leaflet **8**

The Potash Development Association

Principles of Potash use

Needs of the plant

Normal plant growth requires large quantities of potassium (K, often referred to as potash, K_2O). In fact, throughout growth most crops contain more potassium than any other nutrient including nitrogen (N). Small quantities of potassium are needed to support many of the crucial enzyme processes within the plant but very much larger amounts are used to control the water relationships in the plant. Potassium also plays a vital role in the transport of sugars and other products of photosynthesis from leaves to storage organs. Adequate quantities of potassium are thus essential for a crop to achieve its full yield potential and also for many aspects of product quality such as grain size and appearance, tuber size, oil content, dry matter and starch content, percentage sugar and fruit ripening and quality.

Many of the functions of potash in the plant are related to physiological conditions and stress. These functions are diverse and include efficient nitrogen and water use, drought tolerance, frost resistance and resistance to pests and diseases. It is therefore not surprising that lack of plant-available potash in the soil results in weaker, less vigorous crops that suffer major penalties in difficult growing seasons. In years when growing conditions and yields are good the response to potash may be modest, especially for crops like cereals, but in adverse years its contribution to optimum yields will be substantial. Adequate potassium thus provides some 'insurance' against adverse conditions in difficult growing seasons.

'Potash' and 'potassium'

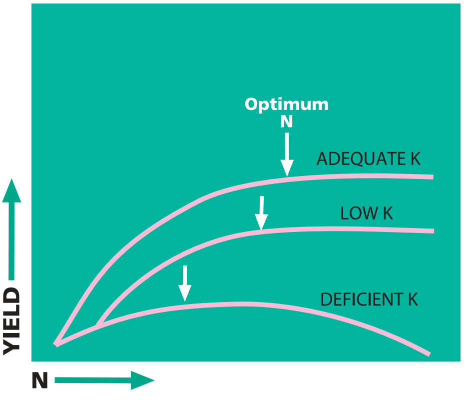
Fertilisers and organic manures release potassium into soil solution as the potassium ion, K^+ and plants take up potassium in this same form. However the potassium content of fertilisers is usually referred to and measured as 'potash' or K_2O. This is just a convention and 'potassium', 'potash', 'K' and 'K_2O' are often used interchangeably when referring to fertilisers or application rates. Soil analysis results are given as mg/litre (or ppm) of K (potassium) which relates to an Index, not to an amount of fertiliser, and should not be confused. If it is necessary to convert K_2O to K (for example if converting the UK recommendations in this leaflet for use in the Irish Republic) the K_2O value should be multiplied by 0.83. Similarly K values can be converted to K_2O by dividing by 0.83.

The N and K partnership

Potassium and nitrogen are strongly associated in plant processes and should be considered together.

Firstly in terms of uptake, both nutrients are needed in large amounts at the same time. N is mainly taken up as the negatively charged nitrate anion NO_3^- and potassium as the positively charged cation K^+. When equal amounts of both are taken up together, the neutrality of the system is maintained. Nitrogen application and uptake stimulates the growth of plant cells which take in water. Potassium is required to maintain the turgor (rigidity) and regulate the water content of the cell. Maintenance of cell turgor is essential to optimise the interception of solar radiation (sunlight) to provide energy for the conversion of carbon dioxide to sugars, the basic building block for the production of harvestable yield.

Fig 1: **K effect on N response**



Within the plant the complex formation of protein from nitrate and its distribution around the plant are highly dependent upon adequate K supply. If 'normal optimum' rates of N are applied in the absence of sufficient K, full response to nitrogen will not be obtained and residues of nitrogen may remain and be leached at the end of the season (see Figure 1).

Typical patterns of K uptake for cereals and roots are shown in Figures 2 and 3. For combinable crops, uptake will peak at around flowering, whereas for root crops maximum uptake is shortly before harvest or at haulm destruction.

In most plant species the total content of potassium is larger than that of any other nutrient, even nitrogen. For optimum growth the plant-available supply of potassium in the soil must meet both the maximum total demand and the required rate of daily uptake. This will vary from season to season depending on soil conditions and weather. Whenever there is a rapid surge in growth the soil supply must be able to meet the demand of the crop. Hence the need to maintain soil reserves is a sound insurance. Typical peak rates of uptake are 5-10 kg K_2O/ha/day for root crops and oilseed rape.

