SEWAGE SLUDGE AS A PHOSPHATE FERTILIZER

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Quantities of phosphorus in sewage sludge

In the Netherlands the average production of sewage is appr. 50 m^3 per PE (population equivalent) per year, containing appr. 1 kg of phosphorus (P = 0.44 P_2O_5; P_2O_5 = 2.3 P). After mechanical-biological treatment 25% of the phosphorus is still present in the sewage sludge. Assuming a sludge production of 20 kg DM (dry matter) per PE per year, the P concentration in the dry matter would be appr. 1.25%. By additional chemical treatment, 90% or more of the phosphorus can be removed. In this case the P concentration in the sludge amounts to appr. 5% (of DM). In 570 sludge samples, analysed in the period 1972/76, the P concentration varied from 0.5 to 4.1%, with a mean value of 2.0%. Over 1967/70 the mean value was 1.6%. Apparently there is a tendency to increase in the course of time. A further increase in the future depends on the extent to which chemical treatment to remove additional P from sewage is introduced. On the other hand, legal measures are now in preparation in the Netherlands to gradually halt the use of detergents containing P, which may lead to a lower P concentration in the sludge.

The amount of phosphorus in sludge currently amounts to about 0.4 kg per PE per year in the Netherlands. With 7 people per hectare of agricultural land this would mean an average supply of 2.8 kg P/ha, if all sewage was treated and all sludge was applied to agricultural land. Only about 80% of the sewage, however, is treated as yet and only about 40% of the sludge is applied to agricultural land. Consequently, on average only 1 kg P from sludge is available per ha of agricultural land per year. Corresponding values for P from fertilizers and animal waste are 20 and 30 kg, respectively. The contribution of sludge in the P-supply of agricultural land therefore currently amounts to less than 2%.

Determination of the plant availability of P in sludge in comparison with monocalcium phosphate or superphosphate

Sludge, being an organic fertilizer, contains all other plant nutrients in varying amounts in addition to P. To determine the effect of P the effect of these accompanying nutrients has to be excluded or compensated. This is especially true for the N (nitrogen) effect, which is usually dominant. The effect of N on P uptake at the same supply of P, is demonstrated in figure 1. The data have been obtained from a pot experiment with a combination of five P application rates at five N application rates to ryegrass, of which five cuts were harvested and analysed for N and P. P was applied once at the beginning of the experiment. N-application was repeated for each cut. The effect of N on P-uptake was a combined effect of N on yield and P-concentration in the crop (De Haan, 1980). Contrary to the N effect of P uptake, there was hardly any effect of P on N-uptake.

The effect of the other nutrients can be compensated by regarding sludge as a N + P + K + Mg + minor-element fertilizer and comparing it with a fertilizer containing the same elements in mineral form. The elements should be present in the best possible proportions to meet the needs of the test crop; e.g. for grass the N:P:K:Mg-ratio could be 1:0.5:1:0.3. Minor elements can be supplied, if necessary, in an amount sufficient to prevent deficiency. When in sludge the elements are not present in optimum proportions, they have to be supplemented with fertilizers in mineral form. For N in sludge only the mineral part is taken into account. In most cases the effect of the organic part is negligible. If there is an effect of the organic part, either negative or positive, the P effect has to be corrected for this effect.

The practical execution of this concept will be demonstrated with an experiment in which the P effect of a sludge from a purification plant for calf slurry with lime as dephosphatizing agent, was studied.

