Potassium in Agriculture

Australia and New Zealand
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It aims to provide up-to-date information on the sound and economic use of potassium fertilisers in Australian and New Zealand agricultural industries which can be used to develop best management practices for individual situations.

This booklet is part of a continuing investment in research and development in Australia and New Zealand. It is supported by the ‘Potassium in Australian and New Zealand Agriculture’ website at www.potash-info.com. This site is regularly updated with the most recent research results in a format which is useful for farmers, agronomists and researchers alike.

Edited by Jonnie White
July, 2000
1.0 WHAT IS POTASSIUM?

Potassium (K) is one of the 16 nutrient elements necessary for healthy plant growth. It is needed in comparatively large quantities and so is considered one of the four major plant food elements along with nitrogen (N), phosphorus (P) and sulfur (S).

Although K occurs naturally as 2.3 - 3.5 percent of the earth’s crust, only a small proportion of it is available to plants. After decades of agriculture, and removal of K in produce harvested from the field, even soils which were naturally well supplied with plant available K will become deficient. Where soil K supplies are insufficient to meet plant requirements, supplementation by potash (K-containing) fertilisers is necessary to maintain healthy plant growth, and a sustainable agricultural environment.

This booklet examines the role that K plays in healthy plants and soils. It describes the production of potash fertilisers and presents current information on the use of K in the agricultural industries of Australia and New Zealand.
1.1 An Essential Plant Nutrient

For vigorous and healthy growth, plants require large quantities of K. A key to the importance of K in plants is its high degree of mobility, allowing its involvement in most biological processes in the plant. Potassium plays a vital role in photosynthesis and in the activation of more than 60 enzyme systems in plants, processes that are essential in plant development and yield determination.

Another basic function of K is in regulating the opening and closing of stomata, the tiny pores in leaves that allow the passage of carbon dioxide into, and oxygen and water vapour out of the plant. Potassium facilitates the transport of sugars throughout the plant from the sites of photosynthesis (leaves) to the productive sinks of the plant (tubers, fruit and grain).

1.1.1 Yield and Quality

Potassium plays an important role in determining both yield and quality of crops and pastures. Where soil K is deficient, addition of K fertiliser can have a positive effect on the size of kernels (Figure 1), seeds, fruits or tubers, the juice content of fruits and sugarcane, the oil content of kernels and seeds, the resistance to bruising and physical breakdown of fruit in storage, the strength, length, fineness and colour of cotton fibre, and the botanical composition of pasture.

Figure 1. Size and quality of soybean grain is affected by inadequate K.
In Western Australia, K fertiliser application increased yield and reduced screenings (% of whole grains <2mm) in wheat (Table 1).

<table>
<thead>
<tr>
<th>K rate (kg/ha)</th>
<th>Grain Yield (t/ha)</th>
<th>Screenings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.75</td>
<td>5.0</td>
</tr>
<tr>
<td>10</td>
<td>2.92</td>
<td>4.8</td>
</tr>
<tr>
<td>20</td>
<td>3.48</td>
<td>4.2</td>
</tr>
<tr>
<td>40</td>
<td>3.04</td>
<td>3.2</td>
</tr>
<tr>
<td>60</td>
<td>3.35</td>
<td>2.6</td>
</tr>
<tr>
<td>80</td>
<td>3.50</td>
<td>2.9</td>
</tr>
<tr>
<td>160</td>
<td>3.36</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Table 1. The effect of K fertiliser on yield and screenings in wheat.


Also in Western Australia, it was found that the level of alkaloid production in sweet lupin varieties was reduced by the application of K, where soil K content was low. Alkaloids are responsible for bitterness and unpalatibility in lupin grains.

Fertiliser K is particularly important for yield and quality of bananas, improving the number and size of fruit in each bunch (Table 2).

Table 2. The effect of K supply on banana production

<table>
<thead>
<tr>
<th>K rate (kg/ha)</th>
<th>Bunch wt (kg)</th>
<th>Avg hands per bunch</th>
<th>Avg fruit per hand</th>
<th>Fruit length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15.9</td>
<td>7.5</td>
<td>15.2</td>
<td>18.5</td>
</tr>
<tr>
<td>125</td>
<td>33.1</td>
<td>8.1</td>
<td>16.0</td>
<td>19.3</td>
</tr>
<tr>
<td>375</td>
<td>35.8</td>
<td>8.9</td>
<td>15.7</td>
<td>19.9</td>
</tr>
<tr>
<td>625</td>
<td>38.7</td>
<td>9.2</td>
<td>17.8</td>
<td>20.2</td>
</tr>
</tbody>
</table>

(source Potash and Phosphate Institute)

Potassium is also able to help maintain quality of crops which must be stored. For example, application of 135kg/ha of K to a crop of onions grown in K deficient soil was able to reduce storage losses by over 50%.
1.1.2 Stress Tolerance
Ensuring an adequate supply of K can improve the ability of crops and pastures to tolerate stress from soil moisture, temperature, disease and pests.

Water Use Efficiency
Where crop yields are limited by soil moisture, correcting K deficiencies can ensure the most efficient use of available water. Water use efficiency (WUE) is defined as the amount of plant yield produced per unit of water used. Water can be lost from a field by transpiration through the plant, and by evaporation (collectively evapo-transpiration).

\[
\text{Water Use Efficiency} = \frac{\text{Crop Yield}}{\text{Water Used in Evapo-transpiration}}
\]

Adequate K fertilisation can improve WUE by increasing yields and decreasing water lost by evapo-transpiration. The positive effect of K on photosynthesis means that the plant has more photosynthetic substrate available to produce vegetation and grain. In addition, the canopy of a rapidly growing crop will close earlier than that of a nutrient deficient crop, and will therefore reduce evaporative losses from the soil surface.

Improved control of stomata because of adequate K supply can also improve the efficient use of water by speeding up the opening and closing response to environmental conditions such as hot dry weather.

Disease and Insect Resistance
Potassium is known to affect plant susceptibility to diseases and pests by influencing tissue cell structures and biochemical processes. Physical resistance to pests is improved because adequate K supply ensures complete closure of plant stomata and increases the lignification of vascular tissue.
Potassium deficient plants have low total carbohydrate content, but have a higher concentration of soluble sugars which provides a suitable substrate for the growth of many pathogens. Where N is well supplied, cell walls of plants can be thinner because of rapid growth rates, exposing plants to attack from pests or diseases. Therefore it is important to ensure that N application is balanced with adequate K.

**Lodging Resistance**
The positive effect of K on cell and tissue structure means that crops which are well supplied with K are more resistant to lodging than crops which are K deficient. Application of K fertiliser to a North American sorghum crop in a soil with very low K supplies resulted in a dramatic decrease in lodging (Figure 2).

![Figure 2. The effect of K nutrition on the lodging percentage and yield of sorghum in a low K soil.](source Potassium in Agriculture, ed. Munson, 1985)

**Frost Resistance**
Overseas research has suggested that adequate K nutrition can reduce frost damage in tree fruits, potatoes and ornamentals. Attempts by Australian researchers to measure the effect of K application on frost damage in wheat have so far been inconclusive.
1.1.3 Efficient Use of Other Nutrients

Application of K can improve the efficiency of use of other plant nutrients. Where K is deficient, applications of N and P may not produce the yield responses targeted, leaving these nutrients at risk from loss by leaching or runoff.

Overseas research has shown crop responses to N and P are reduced where K is deficient. Research in Australia has shown similar effects. For example, in Western Australia, application of N alone actually reduced the yield of wheat, but application of K and N together produced the best yield and highest N recovery in grain (Table 3).

<table>
<thead>
<tr>
<th>N applied kg/ha</th>
<th>K applied kg/ha</th>
<th>Yield t/ha</th>
<th>N in grain kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>2.8</td>
<td>63</td>
</tr>
<tr>
<td>60</td>
<td>0</td>
<td>2.2</td>
<td>76</td>
</tr>
<tr>
<td>0</td>
<td>50</td>
<td>3.0</td>
<td>82</td>
</tr>
<tr>
<td>60</td>
<td>50</td>
<td>3.4</td>
<td>87</td>
</tr>
</tbody>
</table>

Table 3. Yield and N uptake of wheat on a K deficient site with applications of K and N.

The reverse is also true, and yield responses to K application are unlikely if adequate N and P are not supplied. A balanced approach to nutrition will ensure the most economical production responses, while protecting the environment from nutrient accumulation.

