Managing soil phosphorus levels on intensive dairy farms

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Introduction

Satisfying the phosphorus (P) requirements of plants and animals in agricultural systems is a well established practice in crop and animal husbandry. Adequate P nutrition is essential to plant and animal health for energy utilisation, DNA, cell division, and cell structure. In animals, P is also a constituent of bone, and deficiency, known as aphosphorosis, can lead to bone malformation, depraved appetite, poor reproductive performance or low liveweight gain. Aphosphorosis was a common occurrence on Irish farms prior to the onset of regular application of mineral P fertilizer in the 1960s and 1970s. In plants, P enhances many aspects of physiology, including photosynthesis, root development, flowering, seed production and maturation. Phosphorus deficiency in plants is often difficult to recognise, and can result in stunted, thin-stemmed and spindly plants, often with dark, bluish-green foliage, particularly on the older leaves.

Although adequate P fertilization is essential to sustain plant and animal health, over fertilization can also result in surplus P becoming available for loss to waters. The regulations introduced in 2006 in response to the Nitrates Directive restrict the use of P fertilizers as a measure to protect water quality and avoid eutrophication caused by P enrichment. While the guiding principles of water protection and agronomic sustainability within these regulations are worthwhile, they do create an additional layer of complexity in nutrient management planning on farms.

P behaviour in soil

In comparison to nitrogen (N), P is largely an immobile element. The majority of P applied to grassland is either utilised by the grass crop, or firmly bound to soil particles at so-called “binding sites” through a process called adsorption. In grassland, most P is adsorbed in the upper few centimetres of the soil profile, and only a small proportion of the total soil P is available to plants, as measured by Morgan’s P-test. However, at high soil P levels, the majority of high-energy binding sites may be utilised and further P additions may not be held as tightly by the soil particles. This P, when not taken up by the plant, is susceptible to being moved from soil to water by overland flow. Although quantities lost to water may be small in agronomic terms, losses of one or more kilograms of P per hectare may have undesired environmental side-effects and result in eutrophication of surface waters. Eutrophication is the process of nutrient enrichment of surface waters, which may lead to excessive growth of algae and produce algae mats. Rotting of this

vegetation extracts oxygen from the water, which impacts negatively on water quality.

For the past ten to fifteen years, the main preoccupation surrounding P use has been the claims that excessive usage was leading to eutrophication of water. In the course of these debates, the fertilizer recommendations for grassland were critically examined, and new recommendations have been drawn up. These recommendations are designed to ensure optimum grassland productivity while minimising losses to water.

As with all nutrients, fertilizer P advice is constantly being revised and updated in line with changing agricultural systems and economics.

Basis to P fertilizer advice

Fertilizer P advice has been derived based on the following principles:

1. The soil P Index system (Table 1) is used as an indicator of background soil P fertility status. Index 3 (between 5 and 8 mg/l soil test P) is the target level of soil test P required for optimum grass production, and minimal risk of P loss in run-off.

2. At soil Index 2, some soils will produce maximum herbage yields without additional fertilizers, but Index 3 is recommended in order to ensure that the persistence of ryegrass and clover, along with adequate herbage P content are achieved. Index 4 soils generally show no response to P fertilizer, and are more at risk of P loss to waters through overland flow.

Table 1. Soil P Index system

Soil Index	Index description	Response to fertilizers	Morgan's Soil test P range (mg L^{-1})
1	Very low	Definite	0 - 3.0
2	Low	Likely	3.1 – 5.0
3	Medium	Unlikely/tenuous	5.1 – 8.0
4	Sufficient/excess	None	> 8.1

3. Assuming the soil P levels are in Index 3, the P fertilization rate should be based on replacing the P removed in product, be that milk or meat. The amount of P removed will vary depending on the farming system.

4. At low soil P levels (Index 1 and Index 2), in addition to replacing the P removed as per Index 3 soils, extra P must also be added to build up the soil P reserves. The rate of build up can be slow. It is recommended that an extra 10kg/ha of P should be applied above maintenance rates for Index 2 soils, and an extra 20kg/ha P should be added for Index 1 soils, in order to build up the soil P levels to target Index 3 levels. This strategy should be

continued until the soil test levels are increased to Index 3 levels. This can be monitored with regular soil testing, and normally takes a number of years to achieve.

5. When soil P levels are high (Index 4; above 8mg/l soil test P), there is sufficient P present in the soil without applying P fertilizer. Responses to fertilizer applications to Index 4 soils are rare. Soils with P levels in Index 4 will be productive without P fertilizer applications until the soil test P reverts to Index 3 levels, at which time, P applications to replace offtakes should recommence.

