Phosphorus Adsorption-Desorption Characteristics of Two Soils Utilized for Disposal of Animal Wastes[1]

K. R. REDDY, M. R. OVERCASH, R. KHALEEL, AND P. W. WESTERMAN[2]

ABSTRACT

The purpose of this study was to determine the effect of animal waste loading rates on P adsorption-desorption characteristics of two soils. In a laboratory incubation study, Norfolk soil was treated with beef, poultry, or swine wastes; and allowed to decompose under optimum moisture conditions for a period of 30 days. Phosphorus adsorption-desorption characteristics of the soil were measured at the end of the incubation period. Application of beef, poultry, and swine wastes to a Norfolk soil decreased adsorption capacity of the soil and increased soluble P (in $0.01M$ $CaCl_2$), acid-extractable P ($0.05N$ HCl + $0.025N$ H_2SO_4), equilibrium P concentration (EPC), and P desorption (after four 1-hour extractions).

In a field study, increased rates of swine lagoon effluent application over a period of 5 years to a Norfolk soil (Site 1) and for 3 years to a Cecil soil (Site 2) also increased soluble P (in $0.01M$ $CaCl_2$), acid extractable P, P desorbed, and EPC values, and decreased the adsorption capacity. At high loading rates of swine lagoon effluent, soluble P movement occurred to a depth of 75 and 30 cm at Site 1 and 2, respectively. Phosphorus adsorption increased with depth, and EPC values decreased with increasing depths of soil profile. A significant relationship was observed between EPC values, and soluble and acid extractable P.

Additional Index Words: **equilibrium P concentration, loading rate, swing lagoon effluent, beef waste, poultry waste, swine waste, P migration.**

Reddy, K. R., M. R. Overcash, R. Khaleel, and P. W. Westerman. 1980. Phosphorus adsorption-desorption characteristics on two soils utilized for disposal of animal wastes. J. Environ. Qual. 9:86–92.

Application of animal wastes on farm land is usually regulated according to N requirement of crops to preclude nitrate leaching and ground water contamination, resulting in no control or consideration of P application rates. When soils are utilized for disposal purposes, P application rates of animal wastes are considerably higher than crop uptake, resulting in greater accumulation of P in the soil. Accumulation of P in soil increases with increasing waste application rates as measured for beef wastes (Herron and Erhart, 1965; Murphy et al., 1972; Vitosh et al., 1973), dairy wastes (Olsen et al., 1970),[3] swine wastes (Collins et al., 1978; Sutton et al., 1974; Cummings et al., 1975), and poultry wastes (Perkins et al., 1964; Shortall and Leibhardt, 1975).[4] These researchers concluded that application of animal wastes increases plant available P in acid or alkaline soils.

A few studies have observed significant amounts of P movement in the soil profile (Adriano et al., 1975; Bielby et al., 1973). The movement of P in the soil profile is dependent on the rate of P application, type of waste, and P reaction with the soil. Several researchers have observed a P sorption by soils in the presence of organic residues (Dalton et al., 1952; Gaur, 1969;

---

[1] Contribution from the Dep. of Biolog. and Agric. Eng., and North Carolina Agric. Exp. Stn., Raleigh, NC 27607, as Journal Article no. 5833. The use of trade names in this publication does not imply endorsement by the North Carolina Agric. Exp. Stn. of the products named, nor criticism of similar ones not mentioned. This research was supported in part by the U.S. Environ. Prot. Agency on a grant, no. R-805011-01-0. Received 16 Oct. 1978.

[2] Assistant Research Scientist, Univ. of Florida, Agric. Res. and Educ. Center, Sanford, FL 32771; and Associate Professor, Research Associate, and Assistant Professor, Dep. of Biolog. and Agric. Eng., North Carolina State Univ., Raleigh, respectively.

[3] A. L. Sutton, D. W. Nelson, J. J. Moeller, and L. F. Huggins. 1974. Application of anaerobic liquid dairy waste on slopping frozen land. Presented at 69th Annu. Meet., Am. Dairy Sci. Assoc., 23–26 June 1974, Univ. Guelph, Canada.

[4] S. R. Crane. 1978. A laboratory investigation of the short-term chemical and microbial transformations in the soil following surface land application of poultry manure. M.S. Thesis, North Carolina State Univ., Raleigh, N.C.

Struthers and Sieling, 1950; Vyas, 1964). It was concluded from these studies that during decomposition of organic residues, organic acids form stable complexes with Fe and Al, and consequently block P retention in the soil. However, increased retention due to organic residue application has also been observed (Fokin and Chistova, 1964; Harter, 1969; Jackman, 1955; Larsen et al., 1959; Rennie and McKercher, 1958). So far, very little is known about the effect of animal waste application on P sorption by soils.

The objectives of this study were to determine the effect of various animal waste loading rates on: (i) the phosphorus adsorption-desorption characteristics of the soils treated with fresh beef, poultry, and swine wastes (studied under laboratory conditions), and swine lagoon effluent (studied under field conditions); and (ii) the characteristics of P movement in the soils treated with long-term application of swine lagoon effluent.