Fig 2: **Nutrient uptake of a typical 8 t/ha wheat crop**

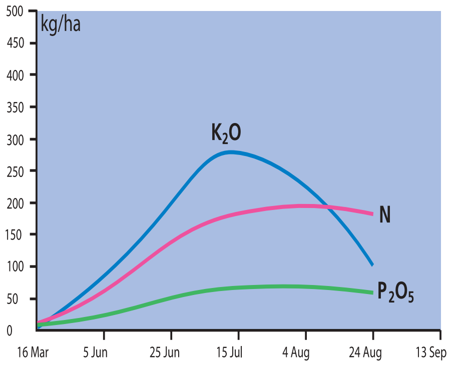


Fig 3: **Nutrient uptake of a typical 55 t/ha potato crop**

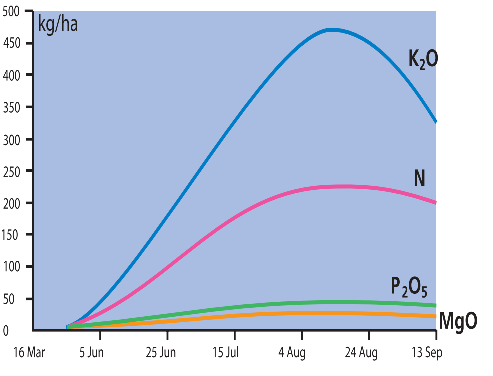
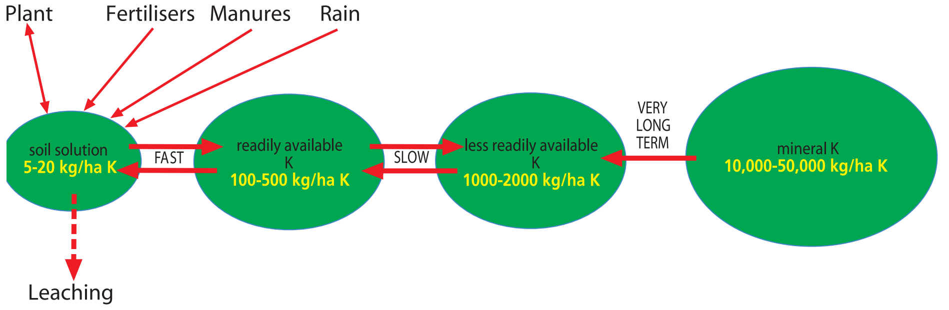


Table 1: **Typical total uptake of potassium by large yielding crops expressed in kg/ha K_2O**

Cereals	300-350
Oilseed rape	350-400
Potatoes	400-450
Sugar beet	400-450
Pulses	150-200
Forage crops	300-500
Grass silage (single cut)	100-170

Sources of potash

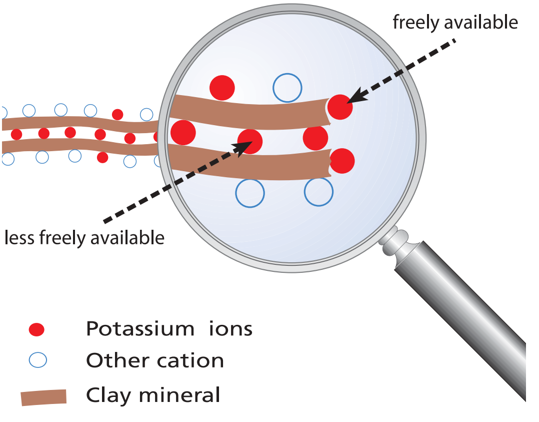
Fig 4: **The K cycle**



Plant roots take-up potassium as the cation K^+ from the soil solution and it is this, plus the 'readily available K', which is measured by soil analysis as being potentially available to the crop (Figure 4). Small quantities can be taken in from a foliar application but the amounts are usually insignificant in relation to overall potassium needs. (It is also a costly method.) Rainfall contributes very small amounts of potassium (less than 5 kg/ha/year). Fertilisers, manures and crop residues all add potassium to the soil as K^+. Almost all potassium sources are soluble* and increase the concentration of K in the soil solution immediately they are applied. In some cases manures and crop residues may require biological breakdown for the K to be released, perhaps over 12 months.

