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Fertiliser recommendations for grassland

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Summary

- **The main limitations to grass production are temperature, moisture, soil pH, soil drainage, soil structure, and nitrogen (N).**
- **Recommendations take account of nutrient management planning in the PLANET Scotland software tool and NVZ Action Programme rules.**
- **Good soil management is required to optimise nutrient use and maximise grassland productivity.**
- **Regular soil analysis is essential to manage soil pH and optimise phosphate (P_2O_5) and potash (K_2O) inputs for maximum yields and profitability.**
- **Considered application of nitrogen to meet grass needs can reduce the loss of harmful greenhouse gases.**
- **Appropriate use of livestock manures can result in considerable savings on purchased fertilisers.**

1. Introduction

The main limitations to grass production are temperature, moisture, soil pH, soil drainage and structure, and nitrogen (N). This technical note shows how to calculate the optimal amount of N that should be applied based on:

- Assessment of "*site class*" (grass growing conditions). This is a measure of the production potential of the farm and determines the area of grass and quantity of fertiliser N needed to produce the grass required for your intended grassland management.
- Predictions from tabulated data of the *annual N use* to support a particular grassland management at a given site class.

Phosphate, potash, and sulphur recommendations have been updated in the light of current advances in understanding of soil nutrient management. Regular soil analysis is essential to optimise phosphate (P_2O_5) and potash (K_2O) inputs for maximum yields and profitability. Soil should be sampled and tested every 4–5 years and prior to establishment. P and K inputs from organic manures reduce annual P and K requirements. Over-use of P is wasteful and can lead to the loss of phosphorus from agricultural land to fresh water and impair water quality.

This technical note can be used along with PLANET Scotland, a software tool designed for routine use by Scottish farmers and consultants to plan and manage nutrient use on individual fields (http://www.planet4farmers.co.uk).

Effective nutrient management will help to reduce the loss of nutrients to the environment; an important factor in terms of protecting water quality and reducing emissions of greenhouse gases such as nitrous oxide (N_2O). Precision slurry spreading, avoiding application on windy days and not applying fertilisers to wet, saturated or compacted soils will all help to minimise the loss of greenhouse gases. Further information on climate change and farming is available at https://www.farmingforabetterclimate.org

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2. Soil Management

The efficient and profitable use of organic and manufactured nutrients in grassland systems requires good soil conditions and effective soil management. The priorities in grassland are soil pH, drainage and soil structure. The profitable use of the maximum levels of nutrient inputs can only be realised when the soil is in good condition.

Soil pH values

The optimum availability of most plant nutrients in soil occurs over a small range of soil pH values. Maintaining the optimum pH in the topsoil in all parts of the field is important to achieve optimum yields and consistent quality. Clover is more sensitive to soil acidity than many grass species and soil pH should be maintained to encourage a clover-rich sward. Aim for an optimum soil pH of 6.0 on mineral soils. Aim lower at pH 5.3 to 5.5 on peaty soils. Liming materials should be purchased on the basis of the price relative to the neutralising value and fineness of the products on offer. The fineness will usually include the maximum size of particles and the amount passing a 150 micron sieve. The finer the grinding of the product the more rapid the rate at which neutralisation occurs. More information is available in FAS technical note TN714 "Liming materials and recommendations (2019)."

Soil structure will determine the rooting depth and soil drainage capacity. Compaction of the upper soil layers arising from poaching and wheel ruts limits root development restricts nutrient uptake and reduces growth potential. Soil compaction should be addressed when identified using a combination of cultivation, ploughing and changes to land management practices. an SRUC/Aarhus Universitet/UEM field guide to identifying soil compaction is available at https://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure.

Excess soil moisture on heavy land limits the length of the effective growing season. This may require the installation and maintenance of an artificial drainage system to fully justify the use of moderate to high levels of nutrient inputs.

The application of lime, organic fertilisers and more insoluble forms of P, prior to any land work during grass and clover establishment, is an opportunity to directly improve soil fertility below the first few cm of the soil profile.

A review of SAC laboratories data found that nationally 61,702 samples were taken from 1993 to 2017 in order to provide a recommendation for grass. The data have been separated into 4 Regions: 1 – NE Scotland and Tayside; 2 – SE Scotland; 3 – SW Scotland; and 4 – Highland and Islands; and split in to 5 pH categories in Table A.

