The effectiveness of different precipitated phosphates as sources of phosphorus for plants

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Summary

Eleven precipitated phosphate materials were evaluated as sources of phosphorus (P) for plant growth. The standard material for comparison was monocalcium phosphate, a source of water-soluble P that is generally considered to be fully plant available. The precipitated phosphates comprised recovered struvites (magnesium ammonium phosphate), laboratory synthesised struvites, a synthetic iron phosphate and a recovered calcium phosphate

Evaluation was by pot trials on two different soils using perennial ryegrass as the test crop. Soils differed in pH (6.6 and 7.1) and in Olsen P (28 and 11 mg/l). Measured variables were grass dry-matter yield, grass P concentration and offtake of P in the harvested grass.

The recovered phosphates varied in physical form from fine powders (recovered struvite no. 3), to flowable small particles (recovered struvites nos 1a, 1b and 4) to dark, damp powders (recovered calcium phosphate), to large, crystalline particles (recovered struvite no. 6). To allow a fair comparison and accurate weighing out of representative samples for testing, every material was ground to pass a 0.5mm (30 mesh) sieve.

On both soils there were dry-matter and P offtake responses to applied P though these took longer to develop on the soil that was higher in Olsen P, a well recognised method of estimating readily available P in soil.

The effectiveness of the materials as P sources was similar to that of monocalcium phosphate with the exception of the calcium phosphate which was somewhat less effective than monocalcium phosphate.

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Background

Phosphorus is essential to all life forms because it is a key, irreplaceable element in many physiological and biochemical processes in plants and animals. Yet of the elements required by plants in the largest amounts, namely nitrogen, phosphorus, potassium, sulphur, calcium and magnesium, P is the non-renewable resource with the least reserves/resources globally. However large the reserves (estimates 100 to 250 years) and resources (estimates 600-1000 years) they are finite and must be used efficiently and in a sustainable way.

Of the total amount of P used in Western Europe, some 79% is used in fertilizers to support plant and animal production. Justus von Liebig, the German chemist, was among the first to point out that the sewage from urban areas should be applied to the land to return plant nutrients. In England, Lawes and Gilbert at Rothamsted were much involved in the 1860s in the Rugby sewage experiments and the Report to the UK Parliament by the Royal Commission on the Sewage of Towns. However, in the UK there has only been real interest in the use of sewage sludge in agriculture during the first and second World Wars. The Market Garden experiment started in 1942 by Rothamsted on the Woburn Experimental Farm showed that applying large amounts of anaerobically digested sludge did increase the readily available plant P in the soil but not to the same extent as did farmyard manure. This can be explained because much of the water-soluble P in the sludge received at the waste treatment plants was being discharged to rivers.

In recent decades such discharges have become an issue because the P they contain is one of the sources of P responsible for the disturbance of the biological balance in some surface fresh waters. Steps can be taken to lessen the amount of soluble P in the discharge by precipitating it in various chemical forms. These include magnesium ammonium phosphate and magnesium potassium phosphate, members of a group of related compounds called struvites. Additionally P can be precipitated as calcium, iron and aluminium phosphates. One outlet for these materials is application to agricultural land partly closing the loop in the soil-plant-food P cycle. The P in these materials is, however, not water soluble and there could be a reluctance by farmers to use them until more is known about their value as a source of P for crop production.

Plants can only acquire the P they need by roots taking it up in simple ionic forms $(H_2PO_4^- \text{ and } HPO_4^{2^-})$ from the soil solution. Thus the value of any soil amendment intended to supply P depends on its ability to release P in these ionic forms to the soil solution.

In the early years of the 19th century, bone trimmings (from making handles for steel cutlery) were found to increase crop growth and yield on some but not all soils in the UK. The lack of universal effectiveness lead to treating bones with sulphuric acid to produce superphosphate, which was effective on all soils. It is now realised that it was on calcareous soils that bones were ineffective because there was no natural acidity to release P to the soil solution.