1.1.4 Luxury uptake

Unlike most other nutrients, K can be taken up in quantities far exceeding that necessary for plant growth, without becoming toxic. This response, called luxury uptake, can be undesirable, particularly where produce is removed from fields or in pastures where nutrients are redistributed within paddocks through transfer to stock camps. Luxury uptake of K can also interfere in the supply of other nutrient elements.
1.2 Potassium in Soil

1.2.1 Types of Soil Potassium

Potassium is present in the soil in several forms of varying plant availability and these are illustrated in Figure 3.

The most available but smallest pool is soluble K, which is dissolved in the soil water (soil solution). Plants take up most of their K directly from this pool, and thereby deplete it very rapidly. Soluble K is closely linked to the much larger pool of exchangeable K which is held on the negatively charged surfaces of soil particles (cation exchange sites). Exchangeable K is released into solution as plants deplete the soluble K, allowing for a regular re-supply. However this is a function of the size of the exchangeable K pool. The reverse can also apply, with K moving from solution onto exchange sites when soil solution concentrations are high (e.g. within a fertiliser band). Between them, the soluble and exchangeable K pools are the most important sources of plant available K.

The exchangeable K pool is in turn linked with the fixed K pool. This K is temporarily trapped between the expanding layers of some clay minerals such as illite and montmorillonite. This pool is slowly available to plants over time. Soils that do not contain expanding clay types have only a very small pool of fixed K.

The largest amount of K within a soil exists as a structural component of primary minerals and only becomes available upon long-term weathering. Generally, highly weathered soils from humid, tropical areas have much less structural K remaining than newer soils, or soils from cold, arid climates. The weathering process is slow and not considered of any significance to plants, except in very recent sedimentary soils such as some alluviums in New Zealand.
Figure 3. The forms of K in soils and the main mechanisms of input and loss.
The different K pools will have lesser or greater importance to plant nutrition in different soil types. In most virgin soils, plants rely totally on the soluble and exchangeable K pools for their requirements. However, after prolonged periods of agricultural production and removal of produce, these pools are slowly depleted. For example, Figure 4 shows the exchangeable K content of a patch of virgin scrub in Queensland, and of an adjacent field which has been cultivated for more than 50 years. It is apparent that there is much less exchangeable K available in the cultivated soil.

![Figure 4. The amount of exchangeable K in the profile of a virgin soil and an adjacent field which has been cultivated and cropped for over 50 years.](source Queensland Department of Primary Industries)

Once depletion of exchangeable K occurs, plants rely on the release of fixed K to recharge the exchangeable and soluble pools. However in many soils the size of the fixed K pool, or the rate at which it is released, are insufficient to meet plant demand. This is particularly the case where intensive, high-yielding production systems are established. In these instances, fertiliser K must be applied to ensure healthy plant growth.
1.2.2 Measuring Soil Potassium

Soil testing laboratories in Australia measure plant available K by one of two accepted methods.

1) The sampled soil is mixed with a pH-neutral salt to extract the soluble and exchangeable soil K pools. Since the size of the soluble pool is negligible in relation to the other soil pools, the K extracted is reported as exchangeable K in units of centimoles of positive charge per kilogram of soil (cmol (+)/kg) or the directly comparable term milliequivalents per 100g of soil (meq/100g).

2) A more vigorous extractant, such as the Colwell extractant (sodium bicarbonate), removes soluble, exchangeable and some fixed K. These values are usually reported in milligrams per kilogram of soil (mg/kg).

In New Zealand a neutral salt is also used to extract solution and exchangeable K, with the result expressed in parts per 250 000 of the extracting solution and is called ‘quick test K’ (QTK). Additionally, in some circumstances New Zealand laboratories estimate the size of the fixed K
Potassium in Soil

pool using a tetraphenyl boron (TBK) test which is reported in cmol (+)/kg.

The units of measurement of soil K can be converted as follows:
\[
\text{cmol (+)/kg} = \text{meq/100g} \\
\text{cmol (+)/kg} \times 390 = \text{mg/kg} \\
\text{cmol (+)/kg} \times 24.375 = \text{QTK} \\
\text{QTK} \times 16 = \text{mg/kg} \\
\text{mg/kg} = \text{ppm}
\]

However, remember that different extraction techniques are not removing exactly the same K pool and so are not directly comparable.

**Sampling Strategies**

The result of a laboratory analysis can only be as good as the sample which was provided. Soil K content can vary markedly over a small area, particularly in grazing situations. It is important to take a representative soil sample from a field, avoiding stock camps, laneways and other unusual areas. The number of cores or sampling points which are mixed to form each sample should increase with the size of the area being sampled and the likely variability within it. The establishment of permanent soil sampling sites or transects which can be monitored over time can reduce some of the variability associated with sampling programs.

It is also important to note that soil K measurements are also subject to seasonal changes. For example, pastures in southern Australia contain a lot of K in plant material during late spring/early summer. Soil tests for K will be lower at this time than in autumn when K has leached from plant residues and into the soil. An ongoing soil monitoring program should ensure that samples are collected at the same time each year.
1.3 Potassium in Fertilisers

Where soil K reserves are inadequate for targeted crop or pasture production, fertilisers containing K must be applied. Potash fertilisers in Australia and New Zealand are predominantly sourced from Canada, which has large reserves of high-grade potash ore.

1.3.1 Types of Potash Fertilisers

Potassium can be applied as a straight fertiliser, or as part of a blended or compound fertiliser with N and P.

The main forms of straight K fertilisers are listed in Table 4. Of these, potassium chloride (commonly referred to as Muriate of Potash or MOP) has the dominant role in agriculture, accounting for about 95% of all potash fertilisers used worldwide. The reasons for this dominance are its high nutrient concentration (49-52% K), and its relative price competitiveness with other forms of K.

The chloride (Cl) content of MOP can also be beneficial where soil Cl is low. Recent research has shown that Cl improves yield by increasing disease resistance in crops. In circumstances where soil or irrigation water Cl levels are very high, addition of extra chloride with MOP can cause toxicity. This is unlikely to be a problem, except in very dry

<table>
<thead>
<tr>
<th>Common name</th>
<th>Chemical name</th>
<th>K</th>
<th>Mg</th>
<th>S</th>
<th>N</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muriate of Potash</td>
<td>Potassium chloride</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>46</td>
</tr>
<tr>
<td>Sulfate of Potash</td>
<td>Potassium sulfate</td>
<td>41</td>
<td>-</td>
<td>18</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nitrate of Potash</td>
<td>Potassium nitrate</td>
<td>38</td>
<td>-</td>
<td>-</td>
<td>13</td>
<td>-</td>
</tr>
<tr>
<td>K-Mag® or</td>
<td>Potassium magnesium</td>
<td>18</td>
<td>11</td>
<td>22</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sul-Po-Mag®</td>
<td>Potassium magnesium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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environments, since Cl is readily removed from the soil by leaching.

Potash fertilisers other than MOP are used where special crop or soil needs exist. Potassium sulfate (Sulfate of Potash or SOP) is used in crops that are sensitive to chloride or fertiliser burn (e.g. tobacco, pineapple, avocado) or where sulfur (S) is deficient. Potassium magnesium sulfate is an excellent source of the three nutrients (K, Mg, S) and is mostly used in high value crops. Potassium nitrate is often used in foliar sprays or fertigation.

Each of the major potash sources are soluble in water and will readily dissolve when there is adequate rainfall or irrigation is applied. Under high rainfall or excessive irrigation, K can be lost in surface runoff, or from the root zone by leaching, especially in permeable soils with a low cation exchange capacity.

Potassium is not volatilised or lost to the atmosphere as can occur with some N fertilisers under certain soil and environmental conditions. Potassium can become unavailable if it is fixed by expanding clay minerals, but will be slowly re-released if soil exchangeable K levels fall.

Figure 6. Various forms of K fertilisers
1.3.2 Production of Potash

Muriate of potash is the most common source of fertiliser K. It is found as a natural mineral in the sedimentary salt beds of ancient seas and is often interbedded with common salt (sodium chloride). Potash deposits that can be mined economically are known to occur in beds in only a few sedimentary basins in the world. The most extensive of these are the deposits underlying the Canadian province of Saskatchewan at depths of 1000 to 3000m (Figure 7). Other mined deposits are found in the US, Western Europe and the former Soviet Union.

![Location of Potash Mines](image)

**Figure 7. The location of Canadian potash reserves.**

Most potash deposits around the world are mined by conventional underground methods. Because of their plasticity, salt and potash flow under pressure and cannot be mined below a depth of approximately 1100m. This characteristic also controls the choice of shape, size and spacing of mine openings, and about 60% of the ore must be left as support during mining operations.
Electrically operated mining machines cut openings up to 3.7m in height and 8.1m in width (Figure 8) and remove up to 11 tonnes of ore per minute. A series of conveyors transfer the mineral ore to a vertical shaft where it is hoisted to the refining mill in 20-25 tonne lots.