MATERIALS AND METHODS

The soils used in this study belong to the Norfolk and Cecil series (Table 1). Norfolk series, a loamy sand, typical of the Coastal Plains region, is a member of fine loamy siliceous, thermic family of typic paleudults. These soils often consist of a deep, well-drained profile formed in a loamy Coast Plains sediments, with a grayish brown Ap horizon (0 to 22 cm) and a light yellowish brown A2 layer (22 to 35 cm). The Cecil series, a sandy loam typical of the Piedmont regions, is a member of the clayey, kaolinitic, thermic family of typic Hapludults. The soils have dark grayish brown or brown sandy loam A horizons (0 to 15 cm) and red Bt horizons. In all experiments, animal waste application rates were based on the N content.

EXPERIMENT I (LABORATORY)

Laboratory incubations were carried out in 400-ml plastic containers, which received 200 g of Norfolk soil (0 to 15 cm layer) incorporated separately with fresh beef, swine, or poultry wastes at 600 µg of total N/g soil. Incorporation of the waste into the soil was achieved by mixing soil-waste complex for a period of 5 min with a spatula. Some of the selected characteristics of the wastes used in this study are presented in Table 2. The moisture content of the soil-waste system was adjusted to field capacity (10% soil moisture). Duplicate incubations were carried out for a period of 30 days at 25°C. At the end of incubation, soil was dried at 40°C for a period of 48 hours and stored at 4°C in tightly sealed containers.

EXPERIMENT II (FIELD)

Soil samples were obtained to a depth of 105 cm, from two experimental sites, where swine lagoon effluent was applied at a rate of 650 and 1,300 kg N/ha per year for a period of 3 years (at the Unit II station) and at a rate of 325, 650, and 1,300 kg N/ha per year for a period of 5 years (at the Central Crops Research Station, Clayton). At the Unit II station, soil samples were also obtained from plots receiving 31 kg P/ha per year as fertilizer P only. At the Unit II station, the soil type belonged to the Cecil series with a fescue grass system, whereas, at the Clayton site, the soil type belonged to the Norfolk series with a coastal bermudagrass system. At the Unit II and Clayton sites, the plot sizes measured 9 m^2. Plots at Unit II were irrigated with effluent from about March through mid-November. At the Clayton site, plots were irrigated with effluent from about late April through mid-September. To achieve desired loading rates, about 12, 24, and 36 cm/year of swine lagoon effluent were applied at weekly intervals. Selected characteristics of the swine lagoon effluent are presented in Table 3. Details of the system layout and procedures were given by Cummings et al. (1975).

Table 1—Selected characteristics of the two soils used in the study.

Soil depth	Clay	Silt	Sand	Desorbed-P in 0.01*M* $CaCl_2$	Acid ext. P	pH in 0.01*M* $CaCl_2$
cm		%		µg/g of soil		
			Norfolk soil			
0-15	3.2	11.8	85.0	0.20	43.5	4.2
15-30	4.3	9.7	86.0	0.10	5.5	4.1
30-45	3.1	9.4	87.5	0.08	1.5	4.0
45-60	3.7	10.0	86.3	0.08	0.5	4.0
60-75	7.9	8.7	83.4	0.01	0.2	3.9
75-90	28.2	6.0	65.8	0.00	0.2	3.9
90-105	21.9	6.5	71.0	0.00	0.1	3.7
			Cecil soil			
0-15	16.1	16.5	67.4	0.15	18.5	4.9
15-30	27.6	20.4	52.0	0.05	11.0	4.7
30-45	48.2	16.9	34.9	0.05	1.5	4.6
45-60	58.2	15.5	25.8	0.02	0.2	4.5
60-75	56.7	14.5	28.8	0.01	0.1	3.9
75-90	42.5	15.7	41.8	0.00	0.1	3.9
90-105	33.1	18.8	48.1	0.00	0.1	3.8

Table 2—Selected chemical characteristics of fresh animal wastes used in Experiment I.

Parameter	Beef	Poultry	Swine
	Type of waste		
		%†	
Moisture	83.3	73.0	72.9
Total C	48.8	22.4	44.6
Total N	2.45	6.03	3.97
Total P	0.71	1.79	2.29
PO_4-P	0.23	0.43	1.59

† Dry wt basis.

On soil samples obtained from Experiments I and II, soluble P in 0.01*M* $CaCl_2$, P in 0.05*N* HCl + 0.025*N* H_2SO_4, P desorbed after four 1-hour extractions, and P sorption characteristics such as equilibrium P concentration (EPC) and P adsorption maximum were determined as described below.

PHOSPHORUS IN 0.01*M* $CaCl_2$ EXTRACTS

Twenty g of soil samples were shaken in 50 ml of 0.01*M* $CaCl_2$ solution for 60 min. At the end of the shaking period, pH ofthe soil suspension was measured. The suspensions were then filtered through a 0.45-µg Millipore filter and analyzed for ortho-P.

PHOSPHORUS IN 0.05*N* HCL + 0.025*N* H_2SO_4 EXTRACTS

Five g of air-dried soil were shaken for 5 min with 0.05*N* HCl + 0.025*N* H_2SO_4, in a soil to extracting solution ratio of 1 to 10. The soil suspensions were filtered through a 0.45-µm Millipore filter and analyzed for ortho-P.

DESORPTION OF P

Soil samples obtained from Experiment I and II were subjected to four 1-hour extractions. Five g of soil were shaken with 100 ml of 0.01*M* $CaCl_2$ for a period of 1 hour. The soil suspensions were then centrifuged. The supernatant liquid was removed for analyses, and re-

Table 3—Selected chemical characteristics of swine lagoon effluent used in Experiment II.