The P in superphosphate is monocalcium phosphate, which is fully water-soluble and thus water solubility and the effectiveness of superphosphate for increasing growth are firmly linked in the minds of many farmers. Subsequently, however, other phosphatic materials with much less or no water soluble P (nitrophosphates, dicalcium phosphate) have been shown to be very effective sources of P for crops on some soils because they can release P to the soil solution sufficiently quickly to meet the demand for P of most crops. For these materials, reagents other than water soluble P are used to characterise

them. The project reported here seeks to determine whether the recovered phosphates listed in 'Methods and materials' below could supply an adequate amount of plant available P within an acceptable time frame

Much of the literature on struvite collected by CEEP highlights its possible usefulness as a slow release fertilizer, possibly supplying all three plant nutrients, namely nitrogen (N), magnesium (Mg) and P. This could be useful for container grown ornamentals for the horticultural trade but much less appropriate for broad acre crops, like cereals, grassland, sugar beet, etc that offer a much larger potential market than horticulture. The slow release of N and Mg could be much less appropriate for such crops. So the availability of P becomes the more important agronomic factor. This is especially so because although the ammonium-N in synthetic struvite could be as available to plants as that in any ammonium-N fertilizer, much of the total N in recovered struvite could be in organic forms. This organic N would have to be mineralised (converted to the ammonium and nitrate forms) before it became available to plants. If subsequently there was an interest in testing the availability of the N in struvite this could be done in a glasshouse pot experiment similar to those reported here but using different soils known to be very low in available nitrogen,

Ideally these recovered phosphates could best enter the market as a suitable material to maintain the readily available P status of the soil when the amount applied replaced that removed in the harvested crop. Maintenance or replacement fertilization is now being widely adopted once the available soil P level is about the critical level, i.e. the level at which a further increase in soil P does not further increase yield. This would take many years to test. The approach adopted in the present project was to compare the effectiveness as P sources of the test materials and monocalcium phosphate (a water-soluble P source). One method of determining readily available soil P is by extraction with 0.5M NaHCO₃ at pH 8.5 (Olsens method). This method was used to analyse soils for the present project.

Materials and methods

The testing technique comprised pot trials, using perennial ryegrass as the test crop, on two soils of pH 6.6 and 7.1. Every pot contained 1kg soil. The trials were carried out in a glasshouse and blinds and louvres were used to minimise the risk of high temperatures during the summer months. Trials were conducted by AgroChemical Experimentation Ltd, a Good Laboratory Practice (GLP) accredited facility.

Soil 1 (pH 6.6) contained 28 mg/l of Olsen P and 1.0% organic carbon (equivalent to 1.7% organic matter). Soil 2 (pH 7.1) contained 11 mg/l of Olsen P and 1.8% organic carbon (equivalent to 3.1% organic matter). These levels of Olsen P would be regarded as medium and low for soils 1 and 2 respectively. Details of the soils are shown in Table 1.

Table 1	Properties	of the soils	used in the	pot trials.
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	Units	Soil 1	Soil 2
pH		6.61	7.08
Phosphorus (Olsen)	mgP/l	28.0	11.2
Potassium (AN extraction)	mgK/l	265	92
Magnesium (AN extraction)	mgMg/l	155	59
Organic carbon	%C	1.0	1.8
Sand	%	61.5	60.5
Silt	%	22.6	10.8
Clay	%	15.9	29.1

In each trial, there were 11 test materials (Tables 2 and 3) applied at a rate of 0.20 gP_2O_5 /pot based on the total P_2O_5 content of the material as received. A standard watersoluble P source, monocalcium phosphate (MCP) was included at 5 rates (0.10, 0.15, 0.20, 0.25 and 0.30 gP_2O_5 /pot). These rates were chosen to be consistent with a large amount of previous trials data on water-insoluble P sources. The amounts of P_2O_5 are equivalent to 0.044, 0.065, 0.087, 0.109 and 0.131 gP/pot. In addition, there was a control treatment which received no P. The test and standard P sources were mixed with soil immediately before sowing the grass. The total number of treatments was 17 (Table 4) and these were replicated 3 times in a randomised block design for each soil. There were therefore two trials, each of 52 pots, one on each soil.

Perennial ryegrass cv Vigor (RvP) was sown at 0.3g seed/pot.