At depths greater than 1100m it is possible to extract potash by dissolving it and pumping the solution to the surface where it is recovered by evaporation. Some potash is also obtained by evaporation from surface brines and saline waters such as those from the Dead Sea in the Middle East and Great Salt Lake in Utah, USA.

**Processing**

In above-ground refining mills, potash ore is crushed to 3-5mm and a salt brine is added to wash clay from the ore particles (a process called desliming). A flotation process is then used to separate potash from common salt in the brine. The potash is eventually separated from the remaining brine using a centrifuge, and dried in large kilns.

Dried potash is sized by passing the particles through screens with various mesh sizes. Granular potash has a particle size range of 0.8 to 4.7mm, although there are a number of grades produced within this range. Pink or red potash contains about 0.05% iron and other metal oxides which give the reddish colour.
Processing at solution mines differs markedly from the conventional mining system as the ore brines must go through heat exchangers/dissolvers, decanters and crystallisers before drying and sizing. Solution mined potash is white in colour.

**Storage, Shipping and Quarantine Controls**

Potash is stored in warehouses at mines and later at the shipping ports. To improve durability of the potash crystals and prevent caking and dust problems, the product is treated with oils or animal fats. Potash is moved by rail to terminals for shipping overseas.

Importers of fertiliser into Australia must meet the Australian Quarantine Inspection Service (AQIS) requirement for zero organic matter contamination, and in New Zealand the standards of the Ministry of Agriculture and Fisheries (MAF). These protect our agricultural industries from foreign plant and animal pathogens such as karnal bunt, which affects wheat crops in other countries.

Contamination from seeds or soil can occur in transit or in the hold of bulk carriers if the ship has been used to carry grain. For this reason, potash fertiliser coming to Australia and New Zealand from Canada is transported in dedicated potash railcars and in ships which have passed stringent quality assurance tests (Figure 9).
1.3.3 Methods of Application

**Timing and Frequency**
The most appropriate rate and timing of K application depends on both the soil type to which it is being applied, and the K requirement of the crop or pasture. In most annual crops it is usual to apply the crop K requirements at or before planting. However, where soils have very limited capacity to retain K from leaching (for example a sandy soil with a low cation exchange capacity) it may be preferable to make two or three applications of K fertilisers. On the other hand, soils which contain a lot of K fixing minerals may also require several applications to reduce the time of contact between the added K and the soil minerals. The objective of potash fertiliser application is to ensure adequate K is available during periods of peak K demand by the crop.

In pastures, K is applied prior to the growing season in early spring, autumn or both. Split applications are recommended on soils with a high leaching potential, or to minimise luxury uptake where high rates are used.

**Placement**
Decisions regarding placement of K fertiliser should be based on:

1. *The pattern of plant K requirement.*
   For those crops which require K early in the growing season (e.g. maize), fertiliser should be placed in the soil where it will be readily accessible to seedling roots.

2. *Prevention of salt injury to seed.*
   Too much K fertiliser placed too close to the seed can reduce germination or injure new roots because of high salt concentrations.
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3. **Available labour, equipment and timing of other farming operations.**

   Ideal fertiliser placement may not be possible because of a need to perform operations within a given time frame, or because suitable equipment is not available.

   In cropping situations pre-plant applications of K are often broadcast and incorporated with cultivation or planting operations. Occasionally deep banding (ie. below the seed bed) of K fertilisers is undertaken with a tyned implement prior to planting. At planting time, fertiliser can be banded with the seed or 5cm to the side of, and below the seed. During the growing season, follow-up applications of K can be broadcast over the crop or side-dressed along the row. Banded applications may be more effective in soils with a large capacity to fix K since there is less contact between fertiliser and soil particles. In contrast, banding on soils which are prone to leaching may lead to greater losses.

   Pasture application is usually broadcast and relies on rainfall or irrigation to move nutrient to the root zone. However, there are investigations underway in Victoria examining the effect of deep banding fertilisers under clover based pastures.

   Placement of soluble K supplied in irrigation water will depend on the particular irrigation system employed. Potassium applied in flood and surface spray systems will move into the soil with the irrigation water. Drip irrigation systems will place K at the base of individual plants or plant rows, and sub-surface drip irrigation applies K directly to the root zone. Once the soluble K has reached the soil its movement will depend on the rate of uptake by the crop as well as the leaching potential or fixation capacity of the soil.
Safe Rates With Seed

When placed with, or in close proximity to seed at planting, fertiliser can delay or prevent germination and establishment. This is due to the osmotic effect of the fertiliser salt. Because of its relatively high salt index (Table 5), seed damage is more likely to occur with applications of MOP, than with SOP. This will limit the amount of K fertiliser which can be placed with the seed at planting. In addition, the added effect of N or P compounds must also be taken into account when using blended or compound fertilisers.

<table>
<thead>
<tr>
<th>Fertiliser</th>
<th>Salt index</th>
<th>Salt index / unit K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muriate of Potash (50% K)</td>
<td>114</td>
<td>2.28</td>
</tr>
<tr>
<td>Potassium Nitrate (38% K)</td>
<td>74</td>
<td>1.95</td>
</tr>
<tr>
<td>Sulfate of Potash (41% K)</td>
<td>46</td>
<td>1.12</td>
</tr>
<tr>
<td>Ammonium Nitrate</td>
<td>105</td>
<td>-</td>
</tr>
<tr>
<td>Urea</td>
<td>75</td>
<td>-</td>
</tr>
<tr>
<td>Sulfate of Ammonia</td>
<td>69</td>
<td>-</td>
</tr>
<tr>
<td>MAP</td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td>DAP</td>
<td>34</td>
<td>-</td>
</tr>
<tr>
<td>Single super phosphate</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Triple super phosphate</td>
<td>10</td>
<td>-</td>
</tr>
</tbody>
</table>

Other factors also contribute to the likelihood of seed damage from fertiliser and include environmental factors, application equipment, soil characteristics and the crop species planted. Lower rates of fertiliser should be placed with seed where soil moisture content is low, or soil texture is light. Similarly, equipment or environmental conditions which are conducive to soil drying will increase the risk of seed damage from a given rate of fertiliser application.
Wide row spacings, or a narrow fertiliser band mean that fertiliser concentration in the seed zone is higher at a given per hectare application rate. Seedbed utilisation (SBU) is a term which describes the physical spread of fertiliser bands over the seedbed as a percentage (Figure 10). A lower SBU (wider rows, narrower band spread) indicates a higher risk of seed damage.

Figure 10. Seedbed utilisation (SBU) describes the physical spread of fertiliser bands over the seedbed as a percentage.

Table 6 demonstrates how several of these factors can impact on the maximum safe rate of MOP application with wheat seed. This table is a guide only and rates should be adjusted for different crop species, blended and compound fertilisers, and prevailing environmental conditions.

Table 6. An example of the effect of soil texture, moisture content and SBU on the maximum safe rates of muriate of potash which can be placed with wheat seed.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Soil Moisture Content %</th>
<th>Maximum safe rate (kg MOP/ha)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SBU = 28%</td>
<td>SBU = 14%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7” rows, 50mm spread</td>
<td>14” rows, 50mm spread</td>
<td></td>
</tr>
<tr>
<td>Heavy Clay</td>
<td>30</td>
<td>40</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>27</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>10</td>
<td>32</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>19</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(source Incitec)
1.3.4 Making Fertiliser Rate Decisions

Calibration of Soil Tests
Soil test results are interpreted in the light of nutrient response curves that have been developed for particular soil type – crop combinations. Response curves such as that in Figure 11, are usually the result of several years of experimentation with each crop and soil type using a range of potash application rates. The availability of other nutrients, the form of fertiliser, the method of application and seasonal conditions may affect the shape of the response curve.

Figure 11. A typical nutrient response curve showing relative yield and its relationship to soil potassium

Soil test values needed to obtain a percentage of maximum yield (typically between 90-97%) can be estimated from response curves and act as guides to separate K responsive and non-responsive soils.

For those sites with soil test results below the critical value, the amount of fertiliser required to reach maximum production is estimated by considering soil buffering capacity and supply of nutrients from organic or slow release soil pools. The economics of fertiliser application, however, are dictated by the cost of the fertiliser and the price received for extra production and farmers should aim for the yield at which net profit (ie. the difference between
In addition to interpretation of soil test values, a budgeting approach can be used to determine the nutrient deficit or surplus of a farming system. A nutrient budget quantifies the outputs and inputs of a production system to identify if a positive or negative nutrient balance exists. For example, in a dairy system (see Figure 21), K outputs result from sale of products, runoff, leaching, and transfer of urine and faeces to the dairy or stock camp. Inputs occur as soil release of fixed K, and K in supplementary feed, rainfall and irrigation. Such a system is likely to have a negative K balance that must be met with K fertiliser inputs to maintain production. The budgeting principles are the same for field and horticultural crops.

