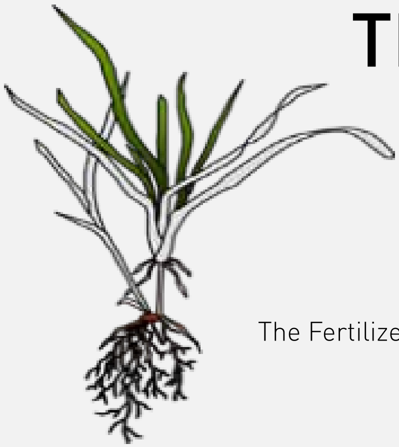
The Efficient Use of Phosphorus in Agricultural Soils



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10 Things to know about Phosphorus

1. First discovered in 1699 by - Hennig Brand
2. Phosphorus is a Greek word meaning the "bringer of light"
3. The phosphate ion (PO_4^-) carries a negative charge and is not easily lost from the soil
4. Immobile nutrient in the soil
5. An essential macro nutrient for all life including human, animal and plant life
6. Phosphorus deficiency results in stunted plant growth & older leaves turn dark blue / green & purple stems
7. Most plant available in mineral soils at pH 6.3 to 6.5
8. A non-renewable resource mined from phosphorus rock
9. Predicted "peak phosphorus" between 2030 to 2040 and world reserves expected to last for approximately 99 years
10. Five countries in the world hold up to 85% of known world P reserves

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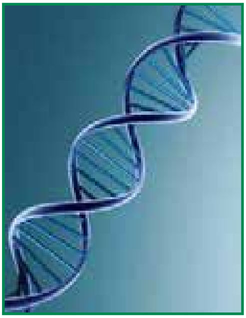
Introduction

Phosphorus (P) supply in soil is critical for crop growth and is an essential nutrient for plants to complete their growth cycle. Its role in plants cannot be replaced by other nutrients.

Phosphorus plays a key role in plants as follows;

- Cell function and is involved in a number of cell biochemical functions such as energy transfer through adenosine di-phosphate (ADP) & adenosine tri-phosphate (ATP) cycles in the plant
- Component of DNA & RNA and vital for cell division
- Required in relatively large quantities during critical plant development phases such as;
    - Seed germination
    - Rooting
    - Flowering
    - Seed production



Section 1

Phosphorus in soils, plants and the environment

Section 1. Phosphorus in soils, plants and the environment

1.1 Mineral Soils

The proportion of total P in soils that is immediately plant available P is less that 1% of the total P. Phosphorus in soils can be found in both inorganic-P and organic-P forms. The majority of soil P is relatively stable and largely inaccessible by plants. In mineral soils the inorganic P pools usually control soil P supply. Four main P pools can be described to summarise inorganic P in soils as follows (figure 1);

- "available P" tends to be the smallest P pool in the soil and contains water soluble P. The P that the plant takes up mainly comes from this pool.
- The "readily available P" pool replenishes the available P pool many times during the growing season as P is solubilised. These are the 2 pools of soil P measured by the soil test which is an indication of the soils ability to supply P to the crop
- "less readily available P" is interchangeable with the readily available P pool
- "very slowly available P" pool is made available over time through weathering and organic matter decomposition processes and this pool of P tends to be very stable

As P fertilisers are repeatedly applied over time a proportion of the P that is not utilised by plants will move between the different soil P pools and become more slowly available or recalcitrant over time. Phosphorus additions to the soil (fertilisers or organic manures) will generally replenish / build-up the readily available P pool which is what we measure through soil testing.

However, all soil pools help to replenish soil available P reserves over time especially if the available P pools become depleted through continuous cropping. As plants only take up P from the soil solution (available P pool which is the smallest P pool) more P is made available by P moving from the readily available pool. However, in soils with very low soil test P status the reserves of P in the readily available pool may be not sufficient to fully replenish the available P pool and to meet the crop demand for P over the growing season. In these circumstances P applications as manures or fertilisers are necessary to increase the P supply, especially during periods of peak crop growth. The practice of applying P as manures or fertilisers ensures that there is an adequate P supply at peak uptake periods during the growing season.

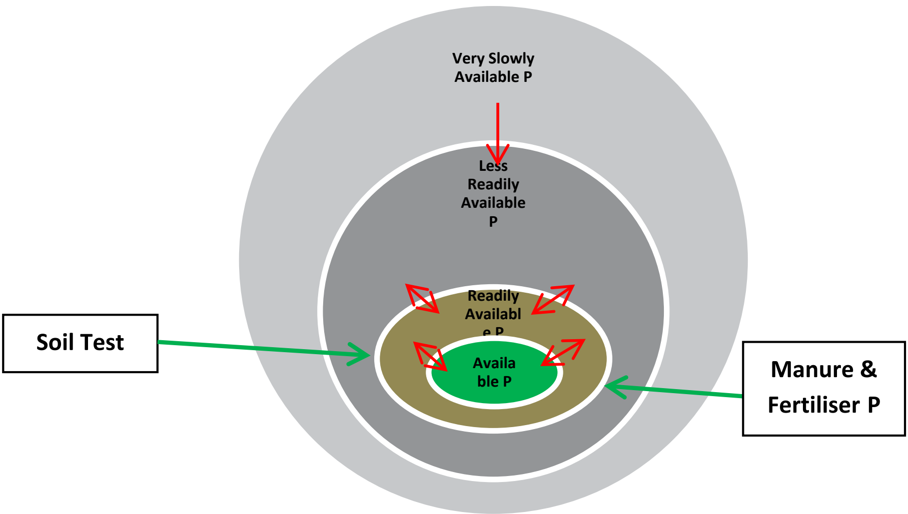


Figure 1. Different soil phosphorus pools and phosphorus movement between pools

Phosphate is an anion (negatively charged) and therefore is highly attracted to cations (positively charged particles) in the soil. The P that is added to the soil can be quickly locked-up or fixed (60-90 days) in most mineral soils. Soil properties such as texture/ pH and soil P status are important factors controlling the speed of soil P lock-up. Soils with high clay content, low pH and low soil P status will in general have the most rapid and largest P fixation capacity. On such soils, fertiliser P recovery by crops is usually very low (<10 %). In general the fertiliser P use efficiency within the year of application for grassland and crops on mineral soils with low P fertility status (P index 1 and 2) is less than 50%.

