Technical Note TN668

SRUC

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Managing soil phosphorus.

- A new soil specific approach to P management is presented that takes into account the relationship between differing soils capacity to regulate P availability for plant uptake.
- Soils have been designated and mapped as index 1, 2 and 3 to reflect inherent soil phosphorus sorption capacity (PSC).
- Soil association groups are listed in order of the most spatially extensive association mapping units for each PSC index.
- For cereal-based arable rotations, and established grass/clover swards the target soil P Status has now been lowered to M- on PSC 1 and 2 soils but stays at M+ on PSC 3 soils.
- Adjustments to P fertiliser recommendations are made taking account of PSC indices to build up or run down to the new target soil P tests (SPT).
- Soil association maps and associated PSC indices can be used to aid zone selection as part of GPS soil testing.
- P treatment options are described including livestock manures and some bulky organic fertilisers.

1. Introduction

Efficient soil P management is challenging due to the varying ability of soils to mediate and regulate plant available forms of P. Farmers and land managers in Scotland are now able to access farm level information about their soils making it possible to provide more accurate P management advice.

Well designed P fertiliser policies should have a build-up or run-down component for low/high soil P status respectively in order to target the moderate status. It is known that build-up rates vary with soil type but currently only very general guidelines are provided. The assignment of P sorption capacity (PSC) indices to different soil types provides a significant advancement in the understanding of the amount of P required to change soil P tests (SPT). It also provides the possibility to expand the potential for precision farming by developing improved recommendation systems based on soil type for variable management of soil resources and P inputs.

The James Hutton Institute, who holds the National Soils Database for Scotland, has created the Soil Information for Scottish Soils (SIFSS) website (http://sifss.hutton.ac.uk/SSKIB_Stats.php) which allows you to access information on your soils. SIFSS is also available as a free iPhone app for you to find out what soil type is in your area. The SIFSS system enables the user to select a soil 'map unit' by zooming in on a particular area (i.e. a field). This can be done by specifying a postcode, grid reference, or simply by zooming in using the interactive map. The user can then select a soil series from a soil association within this map unit. A soil series comprises soils with a similar type and arrangement of horizons which are developed on similar parent material, and a soil association is a collection of one or more soils of the same parent material typically found together in the landscape for an area.

2. Soil P sorption capacity

The P sorption capacity of a soil refers to the differing capacity of soils to bind with applied P making it temporality unavailable for plant uptake. In most soils most of the P that you supply to your crops goes through this soil binding process (Figure 1). Experience has shown that this soil binding effect can be controlled by the slow build-up of P in the soil to a point where the soil can be shown to reliably release sufficient P to meet crop demand on an annual basis. In Scotland this is managed by regular soil analysis to test if sufficient plant available P is present. The P sorption capacity varies depending on soil chemistry, texture, pH and organic content of your soil.

Data from the Soil Survey of Scotland for each soil association have been used to create a map of ranking of P sorption capacity (PSC) for non-calcareous soils from low (PSC 1) to high (PSC 3) (Figure 2). The mapped area is 67.8% of the total land area of Scotland. Blank areas cover built-up areas, open water, rock and scree, organic and calcareous soils for which these data are not currently available. Soil association groups are listed in Table A in order of the most spatially extensive association mapping units for each P sorption capacity index, along with the area that they cover (presented as % of the mapped area).

Figure 1. P supply to crops.