Nutrient budgeting is increasingly being used to determine nutrient balances in Australia and New Zealand, and worldwide. In Tasmania, the dairy industry utilises whole farm nutrient budgets to determine the need for replacement of K as fertiliser. Soil analyses from individual paddocks are then used to determine how this should be distributed within the farm.

Figure 12. The most economical fertiliser rate is the one at which net profit is maximised. Growers should target this maximum economic yield, rather than maximum crop yield.
The nutrient budgeting approach is most appropriate where soil nutrient levels are known to be near to adequate for maximum economic production and only maintenance applications are required. If soil K levels are too low, budgeting will continue to produce less than potential yields. On the other hand, if soil K levels are high then there is a risk of losing extra nutrients from leaching or luxury uptake. Regular soil tests to monitor performance should be part of a budgeting program.

**Computer Models**
The principles of soil analysis calibration and nutrient budgeting can be used to create computer models (decision support systems) which assist farmers in fertiliser decision making.

In New Zealand, the pastoral research body, AgResearch, has developed the OVERSEER™ model which calculates the nutrient balance of grazing systems based on information about stocking rates, production, supplementary feed, fertiliser inputs, rainfall and so on. Using this tool, researchers and graziers can answer ‘what if’ questions about the nutrient balance of various farming systems. For example they can determine whether their farm has a negative or positive nutrient balance, and how this would change in with increased stocking rates or reduced fertiliser inputs (see Table 15).

Using the same basis, but including the principles of soil analysis calibration and maximum economic yield, AgResearch has produced a second decision support system called PKSLime. This model takes into account the response of pastures to added fertiliser, the cost of that fertiliser, and the value of increased production, to calculate the most economical rate of fertiliser application for individual paddocks.
Other decision support systems exist. In Australia, most large soil analysis services have created their own decision support systems using soil test data calibrated against crop yields, to make fertiliser recommendations. Where calibration data was measured under particular local conditions, these will give the best quality recommendations for those same conditions. Decision support systems provide a quick and effective method for incorporating the elements of nutrient balance, fertiliser response and price into a fertiliser rate decision. However the output should always be reviewed in the light of local knowledge and information on individual circumstances, and evaluated in the context of the farmer’s production and management objectives.

1.3.5 Use of Potash in Organic Agriculture

Regardless of the farming system employed, nutrients will be removed in produce and must be replaced to sustain production and maintain the fertility of the soil. Organic farming systems aim to do so using products which have not been manufactured.

The international body Codex Alimentarius has recently produced guidelines that outline the approved inputs for production of organic food for international trade. The guidelines allow for the use of “rock potash” and “mined potassium salts” which are “less than 60% chlorine”. Under these guidelines mined potassium fertilisers, including MOP and potassium magnesium sulfate, are acceptable. Some organic certification bodies, however, do not allow the use of MOP.
2.0 POTASSIUM NUTRITION IN AGRICULTURE

This section will describe the role of potassium in the major agricultural industries of Australia and New Zealand. The K content of agricultural commodities removed from the farm are examined along with examples of yield, production and quality responses to applied K. Information is provided for the development of best management practices for K use in agriculture.

2.1 Potassium in Cropping

Much of Australia and New Zealand's most productive cropping is based on fertile soils, which in their native state have a good supply of both exchangeable and fixed soil K pools. However some soils, such as the sandy soils of Western Australia, do not have a natural supply of slow release fixed K, and once the exchangeable K pool is depleted there is no natural replenishment from soil supplies. In future, even the more fertile soils will begin to show yield responses to applied K as their reserves are depleted and are unable to meet the large K demand of crops with high yield potentials.

Nutrient Removal
There are several mechanisms by which the K content of a cropped soil is depleted and include: removal of K in harvested grain or hay; loss of K in eroded soils, and; leaching of K below the root zone. In most cases, the removal of K in harvested produce has had the greatest impact on soil K reserves. For example, Table 7 gives an indication of the amount of K found in one tonne of produce from a variety of crops.
Vegetative plant material is often much richer in K than grain. Consequently a crop requires much more K to produce maximum yield than what is contained in the grain. There is a greater removal of K where hay is taken from a field and this should be taken into account when fertilising subsequent crops. A stand of lucerne hay yielding 60t/ha over its life cycle removes 20kg K/t hay which equates to an export of 1200kg K/ha.

Where crop stubble is baled and sold, there is a significant cost to replace the K removed. One and a half tonne per hectare of wheat stubble removes 18 kg/ha of K, which alone could cost from $8 to $12 to replace.

<table>
<thead>
<tr>
<th>Crop</th>
<th>K kg/t grain</th>
<th>K kg/t hay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat/barley/oats</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Maize</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Rice</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Millet</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Lupin</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Chickpea</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>Mungbean</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Navybean</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Soybean</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Canola</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Sunflower</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Peanut</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>Lucerne</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Hay/silage</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

(source *Australian Soil Fertility Manual*, 2000)
Potassium Requirements During the Growing Season

Examining only the K content of harvested products can give a misleading indication of the K requirements of a crop. In most annual crops, K is absorbed early in the growing season, with a rapid uptake period preceding the maximum dry matter accumulation rate. For example, Figure 13 shows the relative K and dry matter accumulation rates of a maize crop. It shows that the period of rapid K uptake is relatively narrow and occurs early in the crop’s growing season.

There are important differences in the rate at which K is required by various crop species during this peak uptake period. Table 8 shows the peak daily uptake rates for several crops species. For example, while sugarcane removes several times more total K than a crop of maize, during critical growth stages maize may require six times more K on a daily basis than sugarcane which has a lower daily requirement over a longer growth period. In soils where the crop is relying on a slow release pool of fixed K, the rate at which the soil releases K is often insufficient to keep up with daily plant demand. Agronomically, the K release characteristics of a soil are just as important as the absolute size of the soil K store.

Figure 13. The relative accumulation of K and dry matter over the growing season of maize grown in Queensland.

(source Queensland Department of Primary Industries)
Furthermore, the maximum K content of the plant may be 40-50% more than that measured at maturity. Between flowering and maturity many crops (particularly those with determinate growth patterns like soybean, lupins and canola) lose K due to leaching from aging leaves, leaf fall and possibly leakage from mature roots. The K requirement of a crop is much greater than indicated by the quantities present in the crop at harvest.

**Potassium Requirements Increase with Yield Potential**

Crop requirement for K will increase with higher yield potentials due to improvements in:

- plant breeding
- farming systems, and
- application of other limiting nutrients.

In the years following World War II, average Australian wheat yields were just over 1.0 t/ha. Today the Australian average is over 2.0 t/ha because of agronomic improvements including pest and disease control, mechanisation and improved nutrition, varieties and rotations. More recently, conservation farming systems which protect soil structure and improve soil water storage have improved yields in dry years and increased opportunities for double cropping.

### Table 8. Maximum daily K uptake rates of some crop species.

<table>
<thead>
<tr>
<th>Crop</th>
<th>K Uptake kg/ha/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>5.2</td>
</tr>
<tr>
<td>Cotton</td>
<td>3.7</td>
</tr>
<tr>
<td>Wheat</td>
<td>2.9</td>
</tr>
<tr>
<td>Rice</td>
<td>1.6</td>
</tr>
<tr>
<td>Soybean</td>
<td>1.5</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>0.5</td>
</tr>
</tbody>
</table>

(source Potash and Phosphate Institute)
These improvements have increased both crop demand for K and its export from the field. Where wheat nutrition and yield is improved by the application of N and P, K uptake rates can be much higher (Figure 14). Improved yield potential due to N and P fertilisation may not be achieved if adequate K is not also applied (Figure 15).

**Chronic Deficiency**
Occasionally chronic K deficiency occurs, where small potash applications do not produce yield responses, but large applications do. In these cases the response curve is
‘sigmoidal’ in shape (Figure 16). This usually only occurs in severely deficient soils where yields are extremely limited. In the case of K, this type of response may be due to soil fixation of added K before any is available for plant growth.

An example of such a response has occurred in lucerne growing soils in the Peel Valley, New South Wales. Strip trials of K fertiliser (60 - 125 kg K/ha) failed to produce yield responses in irrigated lucerne crops, despite obvious visual deficiency symptoms, whereas applications of 500 kg K/ha were accompanied by dramatic yield increases, increased persistence and resistance to waterlogging, and improved leaf retention, therefore providing a longer window for hay-making. Anecdotal evidence exists of similar responses to K fertiliser by soybean in Queensland.