Organic P Pools

A large proportion of the P in mineral soils is stored in soil organic matter. However, this organic P is more stable and has reduced risk of loss from the soil. Organic P in soils can be mineralised by soil biology making P available for plant uptake. The breakdown of organic P is very much dependent on soil and weather conditions which influence microbial activity. These microbiology are most effective and releasing organic P under optimum soil pH levels (pH 6 to 7), when soils have good structure and in warm moist soil conditions. Soil biology, including arbuscular mycorrhiza fungi, are usually more active in supplying P for plants when grown on soils with very low soil test P levels.

Phosphorous in high organic matter (Peaty) Soils

Organic matter rich soils, and peat soils (organic matter concentration >20%) have much lower capacity to retain P (due to lower mineral matter levels) (Wall & Plunkett, 2016). Conventional P fertiliser strategies cannot be applied to these soils and a different approach to fertiliser needs to be implemented.

The appropriate P fertiliser strategy for high organic matter soils (peat soils) is to apply maintenance P fertiliser rates that appropriately match the crop P demand over the growing season. Single, large one-off applications of P are not recommended for these soils. Fertiliser P should be applied close to the onset of spring growth when soil moisture and temperature conditions are favourable to kick-start growth. Phosphorus should be applied using a "little and often approach" thereafter.

It is not advised to apply fertilisers for P build-up on peat soils as this extra P cannot be stored by the soil. Surplus P, in excess of crop requirements, is therefore more likely to be lost during periods of high rainfall and when water begins to drain from these high organic matter soils. This can result in an increased risk of surface- and ground-water body pollution from these soils.

Peat soil > 40cm deep

Peat over mineral soil

1.2 Soils and soil phosphorus availability

The soil parent material (bedrock geology) will have a large influence on soil P supply capacity as it is the primary source of cations and anions which are made slowly available for plant uptake over time through weathering processes. Phosphorus concentrations in Irish bedrock are usually low and therefore weathering processes supply relatively small quantities of P for plant uptake. However, P concentrations will differ by soil type and parent material (Whitehead 2008, figure 2) and this information is important when managing P supply for crops and understanding the soil test response to P applications as manures or chemical fertilisers.

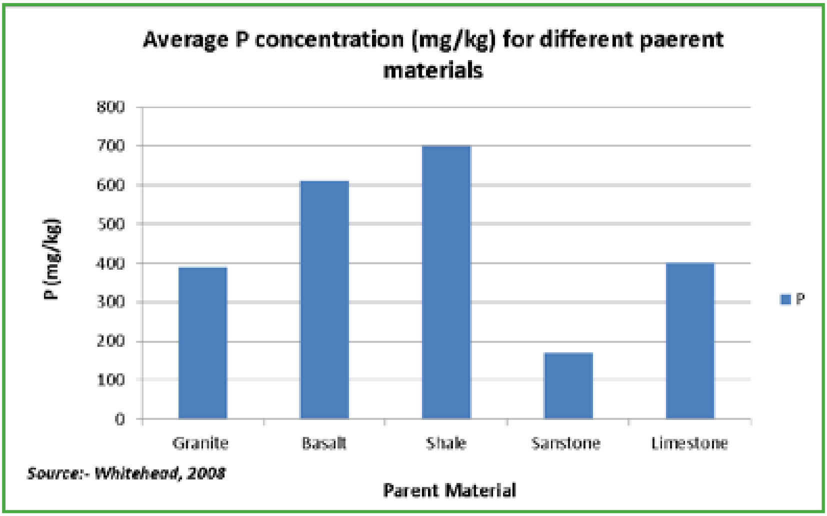


Figure 2. Soil P supply based on soil parent material

Overall a relatively small proportion of the total soil P pool is made available through soil weathering processes and plant roots mostly interact with P that has been stored within agricultural soils following previous fertiliser or organic manure applications. Much of the P solubilised by weathering and plant processes becomes insoluble over relatively short time frames as it is bound to soil particles close to where it is weathered.

Effect of soil pH on phosphorus fixation and availability

Soil pH is a basic soil property which influences the soil chemistry and the availability of many nutrients, including P. In Ireland soil pH is of particular importance due to the wide soil pH range (pH 4.5 to 8.0) typically found across agricultural soils. Soil P becomes less available for plant uptake under both alkaline and acidic soil conditions.

In acidic (low soil pH) soils, free iron (Fe) and, or aluminium (Al) are more abundant and form strong bonds with P. Once P is bound to Fe and Al it will be less plant available. Rising soil pH towards more neutral levels (6.3-7.0) reduces the concentrations of free Al and Fe and reduced the potential for further Fe-P and, or Al-P bonds to be formed with freshly applied P fertilisers. Increasing the soil pH will also release some of the Fe- and Al- bonded P previously "locked up". Figure 3 shows the forms of P that dominate in soils across the soil pH range typically found in agricultural soils. Note that P is most plant available between the pH range of 6.3 to 7.0.

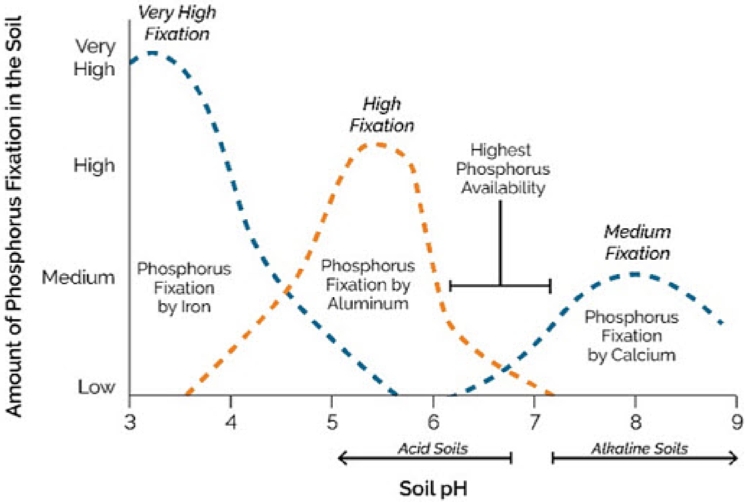


Figure 3. Typical strength and P bond types found in soils across the soil pH range

In naturally alkaline (high pH) soils higher levels of free calcium (Ca) can react with soluble P forming Ca-P precipitates. As Ca bonds with P, applied in fertilisers and manures, it reduces the proportion available for plant uptake. The Morgan's P soil test method is less suitable on naturally alkaline soils (natural pH >7.0) as this method is very efficient as breaking Ca-P bonds and may indicate higher soil P availability than the quantities of P actually available for plant uptake i.e. giving a false-positive result.