Only small amounts of K are maintained in the soil solution 5-20 kg/ha K (6-24 kg K_2O). The majority of potassium reserves in the soil are held by the negative charges on clay minerals and organic matter (Figure 5). The potassium may be held weakly or strongly according to the position in the clay lattice. K^+ which is loosely held ('exchangeable K') is rapidly released for plant uptake, whilst the more firmly bonded reserve ('non-exchangeable K') is released more slowly. Individual soils have different capacities to hold potassium according to clay type and content and amount of soil organic matter. Sand soils have very limited reserves of exchangeable K.

Fig 5: **Clay minerals and cations**



The clay minerals themselves contain potassium as an integral part of their structure (mineral K) and this is released only over very long time periods by the breakdown of the minerals (weathering). In UK conditions the amount of K released by weathering of the clay minerals is too small to meet the needs of even average crops. The different pools of soil K shown in Figure 4 are defined in relation to the plant availability of the K and are not distinct. The amount of K in each pool varies with potash additions, crop uptake, N use, soil wetting and drying, cultivations, etc.

* *except specific clay mineral fertilisers used in organic farming - see PDA Leaflet 23.*

Potash leaching

Potassium does not leach anything like as readily from soils as does nitrate and sulphate. Potash additions not taken up by the crop will be held in the soil by the clay minerals or organic matter as described above. For the great majority of soils, which have a clay content of 5% or more, where normal rates of potash are applied, potassium not used by the crop will remain in the cultivated layer of soil and will not move further down the profile. However, significant losses of potassium can occur when any source of potash (fertiliser, slurry or manure) is applied under adverse conditions i.e. when soil is water-logged, frozen or very dry and deeply cracked. Most of this loss is by surface run-off and can be avoided by following codes of good agricultural practice. Soils with less than 5% clay (the sands and loamy sands) have a much lower retentive capacity for potassium. Such soils, especially if shallow and subjected to rainfall producing large amounts of through-drainage, have a greater risk of potassium loss. On these soils, potash should be applied 'little and often' and applications timed to suit crop uptake and amounts carefully matched to crop offtake.

Soil analysis

Many decades of detailed research work have resulted in the present soil analysis system as the best practical approach for assessing the adequacy or deficiency of soil potassium supply (see PDA Leaflet 24). Soil analysis measures the K in the soil solution and exchangeable K to give a guide to the amount of potassium that is available to the crop. All soils contain much larger total quantities of K as shown in Figure 4. Slowly available reserves (non-exchangeable K) may contribute to plant supply over the course of a season but this release is variable and impractical to measure. For many soils the slowly available reserve provides only a minor annual supply but it can be more important on some very clayey soils (see PDA Leaflet 19).

Soil K and crop response

Fig 6: **Response of winter wheat & spring barley to soil K**

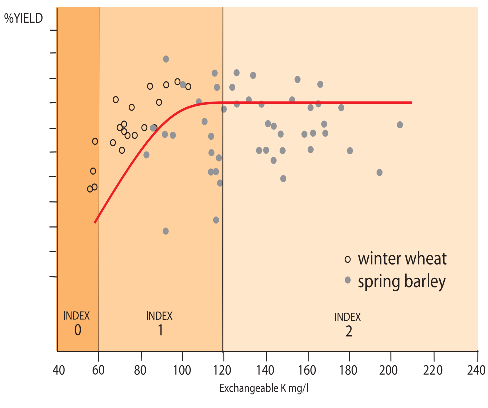
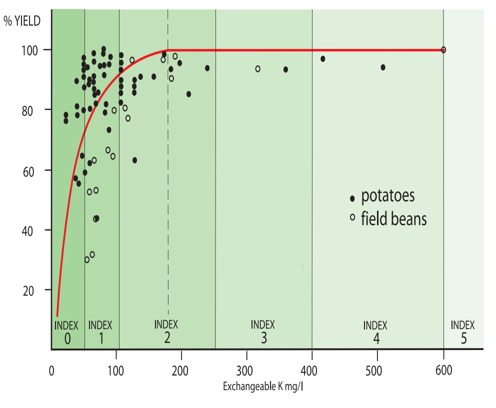


Fig 7: **Response of potatoes & field beans to soil K**



The yield response curve to soil potassium supply follows the same principles as for other inputs. At very low levels of available soil K, the response to applied potash is large and the response decreases to nil as soil supply increases. Target levels for soil K which represent the level at which K supply is adequate for full yield but not excessive have been established from large numbers of response experiments for different crops.