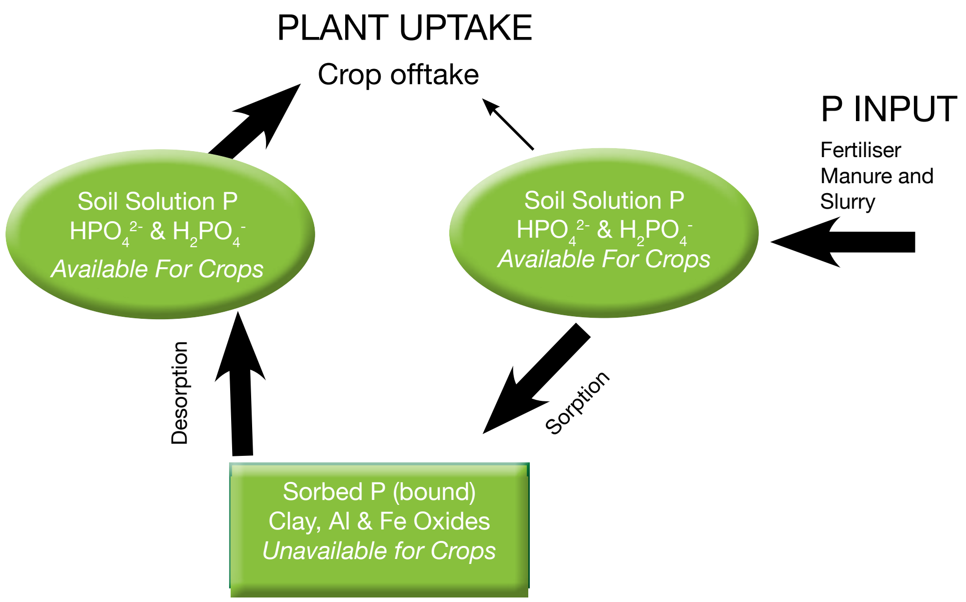

Table A. Soil associations with P sorption capacity (PSC) indices and areas of association groups (presented as % of the mapped area).

PSC 1	% area	PSC 2	% area	PSC 3	% area
Arkaig	23.6	Ettrick	13.6	Darleith/ Kirktonmoor	5.19
Countesswells/ Dalbeatie/ Priestlaw	8.33	Strichen	11.5	Rowanhill/ Giffnock/ Winton	4.67
Corby/ Boyndie/ Dinnet	4.50	Alluvial soils	2.50	Foudland	4.65
Balrownie	2.56	Sourhope	2.37	Tarves	3.00
Thurso	2.03	Yarrow/ Fleet	0.86	Insch	0.98
Sorn/ Humbie/ Biel	0.87	Forfar	0.70	Kintyre	0.94
Kippen/ Largs	0.54	Darvel	0.69	Stirling/ Duffus/ Pow/ Carbrook	0.70
Millbuie	0.38	Kilmarnock	0.62	Bargour	0.18
Gleneagles/ Auchenblae/ Collieston/ Darnaway	0.28	Eckford/ Innerwick	0.57	Lanfine	0.18
		Mountboy	0.54		
% of mapped area	43.1		34.0		20.5