Interaction of lime and phosphorus fertiliser

The management of lime and P fertilisers go hand in hand on acidic soils. Continuous application of P fertiliser on low pH (acidic) soils are a false economy due to the risk of the P applied been locked up and unavailable for plant uptake. On acidic soils the first step in soil fertility management should be to correct soil pH with lime applications. Once soil pH has been optimised (grassland soils pH ≥6.3 and arable soils pH ≥6.5) the efficiency of applied P in fertilisers and manures will also improve.

Research conducted at Teagasc, Johnstown Castle investigated the interaction of lime and P fertiliser across 16 acidic mineral soils from across Ireland (fig. 4). The application of lime only increased soil test P by on average 5.7 mg/L P while the application fertiliser only (100 kg/ha P) raised soil test P by 40% more (8.1 mg/L P). However, where both lime and fertiliser P was applied the largest increase in soil test P was achieved (17.7mg/L), indicating higher availability of P from both soil reserves and fertiliser application.

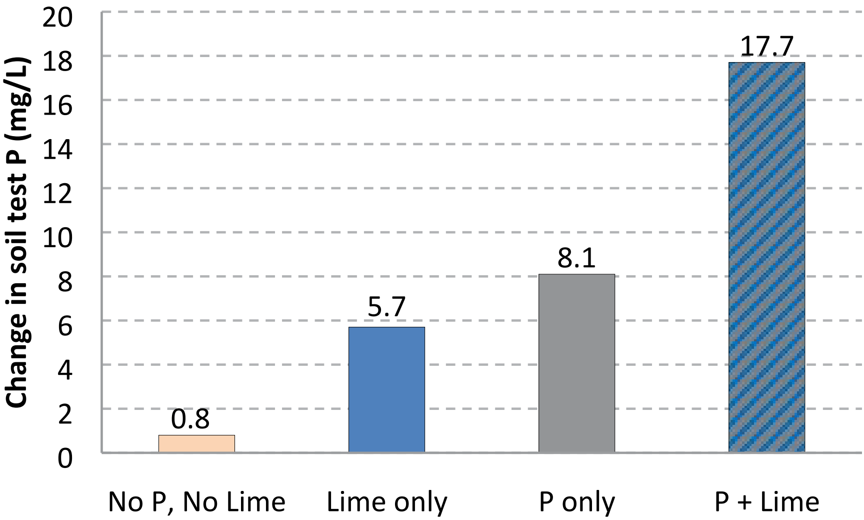


Figure 4. Average change in soil test phosphorus (Morgan's P) across 16 soils after 12 months incubation which were treated with lime only (5 t/ ha of lime), fertiliser P only (100 kg/ha of P), and fertiliser P + lime.

1.3 Soil P mobilisation and movement in soils

Phosphorus is a relatively immobile nutrient (figure 5) in the soil and in permanent grassland soils the levels of P tend to be stratified in the top few centimetres due to minimal disturbance of soil aggregates over time and continuous P recycling in dung and urine by grazing livestock. In addition organic manure and P containing fertilisers are surface applied adding to the concentration of P near the surface in grassland soils.

When grass swards are being regenerated during reseeding the P stratified in the surface soil layers may be distributed deeper into the soil compared to soils under permanent grass swards. Where plough based grass reseeding is used this distribution of P will occur within the plough layer due to the inversion of soil. This will typically lower the soil test P levels in soil surface layers. Ideally, where ploughing is not required, minimum cultivation during seedbed preparations for grass sward reseeding is preferred as it will help retain soil P fertility in the top 10cm of the soil corresponding with the main grass rooting zone.

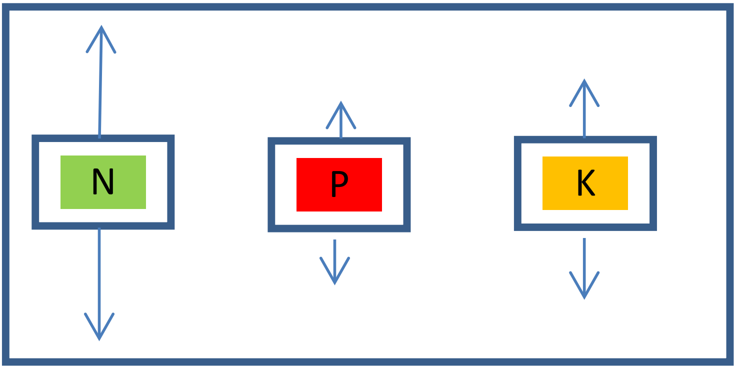


Figure 5. Relative movement of N, P & K in soil (Soil Fertility Manual, 2006).

1.4 Soil test phosphorus

As soil is so variable across the world P fertiliser advice is not transferable and is unique in each country or region where the recommendations or calibrations have been established. During the development of P advice for specific crops and grazing systems each country or region will have evaluated proven scientific approaches to predict crop responses to P inputs. There are numerous scientific methods available that indicate the levels of plant available P in soils. In Ireland soil P is extracted using the Morgan's P test which has been calibrated to crop P responses. The Morgan's test is currently the standard soil test used by the agricultural industry in Ireland and is approved by the Department of Agriculture, Food and the Marine (DAFM) for use under agri-environmental regulations and voluntary farm schemes. This soil P test is most suitable for use on acidic soils which are naturally most prevalent across Ireland.

The Morgan's P test extracts the labile P pool (available & readily available P pools as shown in figure 1) in the soil that indicates plant available P supply. The Morgan's P test has been calibrated, and translated into critical soil test thresholds, for all the major crops produced in Ireland.