The supply of test materials was arranged by the project sponsors. Details are shown in Table 2 The order in which test materials are listed in Tables 2 and 3 is that in which they were numbered by the project sponsors. This order has been retained in the Tables of results but in the discussion section, materials are grouped according to their type in order to aid interpretation of the data.

The total P concentration in every material was measured by digestion with mineral acids (HCl/HNO3) followed by determination using the inductively coupled plasma (ICP) technique (Table 2). These analyses were carried out by Levington Laboratories who were familiar with fertilizer analysis. MCP (56.18% P₂O₅) was purchased commercially (ANALAR grade).

The test materials were supplied in powder form though the degree of agglomeration in the powders varied considerably among the materials. Some were dry, easily flowing powders whilst others appeared wetter and sticky (Table 3, Photographs 1 to 9). To allow a fair comparison, accurate weighing and mixing with soil of the small amounts required, all materials were passed through a 0.5mm (30 mesh) sieve. Some samples required grinding but others passed through the sieve easily.

Material	Source	$%P_2O_5$
Synthetic stuvite	Laboratory synthesised 'pure' struvite	29.32
no. 1	provided by Rhodia	
Sewage recovered	Calcium phosphate recovered by the full-	19.02
calcium phosphate	scale Crystallactor process at the	
(refs 1 and 2)	Geestmerambacht municipal sewage	
	treatment works, The Netherlands	
Recovered struvite	Struvite recovered by the full scale Unitika	29.55
no. 1a	process from municipal sewage works in	
(refs 3 and 4)	Japan	
Recovered struvite	Struvite recovered by the full scale Unitika	29.32
no. 1b	process from municipal sewage works in	
	Japan	
Recovered struvite	Struvite recovered from corn steep liquor	30.01
no. 2	by the Audobon Sugar Institute/Lousiana	
	State University Agricultural Center, USA,	
	AECI-Bio pilot process	
Recovered struvite	Struvite recovered from the Kiakyushu	29.32
no. 3	City municipal sewage treatment plant,	
(ref 5)	Japan, using seawater as a magnesium	
	source (Nishihara Co pilot plant)	
Synthetic struvite	Laboratory synthesised 'pure' struvite	30.70
no. 2	provided by Cranfield University, UK	
Recovered struvite	Struvite recovered from carmin red dye	19.02
no. 4	industry waste liquors (CHR Hansen	
(ref 6)	SA/University of Barcelona)	
Recovered struvite	Potassium struvite KMgPO ₄ recovered	19.70
no. 5	from veal manure at the full scale plant of	
(ref 7)	the Putten agricultural co-operative, The	
	Netherlands	
Synthetic iron	Laboratory synthesised by Cranfield	32.35
phosphate	University, UK using commercial water	
	treatment iron chloride (Analar grade) and	
	pure hydrogen phosphate solution	
Recovered struvite	Spontaneously occurring deposit material	28.41
no. 6	(mainly struvite) from digestor outflow	
(ref 8)	pipes at the Wassmansdorff municipal	
	sewage works, Berlin Wasser Betriebe	

Table 3. Description of treatment materials

Material	Description
МСР	White crystalline powder, free flowing
Synthetic stuvite no. 1	White powder, some clumping into
	lumps that easily broke down
Sewage recovered calcium phosphate	Dark brown moist powder, strong foul,
	unidentified smell
Recovered struvite no. 1a	Cream coloured small particles
	(0.1mm?), free flowing
Recovered struvite no. 1b	Cream coloured small particles
	(0.1mm?), free flowing
Recovered struvite no. 2	Fine white powder, some formation of
	lumps that easily broke down
Recovered struvite no. 3	Similar to Unitika material, cream
	coloured small particles (0.1mm?), free
	flowing
Synthetic struvite no. 2	White cores, approx 3mm diameter,
	crumble to white powder
Recovered struvite no. 4	Very fine, pale brown powder, free
	flowing
Recovered struvite no. 5	Yellow/brown moist powder with lumps
Synthetic iron phosphate	Pale brown powder
Recovered struvite no. 6	Large crystalline chips (up to 8mm) with
	some smaller dark particles

To ensure that other nutrients were not limiting, 0.05 gN/pot and 0.1 gMg/pot were mixed with the soil for every pot as ammonium nitrate and magnesium sulphate before sowing the seed. This was followed by top-dressing with 0.15 gN/pot and 0.1 gK₂O/pot after every cut as ammonium nitrate and potassium sulphate and by top-dressing with 0.05 gMg/pot after cut numbers 2 and 4 as magnesium sulphate.