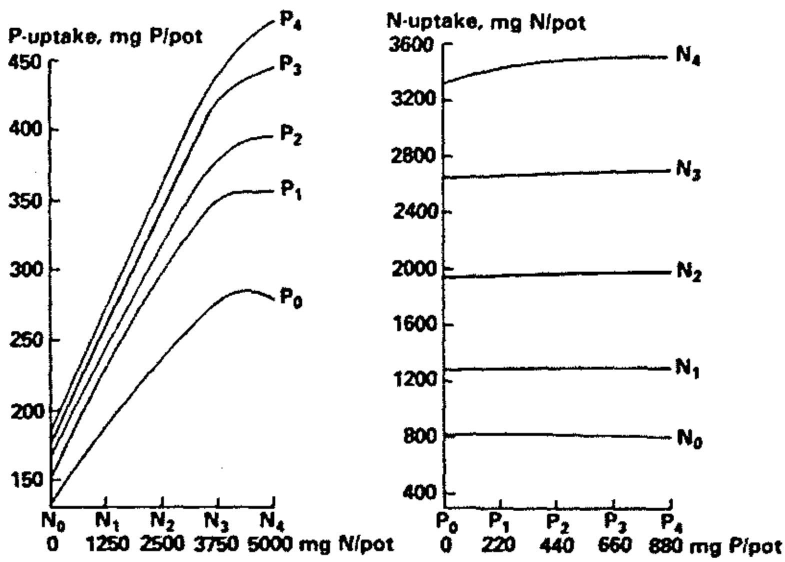

Figure 1. Effect of application of nitrogen (as NH_4NO_3) on phosphorus, and of application of phosphorus (as $Ca(H_2PO_4)_2$) on nitrogen, taken up in five cuts of ryegrass given the same application rates of phosphorus and nitrogen, respectively.

Plant availability of P in sewage sludge from calf slurry, treated with lime for P-removal

The experiment was carried out with ryegrass on a sandy soil in Mitscherlich pots. The soil was slightly acid (pH-KCl 4.34) and poor in plant-available P. Three cuts were harvested, weighed and analyzed for N and P.

On a dry matter basis the sludge contained 7.35% P (5.40% as ortho-P, the remainder as organic P), 1.75% mineral N, 1.76% K and 0.66% Mg.

P in the form of sludge in comparison with MCP (monocalcium phosphate) was mixed through the soil at the beginning of the experiment in amounts of 0, 220, 440, 660 and 880 mg/pot. N (as NH_4NO_3) and K (as K_2SO_4) were added in amounts of 0, 250, 500, 750 and 1000 mg/pot, and Mg (as $MgSO_4.7H_2O$) in amounts of 0, 75, 150, 225 and 300 mg/pot. Applications of N, K and Mg were repeated after the first and second cut. For the first cut the amounts of N, K and Mg applied with sewage sludge were deducted from those given in mineral form.

The cumulative dry matter yield is presented in figure 2. It is evident from this figure that the yield was somewhat higher with sludge compared

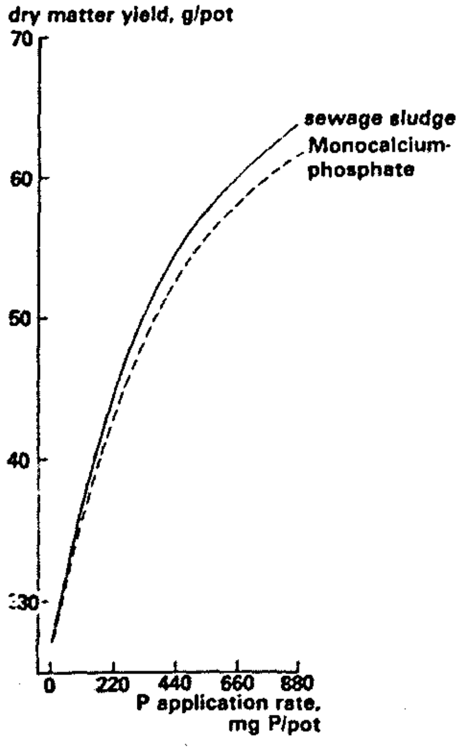

Figure 2. Effect of application of phosphorus in sewage sludge and as monocalcium phosphate on dry matter yield of English ryegrass.