Parameter	Average concentration
	mg/liter
Chemical oxygen demand	1,140
Total organic C (C)	375
Total N (N)	224
Total P (P)	55
PO_4-P	50
Total solids	3,000

placed with an equal amount of 0.01M $CaCl_2$ (containing no P). This procedure was repeated for four consecutive extractions. Phosphorus desorbed at the end of each extraction was measured and summed to obtain the total quantity of P desorbed from four extractions.

EQUILIBRIUM P CONCENTRATION (EPC)

Five g of soil, mixed with 100 ml of volumes of phosphate solution (made in 0.01M $CaCl_2$) of known initial concentration ranging from 0, 5, 10, 20, and 50 μg/ml, plus three drops of toluene, were equilibrated under continuous shaking for a period of 18 hours. Longer equilibration periods were not used because of problems associated with suspressing the microbial activity beyond 18 hours. This was due to high availability of energy source in the soils treated with animal wastes. After equilibration, the supernatant liquid was filtered through a 0.45-μm Millipore filter and analyzed for P remaining in solution.

The method used to determine EPC was essentially the same as described by White and Beckett (1964). EPC is the concentration that is supported by the soil samples when in contact with an ambient solution such that no P is either gained or lost by the solid. Phosphorus adsorption parameters were determined using the Langmuir isotherm in the following general equation:

$$C/S = C/S_{\max} + 1/K\,S_{\max}$$

where C is final solution concentration and C/S is quantity of P adsorbed or desorbed per unit mass of adsorbent. A linear regression analysis was performed between C and C/S. The $S_{\max}$, the adsorption maximum, was obtained from the slope and intercept of the regression equation, respectively. Phosphorus adsorbed at 1,000 μg P/g added (50 μg P/ml in 0.01M $CaCl_2$) was compared with the adsorption maximum estimated from the Langmuir isotherm.

ANALYTICAL METHODS

Soil extracts obtained either by 0.01M $CaCl_2$ or dilute acid were analyzed for ortho-P using an automated colorimetric ascorbic acid reduction method on a Technicon Auto analyzer (USEPA, 1974).

RESULTS AND DISCUSSION

EFFECT OF DIFFERENT ANIMAL WASTES ON P ADSORPTION-DESORPTION CHARACTERISTICS OF NORFOLK LOAMY SAND

Addition of different types of animal wastes, based on N loading rate, resulted in varying amounts of total and ortho-P applied to the soil. The ratios of total P to total N were 0.29, 0.30, and 0.58 for fresh beef, poultry, and swine wastes, respectively (Table 2). Application of animal wastes increased soluble P (in 0.01M $CaCl_2$) and acid extractable P (Table 4) in the soil at the end of a 30-day decomposition period. Similarly, increases in soluble P (in 0.01M $CaCl_2$) due to animal waste application to alkaline soils were also reported by Olsen and Barber (1977).

In this study, P desorbed during four 1-hour extractions was highest (Table 4) in the soil treated with swine waste, followed by poultry and beef wastes. Phosphorus adsorbed at 1,000 μg P added per gram of soil was 28, 52, and 140 μg P/g of soil for beef, poultry, and control treatments, respectively; while the soil treated with swine waste desorbed an additional 54 μg P/g of soil rather than adsorbing any P. This indicates that swine waste P was applied beyond the assimilatory (adsorption + precipitation) capacity of the soil. EPC values (Table 4) determined at zero sorption from isotherms were 14.0, 7.8, and 0.06 μg/ml for beef, poultry, and control treatments, respectively; whereas, the soil treated with swine waste did not reach zero sorption in the concentration range (0 to 50 μg P/ml) studied. This indicates that EPC values for the soil treated with swine wastes are much higher than those obtained for the soil treated with beef and poultry wastes.

The parameters shown in Table 4 are also presented based on 100 μg P applied through animal waste. The data indicate that swine waste application increased soluble P in the soil per unit of P added as compared to beef and poultry wastes. The ratio of ortho-P to total P was 0.66 for swine waste followed by 0.32 and 0.24 for beef and poultry wastes, respectively. However, very little difference was observed in acid-extractable P values between swine and poultry wastes applications. This was probably due to the nature of waste material. The data reported by Reddy et al. (1980) indicate that poultry and swine wastes have a large fraction of easily decomposable organic matter, compared to beef wastes.

EFFECT OF LONG-TERM DISPOSAL OF SWINE LAGOON EFFLUENT ON P ADSORPTION CHARACTERISTICS OF NORFOLK AND CECIL SOILS

Continuous application of swine lagoon effluent for a period of 5 years on a Norfolk soil and for 3 years on a Cecil soil increased the soluble P (in 0.01M $CaCl_2$) in response to the increase in loading rate (Fig. 1). In the Norfolk soil, soluble P concentration increased to about 12 μg P/g of soil in the surface soil samples (0 to 15) for the application rate of 322 kg P/ha per year. This was followed by 3.4, 2.5, and 0.2 μg P/g of soil for application rates of 161 kg P/ha per year, 81 kg P/ha per year, and a control (no P applied), respectively. The bulk density of the soil was about 1.65 g/cm^3, yielding a

Table 4—Effect of animal waste application on P behavior in a Norfolk soil, after a 30-day decomposition period.