Pots were watered with rain water applied to the surface as required. The grass in the pots was cut manually at 13, 20, 38, 49/50, 66, 85 and 100 days after treatment application. The cut at 20 days was to trim some rapidly elongating grass leaves during a period of hot weather. For yield and chemical analysis, the samples at 13 and 20 days were bulked on a pot basis to form 'cut 1'. Samples taken at 100 days were not chemically analysed as, by cut 6, dry matter yield responses had declined on both soils and there were no significant treatment differences in grass P concentration at cut 5. The sample sets therefore comprised cut numbers 1 to 6 for dry-matter yield and cut numbers 1 to 5 for P concentration and P offtake. Grass samples were dried overnight at 100⁰C and were milled before chemical analysis for total P concentration. Analysis of the grass samples was conducted by NRM Ltd, a Good Laboratory Practice (GLP) accredited laboratory. P offtake was calculated on a pot basis by multiplying dry-matter yield by P concentration.

Experimental procedures are outlined in the Project Plan (Appendix 1) and the trial diary is shown in Appendix 2..

Results

Although a well tested pot trial technique was used, experimental error reflected in the coefficients of variance (CV) tended to be higher than would be expected. This may have been related to a period of very hot weather during the early days of the trials which affected grass growth throughout the trial period. The small amounts of grass harvested at later cuts, especially on control treatments, also caused some problems for

chemical analysis as these were less than the amounts usually used for P determination. Where necessary, the whole sample was used for analysis.

Dry matter yield

DM yield responses (the difference in yield between a treatment and the untreated control) to applied P first appeared at cut 3 in soil 1 and at cut 2 in soil 2 (Tables 4 and 5, Figs 5 and 6). This is a reflection of the higher concentration of Olsen P in soil 1. Total dry-matter yield over 6 cuts for the control and MCP treatments was related to the rate of P application by regression using a quadratic function (equations (1) and (2) for soils 1 and 2 respectively) (Figs 11 and 12):

$Y_{dm} = 3.39 + 37.82 P - 102.09 P^2$ $R^2 = 0.92$ standard error = 0.481	(1)
$\begin{split} Y_{dm} &= 2.39 + 19.85 \ P - 19.67 \ P^2 \\ R^2 &= 0.89 \ \ \text{standard error} = 0.702 \end{split}$	(2)

Where: Y_{dm} is total dry-matter yield (g/pot) P is rate of P application (gP₂O₅/pot)

In both soils, analysis of variance revealed treatment differences significant at P<0.10 but not quite reaching significance at P<0.05. Recorded yields for the control were lower than were those for other treatments in both soils.

Soil 2, with the lower Olsen P, provided the clearer response curve for the MCP treatments. In both soils, recorded yield for MCP at the $0.3gP_2O_5$ rate was lower than that at the $0.25gP_2O_5$ rate although the differences were not statistically significant. There also were recorded differences in yield for the two similar recovered phosphate materials from Unitika (nos 1a and 1b) but again these were not statistically significant.

P concentration in the grass

The P concentration in the grass tended to decline during the course of the trials in both soils (Tables 6 and 7, Figs 7 and 8). Concentrations were high at cut 1, 7000 to 9000 mgP/kg in soil 1 and 4000 to 7000 mgP/kg in soil 2. At cut five, concentrations had declined to 3700 to 5300 mgP/kg in both soils. In both soils, the P concentration in the control treatment was higher than that in any other treatment at cut 3 (Figs 7 and 8).