As shown by the scatter of points in Figures 6 and 7 for a number of field experiments, the response to soil K can vary. Often variation is due to factors other than the availability of soil K. For this reason the K Index system, as in RB 209, gives a range of soil K values for each Index and is intended to provide a general guide to interpretation.

	soil K mg/l	
Index 0	0-60	Large responses likely
Index 1	61-120	Smaller responses probable
Index 2	121 - 240	Responses unlikely
Index 3	241 - 400	Nil response from grass & most arable crops
Index 4	400 - 600	Unnecessarily high levels of reserve for arable crops & grass

Principles of manuring

It is the soil that feeds the crop, while fertilisers feed the soil.

Critical values of soil K for different crops have been established from numerous experiments as illustrated in Figures 6 and 7 at which full crop yield will be achieved. For all soils, except the lightest textured soils which cannot sustain these levels without risk of leaching, the aim is to maintain soil K above the critical level appropriate to the rotation, using fertiliser and manure to replace the potassium removed by cropping.

It should be recognised, therefore, that potash is unlike most other farm inputs, which are justified on the basis of direct yield response and financial return per £ spent. Correct use of potash to replace crop offtake and maintain soil reserves may not result in an immediate yield response. Failure to replace the potassium removed in the crop and maintain an adequate soil reserve prejudices future yields and crop quality and unnecessarily jeopardises the response to all other inputs.

Policy for the lightest textured soils (sands and loamy sands) should be to ensure at least the replacement of removals but not to expect to be able to raise the inherently low levels of soil K to the same values as for other soils.

Benefits of maintaining soil fertility

- Fertile soils have a better distribution of nutrients throughout the soil profile, and this cannot be achieved immediately from fresh fertiliser applications. This results in more effective uptake, especially for poorer rooting crops such as potatoes, and better yields than can be achieved from low soil fertility and high fertiliser regimes.
- Soils with adequate nutrient levels avoid the risk of damage to roots from local, high concentrations of salts from large fertiliser applications.
- Satisfactory fertility removes the urgency of timeliness in application of fertilisers, which eases peak work-loads, offers cash flow benefits and allows fertiliser application to be undertaken at the best time without risk to soil structure or seedbeds from tractor wheelings. Crop response to nitrogen fertiliser depends on having appropriate amounts of other nutrients (e.g. P, K, S, and Mg) in the soil profile explored by roots. Shortages of these nutrients will result in poorer responses to nitrogen and the risk of leaving unused nitrogen residues in soil.

Target levels of soil fertility

Crop	Soil P *	Soil K	
		Sands/loamy sands **	Other soils
Vegetables, pulses potatoes	Index 3 26-45 mg/l	Upper index 1 100-120 mg/l	Index 2+ 181-240 mg/l
Grass, other arable crops	Index 2 16-25 mg/l	Upper index 1 100-120 mg/l	Index 2- 120-180 mg/l

* *Soil target concentrations are for Olsen P. Some laboratories use other extractants.*

** *These soils cannot be maintained at higher levels of K without risking unacceptable losses. Regular use of organic manure is of considerable benefit in these situations.*

Soil K levels cannot be rapidly changed up and down to suit individual crops and the appropriate target level must be set for the most demanding crop in the rotation.

Low fertility soils

The rate at which reserves in a low K soil should be built up is largely an economic decision. Consideration should be given to the likely loss of crop yield and quality of all the crops grown in the rotation on a low K soil, as well as the cost of fertiliser. Soils vary in their capacity to retain potassium (buffering capacity) and require different quantities of potash to increase plant-available K as measured by exchangeable K.