Figure 16. Typical and sigmoidal yield responses to applied nutrients.

Hidden Hunger
Severe nutrient deficiencies can cause identifiable symptoms on plants. Examples of K deficiency symptoms from many common crop and pasture species are given in the back of this booklet. However, by the time nutrient deficiency symptoms are apparent, a considerable amount of yield potential has been lost. A program of regular soil and plant analysis and nutrient budgeting can ensure that hidden hunger does not go unnoticed.
2.2 Potassium in Cotton Production

Nutrient Uptake and Removal
Cotton has a high daily requirement for K. Maximum uptake rates of 3.7 kg/ha/day and a total crop uptake of over 200 kg/ha have been measured in New South Wales.

Removal of K from cotton fields can also be high and will depend in part on crop residue management. In a crop yielding 7 bales/ha, up to 90 kg K/ha is stored in boll walls, 40 kg K/ha in seed and 15kg K/ha in lint. Where crop residue is windrowed or burnt, distribution of K across the field will be affected.

Low Soil K Can Reduce Cotton Yield and Quality
In some Australian cotton growing areas, soil K reserves have been depleted to the point where cotton yield and lint quality are adversely affected. In the Emerald Irrigation Area of Queensland a considerable area is responsive to applied K fertilisers. Trials have confirmed that economic responses to K fertilisers are common where soil exchangeable K content is below 0.40 cmol(+)/kg. At one site with a soil exchangeable K content of 0.12 cmol(+)/kg, lint yield was improved by 24% by banding 125 kg K/ha in the bed prior to planting, and 8% by applying the same rate of K in the flood irrigation water two weeks after first flowering (Figure 17). Other regions which have small areas responsive to potash fertiliser include the Darling Downs and Macquarie Valley.

North American research has shown that cotton fibre quality can be adversely affected by poor K nutrition. In California, fibre strength has been shown to be positively related to soil K and mid-season leaf K content. Fibre length, micronaire, uniformity ratio and elongation have also shown positive correlations with K fertility in a variety of studies.
Potassium Deficiencies in Soils With Adequate Potassium Supply

As with most crops, K deficiency symptoms of cotton generally occur on older leaves, as plants relocate highly mobile K to areas of new growth. However, in the 1990’s symptoms consistent with K deficiency began appearing on the newest upper leaves of growing cotton crops. This often occurred on soils which tested high in plant available K. The condition was called premature senescence (PS).

Symptoms of PS appear first on young leaves near the top of the canopy with leaves turning red during the early fruiting stage of the crop. As the season progresses symptoms may spread further down the canopy and cause defoliation, ultimately affecting lint yield and quality.

Research in Australia has shown that rather than being related solely to soil supply of K, PS is due to a complex interaction of plant uptake, translocation and stress. In cases where root uptake of K is reduced (for example because of water-logging) the K demand by filling fruit may
outweigh supply. Hence, K is re-routed from young leaves to the priority reproductive plant parts, resulting in the PS symptoms observed in field (Figure 18).

Susceptibility to PS can be linked to:

- Soil supply
- Boll load
- Variety
- Stress

Soils which are low in K, particularly in the subsoil, are probably more susceptible to PS. In these cases surface applied potash may be sufficient to overcome the problem, but broadcast applications have had only limited success in overcoming PS in most situations. Research is underway in New South Wales which attempts to link soil K supply characteristics with a field's susceptibility to PS.
Plants with heavy boll loads have a greater susceptibility to PS. A large, even boll load creates a high demand for nutrients, particularly K. Consequently those varieties which have a greater boll load potential, or which retain bolls better are more susceptible to PS. Transgenic Bt cotton crops often have a heavier boll load because less fruit are lost from insect damage compared to conventional varieties. They also appear to be more susceptible to PS. It has also been observed that most longer season varieties have a lower susceptibility to PS.

Waterlogging has been shown to reduce root activity and the uptake of K and P from soil. As a result crops are less capable of meeting the demands of rapidly filling bolls. Stresses such as waterlogging are often the trigger for development of PS.

**Strategies for Avoiding K Deficiencies in Cotton**

1. Examine paddock history. Long term cropping or a history of high nutrient removal may indicate a potential for K deficiency.

2. Take soil tests. Soil apply K fertilisers if levels are below critical.

3. Assess the susceptibility to PS. What variety is being grown, what boll load is present, what is the probability of waterlogging or other stresses such as extended cloudy weather? Has this field displayed PS symptoms in the past?

4. Consider foliar K applications of potassium nitrate if PS susceptibility is high. Preventative foliar sprays of 4kg K/ha at four 1-2 week intervals starting soon after first flower can improve yields and provide some protection from PS.
2.2 Potassium in Horticulture

Intensive horticultural production in Australia and New Zealand has a high yield potential and consequently a high nutrient requirement.

**Nutrient Removal**

A guide to nutrient removal rates and typical yields of some horticultural crops is given in Table 9. Horticultural crops remove much larger amounts of K per hectare than do grain crops because of the greater tonnage of product removed. In the case of some crops, such as broccoli, the removal of large amounts of vegetative material (leaves and stems) which is generally higher in K than reproductive material (grains and kernels), also contributes to very high removal rates.

**Table 9. A guide to the K removal rate of a range of horticultural crops at typical yields.**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield t/ha</th>
<th>K kg/t</th>
<th>K Removal kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>45</td>
<td>2.0</td>
<td>90</td>
</tr>
<tr>
<td>Citrus</td>
<td>50</td>
<td>2.0</td>
<td>100</td>
</tr>
<tr>
<td>Banana</td>
<td>21</td>
<td>10.5</td>
<td>220</td>
</tr>
<tr>
<td>Kiwifruit</td>
<td>25</td>
<td>3.0</td>
<td>75</td>
</tr>
<tr>
<td>Avocado</td>
<td>10</td>
<td>20.0</td>
<td>200</td>
</tr>
<tr>
<td>Grape (Shiraz)</td>
<td>30</td>
<td>3.0</td>
<td>90</td>
</tr>
<tr>
<td>Potato</td>
<td>60</td>
<td>4.5</td>
<td>270</td>
</tr>
<tr>
<td>Tomato</td>
<td>60</td>
<td>2.5</td>
<td>150</td>
</tr>
<tr>
<td>Carrot</td>
<td>45</td>
<td>2.0</td>
<td>90</td>
</tr>
<tr>
<td>Broccolli</td>
<td>7</td>
<td>16.0</td>
<td>110</td>
</tr>
<tr>
<td>Bean</td>
<td>4.5</td>
<td>2.0</td>
<td>10</td>
</tr>
<tr>
<td>Lettuce</td>
<td>50</td>
<td>4.0</td>
<td>200</td>
</tr>
<tr>
<td>Cucumber</td>
<td>18</td>
<td>2.5</td>
<td>45</td>
</tr>
<tr>
<td>Watermelon</td>
<td>13</td>
<td>1.5</td>
<td>20</td>
</tr>
</tbody>
</table>
2.2.1 Potassium for Yield, Quality and Disease Control

Potatoes

Potatoes can remove more than 270 kg K/ha in harvested tubers. Production of high yield potato crops depends on adequate K fertilisation. Potassium improves yield of potato crops through an increase in tuber number, but primarily tuber size (Figure 19).

Potassium is also important for processing quality of tubers. Deficiency can increase bruising, black spot and will darken chip colour. Where K is severely deficient application of potash fertilisers can improve specific gravity of potatoes, however where K is adequately supplied for maximum yield, additional K can sometimes reduce specific gravity.

There is much debate about the effect of different forms of K fertilisers on the yield and quality of potatoes. Some research suggests that sulfate of potash (SOP) is superior to muriate of potash (MOP) in maintaining quality of tubers at high application rates. Trials in New Zealand have demonstrated that MOP is superior to SOP in increasing tuber yield, but SOP has a smaller negative impact on specific gravity at high application rates (Table 10). Commonly growers will choose to apply up to 140 kg/ha of K as MOP, with the remainder as another form of K, however there is no research to indicate if this is economical.
Table 10. The effect of rate and form of K fertiliser on the yield and specific gravity of process grade potatoes in New Zealand.