Table A. Number of soil samples nationally and regionally and percentage in each pH category

Region	Number of samples	pH category <5.3 (%)	5.3-5.5	5.6-5.8	5.9-6.1	>6.1
Nationally	61,695	11.5	20.8	29.7	21.8	16.2
1	15,006	8.0	17.9	33.1	27.0	14.0
2	8,715	6.2	16.7	30.1	25.3	21.6
3	24,684	12.2	24.1	29.3	19.5	14.9
4	13,290	17.4	20.6	26.4	18.2	17.4

The results in Table A show that on a national basis pH results are distributed into approximately three groups: about a third of Scotland's grassland soils have an acceptable pH or fall just below a target for pH (5.9 and above) and require maintenance liming; an additional third of samples fall between the pH range 5.6-5.8 and these require appropriate lime recommendations based on technical note TN714 "Liming materials and recommendations (2019)" (https://www.fas.scot/publication/technical-notes/) and another third have a pH 5.5 or below which require careful attention. The regional trend is similar but shows a greater proportion of samples from Regions 1 and 2 fall into the first group while those from Regions 3 and 4 fall into the lowest pH group. The application of fertiliser, both organic and manufactured, onto grassland soils that are below target for pH is inefficient, poses a risk to water quality can contribute to climate change.

Soil sampling programme

Grassland soils should be analysed when cultivated or once every 4 to 5 years for soil pH, and extractable P, K and Mg. Grass does not generally respond on Moderate PK Status soils and sampling time is therefore not crucial, but be aware that the application of fertilisers and manures may influence results for up to 12 weeks after application. Analyses for P and K can vary considerably metre by metre. Taking one average soil test value for a whole field inevitably masks this variation. 'Grid' or zonal sampling can help overcome this and identify areas in the field where P and/or K are under- or over-supplied. Identifying major soil types in the field is a key step in establishing the need for grid or zonal sampling, but it is not economic to sample soils more intensively than 1 sample/ha for PK soil testing.

Target soil P and K levels

Phosphate helps root development and early growth. Newly seeded grass and clover benefit from applied soluble phosphate since their root systems are insufficiently developed to tap the main P reserves in the soil. 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 (9 mg/l - middle of the Moderate Status) compared to grass only swards (6mg/l - lower end of the Moderate Status). P deficiency is generally more common in the wetter upland areas than in drier lowland areas, partly because the availability of P is low in acid soils, and acid soils are more widespread in upland areas. Soil P supply to the plant is dependent on soil reserves, which must be converted to a soluble form before being absorbed by plant roots. P availability is reduced at low temperatures such as when growth is beginning in early spring. A fresh boost of soluble P at this time can have a greater impact on growth until soil temperatures rise sufficiently to increase P-release from the soil reserve. Trials in Scotland have shown that an enhanced response to P applied in early spring is obtained on soils of Low or Very Low P Status if P is combined with nitrogen. A number of proprietary fertilisers include NP formulations. In all other situations, P applications to established grass are aimed primarily at maintaining target P Status in the soil rather than increasing grass growth. It is important that the soil P Status is not built up over and above the target level. Besides being wasteful, the loss of soluble P in sediment during bouts of surface run-off can contribute to poor water quality.

After nitrogen, potash is the second most important nutrient for grass and maintaining soil potash levels in the lower half of the Moderate Status must be the objective in good grassland management. The clovers (both red and white) are particularly sensitive to shortages of potash. Under grazing only relatively modest levels of additional potash are required as there is considerable re-cycling of both P and K in dung and urine but it is important not to apply potash to fresh young grass in spring for fear of inducing hypomagnesaemia (grass staggers) in freshly turned-out stock. Heavy dressings of potash in spring can reduce magnesium uptake. Consequently, applications to grazed grass should be made mid-season onwards. The situation under conservation for silage and hay is rather different. Offtakes of potash in conserved grass can be considerable (equivalent to 180 – 330kg K_2O/ha from 2 or 3 cuts totalling 10t DM/ha) and soil potash reserves can quickly become depleted especially on light sandy soils. Heavy clay soils generally have higher potash reserves. If maximum benefits are to be realised from nutrient application to grassland then it is important to balance the use of nitrogenous fertilisers with potash. Typical application rates for 1st cut silage should be in the order of 60 – 90 kg K_2O/ha and 50 – 60 kg for 2nd cut. Exact rates will vary with soil potash Status, nitrogen application rates and anticipated grass yields but a useful rule of thumb is to apply 2/3rds kg K_2O/ha for every 1 kg of N applied. Where grass offtakes suggest application rates should be in excess of 90 kg K_2O/ha for 1st cut, any surplus over and above 90kg K_2O/ha should be applied later in the season otherwise luxury uptake can occur. In practice the price of potash fertiliser is likely to make application rates above 80 – 90kg K_2O/ha uneconomical.