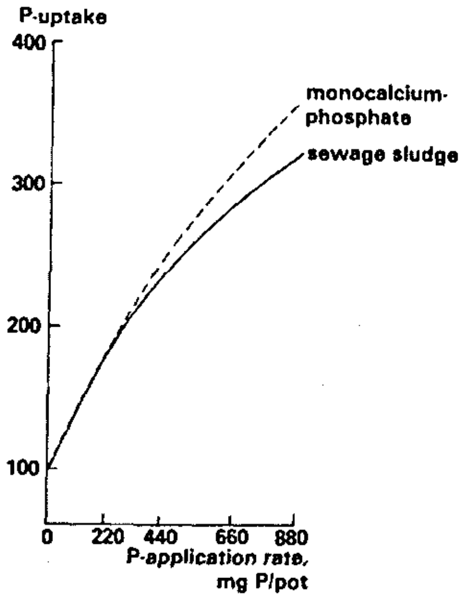

Figure 3. Effect of phosphorus in sewage sludge and as monocalcium phosphate on the amount of phosphorus taken up by English ryegrass.

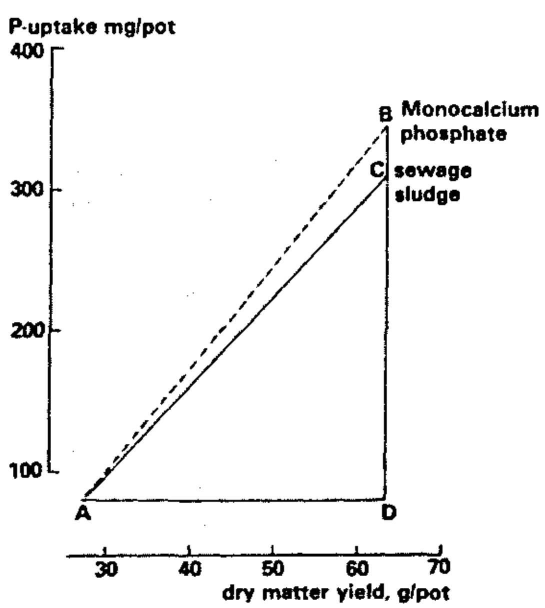

Figure 4. Relationship between dry matter yield and phosphorus in ryegrass, supplied with phosphorus as monocalcium phosphate and as sewage sludge.

with MCP. Figure 3 shows that the contrary was true for P-uptake. Net uptake was about 25% for P from sludge and 30% for P from MCP.

In figure 4 the correction for the difference in dry matter yield has been carried out . P-uptake has been plotted against dry-matter yield. With the same dry matter yield, the relationship between P-uptake from sludge and MCP is CD:BD, or about 90:100.

At the end of the experiment, concentrations of water-soluble P in the soil were determined. Water-soluble P in mg/l soil at a soil/water ratio of 1/60 is used in the Netherlands as a measure of plant-available P. The results are presented in table 1. This table shows that the amount of water-soluble P in the soil with sludge was somewhat less than with MCP; this again points to a somewhat lower plant-availability of P from sewage sludge when compared with P from MCP.

Table 1 — Concentrations of water-soluble P in mg/l soil at the end of the experiment

	P application rate, mg/pot				
	0	220	440	660	880
soil with sludge-P	15.3	12.3	13.3	15.0	16.3
soil with MCP-P	15.3	14.7	16.3	17.7	24.7

Plant-availability of P in sewage sludge, obtained by chemical treatment of industrial waste water with ferric sulphate as a coagulant

The results of an experiment with this sludge are mentioned, because they indicated that ferric or aluminum salts as coagulants or dephosphatizing agents have a much more negative effect on plant-availability of P in sludge than lime. The sludge came from the sewage treatment plant of a polystyrene factory (Hoechst Holland N.V., Breda) and apart from 60% polystyrene, as very small particles, and 8% iron hydroxide it contained 7.75% P in the dry matter, more than 90% of which was soluble in 2% citric acid. P was the only plant nutrient in this sludge.