Farm P balance

To calculate the P requirements of a farm with soil P Index 3, a farm P balance approach is used (Figure 1). The objective is to ensure that soil P levels are maintained constant by replacing P removed from the farm in product with P inputs.

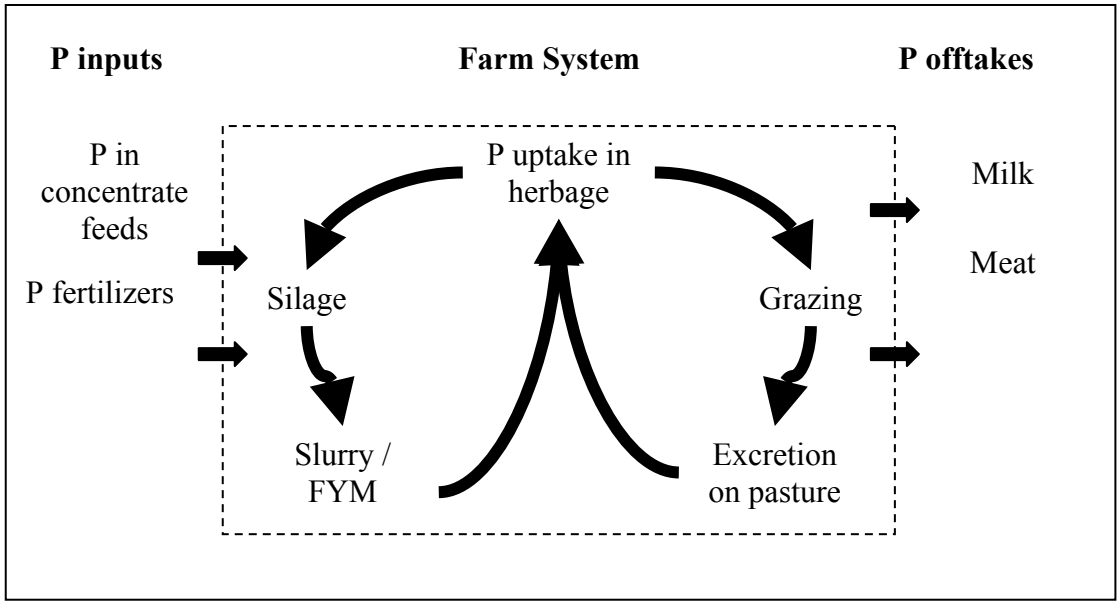

Figure 1. Farm P balance.

Replacing P offtakes

The removal (offtake) of P from a simple dairy system occurs mainly in the form of milk, and also as meat through liveweight gain and livestock sales. Milk typically contains 1 kg of P per 1,000 litres. The P removed in meat is typically equal to 1 kg of P per 100kg of liveweight.

The rate of P offtake per hectare will depend on intensity of the system, usually indicated by the stocking rate and the milk yield per cow or per hectare (Figure 2).