For soils that are above the target levels for P and K, savings can be made in both P and K applications.

Table B and C show the SAC laboratories data review results for grassland soil available P and K analysis for the 4 regions of Scotland (1 – NE Scotland and Tayside; 2 – SE Scotland; 3 – SW Scotland; and 4 – Highland and Islands).

Table B. Percentage (%) of samples of each P Status for grass in each region

			P	(%)		
Region	**VL**	**L**	**M-**	**M+**	**H**	**VH**
1	8.2	34.8	39.8	10.0	6.5	0.7
2	15.5	42.0	28.9	7.2	5.0	1.1
3	8.5	31.3	37.9	12.5	8.8	1.0
4	13.6	35.4	33.4	8.3	7.3	2.0

Table C. Percentage (%) of samples of each K Status for grass in each region

			K	(%)		
Region	**VL**	**L**	**M-**	**M+**	**H**	**VH**
1	4.2	24.6	38.6	18.6	12.9	1.1
2	1.2	13.2	39.0	23.8	20.9	2.0
3	1.9	14.6	36.6	21.8	22.0	3.0
4	5.4	28.4	44.9	15.1	5.9	0.2

The most notable result for P is the high percentage of grassland soils that are being managed at below target, particularly in SE Scotland (Region 2). Failure to supply adequate plant available P with reduce N use efficiency resulting in lower yields and increased risk of contributing to greenhouse gas emissions.

For K, the results are different with the majority of soils across all 4 regions being at or above target. This is due to the large amounts of K that is supplied from livestock manures and slurries due to fertiliser usage and contributions from off farm feeds.

Both results highlight an imbalance between P and K levels in grassland soils. In the absence of sufficient plant available P, the plentifully K supplies will not be used, or will be used inefficiently. Opportunity exist to address this imbalance by taking better account of K supplied by manure and slurries and by ensuing that the fertiliser formulation and rate of application used on farm is based on soil analysis results.

Sulphur

As atmospheric deposition of sulphur (S) continues to decline due to reduced emissions from industrial sources, it is likely that the risk of S deficiency will affect an increasingly wide area of grassland. The best guide for assessing the risk of S deficiency is soil type and field location. Sands, shallow soils or sandy loams with low organic matter levels are most prone to deficiency. Swards that receive high levels of nitrogen fertiliser and are cut regularly for silage are also more at risk whereas fields that receive regular applications of organic fertilisers, or have organic soils, are less likely to show deficiency. Soil analysis can help identify severely deficient soils but in other situations it is not as reliable a guide as herbage analysis. Further information on grassland requirements for S are provided in Section 5.

3. Assessment of site class and nitrogen recommendations

Grassland production is limited by growing conditions, in particular the quantity of rainfall between April and September and soil type. The combined effect of these factors defines the "*Site Class*" as shown in Table D.

Table D. Site Classes

Soil texture	Average April-September rainfall (mm)*			
	More than 500	425-500	350-425	Less than 350
		Site class **		
Sands and shallow soils	2	3	4	5
All other soils	1	2	2	3

* Approx. 50% annual rainfall. Planet Scotland provides annual rainfall estimates for all of Scotland

** Add 1 for farms above 300 m

An area of land classified as:

- *Site Class* 1 is limited by N not by water supply since N is utilised very efficiently and rainfall is above 500 mm between April and September.
- *Site Class* 5 is severely limited by water supply since rainfall is below 350 mm between April and September. The potential yield of grass growing within a Site Class 5 is about half of that growing in a Class 1 site.