It is important to take good soil samples (consistent depth) to ensure that the soil sample presented to the soil laboratory represents the field or sampling area. This will increase the reliability of the of the P fertiliser advice for the crop being grown. On grassland soils ensure that at least 20 representative soil cores are taken from within the area being sampled to the correct depth of 10cm (see figure 6). These 20 soil cores are amalgamated to make one composite soil sample representing the entire sampling area. More information on the correct soil sampling procedure is available in FAI bulletin No 1 https://www.fertilizer-assoc.ie/wp-content/uploads/2015/10/Fert-Assoc-Tech-Bulletin-No.-1-Soil-Sampling.pdf .

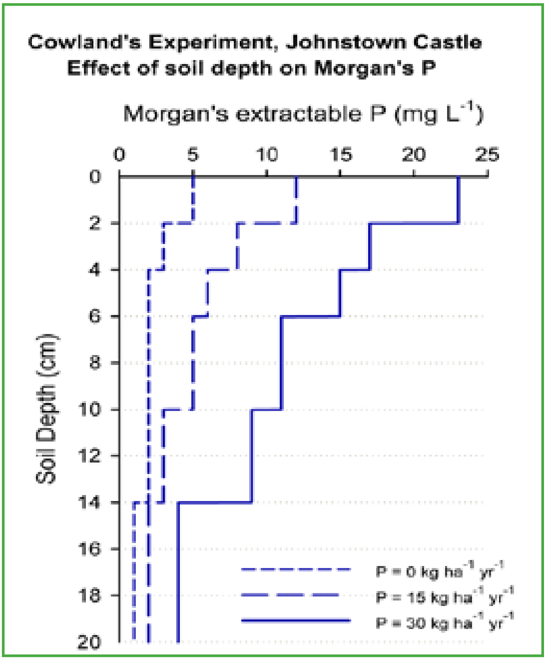


Figure 6. The effect of soil sampling depth on Morgan's soil test P.

1.5 Phosphorus deficiency

Phosphorus deficiency symptoms in plants are typically indicated by dark to purple colour on leaves and stems and these plants may have stunted growth, reduced plant tillering, rooting and total dry matter production (see figure 7A). It is important to monitor crops such as cereals, root and grass crops in the first 3 to 6 weeks (establishment) on very low P index soils. On permanent grassland soils P deficiency is often hidden and be more difficult to diagnose as symptoms may not be visually apparent by looking at the grass plants. In grass swards that have received adequate N fertilisers tell-tale signs of P deficiencies may be observed by comparing the areas within dung and urine patches (healthier plants) with the areas outside these, as grass growth will be very poor in the surrounding area.

Figure 7A. Phosphorus deficiency (plants on left) in spring barley showing reduced rooting & tillering due to lack of available soil P.

P Deficiency in Maize

P Deficiency in Cereals

Figure 7B. Phosphorus deficiency symptoms in maize and cereal leaves.

P deficiency in grassland

Figure 7C. Phosphorus deficiency in grassland. (picture on the left P Index 1, picture on the right P Index 4) Picture taken from the long-term grazed grassland P experiment at Johnstown Castle, Co Wexford.

1.6 Phosphorus and the environment

Where small amounts of phosphorus (<1 kg P /ha) enter a water body it may speed up a range of biological processes which cause eutrophication (growth of plants and algae which use up oxygen) of rivers and lakes. Phosphorus can be transported from agricultural land or from hard surfaces and roads to surface waters (rivers and lakes) during periods or higher rainfall either as soluble P or as particulate P (P bound to soil particles). Following storms or very heavy rainfall soil particles with P attached can move of land surfaces in run-off water and soil erosion during these intense weather events.

Under the Nitrates Directive, National Action Programme (NAP) a suite of agri-environmental measures and regulations has been implemented on farms in Ireland since 2006. The main aim of these regulations is to minimize the risk of P entering water bodies from agricultural land by constraining P use on farms and placing maximum limits of chemical or manure P inputs.

The first place to start to improve P use efficiency and to reduce P loss from agricultural soils is to take soil samples and use soil test results as a basis for fertiliser planning. Under NAP rules soils with high soil test P levels are considered more risky for P loss. Therefore, no further P fertiliser application is allowed on P index 4 soils (high soil test P). It is recommended to re-sample these soils after 2-3 years to check their soil test P status and adjust fertiliser plans accordingly. On fields where P fertiliser has been omitted for a number of years, soil sampling should be conducted to monitor changes in soil P over shorter time frames.

In order to minimise the risk of P loss to water fertiliser and manure management factors such as application timing and application rate must also be considered. It is best to apply P close to the period of rapid crop uptake and at rates that match crop uptake capacity or to meet soil build-up requirements. Phosphorus advice must also consider different soil types and the potential pathway for P loss from these soils. For example on heavy wet soils the main pathway for P loss will be over land flow while on light or drained peaty soil types P may move down through the soil profile.

Losses of P with soil erosion may often be lower compared to run-off P losses on grassland soils with a high soil test P status. Within a river catchment i.e.

the area of land draining in to a river or stream, P tends to be lost from critical source areas (CSA's) which tend to occupy a smaller proportion of a whole catchment. CSA's are relatively small areas within a farm that have higher potential for P loss to water due to the heavy wet nature of the soil and close proximity to surface water bodies. A common rule of thumb is that 80% of the P loss comes from less than 20% of a catchment area (80:20 rule). Depending on the landscape and soil types present implementing the appropriate P management practices and targeting fertiliser and manure applications to lower risk areas will reduce excessive P loss that may impact on water quality.

Section 2

Phosphorus Management and Agronomic Advice

2.1 Phosphorus index system for grassland & tillage Crops

The aim of P nutrient advice is to maintain fields at the optimum soil fertility level for the farming system practiced. On intensive farms where the aim is to maximise crop yields (grass / grain / root crops) aim for soil P index 3. It may be appropriate to have lower soil P levels on land that is not being intensively farms or in field used for low input permanent pasture. The soil test (Morgans) indicates the plant available P in mg/L of soil (see table 1). The soil index system divides soils into one of four soil index levels based on the soil test P result. For grassland and tillage crops the corresponding soil test P ranges for each index are shown in Table 1. The soil index indicates the expected response to nutrients applied.