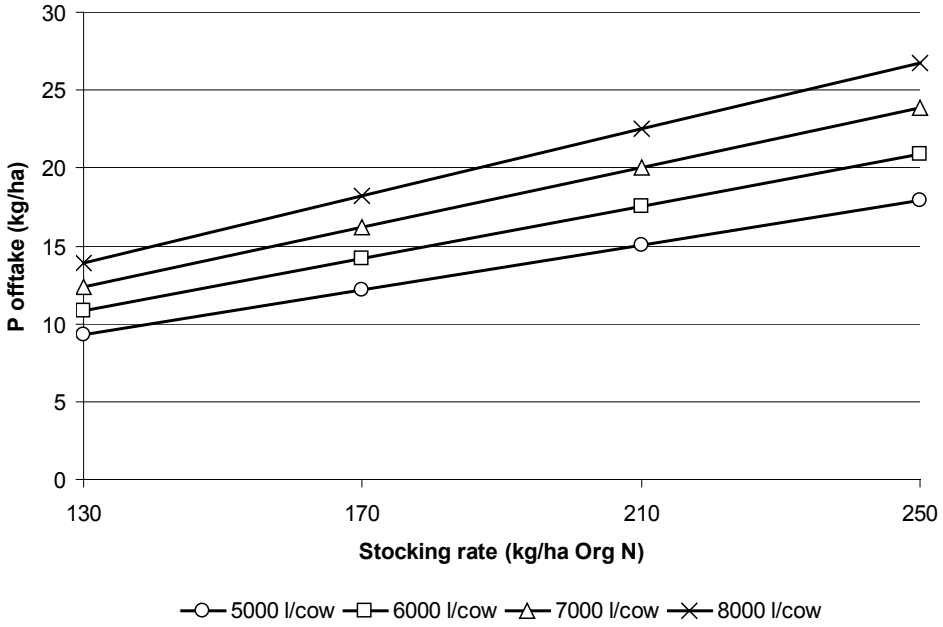

Figure 2. Estimated P offtake in milk and meat for different stocking rates and milk yields. (Replacement rate = 20%; LW of cull cow = 550kg).

In addition to P offtakes in product, the P removed from areas used for silage crops must also be considered. First-cut silage removes approximately 20kg/ha of P, while second or subsequent cuts typically remove approximately 10kg/ha of P per cut.

Where swards are cut for silage as well as grazed, it is advised that the P fertilizer rate should be the combined total of the silage offtake plus the rate of P offtake in milk and meat. The P requirements for grazed and cut swards are simplified and shown in Table 2.

Table 2. Simplified P requirements (kg/ha) of grazed and cut swards for dairy farms. (Adjustments may be appropriate depending on individual farm system). (Rates shown are total P requirements, before deductions for concentrate feeds or organic fertilizers).

	Grazed swards				Silage swards	
	Stocking rate (kg/ha Org N)					
Soil P Index	**< 130**	**130-170**	**170-210**	**210-250**	**Cut once**	**Cut twice**
1	30	34	39	43	+ 20	+ 30
2	20	24	29	33		
3	10	14	19	23		
4	0					

Meeting P requirements

Concentrate feeds

Concentrate feeds used on the farm can represent a significant amount of P input. Typically, concentrate feeds are assumed to have a P content of 5 kg/t. However, where straight concentrate feeds are being used, the actual P content can vary significantly from this average value (Table 3). This is of particular relevance with feeds with very low P contents such as citrus pulp or soya hulls.

It is also important to consider the distribution of P in concentrate feeds. When fed to animals indoors, the distribution of the P excreted can be managed through the application of slurry or farmyard manure (FYM). However, where concentrate feeds are fed to grazing animals, it is impossible to control the distribution of this P around the farm.

Table 3. Typical P content of selected concentrate feedstuffs.

Feed type	P content (kg/tonne DM)
Citrus Pulp	1.1
Soya Hulls	1.8
Maize	2.8
Barley	3.9
Wheat	4.1
Maize distillers	7.5
Soyabean Meal	7.1
Rapeseed Meal	10.9

P in organic fertilizers

Although not an input into the farm system, the recycling of P in slurry and FYM is an essential component of P fertility management. On many farms, chemical P fertilizer is not permitted within the nitrates regulations, resulting in slurry and FYM being the only sources of P available to the farmer for distribution.

The P fertilizer value of slurry and FYM are highly variable. Slurry is the most common organic fertilizer on dairy farms, and its variability is most affected by dilution with water. Where slurry is diluted with soiled water (or rainwater in the case of unroofed tanks), it is important to consider the level of dilution when allocating slurry to fields. Guideline estimates of the P concentration of slurry based on estimated dilution rates are shown in Table 4.

The distribution of slurry around the farm should be based on soil testing and P requirements. As fertilizer prices increase, the economic benefit of applying slurry based on the nutrient sward requirements becomes more important.

Table 4. Typical P content of slurries with varied levels of dilution.

	DM%	Dilution	P fertilizer value	
			Kg/m^3	Units / 1,000 gallons
Slurry	7%	None	0.6	5
	5%	1/3 water; 2/3 slurry	0.4	4
	3%	2/3 water; 1/3 slurry	0.3	3
			Kg/t	
FYM			1.2	

P cycling in grazing systems

P deposited in faeces of grazing animals is also an important part of the P cycle within the farm. The P uptake by the grass sward will all be ingested by the animal in the herbage, but is not all converted into milk or meat. The P not utilised by the animal is excreted by the animal in urine and faeces (faeces contains most the P excreted). In theory, the excreted P will be returned to the soil and be taken up again by the grass, therefore soil fertility levels will be maintained provided the P offtake in animal product is replaced.