<table>
<thead>
<tr>
<th>K rate (kg/ha)</th>
<th>Process Grade Yield (t/ha)</th>
<th>Process Grade Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As MOP</td>
<td>As SOP</td>
</tr>
<tr>
<td>Nil</td>
<td>67.4</td>
<td>1.097</td>
</tr>
<tr>
<td>70</td>
<td>64.2</td>
<td>67.7</td>
</tr>
<tr>
<td>140</td>
<td>69.6</td>
<td>62.5</td>
</tr>
<tr>
<td>210</td>
<td>74.6</td>
<td>71.1</td>
</tr>
<tr>
<td>280</td>
<td>73.9</td>
<td>68.9</td>
</tr>
</tbody>
</table>

(source Ravensdown)

In Tasmania several trials over the past 15 years have found no difference between MOP and SOP in terms of yield or quality with rates of up to 240 kg K/ha. Therefore forms of K other than MOP are recommended only at rates higher than 240-280 kg K/ha (depending on soil type), above which the Cl added in MOP can increase cadmium uptake to undesirable levels.

**Kiwifruit**

Potassium deficiency can cause significant yield losses in kiwifruit, associated mainly with a reduction in fruit number rather than the size of individual fruits. Fertiliser K requirement is affected by soil supply, and crop demand. Varieties with varying yield potentials will require different application rates. For example, Hayward kiwifruit yield between 25 to 30 t/ha and applications of 250-300 kg K/ha are common. The newer variety Zespri Gold can yield up to 60 t/ha and is likely to require much larger applications of K fertiliser.

Both MOP and SOP are suitable K sources to use with kiwifruit. It has been suggested that the chloride content of MOP can contribute to problems of leaf necrosis in kiwifruit.
vines. However, research in New Zealand has indicated that leaf necrosis is linked to N deficiency, and can be overcome by adequate N application regardless of the form of K fertiliser. Poor root growth in summer and autumn may also contribute to necrosis in following years and can be related to soil moisture, pruning or crop load.

Viticulture
Ensuring adequate K supply can improve the yield, disease resistance and juice quality of grapes and has also been implicated in improved winterhardiness.

In most of the eastern states K fertiliser is broadcast or banded in autumn so that winter rains can move it into the root zone. In Western Australia, fertiliser is more often applied in spring. Top up applications, foliar sprays or fertigation may be necessary as fruit fills and ripens.

The K status of vines and the fertiliser requirement for maximum economic production is best indicated by analysis of petiole tissue concentrations and a monitoring program should be implemented. It is also important to note that rootstocks have varying abilities to access soil K reserves.

In temperate areas, grape vines may suffer a K nutritional disorder called “spring fever”. Cold, moist soil conditions in early spring reduce the availability of K to plants during rapid growth periods. These symptoms often disappear as the season progresses and soil becomes warmer, however extra K should be applied if K deficiency symptoms persist after flowering.

Overapplication of K can have a negative impact on the quality of red wine produced through an increase in pH and a reduction in colour and flavour.
Bananas
Potassium is the nutrient used in the largest quantities by banana plants with K uptake exceeding that of N. Between 180 - 250 kg/ha is removed in the fruit, cull fruit and stems of an average crop, with higher amounts in north Queensland where yield potential is greatest. Potassium is important in water relations and transport of starch and sugars. It increases the vigour and disease resistance of plants, improves fruit weight and the number of fingers per bunch. In addition K stimulates earlier fruit shooting and shortens the number of days to fruit maturity. Potassium also improves the storage quality of bananas.

However, because of the recognised importance of K to banana production, over-application of K occurs in some Australian crops where soil fertility is not monitored. This costs money and can result in problems such as soil salinity and interference in Mg and Ca nutrition. It is important to base fertiliser decisions on expected yield and nutrient removal and to monitor performance with soil and leaf analyses. This will ensure that maximum economic yield is achieved, but problems associated with over-fertilising are avoided.

The greatest demand for K occurs during the plant crop of bananas, rather than ratoon crops. Therefore plant crops should be fertilised heavily to provide sufficient nutrients to produce the plant, the fruit of the plant crop and the following sucker.

Potassium applications should be matched to weather conditions, growth rates and expected yield. Fertiliser is usually applied during the warmer months of the year to maximise plant response. Frequent, small dressings are made to minimise leaching losses - four to five applications a year is common in NSW and southern Queensland, and up to ten in north Queensland. Fertiliser should not be
applied if no rain has fallen since the last application. Where irrigation is available it is becoming increasingly common to apply N and K fertilisers with the irrigation water.

**Treecrops**
Treecrop fruit have a high K demand, while the tree growth has a much smaller K requirement. Therefore K should be applied during the fruit growth period and rates should be adjusted according to the annual fruit load.

In stonefruit, K is necessary for fruit quality and size. Similarly in citrus, K deficiency causes fruit to be small, while an excess makes the fruit acid and delays maturity. Potassium is important for fruit development and must be applied before the fruit cell expansion stage. Citrus cultivars vary more in their K requirements than for any other element. Larger sized, higher-acid fruits such as Navel oranges, Ellendale and Wallent mandarins, grapefruit and lemons require less K. Seeded oranges and mandarins including Joppas, Valencias and Imperials which have a tendency towards smaller fruit size should be maintained with high K levels.
2.4 Potassium in Cane Production

Potassium is important in sugarcane production for yield, disease resistance and lodging resistance.

**Nutrient Removal**

The potassium removed in cane stalk can range from 80-140kg K/ha, with a similar amount contained in the tops and leaves. Therefore, as much as 280 kg K/ha is contained in the crop immediately prior to harvest. After harvest most of the K in tops and leaves is returned to the soil as green trash from which it is readily leached. If trash is burnt, around 70% of the K it contains can be lost from the field and deposited as ash elsewhere.

**Potassium Soil Testing for Cane**

Unlike most other crop types, two separate soil tests for K are used to make K fertiliser recommendations for sugarcane. The exchangeable K pool is extracted with a pH neutral salt but the soil is also digested with nitric acid in order to remove fixed K. This allows an assessment of the amount of K available by slow release over the lengthy cane growing period. Both the exchangeable and nitric acid extractable K are used to determine soil K supply and K fertiliser requirement.

**Potassium for Yield and Quality**

Potassium is important in cane production (Table 11), and yield and quality can be depressed by high N applications if K supply is not adequate. Low available soil K can lead to erratic germination of cane sets. Long term deficiency affects the growing tips resulting in a fan appearance.

During fallows and the early period of plant cane growth some K will become available from trash and from slow release soil supplies. Ratoon cane also accumulates K more rapidly than plant cane. For these reasons ratoon cane may require more applied K than plant cane.
Excessive K applications can have a negative impact on manufacturing quality of cane by raising its ash content. High ash content in juice can interfere with the manufacture of raw sugar. For this reason it is important to match K supply with crop K requirement for yield.

**Potassium Sources**
Most K for cane is applied as MOP, however alternative sources are available. Dunder, a liquid waste product from alcohol distilleries, is available in some cane-growing areas and is a good source of recycled nutrients. If dunder is used, some muriate of potash may also be necessary to reach the required application rate of K (Table 12).

<table>
<thead>
<tr>
<th>Product</th>
<th>K %</th>
<th>kg product to get 100 kg K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunder</td>
<td>3-4</td>
<td>2500</td>
</tr>
<tr>
<td>Muriate of potash</td>
<td>50</td>
<td>200</td>
</tr>
</tbody>
</table>

In the Burdekin Delta in Queensland, sugarcane crops are irrigated from underground water which contains K. In some instances this is sufficient to meet crop requirements.

Care must be taken when applying MOP at planting, not to place it too close to cane sets and cause fertiliser burn. Banding beside the row and below the surface is the best method of application.
2.5 Potassium in Dairy Production

Potassium fertilisation is an important input in dairy production systems because K is essential for sustaining productive pastures.

Potassium for Pasture Growth and Composition

Highly productive dairy pastures require inputs of K fertiliser to maximise dry matter production and maintain the legume component of mixed swards. The series of production measurements in Table 13 were taken during spring from New Zealand pastures with a variety of initial QTK values.

Even where soils have significant fixed K reserves, it may not be released at a rate sufficient to meet plant requirements. For instance in North Canterbury, New Zealand, dairy pastures on sedimentary soils with fixed K reserves produced 16% more dry matter during the milking season from K application of 50kg K/ha. All other nutrients such as P, S and N were in adequate supply.

Table 13. Spring pasture production responses to the addition of K fertiliser.