Table 1. Soil nutrient Index, response to fertilisers and soil test range for P. (Source: Teagasc)

Soil Index	Response to Fertilisers	Soil test P (mg/L)	
		Grassland	Tillage
1	Definite	0 – 3.0	0 – 3.0
2	Likely	3.1 – 5.0	3.1 – 6.0
3	Unlikely / Tenuous	5.1 – 8.0	6.1 – 10.0
4	None	> 8.0	> 10.0

Soils within P index 1 and 2 are responsive to applied P fertilisers. Soils at index 1 or 2 have higher P requirements when intensively farmed, as the soil P reserves may not be sufficient to meet crop requirements. Therefore, additional P needs to be applied to meet crop demand to replace P removal in grain, straw, meat or milk, etc. and to build-up soil P reserves to the optimum soil index of 3. The aim is to build soil fertility levels up to index 3 over a number of years. The rate the soil test P levels increase will depend on a number of factors such as the starting soil test P level, the soil type and clay content, the nutrient application rate, and the amount of nutrient removed (e.g. crops, grass grazing v silage etc. see table 2 & 6). Building soil P fertility usually takes a number of years and applications of P for build-up should continue for a number of years until the soil is re-sampled (see table 3 & 4).

Soils with a P index of 3 are at the optimum index for agronomic production, and have soil fertility levels sufficient to feed the crop. In order to maintain the soil P levels within this optimum range, the P applications should replace P removal over the growing season. It is therefore important that P off-take in grain, straw, meat or milk, animals etc. is accurately calculated (see table 2 & 7).

Soils at index 4 are very fertile soils and soil reserves are more than sufficient to meet crop P requirements throughout the growing season. At these very high soil P levels there is increased risk of P loss from the soil. It is not recommended to apply further P fertilisers to soils at P index 4, with exception for certain high value crops such as potatoes, beet, and some horticultural crops, where small qualities of P may be applied at planting to assist good crop establishment. Where grass and tillage crops are grown on index 4 soils it is recommended to omit P for a number of years (2 to 3 years) and then re-sample to monitor changes over time.

The speed of P decline on index 4 soils will depend on the soil type, the level of P in the soil, and the P removal on an annual basis. Regular soil testing is essential to monitor changes over time.

2.2 P Advice for Grassland & Tillage Crops

Phosphorus advice is based primarily on the soil P index system which is supported by soil sampling and soil analysis using the Morgan's soil P test. Adjustments are made to the P advice in grassland depending on farming system, intensity of production and concentrate P usage. In cereal crop production P advice can be adjusted to take account of higher grain yields.

1. Maintenance P Rates (Index 3)

The first component of the P advice is maintenance (replaces P removed in milk / meat / grain) P application which are shown in table 2.

Aim to maintain a soil P index 3 where there is a requirement for optimum grass dry matter production, early spring grass growth and to maintain sufficient P concentration in the herbage to meet animal health dietary requirements.

Table 2. Grazing maintenance rates of available soil P to replace offtakes (kg/ha)

Grassland Stocking Rate (kg/ha) Org N	Farming System	
	Dairy	Drystock
≤100	6	4
130	10	7
170	14	10
210	19	13
≥210	23	16

2. Soil P Build-Up Rates (Index 1 & 2)

The second component of P advice is the requirement for soil build-up P based on the soil test results. Table 3 shows the P build-up rates as per the recommendations (Teagasc, 2016). Additional P is available under nutrient legislation (SI 605, 2017) for building soil P levels on intensively stocked grassland farms (see table 4).

Table 3. Available P rates (kg/ha) for Build-Up on mineral soils	
Soil P Index	**P Rates (kg/ha)**
1	20
2	10
3	0
4	0

Table 4. Additional P rates (kg/ha) for Build-Up on mineral soils as per SI 605, 2017	
Soil P Index	**P Rates (kg/ha)**
1	50
2	30
3	0
4	0

Grassland Grazing Advice

Table 5 below shows the combined (maintenance & build-up) P advice for a dairy farm stocked at 2 LU / ha. These recommended rates need to be adjusted for specific farm details such as concentrate feed usage and / or recycling of animal manures. To determine the required rate of P a farm fertiliser plan must be completed annually.

Table 5. P advice for a Dairy Farm stocked at 2.0LU/ha	
Soil P Index	**P Advice (kg/ha)**
1	34
2	24
3	14
4	0

3. Adjusting for concentrate P

Farm P allowances need to be adjusted for concentrate feed P imported annually onto livestock farms. Each 1 tonne concentrate feed (ration) imported contributes **5kg P** import to the farm. Feed ingredients such as pulp / distillers etc. contain lower P levels. Under Nitrates Directive rules 300kg concentrate feed (1.5 kg P) is deducted for every 85 kg Org. N/ha (=1 cow/ha) on the farm. This small deduction covers the P that cannot be managed / recovered within the farm due to grazing management. This concentrate P deduction is calculated based on the previous years feed usage and total farm organic N loading (stocking rate equivalent).

For example a farm with a total organic N loading of 8,500 kg can deduct 30 tonne of concentrate feed from annual feed use when calculating their whole farm P allowances. In effect this increases the whole farm P chemical allowance by 150 kg P (30 x 5kg P) per year.

Eq.1. 8,500 kg Org.N / 85 kg Org. N/ha = Average 100kg Org.N/ha for the farm

Eq.2.100 kg Org.N/ha x 300kg Conc. Feed = 30 tonnes of conc feed can be deducted.

Organic Fertilisers

The P in farm produced organic fertiliser P (manures / cattle slurry) has been removed from the whole farm chemical P allowance calculations under the Nitrates Directive regulations. This P in manures / slurry which is generated on the farm needs to be recycled back to the areas of the farm where it was generated, for example the silage fields.

Where organic P as manure is applied to P index 1 or 2 soils the P is deemed to be 50% available in the year of application. To make up the remaining 50% of P chemical P fertiliser can be brought onto the farm to achieve total crop requirements for that year. This ensures that the grass crops receive sufficient P during the growing season. For example on a farm stocked at 2 LU/ha it can increase the farm P allowance by ~ 4kg/ha depending on specific farm details.

Cereal Crop P Advice

The P advice for tillage crops is based on maintaining the optimum index 3 for maximum grain production. Table 6 below shows the rate of P required at index 3 for a 6.5t/ha grain crop. Where higher yields are achieved (proof required) an extra 3.8 kg P for each 1 tonne of grain (wheat, barley or oats) yield may be applied.