Type of animal waste	P loading rate	Soluble P in in 0.01M $CaCl_2$	Acid-ext. P	P desorbed after four 1-hour extractions	P sorbed at 1,000 μg P/g of soil added in 0.01M $CaCl_2$	EPC
	μg/g of soil					μg/ml
Control	--	0.2	49	1.5	140	0.06
Beef	174	9.0 (5.1)†	124 (43)	30.0 (16.3)	28 (16)	14.0
Poultry	178	9.8 (5.4)	214 (93)	39.0 (21.1)	52 (29)	7.8
Swine	345	34.0 (9.8)	372 (94)	102.0 (29.1)	−54 (−16)	ND‡

† The μg P/100 μg P added through animal waste.
‡ Soil did not reach zero desorption in the concentration range studied.

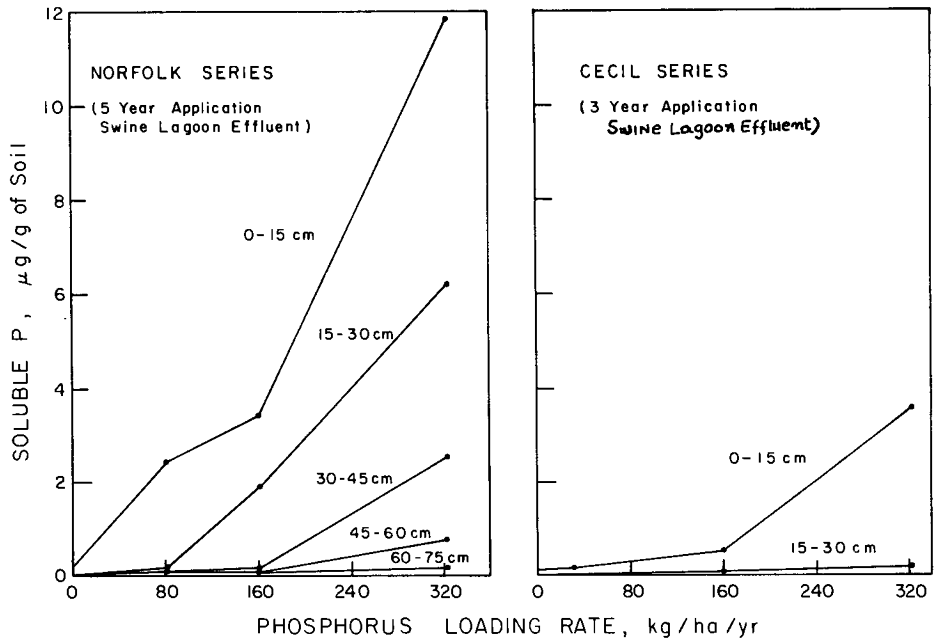

Fig. 1—Soluble P (in 0.01*M* $CaCl_2$) in Norfolk and Cecil soil as influenced by loading rate of swine lagoon effluent.

porosity of 0.38. Appreciable amounts of soluble P were observed even at a depth of 45 to 60 cm for the treatments with a high manure loading rate. However, at all loading rates, soluble P decreased with increasing depth. No detectable amount of soluble P was measured beyond the 75-cm depth. In the Cecil soil, no appreciable amount of P moved beyond the 30-cm depth. Soluble P concentrations of the surface soil samples (0 to 15 cm) were 3.6, 0.6, 0.2, and 0.1 µg/g of soil for high, medium, low, and control (no applied P), respectively (Fig. 1). The bulk density of this soil was about 1.53 g/cm^3, and the total porosity was 0.42. Differences in soluble P concentrations between these two soils were probably due to differences in physico-chemical properties of these two soils and cropping system, and period of swine lagoon effluent application.

Acid extractable P was also increased with an increase in loading rates of swine lagoon effluent (Fig. 2). In the Norfolk soil, acid-extractable P concentrations of surface soil (0 to 15 cm) increased from 27 to 150 µg/g of soil, whereas, in the Cecil soil, the increase in available P was about 18 to 87 µg/g of soil. A measurable

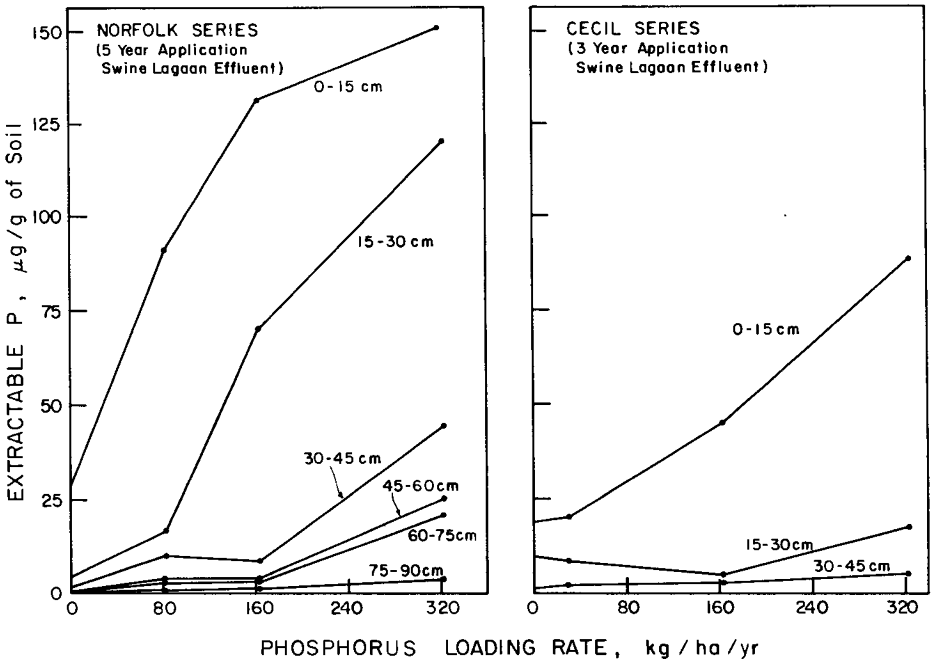

Fig. 2—Acid extractable P (in 0.05*N* HCl + 0.025*N* H_2SO_4) in Norfolk and Cecil soil as influenced by loading rate of swine lagoon effluent.