Standard or maximum N recommendations for each grass field based upon site class and intended grassland management are given in Table E. In practice, levels of N use may be less than the figures shown in Table E to reflect the level of intensity and production that is required on a specific farm unit. Clearly it makes little sense to produce more grass than can be utilised by the farm. Drought can impair growth and reduce N usage where moisture and not nitrogen limits growth. In NVZs the maximum nitrogen that can be applied to the whole grassland area (Nmax) is calculated by adding up the N requirement for each grass field as given in Table E. If you apply organic manures, you must use N efficiency values to determine the percentage of the total N content that will become available to the grass. This available N content contributes to Nmax and must be deducted from Nmax to calculate the balance that can be applied as manufactured N fertiliser. In some situations, lower application rates than those in Table E may be appropriate e.g. where grass management relies on high clover. It should be remembered that red clover cannot be grown on farms in an NVZ that have taken advantage of the Grassland Derogation. Further guidance on NVZ regulations is provided in Scottish Government guidance on NVZs (http://www.scotland.gov.uk/Topics/farmingrural/Agriculture/Environment/NVZintro).

Table E. Standard or maximum total annual N recommendations in kg/ha for each grass field based upon site class and grass management

Grass management	Site Class 1	Site Class 2	Site Class 3	Site Class 4	Site Class 5
2 or 3 cut silage + grazing	310	300	290	280	270
1 cut silage + grazing	280	270	260	250	240
Grazing with low clover	270	260	250	240	230
Hay + grazing	220	210	200	190	180
Grass with high clover*	100	90	80	70	60

* High clover = 20-30% clover content mid-season

Seasonal distribution of nitrogen for existing swards

1) For Grazing:-

Nitrogen should be applied at regular intervals over the grazing season at a *declining rate to match the falling response to N by the grass.*

- Under optimal conditions grass can utilise approximately 2.5 kg N/ha/day of growth.
- The first dressing should be about 6 weeks before turnout (maximum rate 100 kg N/ha) or at the time of 'T-sum 200'.
- Should 'T-sum 200' occur much earlier than normal, delaying application until the first period of mild weather will reduce the risk of N loss.
- No N should be applied after mid-August. This reduces the risk of winter losses of nitrogen from the soil and winter damage to the grass. The response to N will also be lower after this time
- Fertilisers and manures should never be spread on to frozen, waterlogged, or snow covered soils.

2) For Conservation:-

Based on a daily uptake of 2.5 kg N/ha the optimum rate of N application for the first cut of silage is 120 kg N/ha applied 8 weeks before expected date of cutting. Higher rates and delayed application increase the risk of nitrate-N in the grass and poor silage fermentation. A *split dressing* of the optimum N rate may be beneficial in *reducing N losses*, and encouraging earlier growth. If a split dressing is used, apply 40-50 kg N/ha 10 weeks before cutting (i.e. about the same time as the grazing application). Apply the remainder 4 weeks later leaving at least 4 weeks clear before the anticipated cutting date. Applications for second and subsequent cuts of silage should be made as soon as possible after the previous cut. The optimum rate of N for the first cut of hay should be restricted to 80 kg N/ha to avoid too leafy a crop & problems with field drying.

Examples of application patterns for a range of annual N rates for both **Conservation** and **Grazing** are given in Table F (1 – 3) and simplified compared with the PLANET Scotland software. The recommendations in Table F are not exhaustive but are designed to account for specific annual grassland management strategies and are expressed as a set of defoliation sequences with G=Grazing; H= Hay; S=Silage. For example two cuts of silage followed by grazing are represented as SSG. Suggested N rates (kg/ha) are shown for each defoliation in the sequence. For example, if the defoliation sequence is SGG and the N rates 120-60-50, this means 120N for defoliation 1 (Silage), 60N for defoliation 2 (Grazing) and 50N for defoliation 3 (Grazing). More detailed defoliation sequences are available from the Planet Scotland software.

Fertiliser N rates should be adjusted to take account of the available N in organic fertilisers. Information on the N contents of organic fertilisers can be found in FAS Technical notes TN650 (2013) "Optimising the application of bulky organic fertilisers"; and TN699 (2019) "Agricultural use of biosolids, composts, anaerobic digestates and other industrial organic fertilisers" (www.fas.scot/publications/technical-notes/).