Table 6. Recommended rates of P for Cereals at 6.5t/ha

Soil P Index	P Rates (kg/ha)
1	45
2	35
3	25
4	0

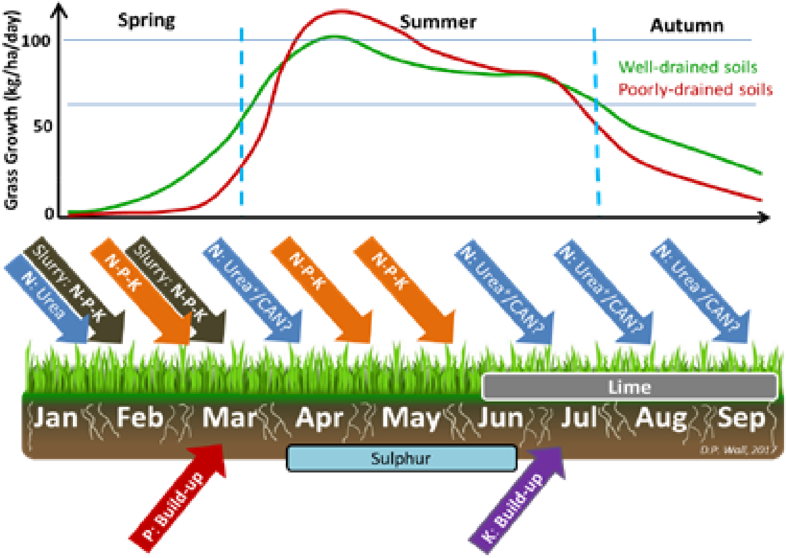
Additional P for higher grain yields is based on the highest grain yield achieved in any one of the previous 3 years at 20% moisture content. Table 7 shows the P rates for cereal crops as grain yield increases.

Table 7. Available P advice for cereals based on crop grain yield (kg/ha)

Soil P Index	6.5	7.5	8.5	9.5	10.5	11.5
1	45	49	52	56	60	64
2	35	39	42	46	50	54
3	25	29	32	36	40	44
4	0	0	0	0	0	0

2.3 Phosphorus programmes for grass and cereal crops

A fertiliser programme should encompass applying the right fertiliser products, in the right place (field), at the right rate, at the right time. Figure 8 shows a typical fertiliser timing schedule for grassland farms. The aim of the fertiliser plan is to match N-P-K-S nutrient requirements with grass demand over the growing season. The fertiliser programme (rate and timing) will be different on well drained versus poorly-drained soils due to different grass growth profile and hence nutrient demand over the growing season, as indicated by the green and red grass growth curves respectively. These differences on well- and poorly-drained soils need to be taken into account especially in early spring in relation to the timing and rates of the 1st and 2nd rounds of fertiliser. For example, on well-drained soils cattle slurry maybe used as a source of P in early February if soil temperatures (> 5.5 °C) and ground conditions are favorable. However, on poorly-drained soils, with very low grass growth during early season, it may be prudent to hold off the 1st round of fertiliser until conditions improve in late February/early March. Where no slurry was applied, an N-P-K compound should be applied in the 2nd or 3rd rounds (March/April) to help boost soil P availability before the onset of high grass growth rates. Aim to apply 50% of total P requirements in springtime. Apply the remaining P in 2 or 3 applications in May / June, during the period of peak grass growth, to ensure sufficient P in grazed grass for livestock.



Urea$^+$ = protected Urea (Urea + NBPT)

Figure 8. Shows fertiliser suggested timings for N, P & K during the grazing season on 2 soil types.

Winter Cereals

Winter cereals have a higher P demand during the growing season compared to spring cereals due to their higher yield potential see table 7.

On very low to low P index soils a winter cereal crop should receive a P build-up application for index 1 and 2 soils of 20 to 10 kg P/ha at sowing time which should be incorporated or combined drilled to ensure it is in the correct zone for root access and reduce loss risk to water. In early spring the remaining crop P requirements can be broadcast in late January / early February. For winter crops sown on P index 3 soils crop P requirements should be broadcast in late January / early February typically with the crops 1st N and K requirements. This will replenish soil P reserves and supply in season crop demands.

Good soil conditions during crop establishment are critical for soil P availability especially in the early stages of crop development.

Spring Cereals

Spring cereals have a shorter growing season compared to winter cereals and a lower yield potential. Apply all crop P requirements at sowing time and incorporate / combine drill into the seedbed at sowing time. This is critical especially for spring barley as the crops develops very rapidly and requires an easily access source of P in the first 3 to 6 weeks after sowing. On very low P index soil (P index 1 or 2) there is merit to combining drilling P especially for spring barley (see figure 9). This readily available source of P close to the rooting zone is critical to drive both root and tiller production.

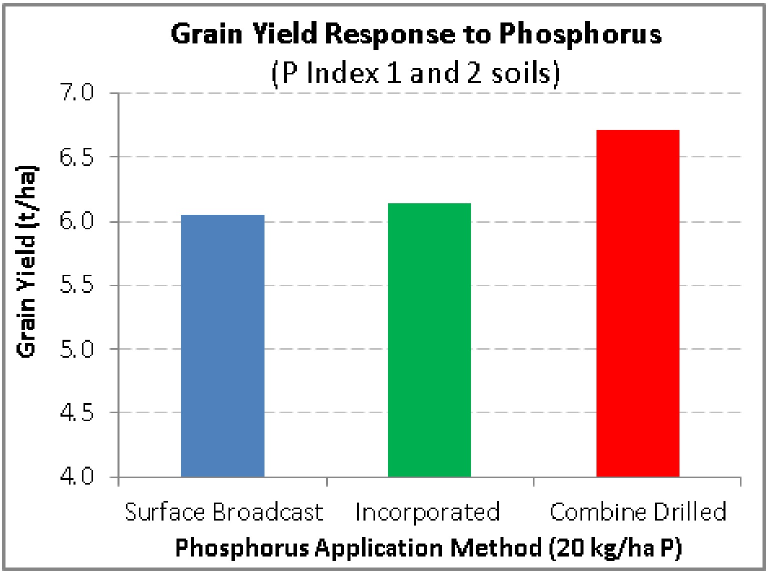


Figure 9. Average spring barley grain yield response to 20 kg/ha P applied using three application methods across 4 sites.