In soil 1, at cut 3 (49 days after treatment application (DAA)) concentrations were significantly lower for the sewage recovered calcium phosphate and the iron phosphate than MCP at the standard rate of $0.20 \text{ mgP}_2\text{O}_5/\text{pot}$. At cut 4 (66 DAA) in soil 1, concentrations were again lower in treatment 8 and 16 than in treatment 4 and also were lower for synthetic struvite no. 2. There were no significant treatment differences at cuts 1 or 5.

In soil 2, at cut 1 concentrations were higher for most of the test materials than than for MCP at the standard rate, exceptions being the sewage recovered calcium phosphate, recovered struvite nos. 1b and 3 and the iron phosphate. At cut 2 (38 DAA), concentrations for the sewage recovered calcium phosphate and the iron phosphate were lower than that for MCP at the standard rate. At cut 4 (50 DAA), the P concentration for the sewage recovered calcium phosphate was lower than that for MCP at the standard rate. There were no significant treatment differences at cut 5.

P offtake in grass

P offtake is generally more sensitive to P treatment than is dry-matter yield and provides a more reliable measurement of the effectiveness of a test material. Thus it is usual to calculate P offtake response (the difference in P offtake between a treatment and the untreated control) and to use this for comparing sources. This offtake response tended to increase during the course of the pot trials (Tables 8 and 9, Figs 9 and 10). Total offtake response over 5 cuts was 5.3 to 14.8 mgP/pot in soil 1, equivalent to an apparent recovery of 6 to 17% of the applied P. In soil 2, total offtake response was 11.1 to 20.6 mgP/pot, equivalent to an apparent recovery of 13 to 24% of the applied P. These recovery values for applied P are typical for pot trials using ryegrass as the test crop and for many arable crops in field experiments.

Total P offtake over 5 cuts for control and MCP treatments was related to the rate of P application by regression using a quadratic function (equations (3) and (4) for soils 1 and 2 respectively) (Figs 13 and 14):

$Y_p = 16.39 + 93.41 P - 196.71 P^2$ R ² = 0.99 standard error = 0.212	(3)
$\begin{split} Y_p &= 8.09 + 74.58 \ P - 8.33 \ P^2 \\ R^2 &= 0.84 \ \text{ standard error} = 4.407 \end{split}$	(4)

Where: Y_p is total P offtake (mg/pot) P is rate of P application (gP₂O₅/pot)

P offtake for both synthetic struvites was higher than that for MCP at the standard rate though not significantly so. For recovered struvites, P offtake was similar to that for MCP at the standard rate although in soil 2, P offtake recorded for recovered struvite no. 6 was lower than that for MCP (though the difference was not statistically significant). The potassium struvite (recovered struvite no. 5) gave a P offtake apparently higher than that for MCP in soil 1 but similar to MCP in soil 2. The sewage recovered calcium phosphate gave the lowest P offtake in both soils, significantly (P<0.05) lower than that for MCP in soil 1.

Discussion

The use of magnesium ammonium phosphate as a source of slow release fertilizer was suggested as early as 1857 by Murray (ref. 9). In the middle decades of the 20th century, a small number of papers was published on the use of magnesium ammonium phosphate as a fertilizer (ref. 10). In many of the experiments, P in magnesium ammonium phosphate was found to be as available to plants as was that in superphosphate but occasionally, lower availability was reported. The perceived slow release properties of magnesium ammonium phosphate were based on:

- low solubility in water
- low rate of mineralisation of the ammonium ion presumably due to the low water solubility and hence dissociation of the ammonium ion.

However, as a slow release N fertilizer for annual arable crops, it is unlikely that magnesium ammonium phosphate would find a ready acceptance due to the variability in rate of N release. Magnesium ammonium phosphate and recovered phosphates are more likely to be accepted as sources of P.

Much of the recent literature on recovered phosphates, particularly struvites, has been concerned with their production and potential use in agriculture but there is little recent

published data on their agronomic value. Thus, this project was undertaken to assess the availability of the P in various precipitated phosphates over a short time period.