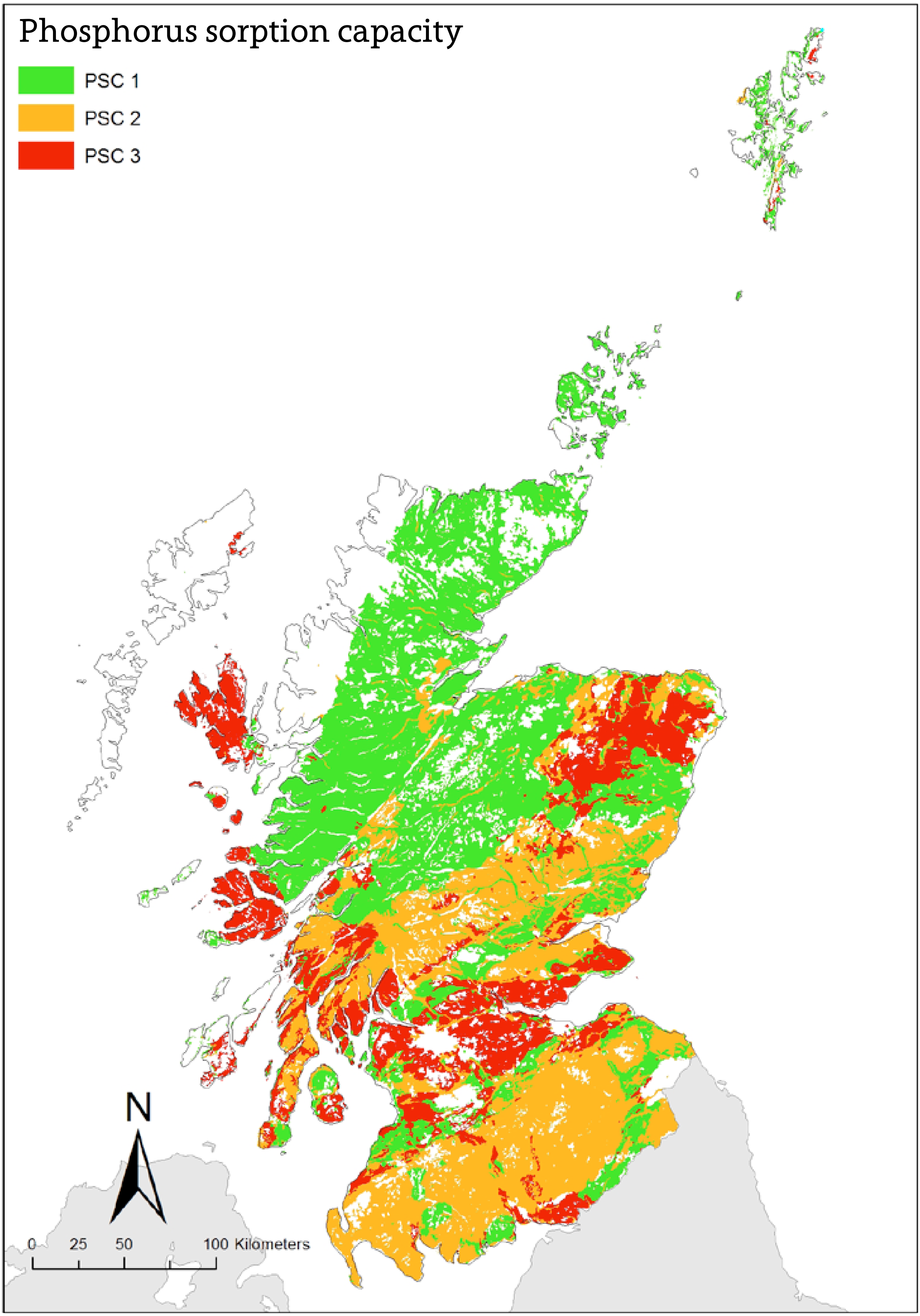

Figure 2. Map of P sorption capacity (PSC) from 1 to 3 by soil association for non-calcareous mineral soils.

3. Adjustments to P fertiliser recommendations taking account of soil P sorption capacity

For cereal-based arable rotations, the current target soil P Status is moderate (M); and rotations with potatoes is the upper half of moderate (M+) (See SRUC TN 633 for further information http://www.sruc.ac.uk/downloads/file/741/tn633). Clover is more susceptible than grass to P deficiency due, in part, to the grass having a more extensive and finely branched root system that enables the grass to compete more effectively. This difference between grass and clover has resulted in a slightly higher target soil P status for grass/clover swards (middle of the M status) compared to grass only swards (M-) (See SRUC TN 652 for further information http://www.sruc.ac.uk/downloads/file/1277/tn652).

On moderate P Status the current recommendation is to apply "maintenance" P fertiliser applications to balance the offtake in cereals, oilseed rape and established grass/clover swards. Soil P levels may decline over the rotation in some soils, due to gradual sorption, when only maintenance applications are made. For a given SPT the soils of high P sorption capacity (PSC 3) will maintain the lowest P concentrations in soil pore water. This relationship explains the observation that despite equivalent soil P status, high P sorption soils often require additional fertiliser to maintain target plant available P. Regular soil analysis detects this, allowing adjustments to be made. Current adjustments to apply additional fertiliser to build up to a moderate P status do not take account of different P sorption capacities of soil. The new data on PSC indices have allowed fine-tuning of these adjustments (Table B). Lower adjustments are recommended for PSC 1 and 2 soils compared with the current recommendation which is retained for PSC 3 soils.

For cereal-based arable rotations, and established grass/clover swards the current target soil P Status is lowered to M- on PSC 1 and 2 soils but M+ on PSC 3 soils (Table B). The target for rotations with potatoes and other P responsive crops should remain as M+ for all PSC indices.

Table B. Effect of P sorption capacity on adjustments (kg P_2O_5/ha/year) to build-up or run-down soil P status.