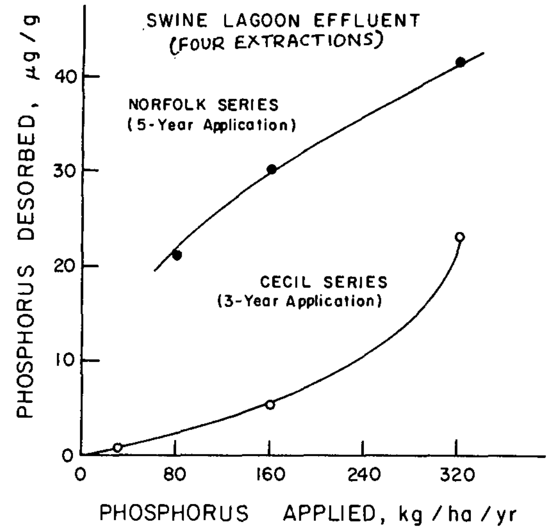

Fig. 3—The sum of phosphorus desorbed after four 1-hour extractions with 0.01*M* $CaCl_2$ in Norfolk and Cecil soils (surface 15 cm) as influenced by loading rate of swine lagoon effluent.

concentration of acid-extractable P was observed at the 75 to 90 cm and 30 to 45 cm depths, in Norfolk and Cecil soils, respectively.

Desorption of P from four 1-hour extractions of the field experiment was measured only for surface soil samples (0 to 15 cm). Phosphorus desorption increased with an increase in P loading rate (Fig. 3). At high loading rates, 41 and 23 µg P/g of soil were desorbed by Norfolk and Cecil soil, respectively. Phosphorus desorbed into soil solution after several extractions was probably a sum of P remaining in adsorbed phase plus dissolution of precipitated P.

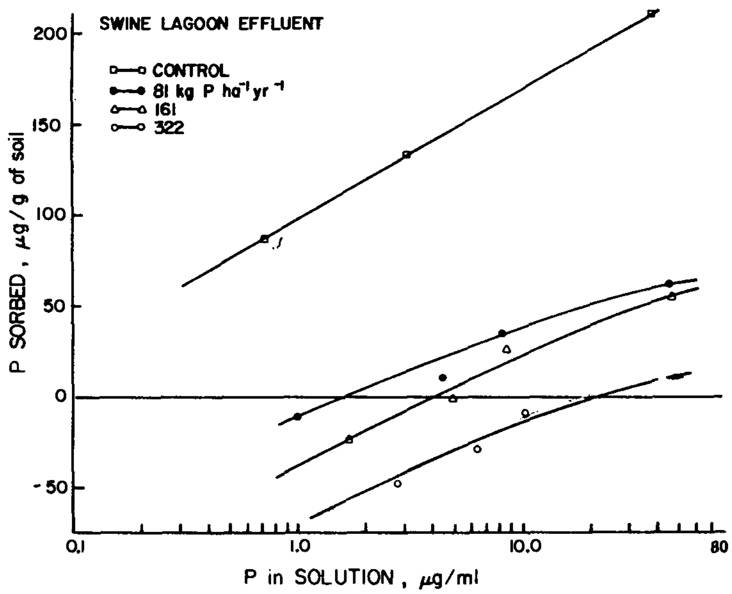

Fig. 4—Phosphorus adsorption isotherm of the Norfolk soil (0 to 15 cm) as influenced by application of swine lagoon effluent for a period of 5 years.

Adsorption isotherms of surface soil (0 to 15 cm) treated with several loading rates of swine lagoon effluent are presented in Fig. 4 and 5, for Norfolk and Cecil soil, respectively. For Cecil soil, no difference in adsorption isotherms was observed between control soil and soil receiving low application rate of P (31 kg P/ha per year). An increase in waste loading decreased the adsorption capacity of a soil, and increased EPC values (Tables 5 and 6).

In a recent study, Singh and Jones (1976) observed that the amount of P sorbed by soil decreased when or-

Table 5—Phosphorus adsorption by a Norfolk soil receiving swine lagoon effluent for a period of 5 years.

Depth	Adsorption maximum	P sorbed at 1,000 µg P added/g of soil	EPC	pH in 0.01*M* $CaCl_2$
cm	µg/g		µg/ml	
		High loading rate (322 kg P/ha per year)		
0-15	–	18	22.0	3.8
15-30	67	49	5.30	3.9
30-45	118	114	0.46	4.1
45-60	138	129	0.29	4.6
60-75	169	162	0.09	4.0
75-90	872	656	0.05	3.6
90-105	877	829	0.02	3.4
		Medium loading rate (161 kg P/ha per year)		
0-15	71	55	4.10	4.0
15-30	84	75	0.74	4.1
30-45	128	124	0.06	4.2
45-60	123	120	0.02	4.2
60-75	154	151	0.01	4.5
75-90	895	586	--	3.9
90-105	1,176	897	0.02	3.5
		Low loading rate (81 kg P/ha per year)		
0-15	90	58	1.65	4.0
15-30	125	117	0.12	3.9
30-45	81	81	0.01	4.2
45-60	103	102	0.46	4.0
60-75	224	221	0.01	4.2
75-90	652	567	–	3.8
90-105	1,058	883	0.03	3.3

Table 6—Phosphorus adsorption by a Cecil soil receiving swine lagoon effluent for a period of 3 years.