Data from the present pot trials are summarised in Table 10 in which the test materials are grouped by type. Also shown are the predicted yield and P offtake for MCP at 0.20 gP_2O_5 /pot derived from equations (1) and (2) (dry-matter yield) and (3) and (4) (P offtake). By using all the information in the MCP response curve, the predicted yield and P offtake can offer a more representative basis for treatment comparisons. As noted previously, P offtake is a better predicted P offtakes are much closer than are the corresponding values for dry-matter yield. Here, dry-matter yield and P offtake refer to the total values over the course of the experiments as shown in Table 10.

At the lower levels of the standard P applications, both dry-matter yield and P offtake were smaller on soil 2 which had the least Olsen P. Differences between the two soils were less at the higher levels of applied P. This suggests that the small difference in pH and the larger difference in Olsen P between the soils did not affect the dry-matter yield and P offtake that could be achieved under the conditions of these pot experiments. This conclusion is supported by dry-matter yields and P offtakes with MCP at 0.25 and 0.30 gP₂O₅/pot. Both were a little lower with 0.30 than with 0.25 gP₂O₅/pot but the differences were not significant suggesting that the maximum dry-matter yield and P offtake had been reached.

For the test materials, there were some small differences in dry-matter yield and P offtake between the two soils. However, these differences were not consistently in favour of one soil or the other and fell within the range of experimental error. It is therefore appropriate to consider the mean of the two soils.

Both synthetic struvites applied at $0.20 \text{ gP}_2\text{O}_5$ /pot gave very similar dry-matter yields and P offtakes and larger than those given by MCP at the same rate of application. The differences to MCP were not statistically significant.

Dry-matter yields and P offtakes were similar for the three struvites recovered from municipal sewage (nos 1a, 1b and 3) and in the ranges 6.26 to 6.44 g dry-matter/pot and 25.97 to 27.27 mgP/pot. These values were larger than, but not significantly different to, the values for MCP predicted using equations (1) and (2) (dry-matter yield) and (3) and (4) (P offtake).

Dry-matter yields given by the struvites recovered from corn steep (recovered struvite no. 2) and the dye industry (recovered struvite no. 4) were only very little smaller than those given by struvites recovered from sewage and P offtakes were the same. Potassium struvite derived from veal manure (recovered struvite no. 5) gave very

similar dry-matter yields and P offtakes to the other recovered struvites. The spontaneously occurring deposit (recovered struvite no. 6, mainly struvite judged by its total P_2O_5 content, gave very similar dry-matter yields to the other recovered struvites but slightly lower P offtakes. Similar results to these have been reported for pot trials conducted in Japan (ref. 11).

The iron phosphate gave dry-matter yields and P offtakes very similar to those given by MCP at 0.20 gP₂O₅/pot. It has generally been considered that iron phosphates are insoluble and that the P they contain is unavailable to plants. This was not so for this synthetic iron phosphate. Recently, Richards and Johnston (personal communication) found that a part at least of the water-insoluble P fraction of triple superphosphate was available to plants. This fraction also was probably largely iron phosphates. Some research needs to be done on iron phosphates that are precipitated from waste water using ferrous or ferric salts. The plant availability of the P may depend on the degree of hydration and perhaps the extent of ageing and slow transformations of the iron phosphate.

	Total dry-matter yield G/pot		Total P offtake Mg/pot			
Material	Soil 1	Soil 2	Mean	Soil 1	Soil 2	Mean
	5011 1	5011 2	Wiedli	30111	3011 2	Wicali
Control	3.25	2.56	2.91	16.35	9.38	12.87
MCP 0.10 gP2O5/pot	6.53	3.66	5.10	23.94	12.55	18.25
MCP 0.15 gP2O5/pot	6.92	5.19	6.06	25.79	18.53	22.16
MCP 0.20 gP2O5/pot	6.19	5.23	5.71	27.36	22.46	24.91
MCP 0.20 gP2O5/pot	6.87	5.57	6.22	27.20	22.67	24.94
MCP 0.25 gP2O5/pot	6.66	7.00	6.83	27.66	32.22	29.94
MCP 0.30 gP2O5/pot	5.63	6.10	5.86	26.80	26.10	26.45
Test materials at 0.20 gP2O5/pot						
Synthetic struvite no. 1	6.40	7.25	6.83	29.68	29.75	29.72
Synthetic struvite no. 2	6.58	7.40	6.99	28.75	30.01	29.38
Struvites recovered from:						
Sewage (no. 1a)	7.00	5.87	6.44	30.44	24.10	27.27
Sewage (no. 1b)	6.40	6.11	6.26	27.09	24.84	25.97
Sewage (no. 3)	6.68	5.88	6.28	29.70	23.92	26.81
Corn steep (no. 2)	6.00	6.18	6.09	26.01	26.48	26.25
Dye industry (no. 4)	6.35	5.89	6.12	28.53	24.75	26.64
Veal manure (potassium struvite no. 5)	6.91	5.99	6.45	31.13	22.22	26.68
Sewage (deposit no. 6)	6.62	5.11	5.87	28.97	20.46	24.72
Recovered calcium phosphate	6.09	6.83	6.46	21.64	20.45	21.05
Synthetic iron phosphate	6.94	7.09	7.02	25.20	22.68	23.94
SE/plot	1.126	1.557	1.359	4.295	5.089	4.709