Approximate amounts of potash needed to increase exchangeable soil K by 60 mg/l (e.g., lower Index 1 to Index 2-)

	kg/ha
Sands	250
Sandy loams	⋮
Loams	⋮
Clay loams	⋮
Clay	800

The quantities required may seem surprisingly large but are a consequence of the fact that some of the added K goes into non-exchangeable reserves that are not measured by soil analysis. In practice, low soil K levels should be improved over a period of years using annual remedial amounts (see for example RB 209). Heavier soils are less likely to be found with low K levels but will take longer to restore to a satisfactory level than lighter soils.

Fertiliser policy

Following the principles of manuring stated earlier, fertiliser recommendations comprise two components:-

Replacement of nutrient removed = R

Calculated from standard offtake x yield/ha - see page 9.

Soil fertility adjustment

Additions to improve low soil K, or reductions to allow unnecessarily high levels to decline.

These can be made annually to each crop or periodically in larger applications depending upon soil type and rotation and financial considerations.

These two components vary with soil K Index as shown in the table below. Fine-tuning of the soil fertility adjustment could be done where soil is in the upper or lower parts of Indices 1 or 3. For example, at low Index 1, the fertility adjustment could be +125 kg K_2O/ha for vegetables or +35 kg K_2O/ha for arable and grassland.

Basis of fertiliser recommendations, kg K_2O/ha:

Vegetables:

Soil K						
index	0	1	2-	2+	3	4 & over
mg/l	0-60	61-120	121-180	181-240	241-400	401+
Replacement	R	R	R	R	R	Nil
Soil fertility adjustment	+150	+100	+50	Nil	-90	Nil

Arable, forage crops and grassland:

Soil K						
index	0	1	2-	2+	3	4 & over
mg/l	0-60	61-120	121-180	181-240	241-400	401+
Replacement	R	R	R	R	R	Nil
Soil fertility adjustment	+50	+25	Nil	-25	-70	Nil

Removal of potash

Under-estimation of K offtake is one of the commonest causes for soil K levels to fall below target and emphasises the need to undertake careful estimations of the amount removed. Standard figures to calculate removal and therefore **replacement** needs are given below:

	kg/t of fresh material P_2O_5	kg/t of fresh material K_2O
Cereals - Grain only	7.8	5.6
- Grain & straw		
Winter wheat/barley	8.6*	11.3*
Spring wheat/barley	8.8*	13.7*
Winter/spring oats	8.8*	17.3*
Oilseed Rape - Seed only	14.0	11.0
- Seed & straw	15.1*	17.5*
Peas - dried	8.8	10.0
- vining	1.7	3.2
Fields Beans	11.0	12.0
Potatoes	1.0	5.8
Sugar Beet - Roots only	0.8	1.7
- Roots & tops	1.9	7.9
Fodder Beet - Roots only	0.6	4.0
- Roots & tops	1.7	7.5
Grass - fresh grass @ 15-20% DM	1.4	4.8
- silage @ 25% DM	1.7	6.0
- silage @ 30% DM	2.1	7.2
- hay @ 86% DM	5.9	18.0
Kale	1.2	5.0
Maize - silage @ 30% DM	1.4	4.4
Swedes - roots only	0.7	2.4
Broad Beans	1.6	3.6
French Beans	1.0	2.4
Beetroot	1.0	4.5
Cabbage	0.9	3.6
Cauliflower	1.4	4.8
Onions - bulb	0.7	1.8
Sprouts - buttons	2.6	6.3

* *offtake value is per tonne of grain or seed but includes nutrients in grain and straw.*

Fine tuning

Where more site-specific information is available it may be possible to 'fine tune' the general offtake guidance in this leaflet. For example in the case of sugar beet, recent studies indicate that the tare-house analysis of root K content (x 1.2 to convert to K_2O), used in conjunction with yield provides an accurate indication of potash offtake, see PDA Leaflet 12.

A number of other specific aspects may be considered.

Soil structure

Compaction, soil pans or other adverse structural problems can inhibit root growth and thus their ability to take up nutrients from a large volume of soil. 'Fertility' embraces other factors as well as nutrients, including soil aeration and water availability and organic matter content. Improvement of these factors leads to better biological activity in the soil and more readily available nutrients. These aspects should be a starting point not an after-thought in fertility management.