Nitrogen for grass and clover establishment

Good establishment of grass and clover depends on a number of factors including seedbed preparation, method of sowing, and use of cover crops, weed control and level of soil fertility.

The N distribution sequences in Table F are suitable for undersown grass once the cover crop has been removed. Nitrogen recommendations for direct-sown grass (autumn or spring sown) are given in Table G. Note that in NVZs because the "cropping year" goes from autumn and winter through to the following spring and summer, N applied in the autumn must be included as part of the N requirement taking account of grassland management and site class. Autumn N includes N applied in the seedbed to direct-sown grass or applied in late summer to an undersown crop where the cover crop is removed by mid-August.

Table F(1). Appropriate nitrogen rates and sequences (kg/ha) - established grassland

Grass management	Defoliations sequence	Site Classes 1 - 5
Grazing with low clover	G	90
	G G	80-60
	G G G	80-60-50
1 cut silage + grazing	S	120
	S G	120-70
	S G G	120-60-50
	G S	40-90
	G S G	40-90-60
	G S G G	40-90-60-40
Hay + grazing	H	80
	H G	80-60
	H G G	80-60-40

Table F(2). Appropriate nitrogen rates and sequences (kg/ha) - established grassland

Grass management	Defoliations sequence	Site Classes 1 - 4	Site Class 5
2 or 3 cuts silage + grazing	S S	120-90	120-90
	S S G	120-90-60	120-90-60
	S S S	120-90-70	110-90-70
	S S G G	120-90-50-40	110-80-50-30
	G S S	40-100-80	30-100-70
	G S S G	40-100-80-50	40-100-80-50

Table F(3). Appropriate nitrogen rates and sequences (kg/ha) - established grassland

Grass management	Defoliations sequence	Site Class 1	Site Class 2 & 3	Site Class 4	Site Class 5
Grass with high clover, or red clover	G	60	60	60	60
	G G	60-40	60-30	40-30	40-20
	G S	30-70	30-60	30-40	30-30
	S G	70-30	60-30	50-20	60-0
	S S	60-40	60-30	50-20	60-0
	H G	60-40	60-30	50-20	60-0
	G H	40-60	30-60	30-40	30-30
	For high clover fields no additional N is recommended beyond the second defoliation. Most systems using red clover will use no N.				

Table G. N recommendations for direct-sown grass and clover (kg/ha)

Timing	Management	N recommendation (kg/ha)
Spring	Grass, grazing	40
	Grass, cutting	60
	Grass/clover	0 - 20
Autumn	Grass, grazing or cutting	40
	Grass/clover	0 - 20

4. Phosphate and potash recommendations

Phosphate and potash recommendations for grass establishment (autumn or spring sown)

Phosphate and potash recommendations for newly sown grass, autumn or spring sown, are given in Table H. These should be adjusted for phosphate sorption capacity (PSC) of the fields as shown in Section 4.3.

Table H. Phosphate and potash recommendations for grass establishment (autumn or spring sown) in kg/ha

	P_2O_5				K_2O			
	Soil P Status				Soil K Status			
Grass management	V. Low	Low	Mod.	High	V. Low	Low	Mod.	High
Grass with high clover, red clover	150	110	70	50	130	90	70	40
All other grass management options	130	90	50	30	110	70	50	20

(Where undersown - use appropriate cereal recommendation plus an additional 40kg P_2O_5 and K_2O/ha)

Phosphate and potash recommendations for established grass

On Moderate PK soils, apply 'maintenance' PK fertiliser applications to balance the offtake in cut or grazed grass but test soil PK Status every 4 – 5 years. PK offtake can be calculated by multiplying grass yield by PK content as given in Table I. The yields in Table I are based on averages over a range of Site Classes and should be replaced by estimated or actual yields where possible. Drought can impair growth and reduce PK offtake and should be taken into account when assessing PK requirement. If the defoliation sequence is Grazing - Silage - Silage - Grazing, then PK offtake would be calculated using the 1st and 2nd occurrence (Silage) and the 1st and 4th defoliation (Grazing). As stated earlier in Section 2 potash offtake from silage is high and should be replaced if soil reserves and grass productivity are to be maintained. However the application in spring prior to first cut silage (or hay) should be restricted to 80 – 90kg K_2O/ha to avoid luxury uptake. Any requirement over and above 80 – 90 kg K_2O/ha should be applied later in the season.