Depth	Adsorption maximum	P-sorbed at 1,000 µg P added/g of soil	EPC	pH in 0.01*M* $CaCl_2$
cm	µg/g		µg/ml	
		High loading rate (322 kg P/ha per year)		
0-15	71	76	0.88	5.4
15-30	482	451	0.01	5.7
30-45	841	825	0.01	5.0
45-60	--	--	--	4.3
60-75	1,081	938	--	3.8
75-90	--	--	--	3.6
90-105	940	876	--	3.4
		Medium loading rate (161 kg P/ha per year)		
0-15	209	190	0.16	5.4
15-30	896	742	0.01	5.3
30-45	951	865	--	5.0
45-60	--	--	--	4.4
60-75	1,192	952	--	3.9
75-90	--	--	--	3.7
90-105	893	875	--	3.3
		Low loading rate (31 kg P/ha per year)†		
0-15	234	220	0.03	4.7
15-30	887	762	0.01	4.7
30-45	480	475	--	4.6
45-60	--	--	--	4.8
60-75	950	895	--	3.9
75-90	--	--	--	3.6
90-105	743	814	--	3.2

† Applied as inorganic fertilizer source.

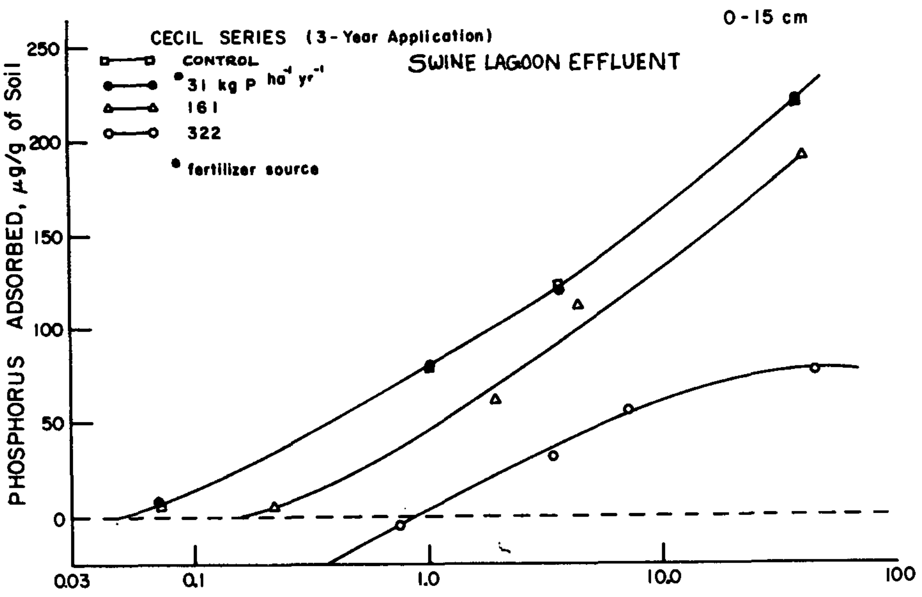

Fig. 5—Phosphorus adsorption isotherm of the Cecil soil (0 to 15 cm) as influenced by application of swine lagoon effluent for a period of 3 years.

ganic material containing >0.31% P had been previously added to the soil. Organic residues containing <0.31% P increased P adsorption capacity of the soil, thus decreasing the level of P in solution. If we assume carbon content of the residues used by Singh and Jones (1976) was 40%, then the critical C/P ratio for decreasing P sorption is about 130. Swine lagoon effluent has a C/P ratio of <130, indicating that swine lagoon effluent application could be predicted to potentially decrease adsorption capacity, and increase P concentration in soil solution.

Adsorption of P (measured as P sorbed at 1,000 μg P/g of soil, added and estimated from the isotherm) by soil samples obtained at various depths are presented in Tables 5 and 6. Adsorption capacity of the soil increased with increasing depth due to higher clay content of the subsoil. Adsorption capacity of the Norfolk soil was low up to a depth of 75 cm, followed by high adsorption of P below 75 cm. This soil has a deep A horizon (up to 35 cm) with loamy sand texture, followed by B1 horizon (35 to 45 cm) with sandy loam texture. From 45 to 95 cm is a B32t horizon with increasing clay content (sandy clay loam). Because of low adsorption capacity of the soil at the 15- to 75-cm depth, P movement occurred to deeper layers in Norfolk soil (see Fig. 2 and 3). In the Cecil soil, adsorption of P in the surface 15 cm soil was low followed by increase in P sorption with increasing depth. This soil profile has a surface A horizon (0 to 15 cm) with a sandy loam texture, followed by B1 horizon (15 to 17 cm) with a sandy loam texture, and below 27 cm depth soil texture was clay. Phosphorus movement did not occur into deeper layers, because the B horizon acted as a sink for P moved from the A horizon and because less total P was applied.