However, in practice, the distribution of the P recycled by grazing animals can be problematic, as the P excreted will be concentrated in dung patches around the field. The proportion of a paddock covered by a dung patch will be approximately 10 to 15% of the total area each year. Considering also that some patches will overlap, it can therefore take many years to ensure that all of the field is affected by a dung patch at some stage.

In permanent grasslands, these may not be a major problem, as the P should be well spread over time. However, in relatively young grassland, the concentration of P into dung affected areas can give rise to high variation of soil P within the field. Elevated P levels can also occur in areas within the field such as near gateways, water troughs or feeders that receive more animal traffic than other areas.

It is advised that soil sampling should be carried out in such a way that areas where P levels are expected to be unrepresentatively high are avoided. Such areas include areas near gateways, water troughs or feeders; or within dung patches where grass growth is visibly different.

Reseeding

The P required when reseeding grassland is normally higher than for established swards. The increased requirement is due to the high demand for P for the rapid cell division that occurs during the development of new roots, shoots and tillers. While, in theory, this P should be available from the release of P from decaying material from the previous sward, the release of this P can be slower than the rate required by the new seedlings.

Ploughing further confounds this issue. Since P is tightly held by the soil and is not prone to leaching, the P in permanent grassland soils tends to be concentrated very close to the soil surface. Ploughing will displace this P to deeper in the profile, often ploughing up a layer of soil with lower P status. As a result, the supply of P to the seedlings will be delayed until the root network of the new grass plants is deep enough to exploit the P ploughed down.

The P requirements for pasture establishment are shown in Table 5. It is advised that these rates should be applied in addition to the annual P requirements of the field. It is also advisable to soil test after the soil has been ploughed, since the soil ploughed up will form the seedbed for the emerging grass plants.

Table 5. P requirements for pasture establishment.

Soil P Index	P advice (kg/ha)
1	60
2	40
3	30
4	0

P usage within the nitrates regulations

The usage of P fertilizer has been restricted in law since 2006. While the protection of water quality is an important goal, these regulations have also increased the complexity of P fertilizer management. The major issues that are causing issues on some farms stem from the maximum P application rates, organic manures, concentrate feed assumptions, and issues surrounding fertilizer planning.

Maximum P application rates

The regulations introduced maximum rates of P application, based on soil P Index and grassland stocking rate (Table 6). The rates shown in Table 6 refer to the total P

application rate. The permitted rate of chemical P fertilizer is calculated by subtracting the contribution of concentrate feeds and organic fertilizers from the rates shown.

Table 6. Maximum P application rates on grassland (SI 101 of 2009).

Grassland stocking rate (kg/ha Org N)	Soil P Index			
	1	2	3	4
≤ 130	35	25	15	0
131-170	39	29	19	0
171-210	44	34	24	0
> 210	49	39	29	0

The most important thing to remember with these rates is that the maximum P limit applies to the whole farm, and not to individual fields. Therefore, it is permitted to exceed the rates in
Table 6 in individual fields, provided that the whole farm is compliant. This is particularly important for silage swards or for reseeding.

The importance of accurate soil analysis is also crucial to ensure that the farm is allowed to receive the P fertilizer applications that it needs. Where soils are not sampled, Index 3 for P is assumed. With this assumption, fields with P Index 1 and 2 will be unable to receive the additional P that is required for soil P build-up. Soil tests are required on a four-year cycle for farms applying of a nitrates derogation.

Organic manures and concentrate feeds

The P concentration in organic manure is fixed within the nitrates directive, being 0.8 kg/t for cattle slurry, and 1.2 kg/t for FYM. On the surface, these fixed values reduce the flexibility required to manage slurry and FYM based on variable nutrient contents. However, while these figures must be used when importing manures onto the farm, a nutrient management plan for manure, using nutrient contents more appropriate to the conditions on the farm (see Table 4), can still be prepared and followed.

The management of organic manures is particularly vital on farms where the use of chemical P fertilizer is prohibited; usually occurring on farms with high concentrate feed usage. In this case, slurry and FYM are the only sources of P that can be managed by the farmer to meet the P requirements around the farm. In this case, the careful distribution of slurry and FYM, based on actual P content and dilution, are critical to ensuring the effects of restricted chemical P application are minimised.

Planning fertilizer usage

The planning of fertilizer usage also creates difficulties within the regulations, since a farmer must plan the fertilizer applications based on planned stocking rate and concentrate feed usage assumptions at the start of the year. However, when a farm is inspected for cross-compliance with the nitrates regulations, it is only the actual stocking rate and concentrate feed usage at the year end that are considered, rather than those in the plan.