The PK applied in organic manures should be taken into account when assessing the need for manufactured fertiliser (see section 8 below). The balance between PK offtake and PK applied in organic manures and manufactured fertiliser can then be made at the end of the season. Allowance should be made for any surplus or deficit in PK when planning the following season's fertiliser. In grazing situations most of the P_2O_5 and K_2O is recycled infield by the animal through its dung and urine. The offtake estimates for grazing in Table I makes allowance for this recycling by assuming that 80% P_2O_5 and 95% of the K_2O is recycled. Under grazing to ensure an application of some P & K to all areas and to replace the small offtake apply 15 – 20 kg/ha P_2O_5 & K_2O **per season** on soils of Moderate P & K Status. Where clover is an important constituent of the sward apply the higher recommendation.

Table I. Typical range of Established Grass yields (Average to High) and standard range of PK content (fresh weight)

Utilisation	Defoliation position	Yield (t/ha)	P content (kg P_2O_5/t)	P offtake (kg P_2O_5/ha)	K content (kg K_2O/t)	K offtake (kg K_2O/ha)
Silage†	1st Cut	12 - 23	1.7	20 - 39	6.0	72 -138
Silage†	2nd Cut	7 - 12	1.7	12 - 20	6.0	42 - 72
Silage†	3rd Cut	6 - 9	1.7	10 - 15	6.0	10 - 54
Hay @ 86% DM	Any	7	5.9	41	18.0	126
Grazing@15–20% DM	Any	10	1.4	3*	4.8	2*
Haylage @ 45% DM	Any	4	3.2	13	10.5	42

† Based on fresh weight – 25% Dry matter

* Under Grazing this calculation assumes approximately 80% of the P_2O_5 and 95% of the K_2O is recycled infield by the animal through its dung and urine

If the soil P or K index is below target, apply additional fertiliser to build up to a Moderate PK Status. By the same token rates of P and K should be reduced where the P K soil Status is high. Phosphate and potash adjustments for PK soil Status in established grassland are given in Table J. If the PK Status is Very Low or Low, then the adjustment should be to defoliation 1 for silage and hay, and defoliation 2 for grazing but note earlier comments about the risks of luxury uptake of potash under cutting and inducing hypomagnesaemia under grazing. Where soil PK Status is high rates of PK should be lower than maintenance at each defoliation e.g. 75% of P offtake on grass with high clover or red clover, and 50% of PK offtake in other grass management options (Table J).

Table J. Phosphate and potash adjustments for PK soil Status in established grassland in kg/ha

Grass management	P_2O_5				K_2O			
	Soil P Status				Soil K Status			
	V. Low	Low	Mod.	High	V. Low	Low	Mod.	High
Grass with high clover, red clover	+80	+40	0	P offtake x 0.75	+60	+20	0	K offtake x 0.5
All other grass management options	+80	+40	0	P offtake x 0.5	+60	+20	0	P offtake x 0.5

Adjustments to PK fertiliser recommendations taking account of soil P sorption capacity (PSC)

The PSC of a soil refers to the differing capacity of soils to bind with applied P making it temporality unavailable for plant uptake. 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. The PSC 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 PSC for non-calcareous soils from low (PSC 1) to high (PSC 3). More information on adjustments to PK fertiliser recommendations taking account of PSC is given in FAS Technical Notes TN715, TN716, TN717 and TN718 which update PK recommendations for all crops (www.fas.scot/publications/technical-notes/) across 4 regions in Scotland.

For established grass/clover swards the target soil P Status has been lowered to M- on PSC 1 and 2 soils but stays at M+ on PSC 3 soils. Adjustments to P fertiliser recommendations may be made taking account of PSC indices to build up or run down to the new target soil P tests (Table K). If the PK Status is VL or L, then the adjustment should be to defoliation 1 for grass silage and hay, and defoliation 2 for grazing. Those soils with a higher PSC that are maintained on target for P represent the greatest erosion risk to water quality as they will contain a higher level of adsorbed P from fertilising. Maintaining soils at target 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. Soils of 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.