EPC values (which is an intercept value at zero P sorption) determined from adsorption isotherms decreased with depth in Norfolk and Cecil soils (Tables 5 and 6). In the Norfolk soil, EPC values ranged from 0.01 to 22 μg/ml, whereas in Cecil soil EPC values were found to be 0.01 to 0.88 μg/ml. Estimate of EPC values was shown to be better related to plant growth than phosphate potential (Wild, 1967). Fox and Kamprath (1970) showed that yields of millet approached 95% of maximum, when P in soil solutions was adjusted to 0.2 μg/ml. In Norfolk and Cecil soil, P at zero sorption is much higher than 0.2 μg/ml, indicating that these soils have sufficient available P in the system potentially available for plant growth.

The EPC values presented in Tables 5 and 6 for several treatments are the approximate solution concentrations of P when each soil in contact with water would neither gain nor lose P (White and Beckett, 1964). Thus, if each soil were present as sediment in lake or stream, these soils tend to release P into lakes or streams since ambient P concentrations are in the range of 0.02 to 0.1 μg/ml (Omernik, 1977). In addition, sediments from manure application sites would have a greater P desorption per gram of soil than sediments from control (untreated) soil, in receiving waters. The amount of P desorbed may depend upon soil (sediment) concentration in runoff, solution P concentration in runoff water, and ionic strength of the runoff water. However, during sediment transport, clay particles having high adsorption capacity constitute a larger fraction of sediment, thus resulting in lower EPC values. Further research is needed to demonstrate the adsorptive capacity of the soil as function of size fractions in the soil.

Significant relationships were obtained between EPC values and soluble P in $0.01M$ CaCl$_2$ ($r = 0.75$) and between EPC and acid-extractable P ($r = 0.61$). An inverse relationship was observed between P sorbed at 1,000 μg P/g added and EPC values ($r = 0.47$). These correlation coefficients were significant at 0.01 level of probability ($n = 43$).

In soils treated with long-term application of animal wastes, P removal cannot be attributed to adsorption alone because of possible precipitation reactions of P with Fe, Al, or Ca. If P application is small compared to the potential sorbing surface, a rapid adsorption reaction removes P from solution and the concentration in solution remains low. However, if the P application is in excess of the potential P sorbing surface, the solution P concentration slowly decreases as soil minerals decompose yielding Fe, Al, and Ca to form precipitates with P. In neutral to alkaline soils, the exchangeable Ca is the first source to be precipitated, whereas in acid soils Fe and Al are involved (Van Riemsdijk et al., 1975; Fordham and Schwertmann, 1977; Walsh et al., 1976).

In conclusion, this study has shown that application of animal wastes increased soluble P (0.01*M* $CaCl_2$), acid-extractable P, and EPC values, and decresed the P sorption capacity of the soil. These parameters were directly related to the loading rates of animal wastes. The positive effects of manure on the solubility of P was due to the application of soluble inorganic P and mineralization of organic P durng decomposition of waste, which probably saturated the adsorption sites. Another reason could be that during decomposition of wastes several organic acids are produced which form stable complexes with Fe and Al and consequently block P retention by them (Gaur, 1969; Nagarajah et al., 1970; Struthers and Sieling, 1950). Thus, when phosphates and organic anions are present together, the decrease in P adsorption by an adsorbent must arise from the specific adsorption of the anion resulting from competition between phosphate and the organic anions for adsorption sites. The capability of organic anions to decrease P adsorption would be determined by the relative stabilities of the Fe (or Al)-organic anion complex and the Fe (or Al)-phosphate complex.

Animal waste application adds organic matter to soils, and may reduce runoff and increase infiltration. The effects of the decrease in P sorption capacity may result in more soluble P moving into deeper soil layers along with percolating waters, and being transported in subsurface runoff or downward movement, leading to potential ground water pollution. Upon using the land for application of animal wastes, serious consideration should be given to the P assimilatory capacity of the soil system, such that risks involved in increasing P concentrations of surface waters may be decreased.

