Fertilizer value of phosphorus in different residues

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Abstract
The phosphorus (P) fertilizer effect of different residues was tested in pot and field trials. Dry matter yield and P uptake were measured in ryegrass grown in pots amended with 15 different residues. The effect on the first cut (after 5 weeks) was significantly higher for residues with a low organic matter content, e.g. ash and biogas residues, than for many other products with higher organic matter content, such as manure, sewage sludge and slurry. However, the effect on two cuts (after 11 weeks) was more similar between residues and was approximately 40-60% that of mineral fertilizer. The effect was correlated to ammonium lactate-extractable P (r^2=0.48). In a field experiment with spring wheat comparing the P effect of four residues and mineral fertilizer, pelleted meat meal had a similar effect on yield and P offtake as mineral fertilizer P, whereas sewage sludge and chicken manure had approximately 50% of the mineral fertilizer effect.

Introduction
Residues rich in phosphorus (P) are used as fertilizers in crop production. However, the P availability to crops is sometimes questioned and may vary between different residues depending on their physical and chemical properties.

Animal manure P is often regarded as equally available to commercial mineral fertilizer P on a long-term basis, but is reported to have lower fertilizer efficiency in the short term [1]. Ash, which can be regarded as a mineral fertilizer, has been found to have varying and rather limited P fertilization effects depending on origin [2; 3]. Sewage sludge is reported to have varying P availability depending on the chemical used for P precipitation [4], while P precipitated as struvite is reported to have similar P fertilization value to the commercial fertilizer calcium phosphate [5]. A citrate extraction method is used to assess P availability in mineral fertilizers and may also be applicable to other materials such as ash [2].

The present study compared the short-term P fertilization effect of different residues rich in P and commercial mineral P fertilizer in pot and field experiments and examined whether this effect can be predicted by extraction with citrate, water or ammonium lactate.

Materials and Methods

Pot experiment
Pot experiments with ryegrass were performed to assess the P fertilization effects of 15 different residues, including different ash products, sewage sludge, biogas residues and manures. Three-litre pots containing 3.3 kg soil were amended with residues corresponding to 12 kg P ha^{-1} (0.031 g P per pot) incorporated into the top 10 cm of soil. In three control treatments, 0, 6 or 12 kg P ha^{-1} were applied as mineral fertilizer. The residues were added to soil two months before sowing and mineral P in controls at sowing time. In each pot, 40 seeds of ryegrass (*Lolium perenne*) were sown and the pots were watered to reach 70% of WHC. The pots were watered to this level regularly. Each treatment had six replicates, three with soil pH 6.2 and three limed to achieve pH 7.2. All pots were fertilized with other nutrients to ensure that only P was limiting. The grass was cut twice, after 5 and 11 weeks. A second dose of N was applied after the first cut. Cut material was weighed and analysed for N and P content. Control treatments were used to calculate P response in terms of DM yield and P offtake. The DM yield and P offtake in treatments with residues were compared against the control response to calculate the mineral fertilizer equivalent (MFE), i.e. the fraction of total P that is equally available to plants as inorganic P.

Extractions
In order to find a suitable extraction method to predict the P effect of residues, P in the residues was extracted with water (EES 2003/2003), citrate (EES 2003/2003) and ammonium lactate (P-AL; SS028310 + T1). Extracted P as a percentage of total P was then plotted against MFE to check correspondence (regression and correlation).

Field experiment
A field experiment with spring wheat was carried out on a clay soil with poor P status in south-west Sweden in 2012. In treatments, residue addition amounting to 16 kg P ha^{-1} was compared with control treatments with 0, 8 or 16 kg P ha^{-1} applied as mineral fertilizer in 3 m x12 m plots arranged in a randomised block design with four replicates. All plots were fertilized with N and K to ensure that only P was limiting. Grain yield and P offtake after addition of pelleted meat meal, two types of sewage sludge and chicken manure was studied. Control treatments were used to calculate P response in terms of grain yield and P offtake. Grain yield and P offtake in treatments with residues were compared with this response to calculate MFE as a percentage of total P applied.

Results

Pot experiment
The P fertilizer effect of the different residues varied with first or second cut, P or dry matter (DM) yield and limed or unlimed soil. The DM yield and P offtake were generally lower for the limed pots (Figure 1). In the unlimed pots, products with a liming effect (lime-precipitated sewage sludge and rapeseed straw ash) resulted in lower yield and P offtake than the other products tested (Figure 1). However, in the limed pots, where all treatments had an unfavourable pH, these products gave similar effects to the other products.