P sorption capacity	Soil P status				
	Very low (VL)	Low (L)	Mod (M-)	Mod (M+)	High (H)
PSC 1	+40	+20	0	-10	-20
PSC 2	+60	+30	0	-20	-30
PSC 3	+80	+40	+20	0	-40

4. Soil P testing

Soils should be sampled every 4 to 5 years. Fields are best sampled immediately before potatoes which often give a yield response to PK fertiliser in the year of application. Cereals, oilseed rape and grassland do not generally respond on moderate PK status soils and sampling time is therefore not so crucial, but the application of fertilisers and manures may influence results for up to 12 weeks after application. Results may be lower than expected if fields are sampled during periods of maximum nutrient uptake, but higher (or more variable) than expected in the spring due to decomposition of crop residues. Fields should be sampled between September and February, depending on timing of fertiliser applications. SAC Consultancy classifies soil P values (SPT) extracted by the Modified Morgan's method into 6 categories (Table C).

Table C. Classification of extractable soil P (mg/l) into P Status

P Status	Very Low (VL)	Low (L)	Moderate (M-)	Moderate (M+)	High (H)	Very High (VH)
Range (mg P/l)	< 1.8	1.8-4.4	4.5-9.4	9.5-13.4	13.5-30	>30

Soil analysis does not predict crop uptake of P only whether sufficient is available for crop uptake over a growing season. Actual uptake depends on crop, yield potential, rooting depth and weather. Large responses to P in the year of application are only expected where the soil P Status is very low, and are infrequent on soils of moderate status. Potatoes are more responsive to P fertiliser than cereals, oilseed rape and grass.

Soil analyses for P can vary considerably, especially at higher P values or where different major soil types exist in a field. One average soil test value for a whole field inevitably masks this variation. GPS sampling can help overcome this and identify areas in the field where P are under- or over-supplied. Identifying major soil types and yield variation in the field is a key step in establishing the need for GPS sampling.

Grid sampling is used for soil pH as the variation in soil pH can be large and unpredictable, and crop response may be high. Soil P, K, and Mg tends to be less variable, analysis is more expensive, and intensive sampling only improves crop response when soil levels are low or high. Zoning fields for P and K sampling aims is to forecast where soil fertility levels are likely to change. With experience where soil fertility levels change can be forecast using old field boundaries, yield levels, and soil textures and type. Soil association maps and associated PSC indices can also be used to aid zone selection and interpretation of SPT.

5. Maintenance P fertiliser recommendations

P fertiliser applications to balance the offtake in cereals, oilseed rape and established grass/clover swards can be calculated by multiplying typical or expected yield by P content as given in Table D. When calculating annual P inputs in low intensity systems it is important to use realistic estimates of annual crop/grass yields to calculate P replacement requirement. This will ensure that annual applications accurately reflect real crop/grass offtake. Any build-up of soil P should be a deliberate decision that is done in conjunction with other investments such as liming, land drainage and increased application rates of other key plant nutrients. To obtain maximum potential yields from any crop requires soil P levels to be on target but for low intensity farming systems soil P is unlikely to be the only or most important limiting factor to production.

The P applied in organic fertilisers should be taken into account in assessing the need for manufactured fertiliser (see section 8 below). The balance between P offtake and P applied in organic and manufactured fertilisers can be calculated at the end of the season when actual yield is known. Allowance should be made for any surplus or deficit in PK in planning for the following season's fertiliser. In grazing situations most of the P is recycled infield by the animal through its dung and urine. The offtake estimates for grazing in Table D makes allowance for this recycling by assuming that 80% P is recycled. Under grazing to ensure an application of some P to all areas and to replace the small offtake apply 15-20 kg/ha P_2O_5 per season on P status M- on PSC 1 and 2 soils; and on M+ on PSC 3 soils. Where clover is an important constituent of the sward apply the higher recommendation. The PLANET Scotland software can be used for field-level nutrient planning and record keeping.

Table D. Typical yields of cereal, oilseed rape and grass crops (fresh weight)* and standard P content (fresh weight) from SRUC TN633 and TN652.