LITERATURE CITED

1. Adriano, D. C., L. T. Novak, A. E. Erickson, A. R. Wolcott, and B. G. Ellis. 1975. Effect of long-term disposal by spray irrigation of food processing wastes on some chemical properties of the soil and subsurface water. J. Environ. Qual. 4:242–248.
2. Bielby, D. G., D. A. Tel, and L. R. Webber. 1973. Phosphorus in percolates from manured lysimeters. Can. J. Soil Sci. 53:343–346.
3. Collins, Jr., E. R., E. T. Konegay, and D. C. Martens. 1978. Swine lagoon effluent on a soil-plant environment: An impact assessment. Bull. 110. Virginia Water Resour. Res. Center, Virginia Polytech. Inst. and State Univ., Blackburg, Va. p. 38.
4. Cummings, G. A., J. C. Burns, R. E. Sneed, M. R. Overcash, and F. J. Humenik. 1975. Plant and soil effects of swine lagoon effluent applied to Coastal Bermudagrass. Managing livestock wastes. Proc. 3rd Int. Symp. of Livestock Wastes. Urbana-Champaign, Ill., ASAE Proc. 275:598–601.
5. Dalton, J. D., G. C. Russell, and D. H. Sieling. 1952. Effect of organic matter on phosphate availability. Soil Sci. 73:173–181.
6. Fokin, A. D., and E. D. Chistova. 1964. Effect of humic substances on phosphate sorption by soils. Agrokhimiya 11:41–46.
7. Fordham, A. W., and U. Schwertmann. 1977. Composition and reactions of liquid manure (gülle) with particular reference to phosphate: I. Analytical composition and reaction with poorly crystalline iron oxide (ferrihydrite). J. Environ. Qual. 6:133–136.
8. Fox, R. L., and E. J. Kamprath. 1970. Phosphate sorption isotherms for evaluating the phosphate requirements of soils. Soil Sci. Soc. Am. Proc. 34:902–907.
9. Gaur, A. C. 1969. Studies on the availability of phosphate in soil as influenced by humic acid. Agrochimica 14:62–65.
10. Harter, R. D. 1969. Phosphorus adsorption sites in soils. Soil Sci. Soc. Am. Proc. 33:630–632.
11. Herron, G. M., and A. B. Erhart. 1965. Value of manure on an irrigated calcareous soil. Soil Sci. Soc. Am. Proc. 29:278–281.
12. Jackman, R. H. 1955. Organic phosphorus in New Zealand soils under pasture. II. Relation between organic phosphorus content and some soil characteristics. Soil Sci. 79:292–299.
13. Larsen, J. E., G. F. Warren, and K. Longton. 1959. Effect of iron, aluminum, and humid acid on phosphorus fixation by organic soil. Soil Sci. Soc. Am. Proc. 23:438–440.
14. Murphy, L. S., G. W. Wallingford, W. L. Powers, and H. L. Manges. 1972. Effects of solid beef feedlot wastes on soil conditions and plant growth. p. 449–464. *In* Waste Manage. Res., Proc. 1972, Cornell Univ. Agric. Waste Manage. Conf. Graphics Management Corp., Washington, D.C.
15. Nagarajah, S., A. M. Posner, and J. P. Quirk. 1970. Competitive adsorption of phosphate with polygalacturonic and other organic anions on kaolinite and oxide surfaces. Nature 228:83–85.
16. Olsen, R. J., R. F. Hensler, and O. J. Attoe. 1970. Effect of manure application, aeration, and soil pH on soil nitrogen transformation and on certain soil test values. Soil Sci. Soc. Am. Proc. 34:222–225.
17. Olsen, S. R., and S. A. Barber. 1977. Effect of waste application on soil phosphorus and potassium. p. 197–215. *In* Soils for management of organic wastes and waste waters. Am. Soc. Agron., Madison, Wis.
18. Omernik, J. M. 1977. Nonpoint source-stream nutrient level relationships: A nationwide study. EPA-600/3-77-105. Sept. 1977. p. 151.
19. Perkins, H. F., M. B. Parker, and M. L. Walker. 1964. Chicken manure—Its production, composition, and use as a fertilizer. Georgia Agric. Exp. Stn., Univ. Georgia Bull. 123, p. 24.
20. Reddy, K. R., R. Khaleel, and M. R. Overcash. 1980. Nitrogen phosphorus, and carbon transformations in a coastal plain soil treated with animal manure. Agric. Wastes Int. J. (in press).
21. Rennie, D. A., and R. B. McKercher. 1958. Adsorption of phosphorus by four Saskatchewan soils. Can. J. Soil Sci. 39:64–75.
22. Shortall, J. G., and W. C. Liebhardt. 1975. Yield and growth of corn as affected by poultry manure. J. Environ. Qual. 4:186–191.
23. Singh, B. B., and J. P. Jones. 1976. Phosphorus sorption and desorption characteristics of soil as effected by organic residues. Soil Sci. Soc. Am. J. 40:389–394.
24. Struthers, P. H., and D. H. Sieling. 1950. Effect of organic anions in phosphate precipitation by iron and aluminum as influenced by pH. Soil Sci. 69:205–213.
25. Sutton, A. L., D. W. Nelson, V. G. Mayrose, and J. C. Nye. 1974b. Effects of liquid swine waste application on soil chemical composition. p. 503–514. *In* Processing and Management of Agricultural Wastes. Proc. 1974 Cornell Agric. Waste Manage. Conf., Cornell Univ., Ithaca, N.Y.
26. U.S. Environmental Protection Agency. 1974. Technology transfer report on methods for chemical analysis of water and waste. EPA-625/6-74-003. p. 249–255.
27. Van Riemsdijk, W. H., F. A. Weststrate, and G. H. Bolt. 1975. Evidence for a new aluminum phosphate phase from reaction rate of phosphate with aluminum hydroxide. Nature 257:473–474.
28. Vitosh, M. L., J. F. Davis, and B. D. Knezek. 1973. Long-term effects of manure, fertilizer, and plow depth on chemical properties of soils and nutrient movement in a monoculture corn system. J. Environ. Qual. 2:296–299.
29. Vyas, K. K. 1964. Availability and uptake of phosphorus by wheat under different moisture and organic matter levels. Curr. Sci. 33:756–757.
30. Walsh, L. M., M. E. Sumner, and R. B. Corey. 1976. Consideration of soils for accepting plant nutrients and potentially toxic nonessential elements. p. 22–47. *In* Land application of wastes. Soil Conserv. Soc. Am., Ankey, Iowa.
31. White, R. W., and P. H. T. Beckett. 1964. Studies on the phosphate potentials of soils. I. The measurement of phosphate potential. Plant Soil 20:1–16.
32. Wild, A. 1967. Soluble phosphate in soil and uptake by plants. Nature 203:326–327.