Table 10 Total dry-matter yield of ryegrass and total P offtake in the grass for both standard and treatment materials on soil 1 (pH 6.6, Olsen P 28mg/l) and soil 2 (pH 7.1, Olsen P 11mg/l)

Conclusions

Dry-matter yields of ryegrass and P offtakes given by the synthetic and recovered struvites in these experiments on the two soils used were not significantly different statistically either between themselves or to MCP applied at the same rate. On this basis these struvites could be used to recycle P on similar soils and the effect of the P should be similar to that in MCP.

The recovered struvites gave consistently smaller dry-matter yields than the synthetic struvites but the differences were not statistically significant. This suggests that the recovered struvites might have slightly lower P solubilities than the synthetic struvites, a conclusion supported by the lower yields given by the spontaneously occurring struvite deposit. These small differences may be due to crystal size. If so, this would suggest that struvite precipitation from waste water streams should be carefully controlled.

Although the soil types used in these experiments are found widely in Europe, it would be necessary to conduct similar experiments on at least three other soil types before wide generalisations could be made. These should be a neutral or slightly acid sandy loam and calcareous soils with about 5% and 20% calcium carbonate. The reactions between soil and applied P on these soils could be appreciably different to those on soils similar to those used here.

The iron phosphate gave dry-matter yields and P offtakes very similar to those given by MCP at 0.20 gP_2O_5 /pot. It has generally been considered that iron phosphates are insoluble and that the P they contain is unavailable to plants. This was not so for this synthetic iron phosphate. Some research needs to be done on iron phosphates that are precipitated from waste water using ferrous or ferric salts. The plant availability of the P may depend on the degree of hydration and perhaps the extent of ageing and slow transformations of the iron phosphate.

As supplied, these struvites could not find favour in agriculture. It will be necessary to find some way of producing physically stable aggregates, ideally of 2 to 4mm, to allow the material to be spread by normal farm equipment.

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Photograph 1 A & W synthetic struvite (1)



Photograph 2 Geestmerambacht calcium phosphate (2)



Photograph 3 Unitika struvite (3/4)



Photograph 4 Audobon struvite (5)



Photograph 5 Nishiwara seawater struvite (6)



Photograph 6 Cranfield synthetic struvite (8)



Photograph 7 Hansen Barcelona struvite (10)



Photograph 8 Veal K struvite (11)



Photograph 9 Struvite (14)

Appendix 1 Project Plan for pot trials

Treatments

Treatments		
		<u>gP₂O₅/pot</u>
1.	Control	0.00
2.	MCP	0.10
3.	MCP	0.15
4.	MCP	0.20
5.	MCP	0.25
6.	MCP	0.30
7.	A & W synthetic struvite (1)	0.20
8.	Geestmerambacht calcium phosphate (2)	0.20
9.	Unitika sample F (3)	0.20
10.	Unitika sample H (3)	0.20
11.	Audobon (5)	0.20
12.	Nishihara seawater struvite (6)	0.20
13.	Cranfield synthetic struvite (8)	0.20
14.	Hansen Barcelona struvite (10)	0.20
15.	Veal K-struvite (11)	0.20
16.	Cranfield iron phosphate (13)	0.20
17.	Struvite (14)	0.20

Treatment Application

Mix treatment materials with soil on an individual pot basis before sowing ryegrass.