Crop type	Grain/seed or straw	Yields (t/ha)	P content (kg P_2O_5/t)	P offtakes (kg P_2O_5/ha)
Winter barley & wheat	Grain only	7.0-10.0	7.8	55-78
Spring barley, wheat, rye, triticale & oats; Winter triticale & oats	Grain only	5.0-8.0	7.8	39-62
Winter barley & wheat	Grain + straw**	7.0-10.0	8.4	59-84
Spring barley, wheat, rye, triticale; Winter triticale	Grain + straw**	5.0-8.0	8.6	43-69
Spring & winter oats	Grain + straw**	5.0-8.0	8.8	44-70
Spring oilseed rape	Seed only	1.5-2.5	14.0	21-35
Spring oilseed rape	Seed + straw	1.5-2.5	15.1	23-38
Winter oilseed rape	Seed only	3.0-5.0	14.0	42-70
Winter oilseed rape	Seed + straw	3.0-5.0	15.1	45-76
Silage	1st cut	14-23	1.7	24-39
Silage	2nd cut	7-12	1.7	12-20
Silage	3rd cut	6-9	1.7	10-15
Hay		5-7	5.9	30-41
Grazing		6-10	1.4	2-3***

*cereals at 15% moisture and oilseed rape at 9% moisture
**Offtake values are per tonne of grain or seed removed but include P in straw when this is removed without weighing
*** Under Grazing this calculation assumes approximately 80% of the P is recycled infield by the animal through its dung and urine.

6. Environmental issues linked to SPT and PSC

Phosphorus levels in Scotland ground and surface waters need to be kept low to protect their ecological and drinking water quality. Any increases in P levels in surface and ground water will cause eutrophication (nutrient enrichment) and impact drinking water quality. Eutrophication can then cause algal blooms, fish death, excessive weed growth, poor water clarity and loss of species diversity. Water with elevated levels of P is unacceptable for drinking purposes and its removal is an expensive requirement. The EU Water Framework Directive is focussing attention on the need to control eutrophication due to P movement from soils by requiring all surface waters to have good ecological and chemical status by 2015.

Agriculture is a source of P pollution to Scotland's surface waters due to P movement from soil to water by:

- Surface run-off of recently spread manures and fertilisers.
- Wind and water erosion of soil containing phosphorus.
- Soil and soluble phosphorus in drain outflows.

The direct movement of P in manures, slurries, and bagged fertiliser from surface runoff should be avoided by ensuring that land is maintained in a well-drained state and that spreading of fertilisers, manures and slurries is not done during high risk times or on land that is steeply sloped.

All soil erosion activity negatively impacts environmental quality but well maintained agricultural soil is enriched in P compared to other managed land such as forestry. They therefore represent a greater risk to water quality when soil erosion occurs. Those soils with a higher phosphorus sorption capacity (PSC 3) that are maintained on target for P represent the greatest risk as they will contain a higher level of adsorbed P from fertilising. Maintaining your soils at optimum soil P levels is only justified if the land is being actively managed for maximum yields. This requires that other good soil management targets such as pH, nutrient planning as well as adequate drainage status are also considered.

7. P fertiliser treatments

Placement of fertiliser P either with the seed or as a concentrated band at some variable distance adjacent to or below the seed has been shown to benefit early season root development, enhance crop yield and P uptake, especially on low P status soils. This benefit to P placement is expected to be greater in PSC 3 soils. Fertiliser placement for arable crops grown in low P soils appears to remain a viable approach to improve P use efficiency and target a lower P status e.g. M- on PSC 1 and 2 soils (Table B).

There is increasing interest in enhancing the efficiency of P fertilisers or mobilising fixed P from soil. Cation-complexing ligands are claimed to increase availability of fertiliser-applied or soil P through sequestration of cations that bind P strongly. There is as yet no evidence to indicate that complexation of P-binding cations is an economically viable process to either release P from stored forms in Scottish soil or to increase efficiency of added fertiliser P.

Ammonium phosphates (diammonium phosphate (DAP) and monoammonium phosphate (MAP)) and superphosphates (mainly triple superphosphate (TSP)) contain phosphate (93 – 95%) in a water-soluble form. There are many different types of water insoluble phosphate with different chemical and physical characteristics. The fertiliser declaration should give details of the amount of P soluble in different acid extractants. This information does not indicate the effectiveness of these sources of P on different soil types. Care should be taken not to compare the solubility of water insoluble phosphates in different reagents (for example, formic acid and citric acid) that extract different forms of phosphate.