Table K. Effects of PSC on annual fertiliser adjustments (kg P_2O_5/ha)

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

Effects of K Status on annual fertiliser adjustments (kg K2O/ha) are shown in Table L.

Table L. Effects of K Status on annual fertiliser adjustments (kg K2O/ha)

Soil K Status				
Very Low (VL)	Low (L)	Mod (M-)	Mod (M+)	High (H)
+60	+30	0	0	K offtake x 0.5

5. Sulphur (S) recommendations

Due to reductions in industrial emissions of S there is an increasing requirement to apply S as a fertiliser. Grass with a high fertiliser N input has a high demand for S, and in certain circumstances a profitable response to S application can be obtained in second and third cuts of silage, and mid-season grazing. S deficiency is most likely to occur on light textured sandy soils (Table M). More information on S fertiliser recommendations is given in the FAS Technical Note (TN685): Technical Recommendations for crops (https://www.fas.scot/publication/technical-notes/)

Table M. Sulphur deficiency risk categories

Soil type	Winter rainfall (Oct-Mar)		
	Low (<175 mm)	Medium (175-375 mm)	High (>375 mm)
Sands and shallow soils	High		
Sandy loams	Low	High	
Other mineral soils	Low		High

Fields that have received regular applications of bulky organic fertilisers, and organic soils, are less likely to show deficiency. S deficiency causes paling of young leaves and crop stunting that can easily be confused with N deficiency (which usually affects older leaves first). A reliable prediction of the likely response to added S can be obtained by chemical analysis to determine the total N: total S ratio in the first cut herbage (Table N). Sampling of silage growth should be carried out within 10 days of the anticipated first silage cut.

Table N. Total N: Total S ratio in herbage and response to applied S

Total N:Total S	Response to applied S
Less than 13:1	Unlikely
13:1 to 16:1	Insurance dressing required
Greater than 16:1	Response highly likely

If deficiency is expected, the best treatment is to apply sulphur in the spring as water soluble sulphate (SO_4), which is rapidly available for crop uptake. Recommended rates are given as SO_3-S (to convert S to SO_3, multiply by 2.5): use 40 kg/ha SO_3-S prior to the 2nd and 3rd cuts of silage or mid-season under grazing.

6. Magnesium (Mg) recommendations

Grass swards must contain a sufficiently high level of magnesium (Mg) if the risk of hypomagnesaemia (grass staggers) is to be reduced. Soil magnesium (Mg) analysis is used to predict the need for Mg application to grassland. Classification into soil Mg Status is given in FAS Technical note TN714 "Liming materials and recommendations (2019)" (https://www.fas.scot/publication/technical-notes/). The uptake of herbage Mg decreases as N and K levels increase and consequently grass staggers can occur when soil Mg appears adequate. In the case of intensively managed grass it is advisable to maintain a high soil Mg Status. Where the Mg Status is low and soil acidity needs to be corrected, applying magnesian limestone is the best way to maintain soil Mg at a satisfactory level. An application of 5 t/ha of magnesian limestone will add at least 750 kg MgO/ha, and this Mg will become plant-available over many years. However, if used too frequently, care should be taken to ensure that there is sufficient available K in the soil to ensure that there is no risk of K deficiency in the crop being grown. Where the Mg Status is low but additional lime is not required, alternative sources of Mg should be used e.g. calcined magnesite (typically 80% MgO) or kieserite (25% MgO). In such cases at least 125kg/ha MgO should be applied.

7. Sodium (Na) recommendations

Sodium will rarely have any effect on grass growth but an adequate amount in the diet is essential for livestock health and can improve the palatability of grass. The Na content of herbage is normally adequate for grazing livestock though it may be reduced if excess potash is applied. Herbage analysis is useful to assess the Na Status of grass. Where Na levels are low, mineral supplements may be required for some classes of stock or a fertiliser containing Na may be used.

8. Availability of nutrients in organic fertilisers

If you apply organic manures, you should use the Technical notes TN650 (2013) "Optimising the application of bulky organic fertilisers" and TN699 (2019) "Agricultural use of biosolids, composts, anaerobic digestates and other industrial organic fertilisers" to determine the total NPK content and percentage that will become available to grassland (www.fas.scot/publications/technical-notes/).