Spring barley grown on a P Index 1 site

Figure 10 Plot on the left is zero P applied compared to plot on the right with 30kg P/ha combine drilled

Figure 11 Trial plot on the left received 30kg P/ha combined drilled compared 30kg P/ha surface applied on the plot on the right

2.4 Fertiliser Selection & programmes

Grassland P fertilisers should be selected based on either grazing or grass silage requirements. In a grazing situation the majority of P and K is recycle back to the soil in the form of dung and urine. Phosphorus and potassium (K) that leave the farm in the form of either milk or meat needs to be returned in a fertiliser blend with a P : K ratio of 1 : 2 to replenish soil nutrient reserves. However, in a grass silage situation there are significant removals of both P and K as there is total crop removal at harvest time. P and K removed in cut grass needs to be return in a fertiliser blend with a P : K ratio of 1 : 6 / 7 to replenish soil nutrient reserves.

Grazing

Tables 8 & 9 show recommended rates of both P and K for dairy and drystock farms and suitable fertiliser products and rates to match P and K requirements as recommended for grazing ground. Where additional P and K is applied for soil fertility build-up the P : K ratios will change due to additional P and K required over index 3 rates. Additional nutrient (Build-Up) can be applied early / late in the growing season. Plan to apply P early (March / April) and K late (August / September).

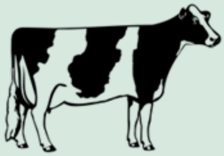


Table 8. Recommended rates (kg/ha) of P & K for Dairy farms stocked at 2 LU/ha & suggested fertilisers

Soil Index	P[1]	K[2]	P:K Ratio	Typical P-K Products
1	34	90	1:2.6	566 kg/ha 18-6-12
2	24	60	1:2.5	400 kg/ha 18-6-12
3	14	30	1:2.1	230kg/ha 18-6-12
4	0	0	--	---

[1] Adjust P rates for concentrate P fed on farm each year

[2] Additional K is required at Index 1 & 2 as 65 to 130kg/ha of 50% K (MOP) once every 3 years (for soil K build-up)

Table 9. Recommended rates (kg/ha) of P & K for Drystock farms stocked at 2 LU/ha & suggested fertilisers

Soil Index	P[1]	K[2]	P:K Ratio	Typical P-K Products
1	30	75	1:2.5	300kg/ha 10-10-20
2	20	45	1:2.25	200 kg/ha 10-10-20
3	10	15	1:1.5	400 kg/ha 27-2.5-5
4	0	0	--	---

[1] Adjust P rates for concentrate P fed on farm each year

[2] Additional K is required at Index 1 & 2 as 30 to 90kg/ha of 50% K (MOP) once every 3 years (for soil K build-up)

Grass Silage

The grass silage crop removes significant amounts of both P and K as shown in table 10 and 11 below. Firstly recycle cattle slurry on the silage fields in order to return both P and K removed at harvest time in the grass silage crop. Table 10 shows fertiliser advice (P & K) and suggested fertiliser products where 33m^3/ha cattle (3,000 gals/ac) is recycled on the silage fields. The 2nd application of fertilisers after the 1st cut is removed is required to replenish / build soil fertility reserves. Table 11 below shows suggested recommended fertiliser products in the absence of cattle slurry. A crop of grass silage will removes approximately 4kg P and 25kg K /tonne of grass DM. The 1st fertiliser applications are shown in table 11 will supply a proportion of the crops P and K requirements during the growing season which is driven by the rate of K and not to exceed 90kg K/ha in a single application. The remaining crop requirements are applied after the 1st cut is removed to balance / build soil fertility levels as shown in table 11.

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Table 10. 1st Cut Grass silage P & K requirements (kg/ha) & suggested fertilisers

Soil Index	P [3]	K [4]	P : K ratio	$33m^3$/ha Cattle Slurry		
				P - K Supplied (kg/ha)		Balance Application (after 1st Cut)[5]
1	40	185	1 : 4.6	13	106[2]	265 kg/ha 0-10-20
2	30	155	1 : 5.2	13	106[2]	170 kg/ha 0-10-20
3	20	125	1 : 6.3	26	116	90 kg/ha 50% K every 5 years
4	0	0	--	---		---

1 Don't exceed 90kg K/ha in single application.

Index 1, 2 & 3 soils apply P & K balance after 1st cut as shown above.

2 Additional K is required at Index 1 & 2 as 90 to 160kg/ha of 50% K (MOP) once every 3 years (for soil K build-up)

3 P availability in slurry reduced to 50% availability on index 1 & 2.

4 K in slurry reduced to 90% availability on index 1 & 2. [5]Rounded to the nearest 5kg/ha

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Table 11. 1st Cut Grass Silage N, P & K Requirements (5t/ha DM) & Suggested Fertilizer Programmes					
Soil Index	**P**	**K**	**P : K ratio**	**Fertilizer Options**	
				1st Application[3]	**Balance Application (after 1st Cut)[3]**
1[1]	40	185	1 : 4.6	310kg/ha 0-7-30	250 kg/ha 0-7-30
2[1]	30	155	1 : 5.2	310kg/ha 0-7-30	185 kg/ha 0-7-30
3	20	125	1 : 6.3	310kg/ha 0-7-30	125 kg/ha 0-7-30
4[2]	0	0	--	---	---

1 Don't exceed 90kg K/ha in single application. Index 1, 2 & 3 soils apply P & K balance after 1st cut as shown above.

2 Additional K is required at Index 1 & 2 as 40 to 100kg/ha of 50% K (MOP) once every 3 years (for soil K build-up

3 Rounded to the nearest 5kg/ha

Winter Wheat

When selecting a suitable fertiliser compound for winter crops it will depend on a number of factors such as soil test results, crop type and yield potential. Table 12 below shows the P and K requirements for a crop of winter wheat or barley yielding 10t/ha and recommended P & K rates based on grain yield and suggested fertiliser products.

