Phosphate compounds in pig slurry and their retention in the soil

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INTRODUCTION

Phosphate in animal wastes, which in some agricultural areas are applied to the soil in excessive amounts, is a potential pollutant of surface and ground water. Especially in The Netherlands, with shallow surface waters and an intensive use of both surface and ground water, phosphorus is a highly undesirable pollutant.

Animal wastes contain both inorganic phosphate and phosphate as part of organic molecules. Inorganic phosphate is usually assumed to be effectively filtered by the soil, though excessive application of solutions of moderate phosphate concentration have been shown to give a rapid movement of inorganic phosphate in the soil (Goodrich, 1970). The predominance of organic phosphates in phosphorus movement in the soil has been noted by Hannapel et al. (1963a, b),Rolston et al. (1975), and Campbell and Racz (1975).

Phosphates, especially organic phosphates, due to their complexing properties may also play an important role in the transport of heavy metals in the soil.

CHEMICAL AND (MICRO)BIOLOGICAL ASPECTS

Data on phosphate compounds in pig slurry have been given by Gerritse and Zugec (1976). In figure 1 these data are shown schematically. Pig slurry contains 1-2% of its dry weight as P. The bulk of this phosphorus (75-85%) is inorganic phosphate. From solubility data this inorganic phosphorus can be said to consist of calciumhydrogenphosphate ($CaHPO_4.2H_2O$) and calciumphosphates of lower solubility (apatites). The

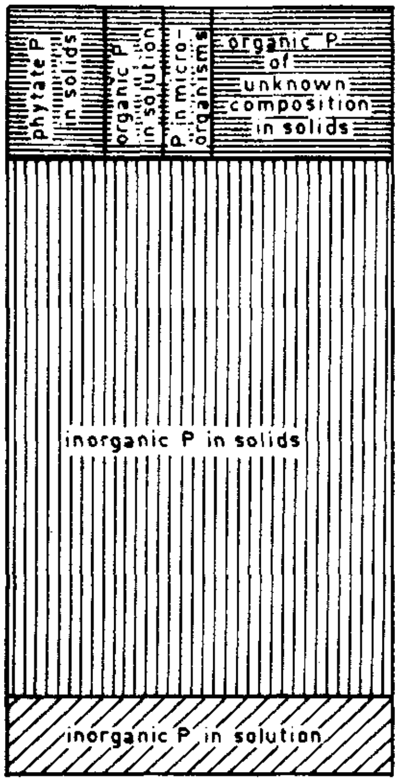

Fig. 1. The relative distribution of phosphate compounds in pig slurry. Total P content of pig slurry lies between 1-2% of dry matter weight. Dry matter content of pig slurry is of the order of 5-10%.

rest of the phosphorus in pig slurry is contained in organic molecules. This organic phosphorus is mainly contained in solids. Liquid chromatographic analysis has shown that 20-30% of this organic P is phytate phosphorus. 2-3% of total P in pig slurry is contained in microorganisms.

The solution resulting after 30 minutes centrifugation of pig slurry at 40.000 *g* and subsequent filtration of the supernatant through a membrane filter of 0.2 µm contains 10-20 mg organic P per liter. Inorganic P content of this solution depends on the feed composition and is usually about 10-100 mg P per liter, though, at low Ca/P ratio in the feed, can be much higher.

Gel filtration studies have shown the dissolved organic P compounds to be mainly of high molecular weight. Further analysis of the gel filtration fractions indicated that these organic P compounds of high molecular weight are complexes of DNA with inorganic phosphate,

TABLE 1. Distribution of phosphorus, calcium and copper in gel filtration fractions of pig slurry solution. The gel used was Sephadex G-100 (Pharmacia) with water as eluent

	Pig slurry solution before fractionation. volume = 1 ml	High molecular weight fraction. (M.W. >10^5)	Intermediate molecular weight fraction	Low molecular weight fraction
pH	8.6	6.55	6.7	8.35
total P	390 µg	20 µg	1 µg	350 µg
inorganic P	370 µg	5 µg	0.5 µg	340 µg
organic P	20 µg	15 µg	0.5 µg	10 µg
Ca	15 µg	3 µg	1 µg	10 µg
Cu	1 µg	0.3 µg	0.1 µg	0.6 µg

calcium and, if present in the feed, copper. Results are shown in table 1.

By adding radioactive phosphorus as $^{32}PO_4$ to pig slurry and measuring the increase of radioactivity in various phosphate fractions obtained after centrifuging, gel filtration and extraction with selective extractants, it is found that in all fractions the specific activity approaches the value calculated for complete distribution of ^{32}P among all phosphates. It thus appears that all phosphorus in pig slurry is mobile and must be part of a microbial cycle. From a simplified model (fig. 2) microbial turnover times for phosphorus in pig slurry were calculated from the rates of incorporation of radioactive phosphorus. Turnover times at a temperature of 20-25°C are of the order of 10-20 weeks. Similar turnover times are found for aerated and non-aerated pig slurry.

