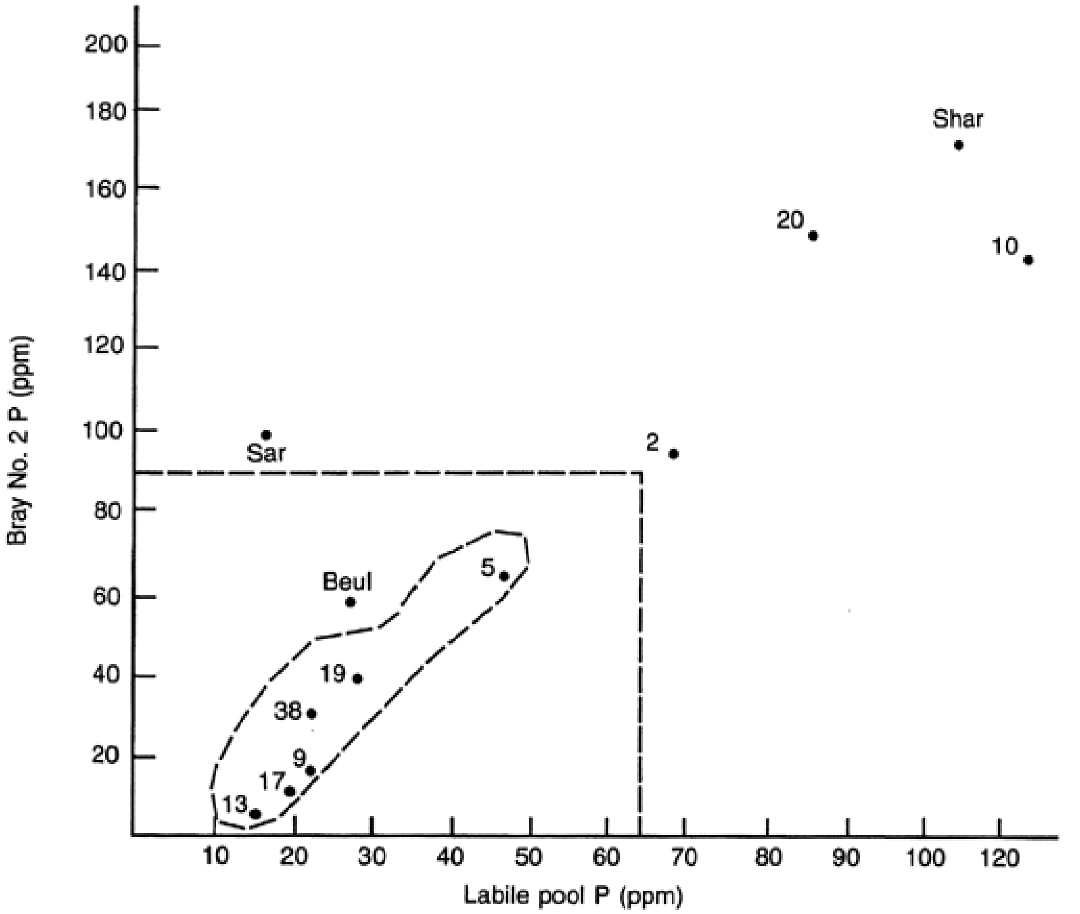

Figure 2. Relationship between Bray No. 2 p and Labile pool P.

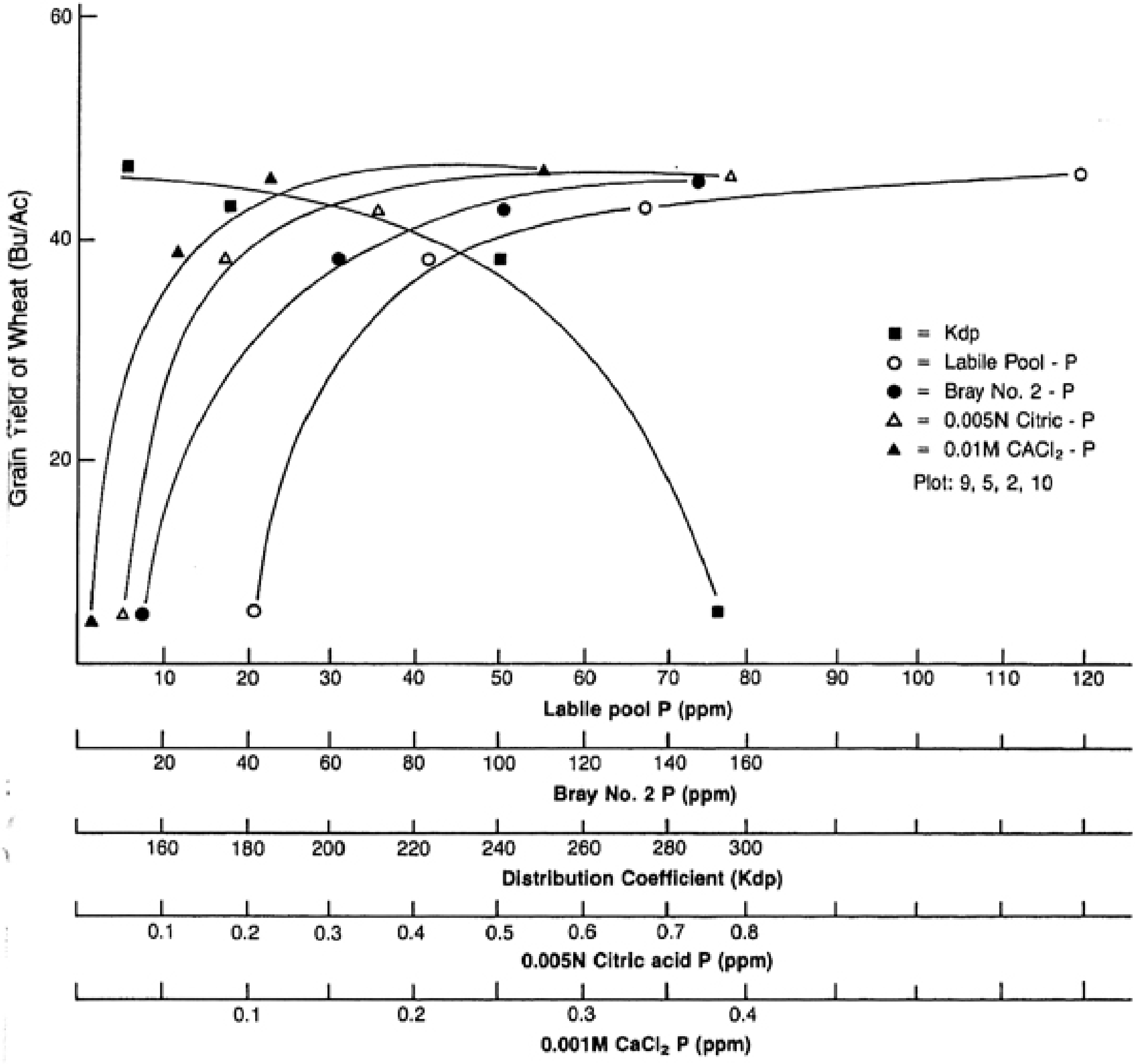

Figure 3. Relationships between Grain Yield of Wheat and some Soil Phosphate Parameters.