Where a farm is close to a grassland stocking rate of either 130, 170 or 210kg/ha organic N (i.e., close to the stocking rates at which the maximum permitted P levels change (see
Table 6)), the P allowance can fluctuate depending on the stocking rate, which can have significant impact on the maximum permitted fertilization rates.

The usage of concentrate feeds can also vary through the year, particularly in the case of dairy farming when weather and grass growth conditions require higher than expected supplementation levels. Where concentrate feeding rates are higher than planned, this also impacts on the maximum fertilizer P allowed.

It is too late to reduce chemical P fertilizer use for the year if the fertilizer is already purchased and spread. In order to overcome this difficulty, it is advisable that a farmer would err on the side of caution. Where the planned grassland stocking rate of the farm is close to 130, 170 or 210 kg/ha organic N, it is best to plan fertilizer application for the lower P allowance of the two bands. In the case of concentrate feeds, it is also appropriate to allow a safety margin in the planned usage levels to allow for unexpected increases in usage. By applying a safety margin in the fertilizer planning process, it may help avoid an unexpected surprise within a cross-compliance inspection.

Separating P and K

The nitrates regulations place no restrictions on K fertilization rates or timing. The application of potassium (K) fertilizer has declined inline with P usage in recent years. This is because P and K are normally applied together as compound fertilizer products. The requirements for K fertilizer (Table 8) should still be considered even where no P fertilizer is required or permitted. The requirements for K are particularly crucial on silage crops. On fields with no P requirement, the use of either straight K fertilizer or N:K fertilizer compounds should be considered where there is a requirement for K.

Table 8. Simplified K requirements (kg/ha) of grazed and cut swards for dairy farms. (Rates shown are total K requirements, before deductions for organic fertilizers).

	Grazed swards				Silage swards	
	Stocking rate (kg/ha Org N)					
Soil K Index	**< 130**	**130-170**	**170-210**	**210-250**	**Cut-once**	**Cut-twice**
1	85	90	95	100	+120	+155
2	55	60	65	70		
3	25	30	35	40		
4	0					

Slurry is a very good source of K fertilizer, reflecting the high K contents of grass silage. The K content of slurry is typically 4.3kg/t (38 units per 1000 gallons), but as in the case of P, this will vary with dilution.

The ratio of P:K in slurry is approximately 1:7. This ratio of P and K is well balanced as a P and K fertilizer for silage swards, assuming medium (Index 3) soil P and K levels. However, the requirement of P and K on grazed swards is between 1:2 and 1:3, depending on the stocking rate. As a result, when slurry is applied to grazed swards at rates sufficient to meet the P requirements, K is often applied in excess. This reflects a poor usage of the K fertilizer value of the slurry. However, this may be unavoidable on farms that are allowed no chemical P fertilizer and must use slurry as a P source on grazed swards. Soil test results will also help determine where slurry can be applied to make best use of both the P and K fertilizer potential.

Soil pH and liming

In light of restrictions on the use of fertilizer P, the importance of soil pH becomes critical. An optimum soil pH of 6.3 should be maintained by regular soil testing and liming where required. The availability of nutrients, in particular N and P, from the soil will decrease below a pH of 6.0, as a result of reduced soil organic matter turnover and decreased chemical release. The average soil pH on Irish grasslands is currently 5.4, with a lime requirement of 9.3 t/ha. On soils that have become acidic, the response to P fertilizers will be reduced as the soils are more likely to bind P more tightly, making it less available for plant uptake.

Conclusions

Fertilizer P advice is based on maintaining soil P levels at a target Index of three by replacing the offtake of P in product. Fertilizer P rates should be calculated based on the production level, stocking rate and intensity of the system, combined with field usage (silage, grazing or reseeding). The soil test P levels are also very important, as is the recycling of nutrients within the farm and implications of factors such as slurry dilution and concentrate feed P content and distribution.

The nitrates regulations make the management of P fertilizer more challenging, and issues such as assumed P content of concentrate feeds and fertilizer applications based on planned vs. actual farm activities create practical difficulties on farms. To manage these difficulties, the following factors will help with P management:

- Regular soil testing – know the P requirements for the farm,
- slurry distribution – spread slurry where P (&K) is required,
- cautious planning – avoid penalties due to unexpected changes in stocking rate or concentrate feed usage,
- soil pH – correct soil pH will help maximise soil P release where P applications are restricted, and,
- do not forget K – soil may still need K even though P is not required or restricted.