From data in the literature and own analyses (Gerritse and Zugec, 1976) it can be further concluded that the analysis results for phosphate compounds in pig slurry can be applied to animal wastes in general. When fresh, however, animal wastes may show large differences

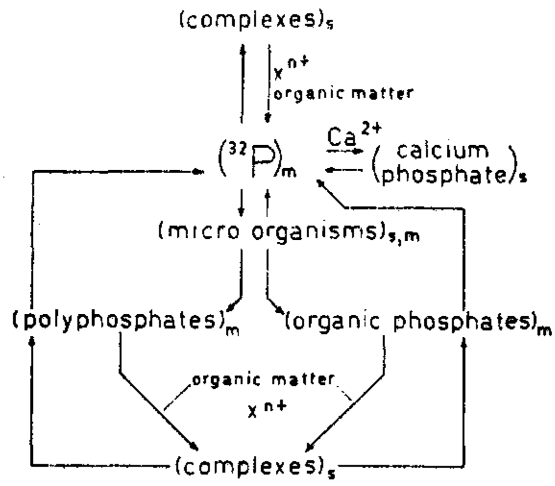

Fig. 2. Model for the phosphorus cycle in pig slurry, according to which labelled phosphorus (^{32}P) is distributed. s = solids, m = in solution.

in organic P content. On storage of these wastes the relative organic P contents tend to approach the same values as in pig slurry, which can thus be taken to be equilibrium values in the microbial phosphorus cycle. This constant microbial cycle also explains the fact that prolonged storage and feed composition hardly affect the contents and distribution of the various phosphate compounds in pig slurry as well as in wastes of other animals.

Phosphatase activities affecting the decomposition of organic P in pig slurry were determined from the decomposition rates of p-nitrophenylphosphate. Results are given in table 2 together with average values from a number of soils in The Netherlands.

Assuming Michaelis-Menten kinetics to apply the decomposition rate of organic phosphate is given by:

$$v = \frac{V_{max} . S}{K_m + S} \qquad (1)$$

where: V_{max} = maximum rate of decomposition (μmoles/ g.h)
K_m = reaction constant (μmoles/l)
S = substrate concentration (μmoles/l)
g = grams dry weight

TABLE 2. Phosphatase activities in pig slurry and measured at $30^{o}C$. Soil samples were taken at various depths.

Matrix	pH of measurement	K_m (μmoles/l)	s.d.(K_m) (%)	r	V_{max} (μmoles/g.h)	n
pig slurry	5	680	7	0.995	700	8
pig slurry	8	1000	10	0.99	1100	12
soils (0-20 cm)	5	140	50	0.90	80	30
soils (20-50 cm)	5	175	40	0.91	25	30
soils (50-100 cm)	5	140	25	0.96	4	30

r = the correlation coefficient in the plot of (S_o-S) versus $\ln(S/S_0)$.

n = total number of analyses.

s.d. = standard deviation in K_m.

Integration of Equation 1 gives:

$$V_{max}.t = (S_0 - S) - K_m \ln(S/S_0) \tag{2}$$

where: t = incubation time in hours

S_0 = substrate concentration at t = 0

The results in table 2 were obtained by incubating one hour with substrate concentrations (S_0) in the range of 50-500 μmoles/l and applying Equation 2.

If it is supposed that the decomposition rate v is a measure for the turn-over time of phosphorus and that the K_m's and V_{max}'s in table 2 are also applicable to organic phosphates in soil and manure, it can be reasoned that phosphate turn-over time in the soil is of the same order as in pig slurry and thus of the order of 10-20 weeks.

RETENTION IN THE SOIL

The retention of inorganic phosphate by the soil is determined by the adsorption characteristics of the soil. The main factors influencing adsorption in the soil are organic matter, aluminium and iron content of the soil and soil pH. Especially soils low in aluminium and organic matter and with a pH of 4-6 show very little affinity for inorganic phosphate.