Treatment Materials

Recovered phosphate materials to be provided by CEEP.

Uniform Applications

0.05 gN/pot and 0.1 gMg/pot mixed with soil before sowing as ammonium nitrate and magnesium sulphate.

0.15 gN/pot and 0.1 gK₂O/pot top-dressed after every cut as ammonium nitrate and potassium sulphate.

0.05 gMg/pot top-dressed after cut numbers 2 and 4 as magnesium sulphate. Note: Top-dressed nutrients can be dissolved in water for application using a liquid dispenser..

<u>Design</u>

Randomised block.

17 treatments x 3 replicates = 51 pots on each of 2 soils = 102 pots in total.

Statistical Analysis

Analysis of variance using ARM software.

Pot size

To hold 1kg soil.

Soil Specification

One soil pH approximately 6.0, other soil pH approximately 7.5. Both soils low in extractable P (MAFF index 0 or 1).

Test crop

Ryegrass. Sow 0.3 g seed/pot and cover with a little soil.

Watering

Use collected rain water.

Harvesting

Cut grass when height is 8 - 10cm in the most advanced pots. Dry samples, weigh and label for submission to laboratory.

Assessments

Timing	Description	No. of samples
Before treatments applied	Soil samples for analysis	2
At every cut	Grass samples for drying and P analysis	102

Other Records

Trial Diary

Data Retention

All data and a copy of the Final Report will be retained in the Project File at Ecopt

Sample Retention

Pots containing soil to be retained for one month after trial completion (soils may be needed for analysis).

Sample analyses

		$%P_2O_5$
2 - 6	MCP	56.18
7	A & W synthetic struvite (1)	29.32
8	Geestmerambacht calcium phosphate (2)	19.02
9	Unitika sample F (3)	29.55
10	Unitika sample H (3)	29.32
11	Audobon (5)	30.01
12	Nishihara seawater struvite (6)	29.32
13	Cranfield synthetic struvite (8)	30.70
14	Hansen Barcelona struvite (10)	19.02
15	Veal K-struvite (11)	19.70
16	Cranfield iron phosphate (13)	32.35
16	Struvite (14)	28.41

Note: All rates of application and analyses above are expressed as P_2O_5 . Where conversion is necessary (eg. for calculating amount of MCP to apply) the conversion factor for P to P_2O_5 is 2.291.

Appendix 2 Trial diary

Date	Operation
20/6	Soil weighed, treatments applied, grass sown
2/7	Grass cut, samples dried, uniform application of NH ₄ NO ₃ and K ₂ SO ₄
3/7	Pots watered
6/7	Pots watered
9/7	Grass cut, samples dried
10/7	Uniform application of NH ₄ NO ₃ , K ₂ SO _{4 and MgSO₄}
11/7	Pots watered
13/7	Pots watered
16/7	Pots watered
18/7	Temperature reduced 25° C to 15° C by shading. Pots watered
20/7	Pots watered
25/7	Pots watered
27/7	Grass cut, samples dried, uniform application of NH ₄ NO ₃ and K ₂ SO ₄
30/7	Pots watered
6/8	Pots watered
7/8	Grass cut, samples dried, uniform application of NH ₄ NO ₃ , K ₂ SO _{4 and}
	MgSO ₄
10/8	Pots watered
13/8	Pots watered
15/8	Pots watered
17/8	Pots watered
20/8	Pots watered
24/8	Grass cut, samples dried, uniform application of NH ₄ NO ₃ and K ₂ SO ₄
27/8	Pots watered
31/8	Pots watered
3/9	Pots watered
6/9	Pots watered
10/9	Pots watered
12/9	Grass cut, samples dried
13/9	Uniform application of NH_4NO_3 , and K_2SO_4
14/9	Pots watered
17/9	Pots watered
21/9	Pots watered
24/9	Pots watered
27/9	Grass cut, samples dried