Lack of water-solubility does not mean the phosphate is unavailable to crops. Finely ground, reactive phosphate rocks with close to zero water-solubility, can be used successfully as a P source on grassland where the surface soil pH is maintained below pH 6.0 and for arable crops grown on acid soils below pH 6.0. Some other water-insoluble phosphates are an effective source of P under appropriate soil and weather conditions and in these situations can replace water-soluble P fertilisers. Some phosphate fertilisers and typical percentage nutrient content are shown in Table E.

Table E. Phosphate fertilisers and typical percentage nutrient content

Phosphate fertilisers	% N	% P_2O_5
Triple superphosphate (TSP)		45-46
Di-ammonium phosphate (DAP)	18	46
Mono-ammonium phosphate (MAP)	12	52
Rock phosphate (e.g. Gafsa)		27-33

Routine use of foliar phosphate is not recommended but there may be circumstances for seed potato growers where uptake of soil applied P is restricted and foliar applied P may increase tuber numbers. Such a situation may occur in a non-irrigated crop grown in PSC 3 soil.

The P content of manures applied to land depends on a number of factors, including the number and type of livestock, the diet and feeding system, the volume of dirty water and rainwater entering storage facilities, and the amount of bedding used. Typical dry matter and total nutrient contents of livestock manure and other bulky organic fertilisers are given in Table F (See SRUC TN650 for further information http://www.sruc.ac.uk/downloads/file/1276/tn650).

The availability of manure phosphate to the next crop grown is lower than from water-soluble phosphate fertilisers. As a general rule, around 50% of the phosphate in pig and cattle slurries and other (non-agricultural) bulky organic fertilisers will become available to the crop in the year of application. Around 60% of the phosphate in solid animal manures will become available to the crop in the year of application.

The nutrient content of other bulky organic fertilisers depends on the materials from which they were made and the processes through which they were treated. In some cases, for example distillery effluent and lime-stabilised biosolids, the degree of variation in chemical and physical properties between different batches from the same producer will be relatively small. The values presented in Table F are likely to be close to those obtained through testing the majority of these types of materials. However, for many other organic fertilisers, there is considerable variability in chemical and physical properties, depending on the input materials (or feedstocks) and the processes used to produce the material. It is always worthwhile having the nutrient content of representative samples determined, particularly where material from the same supplier is used regularly over time. However, analysis is particularly important where the properties of the organic fertiliser concerned are likely to vary widely from the average values in Table F. This is most likely with green/food compost, waste food products and digestate. Producers of PAS100 compost and PAS110 digestate should be able to supply a typical analysis of their product free of charge.

Table F. Typical dry matter (DM) and nutrient contents of livestock manures and other bulky organic fertilisers

Manure type	DM (%)	kg/t (solid manures) or kg/m^3 (liquids/slurries)		
		Total N	Total P_2O_5	Total K_2O
Cattle FYM	25	6.0	3.2	8.0
Pig FYM	25	7.0	6.0	8.0
Layer manure	35	19	14	9.5
Broiler/Turkey litter	60	30	25	18
Cattle slurry	6	2.6	1.2	3.2
Pig slurry	4	3.6	1.8	2.4
Biosolids, liquid digested	4	2.0	3.0	0.1
Biosolids, digested cake	25	11	18	0.6
Biosolids, thermally dried	95	40	70	2.0
Biosolids, thermally hydrolysed	30	10	20	0.5
Biosolids, lime stabilised	40	8.5	26	0.8
Green compost	60	7.5	3.0	5.5
Green/Food compost	60	11	3.8	8.0
Paper crumble, chemically/ physically treated	40	2.0	0.4	0.2
Paper crumble, biologically treated	30	7.5	3.8	0.4
Distillery pot ale	5	2.5	1.8	1.1
Distillery bioplant effluent/sludge	2.5	1.5	1.3	0.4
Digestate (whole), food based	4	5.0	0.5	2.0
Digestate (whole), pig slurry based	2	3.6	1.8	2.4
Digestate (whole), cattle slurry based	4	2.6	1.2	3.2

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