As P-fertilizer the sludge was compared with superphosphate in this experiment on oats as test crop, which was harvested at ear emergence and analyzed for P. P-uptake is presented in figure 5. P-uptake from sludge only amounted to about 10% of that from superphosphate, due to a smaller effect on crop yield, but even more to a smaller effect on the P-concentration in the crop.

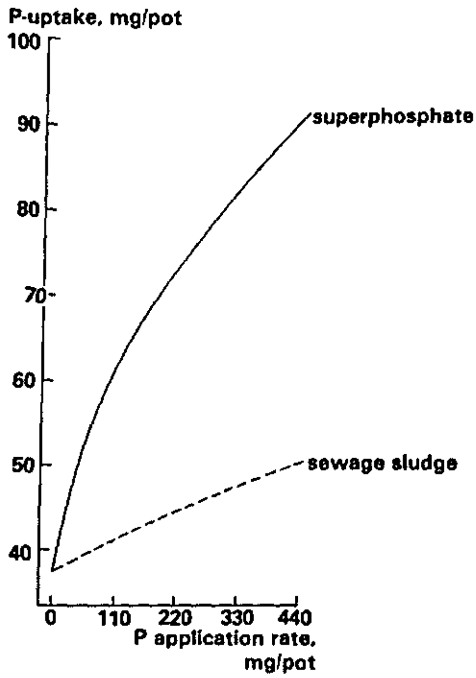

Figure 5. Amount of phosphorus in oats, supplied with phosphorus as superphosphate and as sewage sludge.

Experiment with 15 different sludges

This experiment was carried out in 1975. The sludges are, in the alphabetical order of the names of their places of origin, listed in table 2, together with the results of the experiment. Sludges 1, 3, 4, 5, 9, 10 and 12 came from normal mechanical-biological treatment plants for domestic and mixed waste water. Sludge 3 took a somewhat different position in this series, because, after mechanical dewatering and mixing with sawdust (1:1), it passed a composting process in a so-called bioreactor.

Sludges 2, 6, 7, 8 and 11 came from treatment plants with additional chemical treatment to remove P by means of ferric chloride or a mixture of ferric and aluminium sulphate (sludge 2). The only sludge, which with certainty has been affected by the dephosphatizing process is sludge 11, with an iron content of 15%.

Sludges 13 and 14 were pure chemical sludges, obtained by treating the effluent after mechanical-biological purification with ferric chloride (13) or a mixture of ferric and aluminum sulphate (14). Sludge 15 came from a pilot plant to purify surface water for drinking water purposes, using ferric chloride as a flocculating agent.

The sludges were air-dried and mixed with a sandy soil in amounts corresponding with 0, 220, 440, 660 and 880 mg P per Mitscherlich pot and with the same amounts of P as MCP. N, K, Mg and minor elements were applied in the same optimum amounts at all P application rates. N in sludges

Table 2 — Mean relative values (MCP = 100) for 15 sewage sludges for dry matter yield, P-uptake without and with correction for differences in dry matter yield, and concentrations of water soluble P at the end of the experiment, after subtraction of the values for control (= without P). Absolute values for MCP in parentheses (DM: g/pot; P uptake: % of P supply; water-soluble P in soil; mg/liter).

	dry-matter yield	P-uptake without correction for difference in dry matter yield	P-uptake with correction for difference in dry matter yield	water-soluble P in soil
Monocalcium phosphate	*100(7.66)*	*100(19.0)*	*100(19.0)*	*100(11)*
1. Assen	105	36	34	14
2. Asten	185	54	29	0
3. Deidesheim (FRG)	78	38	52	0
4. Delden	144	46	32	0
5. Eindhoven	169	24	14	14
6. Elburg	34	40	118	14
7. Gieten	104	41	40	0
8. Harderwijk	144	32	22	0
9. Leiden	183	65	36	28
10. Oosterwolde	134	90	68	28
11. Rijsenhout	185	17	9	0
12. Tilburg-Oost	90	51	57	7
13. Harderwijk	44	4	8	−7
14. Svedala (Sweden)	10	−13	−1	−21
15. Schuilenburg	103	0	0	−21