The organic phosphate compounds in solution in pig slurry are much less adsorbed by the soil than inorganic phosphate. Results of some static adsorption experiments with four soils, differing in organic matter, aluminium and iron content, are given in table 4. Characteristics of the soils are given in table 3. It can thus be

TABLE 3. Characteristics of soils used in the determination of phosphate adsorption from pig slurry

No.	Soil type	Organic matter (%)	Fe_2O_3 (%)	pH/KCl	Al (%)	Ca (%)	Mg (%)
1	"Beek" earth	15	2.0	5.4	0.6	0.60	0.018
2	"Beek" earth	14	35.2	5.3	0.8	0.34	0.036
3	peaty/clayey	59	3.2	4.1	3.2	0.90	0.12
4	peaty/clayey	45	16.7	5.1	2.3	1.56	0.10

expected that organic phosphates from pig slurry will be transported rapidly into the soil. To be able to forecast the transport of organic phosphates to deeper layers in the soil it is, however, necessary to know the interaction with the microbiological phosphorus cycle, especially since even down to a depth of 70 cm in soils in The Netherlands 50-80% of the phosphorus is organic phosphorus. Results of phosphate analyses in a number of soils are given in table 5. Organic P is found from the difference between total P, determined after destruction, and inorganic P, determined after extraction with

TABLE 4. Adsorption of phosphate from pig slurry in soils. 5 grams of dry soil were shaken with 10 ml of slurry solution for 24 hours after which total and inorganic P were determined in the supernatant

Soil no.	C_o^{in}	C_o^{org}	C_m^{in}	C_m^{org}	C_s^{in}	C_s^{org}	K^{in}	K^{org}
	(µmoles/ml)				(µmoles/g)		(ml/g)	
1	1.0	0.45	0.03	0.3	2.0	0.3	67	1
2	1.0	0.45	0.05	0.03	1.9	0.3	38	1
3	0.8	0.45	0.001	0.15	1.6	0.6	1600	4
4	0.85	0.4	0.001	0.2	1.7	0.4	1700	2

C_o = initial concentration of phosphorus (as P) in slurry water.

C_m = concentration of P after 24 hours equilibration with soil in the soil solution.

C_s = amount of P adsorbed to the soil.

K = distribution constant = C_s/C_m.

The indexes in. and org. refer to inorganic and organic P, respectively.

a solution of $TiCl_4$ in concentrated HCl (Tinsley and Özsavasci, 1975; Gerritse and Zugec, 1976).

To be able to evaluate inorganic and organic phosphorus movement in the soil properly, columns of undisturbed soil of 80 cm length have been set up under unsaturated flow conditions and treated with pig slurry. Phosphate, chloride and phosphatase activity are monitored in the column effluent, resulting from a simulated rainfall of about 1 cm per day. After about 1-2 years the soil profile will be analyzed for inorganic and organic phosphorus and phosphatase activity. On the basis of various parameters a computer model of phosphate transport in the column will be made and the results of simulation compared with practice. It is hoped that these results can be published in the near future.

TABLE 5. Characteristics of soil profiles in which total and organic P were determined

Soil	Depth (cm)	pH-KCl	Sand	Humus	Fe_2O_3	Al_2O_3	P_{total}	$P_{organic}$
			(%)					
Black "beek" earth soil	5- 14	4.6	85	5.1	1.27	0.53	0.055	0.028
	14- 30	4.6	87	3.4	2.65	0.71	0.033	0.019
	30- 55	4.7	93	0.5	0.46	0.31	0.004	0.002
	55- 85	4.7	95	0.1	0.39	0.32	0.0045	0.001
	85-100	-	-	-	-	-	0.005	0.001
"Veld"podzol soil	5- 17	4.9	88	4.7	0.32	0.70	0.051	0.017
	17- 27	4.5	95	1.4	0.24	0.59	0.008	0.0035
	27- 40	4.6	94	0.6	0.32	0.52	0.005	0.003
	40- 75	4.6	95	0.4	0.29	0.56	0.004	0.002
	75- 85	4.6	96	0.3	0.38	0.60	0.005	0.001
	85-110	4.6	93	-	0.35	0.65	0.005	0.001
Black "enk"earth soil on moderpodzol	0- 22	3.8	86	5.5	0.45	0.32	0.069	0.033
	22- 52	3.9	86	5.6	0.57	0.36	0.046	0.024
	52- 64	3.8	88	3.7	0.61	0.34	0.038	0.021
	64- 77	4.6	92	1.3	0.51	0.05	0.029	0.017
	77- 91	4.5	92	1.2	0.44	1.23	0.019	0.006
	91-108	4.8	94	0.5	0.35	0.94	0.012	0.002
Reclaimed "haar"podzol soil	5- 19	4.2	90	5.3	0.22	0.59	0.055	0.022
	19- 28	4.1	90	5.2	0.08	0.03	0.011	0.009
	28- 41	4.2	92.5	3.2	0.22	0.76	0.007	0.005
	41- 50	4.5	95.5	1.3	0.28	0.71	0.005	0.003
	50- 60	4.6	96.5	0.8	0.29	0.61	0.004	0.002
	60- 75	4.6	97	0.5	0.32	0.59	0.005	0.002
	75-100	4.7	97	0.3	0.31	0.53	0.005	0.000
	100-120	4.7	95.7	0.3	0.38	0.72	0.007	0.001

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