A gap between application of inorganic and organic fertilisers is recommended to minimise N_2O emissions.

The amount of N taken up by the crop following application will depend on how much of the N applied is lost through nitrate leaching and ammonia emissions. The amount of N leached as nitrate following land application is mainly related to the application rate, the readily available-N content (RAN), the amount of rainfall after application and soil texture. As ammonium-N is rapidly converted in the soil to nitrate-N, applying N during the autumn or early winter period should be avoided, as over-winter rainfall is likely to be sufficient to wash a large proportion of this nitrate out of the soil before the crop can use it. Delaying applications until late winter or spring will reduce nitrate leaching and increase the efficient use of applied N. This is particularly important for organic fertilisers with a high content of RAN.

Organic fertilisers are valuable sources of P, K, S and Mg; although not all of the total nutrient content will be available for the next crop. Nutrients which are not immediately available will mostly become available over a period of years and will usually be accounted for when soil analysis is carried out. The availability of manure phosphate to the next crop 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) 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. In some fields, particularly on intensive livestock farms, it may be necessary (or advisable) to limit organic manure applications in order to avoid excessive enrichment of soil P levels. Most of the potash present in organic fertilisers will become quickly available for crop uptake. Around 90% of the potash in organic fertilisers will become available to the crop in the year of application, although potash availability from green composts may be rather lower in the first year (around 80%) and that from dirty water, somewhat higher (estimated to be around 100%).

Where crop responses to P or K are expected e.g. where soils have Very Low or Low P or K Status, the available phosphate and potash content of the manure should be used when calculating the nutrient contribution. Where soil Status is at the target level (usually M-) or above, the total PK content of the organic fertiliser should be used in planning the balance that should be applied as manufactured P and K. At high soil P Status, take care to ensure that total P inputs do not exceed the amounts removed in crops during the rotation. This will avoid the soil P Status reaching an unnecessarily high level. Organic fertilisers also supply useful quantities of sulphur and magnesium, but there is limited data on their availability for the next crop grown. Sulphur and magnesium inputs from manures should largely be regarded as contributing to the maintenance of soil reserves.

Allowing for the NPK content of manures and organic fertilisers can result in large savings in purchased fertiliser (Table O). Assess the nutrient content of these fertilisers using standard 'typical' values, or get them analysed. Analysis of the specific material will provide the most accurate information. The worked example in the table shows fertiliser recommendations and potential and actual savings in fertiliser costs where 30 m^3/ha farm-based whole digestate was applied in spring for a first cut of silage with an expected yield of 20 t/ha (fresh weight). The NPK analytical values used were from the table of typical nutrient contents. The NPK recommendations were based on information from TN633, TN652 and TN699 (https://www.fas.scot/publication/technical-notes/). The soil P and K Status was at the target of Moderate (M-). The actual financial saving from the application of the farm-based whole digestate was £97/ha. In this example there was residual N and P for subsequent grass cuts or grazing but no residual K.

Table O. Example of savings that can be made by fully accounting for the fertiliser value of organic fertilisers

	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Financial (£/ha)
1. Estimated total NPK in whole digestate (kg/t)	3.6	1.7	4.4	
2. Estimated total NPK applied in 30 m^3/ha of whole digestate (kg/ha)	108	51	132	
3. Availability of NPK from whole digestate (%)	55%	100%	100%	
4. Estimated NPK contribution from whole digestate (kg/ha) in year of application	59	51	77	
5. Total NPK requirement for 1st cut of silage (kg/ha)	120	34	120	
6. *Cost of total NPK required (£)*[1]	*80.4*	*23.12*	*54.00*	*157.52*
7. Manufactured NPK required in addition to digestate (i.e. item 5 minus item 4) (kg/ha)	61	0	43	
8. *Cost of manufactured NPK required (£)*[1]	*40.87*	*0.0*	*19.35*	*60.22*
9. *Actual savings in year 1 (i.e. items 5 minus 6)*	*39.53*	*23.12*	*34.65*	*97.30*

[1]Based on prices for N, phosphate and potash of 67, 68 and 45p/kg respectively (The Farm Management Handbook, 2018/19)

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