Table 12. P & K Advice for 10t/ha[1] Winter Wheat or Barley & suggest fertiliser programmes

Soil Index	P kg/ha	K kg/ha	P : K ratio	kg/ha[2]
1	58	130	1 : 2.2	555kg 10-10-20[2]
2	48	115	1 : 2.4	555 kg 12-8-20
3	38	100	1 : 2.6	525 kg 10-7-20
4	0	0		---

[1] Adjust P by 3.8kg/t, K by 10kg/t for lower or higher grain yields

[2] Additional K is required at Index 1 & 2 as 40 to 190kg/ha of 50% K (MOP) once every 5 years (for soil K build-up)

Spring Barley

When selecting a suitable compound fertiliser for spring barley it is important to select a fertiliser that will supply all the P and K in a single application at sowing time. It will be important to consider the N % in the fertiliser compound. Aim to deliver 30 to 60kgN/ha depending on sowing date. Regardless of soil P index it is recommended to apply all P and K at sowing time in close proximity to the seed. Examples of appropriate fertiliser blends / programmes based on P : K ratios and soil P and K indexes are shown in Table 13.

Table 13. P & K Advice for 7.5t/ha[1] Spring Barley or Wheat & Suggest Fertiliser Programmes

Soil Index	P kg/ha	K kg/ha	P : K ratio	kg/ha[2]
1	49	115	1 : 2.2	480 kg 10-10-20[2]
2	39	100	1 : 2.4	480 kg 12-8-20
3	29	85	1 : 2.6	480 kg 13-6-20
4	0	0	--	---

[1] Adjust P by 3.8kg/t, K by 11.4kg/t for lower or higher grain yields

[2] Additional K is required at Index 1 & 2 at 40 & 190 kg/ha as 50% K (MOP) once every 5 years (for soil K build-up)

Figure 12 The picture above shows the effects of method of P application at sowing time on a P index 1 soil in spring barley. The plot on the left received 50kg P/ha surface applied after sowing compared to the plot on the right which received 45kg P/ha combine drilled at sowing time.

2.5 Sources Phosphorus (P) Fertilizers (Source; Teagasc Green Book)

Inroganic (chemical) fertiliser phosphorus

There are two types of P fertilizer available depending on the degree of chemical processing that has been done on the original rock phosphate. These types can be described as "fast acting" and "slow acting".

'Fast Acting' means water soluble. Water soluble phosphorus is the most readily available to plants. The phosphorus in "Super Phosphate" is all soluble in water. 'Slow Acting' means the phosphorus needs to be dissolved by some other method, e.g. by soil acids or soil micro-organisms. Historically basic slag a by-product of ore production was a good source of P (~7%) and widely used to improve soil P levels, the basic slag of today is now more refined and contains less P (~1%).

Superphosphate is produced by treating rock phosphate with acid. Depending on the level of treatment, Single Super Phosphate (8% P) or Triple Super Phosphate (16% P) is produced. It is highly water soluble (over 90%) and is quick acting. Agronomic trials have shown that there is no significant difference in P nutrition from various "fast acting" phosphate fertilizers under most conditions.

Triple Super Phosphate (TSP)

Triple super phosphate is a water soluble source of P produced by treating finely ground rock phosphate with phosphoric acid. TSP is generally >90% water soluble. TSP contains 16% P as phosphate along with 15% calcium. It is used either as a raw material for complex fertilizer or for direct application. TSP has the highest P concentration of any non N containing granular fertilizer.

Mono Ammonium Phosphate (MAP) or Diammonium Phosphate (DAP) is formed when phosphoric acid is reacted with ammonia. These P sources are commonly used to produce blended N, P & K fertilizers.

Mono Ammonium Phosphate (MAP)

Mono ammonium phosphate is a water soluble granular fertilizer containing 11% N and 22% P. Rock phosphate is reacted with sulphuric acid to form phosphoric acid. The phosphoric acid is reacted with ammonia to form mono ammonium phosphate. On dissolution, MAP provides plant available phosphate and ammonium. The pH of the solution surrounding the granule becomes moderately acidic on dissolution, which is particularly beneficial in neutral or alkaline soils. It is not widely used in Ireland as it tends to be more suitable for alkaline soils.

Diammonium Phosphate (DAP)

Diammonium phosphate is a water soluble granular fertilizer containing 18% N and 20% P. It is the most widely used sources of P fertilizer, both globally and in Ireland. Rock phosphate is reacted with sulphuric acid to form phosphoric acid. The phosphoric acid is reacted with ammonia to form DAP. The product of this reaction produces highly plant available source of P. On dissolution, DAP provides plant available phosphate and ammonium. The pH of the solution surrounding the granule becomes alkaline. As a result, ammonia can be produced and caution should be taken on alkaline soils if applying high concentrations of DAP near germinating seeds.

Phosphorus (P) fertilizer can be applied alone as Triple Super Phosphate 16% P or more commonly as Diammonium Phosphate (DAP) in fertilizer blends (18 6 12 or 10 10 20).

Organic fertiliser phosphorus

Animal manures are a valuable source of P but there nutrient content can vary considerably. Such factors as animal type, diet, bedding type and dilution with water will have a large impact on the actual P content of the manure. For example in cattle slurry the P content can range from 0.1% to 1.0% which is a ten-fold variation in P content. Table 14 below shows the typical nutrient P values for a range of animal manures.

It is recommended to test manures to determine their actual nutrient values. This will help ensure that the crop is supplied with the desired rate of P and manure application rates can be adjusted depending on manure dry matter content. Greater than 50% of the P in manures is in the organic form and is unavailable for plant uptake at time of application. Manure P is mineralized by the soil biology over time and made plant available. The availability of P in manures applied to P index 1 or 2 soils is deemed to be 50% available. On low P index soils it is recommended to only supply 50% of the crops P requirements as manure P and the remaining 50% as an available water soluble fertiliser P form. This will ensure that the crop has sufficient P during the growing season. On index 3 soils which have a better soil P supply manure P can be used as the source of P during the growing season.

Table 14. Average available P values in Organic Fertilisers

Manure Type	Dry Matter %	P (kg/m³ or ton)	P (units/1,000gals or ton)
Cattle Slurry	6.3	0.5	5 / 1,000gals
Pig Slurry	3.2	0.8	7 / 1,000 gals
Farm yard manure	20	0.6	1 unit / ton
Broiler Manure	60	3.0	6 units / ton
Layer Manure	55	2.8	5.5 units / ton
Mushroom Compost	35	0.8	1.5 units / ton

2.6 References

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