<table>
<thead>
<tr>
<th>Soil QTK value</th>
<th>K rate (kg/ha)</th>
<th>Pasture production (kg DM/ha)</th>
<th>No K</th>
<th>+ K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>50</td>
<td>2377</td>
<td></td>
<td>3140</td>
</tr>
<tr>
<td>2-3</td>
<td>80</td>
<td>2620</td>
<td></td>
<td>2830</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>3290</td>
<td></td>
<td>3920</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>1700</td>
<td></td>
<td>1870</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>1430</td>
<td></td>
<td>1650</td>
</tr>
<tr>
<td>8-10</td>
<td>70</td>
<td>8287</td>
<td></td>
<td>9177 *</td>
</tr>
</tbody>
</table>

* whole year production
(source AgResearch)
Potassium nutrition will influence the composition of mixed pastures. Grasses, in particular perennial grasses, are more efficient than legumes in obtaining K from the soil. In situations where K supplies are low, grasses can out-compete pasture legumes leaving them susceptible to K deficiency and poor growth. As a result the legume composition of mixed pastures will decrease. Figure 20 demonstrates the effect that K nutrition can have on mixed pasture composition. The effect of P and K fertiliser on the botanical composition of an old pasture in Victoria is presented in Table 14. Often the increase in pasture production from K fertilisation is almost exclusively due to improved legume growth.

Table 14. The effect of K fertiliser application on the composition of a mixed pasture.

<table>
<thead>
<tr>
<th>K rate (kg/ha)</th>
<th>Botanical Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clovers</td>
</tr>
<tr>
<td>Nil</td>
<td>3</td>
</tr>
<tr>
<td>31</td>
<td>16</td>
</tr>
<tr>
<td>63</td>
<td>30</td>
</tr>
<tr>
<td>125</td>
<td>49</td>
</tr>
<tr>
<td>250</td>
<td>49</td>
</tr>
</tbody>
</table>

(from Potassium for Victorian Pastures, Hosking 1986)
**Timing of K Applications to Pastures**
Timing of K application can have an effect of total annual pasture production. In New Zealand, trials have shown that, in high rainfall environments (>1500mm) and on peat and sedimentary soils, spring applications are superior to autumn applications, with most of the difference occurring in spring. On ash and pumice soils with rainfall < 1500mm timing of application has little influence on total annual pasture production.

In Southern Australia autumn application is traditional except on deep sandy soils where leaching losses may occur. Experimental evidence of benefits from different application times has been inconsistent, and often there is no difference in total annual pasture production. Autumn applications are able to increase pasture growth in autumn and winter when there is usually a feed shortage, and application to dry firm land helps avoid fertiliser burn and bogging.

Splitting applications rarely improves annual pasture production compared to a single application, but can change seasonal production. For example in a Victorian trial, application of K in autumn was compared to the same rate of application split between spring and autumn. Total annual pasture production was the same, but where applications were split the autumn and winter yields were decreased and spring yield increased. Split applications are recommended where high annual rates of K are used (>100kg K/ha), in high rainfall areas (>1500mm) or where soils are prone to leaching.

**Potassium Loss Mechanisms**
Additions and losses of K on a typical dairy farm are shown in Figure 21. The major source of K to the system is via fertiliser inputs and imported feed, with a small amount entering in rainfall or irrigation water.
As with other production systems, K can be lost from dairy pastures by leaching, runoff or by soil fixation. These losses can be minimised by careful selection of rate and time of K fertiliser application.

The removal of K in animal products from the farm is a relatively small proportion of overall K losses in a dairy system. Of the K ingested by animals 3% is used to produce body weight, 5% is exported in milk, 10% is expelled in the dung and 80-85% is excreted as urine.

While K in urine and faeces is returned to the paddock, much of this K can be effectively lost through transfer into non-productive areas such as stock camps and yards. A high proportion of the K in urine is also subject to rapid movement into the profile as urine flows through the soil pores. Some of this K will be held in exchangeable or fixed forms and can be accessed by the deeper roots of pasture plants, but the remainder is subject to leaching.

Removal or transfer of hay and silage will have a significant effect on the K status of dairy paddocks and may be as high as 100kg K/ha for a single crop. Fields which have a history of hay or silage production are likely to have low soil K levels in the absence of adequate K fertilisation.
The total K losses for any dairy system will depend on the intensity of the system, and the herd and pasture management. For example, the OVERSEER™ model developed in New Zealand can predict the effect of changing stocking rate on the magnitude of K losses on a dairy farm (Table 15).

Table 15. The effect of stocking rate on the loss of K from dairy systems as predicted by the OVERSEER™ model. Based on a farm with 1100 mm rainfall, on sedimentary soil and with cows producing 300kg milk solids/yr.

<table>
<thead>
<tr>
<th>Stocking Rate cows/ha</th>
<th>Milk kg K/ha</th>
<th>Transfer kg K/ha</th>
<th>Leaching kg K/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>11</td>
<td>46</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>94</td>
<td>34</td>
</tr>
</tbody>
</table>

The net result of K movement within a dairy system is a wide range in soil K levels within individual farms (Figure 22). This has important implications for pasture and grazing management.

Figure 22. Distribution of soil K within a typical dairy farm. Those paddocks which are close to the dairy are used to dispose of dairy effluent and to feed purchased hay, and are high in K. Paddocks from which hay has been regularly removed have relatively low soil K.

(source Agriculture Victoria)
Animal Metabolic Health Issues
Additions of K fertiliser to pastures have been associated with incidences of grass tetany (or hypomagnesaemia) in dairy cattle. This condition develops when insufficient magnesium (Mg) is absorbed from the diet. Application of K fertiliser can predispose animals in two ways. Firstly, improved plant availability of K can reduce the Mg concentration of pasture through dilution in additional dry matter produced, and in direct competition for root uptake. Secondly, high levels of K relative to Mg in the diet can reduce the ability of the gut to absorb Mg.

Problems with grass tetany are more likely to occur in the spring when pasture Mg levels are naturally at their lowest (<0.20%), and demand for Mg by animals is greatest. Lactating cows are more susceptible to the development of grass tetany, and early symptoms include increased excitement and nervousness.

Fertiliser K is only one of several factors which can contribute to the risk of grass tetany. Temperature can influence the incidence of grass tetany, with a prolonged period of cold (<14 °C), wet days raising the likelihood of deaths. Pasture species, composition, soil type and availability of other nutrients also influence whether a paddock is tetany-prone or not and some of these things can be managed to minimise the risk of animal health problems associated with fertiliser K applications to pasture.

Risk Management Strategies
Managing the following aspects of the dairy system and K fertiliser program can help minimise the risk of grass tetany while maximising pasture production. The following information should assist in the development of a tetany risk management strategy to suit individual dairy operations.
1. **Time of K Fertiliser Application**
Application of K fertiliser usually, but not always, results in a reduction in pasture Mg concentration very soon after application which can increase the risk of grass tetany. Trials in the North Canterbury region of New Zealand have shown that this effect lasts for a relatively short period of time with pasture Mg concentrations returning to near original levels within two months of K application. Therefore, on paddocks which have a high risk of grass tetany it is best to avoid applying K to paddocks just prior to or following calving.

2. **Application Rate**
Trials on New Zealand North Island dairy ryegrass and grass/clover pastures found that the effect of K application on pasture Mg content was apparent even at low application rates (25kg K/ha). Application rates up to 250 kg K/ha had only slightly greater effects on pasture Mg concentration. This is supported by Australian data (Table 16). However in all cases, increasing rates of K will continue to increase pasture K concentrations and therefore the ratio of K to Mg in the diet. Therefore it is important to only apply as much K as necessary to sustain maximum pasture production, and to match this with other nutrients which may be limiting. This is best achieved by basing fertiliser application rate decisions on the results of a soil and plant tissue testing program.

<table>
<thead>
<tr>
<th>K rate (kg/ha)</th>
<th>Pasture K (%)</th>
<th>Pasture Mg (%)</th>
<th>Pasture K:Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.3</td>
<td>0.30</td>
<td>4.3</td>
</tr>
<tr>
<td>25</td>
<td>1.8</td>
<td>0.19</td>
<td>9.5</td>
</tr>
<tr>
<td>50</td>
<td>2.5</td>
<td>0.21</td>
<td>11.9</td>
</tr>
<tr>
<td>100</td>
<td>3.8</td>
<td>0.14</td>
<td>27.1</td>
</tr>
<tr>
<td>200</td>
<td>4.3</td>
<td>0.15</td>
<td>28.7</td>
</tr>
</tbody>
</table>

(source *Potassium for Victorian Pastures*, Hosking, 1986)
3. Soil Application of Mg
Application of Mg fertilisers can improve the Mg content of pastures but may not be sufficient to raise dietary Mg to an acceptable level. Long term maintenance of soil Mg levels using Mg fertilisers may be effective in low to moderate tetany risk areas.

4. Dietary Supplementation
Direct dietary supplementation of Mg has proven a more effective method of improving Mg intake in high risk situations. Dusting of pastures or supplementary feeding with Mg compounds is common. In intensive industries it is also possible to give daily Mg drenchings year round or during risk periods. A veterinarian or animal nutritionist will be able to advise on a drenching program. Dietary supplementation must start 2-3 weeks prior to calving and continue for 4-8 weeks after calving.