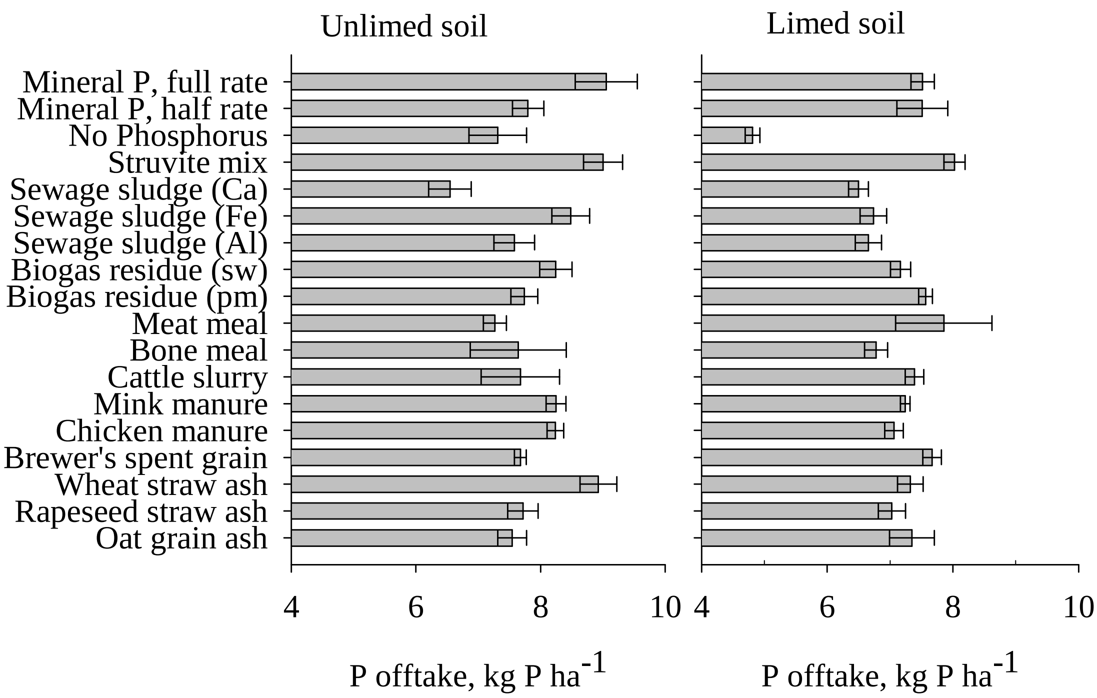

Figure 1. Total phosphorus (P) offtake from the two ryegrass cuts in the different treatments on limed and unlimed soil (error bars indicate standard error).

Yield and P offtake at the first cut were significantly higher for biogas residues, chicken manure, wheat straw ash, oat grain ash and brewer’s spent grain than for the other residues with high organic matter content (Figure 2). The MFE derived from the first cut for these products was 75-85%, compared with 35-55% for most other residues (Table 1). However, the effect from the second cut differed less between residues (Figure 2) and for most residues the MFE derived from the second cut was 40-60% (Table 1).

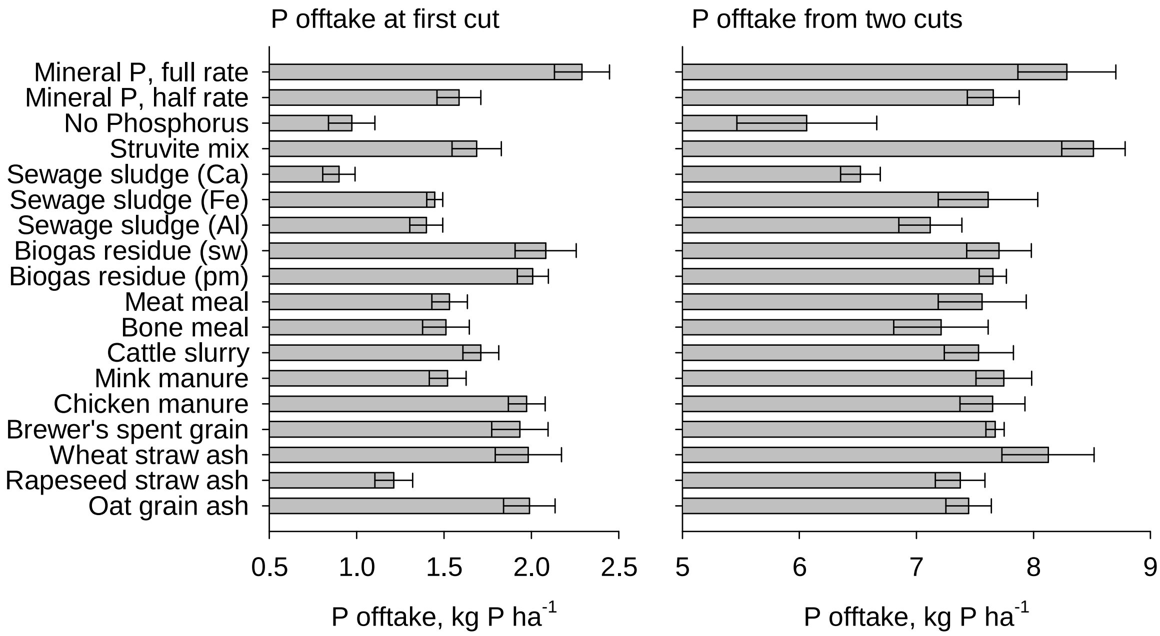

Figure 2. Phosphorus (P) offtake at the first cut and from both cuts in the different treatments on limed and unlimed soil (error bars indicate standard error).