was compensated for by assuming an efficiency index of 30% for total N in the sludge. When N-supply from sludges appeared to be higher or lower than the assumed amount, a correction could be made for yield and P-uptake, because each MCP-rate was applied at five mineral-N rates, ranging from 0 to 1000 mg N/pot. The test crop was English ryegrass, of which five cuts were harvested and analyzed for N and P. Fertilization with mineral N was repeated for each cut, K and Mg fertilization from the third cut. At the end of the experiment concentrations of water-soluble P in the soil were determined.

Table 2 shows dry matter yields obtained with MCP and the different sludges, as well as P-uptake, without and with correction for yield differences, and concentrations of water-soluble P in the soil at the end of the experiment.

Table 2 shows that DM yield for most (10 out of 15) sludges was higher for sludge than for MCP. For P-uptake, however, all values were lower for sludge than for MCP, except for one sludge after correction for difference in yield. Concentrations of water-soluble P in the soil at the end of the experiment were also lower for sludges in comparison with MCP.

There were large differences among sludges. In comparison with MCP-P = 100%, P-uptake for normal sludges (1-12) ranged from 36-90% for sludges without and from 17-54% for sludges with additional P-removal from the sewage by means of Fe- and Al-salts. After correction for yield differences the mean values for P-uptake without and with additional P-removal from the sewage were not significantly different. Uptake of phosphorus from the pure chemical sludges (13-15), however, was practically nil, indicating that additional P, obtained by treating sewage of effluents with ferric and aluminum salts, may not be available to plants.

For the normal sludges, the mean value for P-uptake, measured in five cuts of English ryegrass, was 40-50% of MCP-P. The absolute value for MCP-P was about 20%. From the concentration of water-soluble P in the soil at the end of the experiment it can be concluded that there may be a residual effect for MCP-P, but not for P in sludges.

Discussion

In our experiments plant availability of phosphorus in normal sewage sludges varied from 20-100% in comparison with phosphorus in monocalcium phosphate = 100%. Phosphorus in chemical sludges, obtained by treating effluent or surface water with ferric chloride or a mixture of ferric and aluminum sulphate was not available to plants. The effect of lime as a dephosphatizing agent on the availability of phosphorus in the sludge obtained was very small.

Our conclusion that availability of phosphorus in sewage sludges is rather low and variable, is in agreement with that of Platzen (1974) on the basis of a review of results then available. In general a better availability of phosphorus in sewage sludges, even in those obtained by treating sewage or effluent with aluminum and/or ferric salts, has been reported by Cervenka and Timmermann (1976), Werner (1976), Gleisberg & Taubel (1978) and Gupta & Häni (1979).

Variation among the results of different authors may be due to variation in the dry matter content (drying has a negative effect on availability of P in sludges; cf. Furrer, 1977), the heavy metal (especially iron) content, characteristics of the soil to which the sludge is applied, the test crop, the duration of the experiment and last but not least an inadequate compensation of the nitrogen effect of the sludges. No doubt, if sewage sludge is to be used as a phosphate fertilizer, more research about the availability of its phosphorus will be necessary.

Summary

Plant availability of phosphorus in normal sewage sludges varied in our experiments from 20-100% in comparison with phosphorus in monocalcium phosphate = 100%. Phosphorus in chemical sludges, obtained by treating effluent or surface water with ferric chloride or a mixture of ferric and aluminum sulphate, was practically unavailable to plants whereas lime as a dephosphatizing agent seemed to have practically no negative effect on the

availability of the phosphorus in the sludge obtained. Data from recent literature point to a better availability of phosphorus in sewage sludges than which was found in our experiments.

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