5. Maintain the Legume Component of Pastures
Because of their superior ability to accumulate K, grasses often have a higher tissue K concentration than accompanying legumes in a mixed pasture. For this reason grass tetany incidence is more likely on pastures which are heavily dominated by the grass component. Ironically, where soil K levels are moderately low, ensuring adequate pasture K nutrition can help to improve the legume component of a pasture and therefore reduce the risk of grass tetany. The effect of N application on the legume content of pastures must also be monitored carefully.

6. Ensure Adequate P Nutrition
In some cases inadequate P nutrition can contribute to incidences of grass tetany. Phosphorus fertility is important to ensure optimal plant uptake of Mg and Ca. Furthermore, pasture plants which are P deficient will be stunted and tissue K will be more concentrated.
7. Application of N Fertilisers
The effect of N application on pasture K concentration is difficult to predict. Where soil and forage K levels are already high, application of N fertiliser tends to increase pasture K concentrations. Where pasture N concentration is less than 2%, application of N is likely to have a dilution effect and result in lower pasture K concentration. Recent research in New Zealand has shown no effect of N application on the K concentration of pasture.

8. Grazing Management
If it is possible to identify areas which have a greater risk of inducing grass tetany (for example paddocks which receive large amounts of dairy effluent which is high in K), avoid grazing these areas for 1 month prior to and 2-3 months after calving.

9. Precision Application
Spatial variation in application rate of K whether by paddock, landscape unit or using grid sampled data can minimise the over-application of K to areas with high soil K and under-application to areas with low soil K. As a result production is maximised and risk of luxury uptake and metabolic health issues is minimised. This approach requires a thorough soil testing and monitoring program for all paddocks on a farm.

Figure 23. Developing a risk management strategy can ensure that maximum pasture production can be obtained without animal metabolic health problems.
2.6 Potassium in Sheep and Beef Production

Removal Rates and Transfer Losses

Removal rates of K with produce from sheep and beef enterprises is listed in Table 17.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Greasy Wool kg/t</th>
<th>Live kg/t</th>
<th>Live wt gain kg/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheep</td>
<td>15.8</td>
<td>2.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Cattle</td>
<td>2.2</td>
<td>1.8</td>
<td></td>
</tr>
</tbody>
</table>

(source Australian Soil Fertility Manual, 2000)

NB. Live data refers to an entire animal body, live weight gain data is for additional gain in body weight.

As with dairy pastures, the major mechanism of K loss is not due to removal in produce but to transfer in manure and urine. Concentration of K in unproductive areas such as yards or stock camps is considered a loss mechanism because the nutrient is no longer available for useful pasture production. New Zealand data suggests that in hill country over half of the dung and urine from stock will be excreted on as little as 1/5th of the paddock.

Highly concentrated K in urine patches is also subject to movement below the rooting zone as urine infiltrates the soil or by leaching with rainfall or irrigation. This mechanism of loss is potentially much smaller in sheep than cattle grazing systems since the volume of urine expelled at any one time is approximately ten times less.

Pasture and Production Responses to Potassium

Australian research has shown increases in both pasture and livestock production with K fertilisation, often associated with an improvement in the legume component of mixed pastures.

Table 17.
The K contained in products from sheep and beef enterprises.
On duplex soils in coastal NSW, annual applications of K fertiliser have improved the liveweight (LW) gain of weaner steers on mixed pastures (Table 18). This response was reliant upon seasonal conditions which allowed clover in the pastures to regenerate.

<table>
<thead>
<tr>
<th>Year</th>
<th>Steers/ha</th>
<th>Average LW gain (kg/ha)</th>
<th>Additional LW gain in response to K fertiliser (kg/ha)</th>
<th>Muriate of potash (kg/ha/yr in Years 1, 2 and 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>42</td>
<td>125</td>
</tr>
<tr>
<td>1</td>
<td>2.5</td>
<td>335</td>
<td>-8</td>
<td>108</td>
</tr>
<tr>
<td>2</td>
<td>3.75</td>
<td>251</td>
<td>60</td>
<td>116</td>
</tr>
<tr>
<td>3</td>
<td>3.75</td>
<td>521</td>
<td>60</td>
<td>199</td>
</tr>
<tr>
<td>4</td>
<td>3.75</td>
<td>390</td>
<td>124</td>
<td>210</td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>213</td>
<td>95</td>
<td>140</td>
</tr>
<tr>
<td>6</td>
<td>2.5</td>
<td>293</td>
<td>35</td>
<td>80</td>
</tr>
</tbody>
</table>

Table 18. The effect of annual K applications on the average liveweight gain of weaner steers.

In Western Australia on a low K site, K increased production of a mixed pasture. Where stocking rates were adjusted in accordance with improved pasture growth, wool production per hectare increased (Figure 24).

Figure 24. Greasy wool production from a WA pasture with and without annual K application and at two stocking rates. 95 kg K/ha had been applied in 1994, with a further 30 kg/ha K applied in 1996.

(source CSBP futurefarm)
**Intensity of Production**
The intensity of production will also determine the requirement for K fertiliser. The need for K fertilisers is greater in enterprises which have higher stocking rates or where N and P application, pasture renovation or improved grazing management have increased production. In each of these cases removal and transfer of K will be increased, often resulting in a K responsive situation.

For example, in New Zealand hill country at Te Kuiti, the long-term effects of nil fertiliser application have been compared to regular N and P application. Increased stocking rates have been possible on the fertilised paddocks to take advantage of higher pasture production and have subsequently led to improved profitability. After 13 years, applications of K were trialled on both areas to find that pastures responded to K applications in high input areas, but not in areas where N and P fertiliser had been withheld. This was probably due to increased K losses from animal transfer where production and stocking rates were higher. Most of the increase in pasture production was due to improved legume growth in K treated areas (Table 19).

<table>
<thead>
<tr>
<th>K rate (kg/ha)</th>
<th>P fertiliser history</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nil P</td>
<td>23 kg P/ha/yr</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>361</td>
<td>1572</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>380</td>
<td>1910</td>
<td></td>
</tr>
</tbody>
</table>

*(source AgResearch)*

**Economics of K Fertiliser Use in Extensive Pastures**
While responses to K fertiliser may be possible in many grazing situations, the economics of application may not always be favourable. For example, in extensive grazing systems, response to K application may only occur in years with a high pasture production potential (due to good
rainfall). In these years pasture is already in abundant supply and animals may not be able to utilise the extra production generated by addition of K.

The economic benefits of improved production from fertiliser use must be captured through changes in management. If a grazier has the ability to manipulate stocking rates to improve pasture utilisation, or to conserve fodder, extra production due to the use of K fertilisers could prove profitable.

Furthermore, while it may be uneconomical to apply fertiliser over an entire property, investment in a few well managed paddocks can have excellent returns. Where part of a property is sown to more productive pasture species, fertilised with higher rates of N,P and S, and stocked accordingly with high value livestock (e.g. fat lambs or young cattle for sale) returns on K fertiliser application are likely.

In many regions, the local Grasslands society, government departments, fertiliser companies and farmers work closely together to determine the most economic production system for the region. This often involves the comparison between paired paddocks on individual farms which have been managed under ‘normal’ or ‘high production’ regimes. With many pairs of similarly managed paddocks the results of such trials can be significant across the whole region while still being applicable to individual properties.
Potassium Deficiency Symptoms

3.0 POTASSIUM DEFICIENCY SYMPTOMS

Presented below are photographs of K deficiency symptoms expressed in some common crop and pasture species. They may assist in diagnosing K deficiencies in the field. Potassium deficiency generally appears as a yellowing, firing or spotting on the margins of older leaves.

Clover

Wheat
Potassium Deficiency Symptoms

Cotton

Lucerne

Sugarcane
Potassium Deficiency Symptoms

Maize

Sorghum
Potassium Deficiency Symptoms

Canola

Soybean

Peanut
Photographs
The author would like to gratefully acknowledge the use of photographs provided by:
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(pp 1, 2, 16, 18, 39, 59a, 60a, b, c, 61a),
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Ravensdown Fertiliser Co-operative (cover),
FertResearch (cover),
the Queensland Department of Natural Resources (cover)
Incitec Fertilizers Ltd (p 13), and
the Queensland Department of Primary Industries (p 62b)
and (pp 59b, 61b) from their book
Hungry crops: a guide to nutrient deficiencies in field crops

Additional copies of this booklet may be obtained from
PO Box 936, Biloela Q Australia 4715
or by contacting your local fertiliser distributor.

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