Table 1. Phosphorus (P) content and MFE values of the different residues based on P offtake in the first cut (MFE_{P1}) and second cut (MFE_{P2}) in both limed and unlimed treatments.

Residue	P, kg tonne^{-1}	MFE_{P1}	MFE_{P2}
Struvite mix	4.9	55%	103%
Sewage sludge (Ca precipitated)	1.8	-4%	13%
Sewage sludge (Fe precipitated)	8.0	37%	62%
Sewage sludge (Al precipitated)	7.4	34%	40%
Biogas residue (slaughter waste)	1.2	85%	67%
Biogas residue (plant material)	1.4	80%	64%
Meat meal	26.0	44%	60%
Bone meal	93.0	42%	44%
Cattle slurry	0.9	57%	59%
Mink manure	18.0	43%	68%
Chicken manure	9.2	77%	64%
Brewer's spent grain	4.9	74%	65%
Wheat straw ash	6.3	78%	86%
Rapeseed straw ash	10.0	19%	52%
Oat grain ash	50.0	78%	55%

There was a weak positive correlation between MFE calculated from the first cut and percentage of P extracted from the product with ammonium lactate (P-AL) (r^2=0.48) or water (r^2=0.31). There was a positive correlation with citrate only if sewage sludge was excluded (Figure 3). The P-AL method gave the best correlation with MFE even after the second cut, and better if MFE was calculated from limed soil only (r^2=0.49) than from both limed and unlimed soil (r^2=0.22).

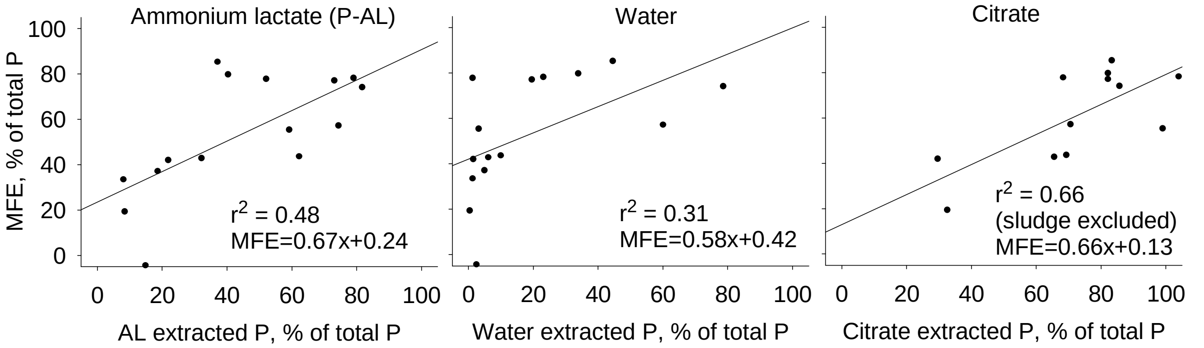

Figure 3. Mineral fertilizer equivalent (MFE, calculated from P offtake from the first cut) as a function of degree of extraction of P with different extraction agents.

In the field experiment, the MFE of pelleted meat and bone meal was close to 100%, whereas that of sewage sludge and chicken manure was around 40-50%.

Table 2. Grain yield, protein content and P offtake in the different treatments in the field trial and P content and MFE values (based on grain yield) of the residues.

Treatment	**Grain yield kg ha^{-1}**	**Protein %**	**P offtake kg P ha^{-1}**	**P content kg tonne^{-1}**	**MFE % of total P**
Control, 0 kg P ha^{-1}	4859	12.3	13.2		
$Ca(H_2PO_4)_2$, 8 kg P ha^{-1}	5187	12.4	13.1		
$Ca(H_2PO_4)_2$, 16 kg P ha^{-1}	5424	12.6	15.1		
Pelleted meat meal, 16 kg P ha^{-1}	5407	12.7	14.8	28.5	94
Sewage sludge, 16 kg P ha^{-1}	5074	12.1	13.8	5.9	35
Sewage sludge, 16 kg P ha^{-1}	5094	12.1	13.7	7.0	39
Chicken manure, 16 kg P ha^{-1}	5155	12.2	14.6	8.5	50

Conclusion and perspectives

Residues with a low organic matter content, e.g. ash products and biogas residues, had a faster P effect than most of those with a higher organic matter content and should thus be more suitable as starter P. However, the P effect after two months was similar for most residues and was 40-60% of that of mineral fertilizer. The pH effect of the residues can be more important for the P fertilization effect than the form of P. In general, P-AL can be used to get a rough estimate of P availability in residues. Citrate-extractable P is also useful, but extracts much more than is plant available from sewage sludge. In the field experiment, pelleted meat meal had a similar P effect to mineral fertilizer P, but for the meat meal in the pot experiment the effect was only half as good. The better effect of pellets could be due to better fertilizer placement in the soil. Chicken manure and sewage sludge had a similar effect in pots and in the field.

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