Soil depth

Soil analysis measures the available nutrients to sampling depth - normally 15 cm for arable soils and 7.5 cm for permanent grassland - and in soil particles less than 2 mm in diameter. The amount of soil in this size range that can be explored by roots is important. Thus soil depth and stoniness can affect nutrient availability, and should be taken into account when interpreting soil analysis results and assessing the amount of nutrient available. Whilst nutrients are generally most concentrated in the plough layer, it is clear that modern high-yielding, well-rooted crops derive considerable amounts of potash from greater depth. It may be valuable to estimate the likely supply of K by analysing samples taken at depth for soil N. However, interpreting the results may not be easy because there is little information on the amount and distribution of roots at depth.

pH

A larger proportion of applied potash tends to become non-exchangeable on neutral and calcareous soils than on soils with pH around 6. Additions of fertiliser to improve low K status will have less impact on such soils and this needs to be considered when calculating fertiliser requirements for these soils.

High magnesium soils

Potassium availability may be affected on soils with very high Mg levels. It has been suggested that where the concentration (mg/l) of soil Mg is more than twice that of soil K, potash availability to the crop may be less than implied by the actual potassium analysis value. In such circumstances no more magnesium in any form should be applied to the rotation and higher applications of K may be used to overcome the imbalance. The application of calcium to replace the magnesium is not recommended, principally because it will also displace K.

Non-exchangeable K

There is still no practical method to estimate the supply of slowly released K, which will vary greatly between soils and between seasons. For some heavy soils it may be sufficient to provide all the needs of combinable crop rotations and permit applications for root rotations to be halved. However, this does not apply to all clay soils - see PDA Leaflet 19. On lighter soils, allowance for non-exchangeable K should only be made where objective information or experience is available.

Organic manures

Inadequate allowance is still frequently made for the nutrient contribution from manures. Use standard figures unless specific analysis is available for consistent materials, and deduct the total amount of potash in manure applied if the soil Index is 2 or more. For soils at Index is 0 or 1, K added in manures can be thought of as helping to increase soil reserves and normal applications of fertiliser K should be given.

Typical nutrient content of animal manures

	DM %	Total Nutrients			Available Nutrients (1)	
		Phosphate	Potash		Phosphate	Potash
Fresh FYM (2)						
Cattle	25	3.5	8.0	kg/t	2.1	7.2
Pig	25	7.0	5.0		4.2	4.5
Poultry Manures						
Layer manure	30	13	9.0	kg/t	7.8	8.1
Broiler/turkey litter	60	25	18		15	16
Slurries						
Dairy (3)	6	1.2	3.5		0.6	3.2
Beef (3)	6	1.2	2.7	kg/m^3	0.6	2.4
Pig (3)	4	2.0	2.5		1.0	2.3
Separated cattle slurries (liquid)						
Strainer box	1.5	0.3	2.2		0.15	2.0
Weeping wall	3	0.5	3.0	kg/m^3	0.25	2.7
Mechanical separator	4	1.2	3.5		0.60	3.2

(1) Nutrients that are available to the next crop

(2) Potash values will be lower if FYM is stored in the open or for long periods

(3) Adjust nutrient content if % DM is higher or lower

Imperial Conversions

Multiply kg/m^3 by 9 to give units/1000 gals

Multiply kg/t by 2 to give units/ton

Cost pressures

A difficult financial situation should not persuade farmers to reduce levels of potash below the guidelines in this leaflet. Whilst the soil K targets are not precise cut-off points, it must be recognised that the risk of yield and quality penalties generally increases with lower soil K levels. In view of the fact that potash is not lost from most soils and that it is the least expensive of all major nutrients, such risks do not seem worthwhile.

The estimation of potash offtake and the replacement of this quantity remains the most important aspect of fertiliser policy for K.

Timing

Individual recommendations for specific crops are detailed in other PDA leaflets.

Other PDA leaflets

FOR MORE INFORMATION ON POTASH CONTACT:-

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The Potash Development Association
is an independent technical organisation formed to support the efficient use of potash fertiliser in the UK

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