Macronutrients - Potassium

by Thomas D. Landis

Introduction

Potassium (K) makes up about 1.5% of the earth's crust but is never found in its elemental form due to its highly reactive nature. Its chemical symbol K comes from the German term for this element (kalium) which comes from the Arabic ("the ash"). Potassium is commonly known as "potash" because people used to burn wood in pots as the first step to making soap. The ashes were rinsed and the water was allowed to evaporate, leaving a residue of potassium salts which they called "pot ashes." These salts were then boiled with animal fat to produce soap.

Potassium is most commonly found in nature as potassium chloride as the result of evaporation of prehistoric lakes and seas including the Great Salt Lake in Utah and the Dead Sea in the Middle East. These brine reserves are now a commercial source of potash. Potassium is an integral part of soil minerals such as micas and feldspars (Figure 1), and their derivative clay soils typically contain from 2% to 4% potassium, as do young volcanic soils. Highly weathered sands and organic soils, on the other hand, are typically low in potassium.

Role in Plant Nutrition

Potassium is the most abundant monovalent cation (K^+) in plant tissue. Of the three "fertilizer elements" (N-P-K), the average concentration of potassium in plant tissue is only slightly below nitrogen (Table 1). Potassium is very mobile in plants and young, metabolically active tissues like new leaves have a much higher concentration than mature leaves or structural tissues.

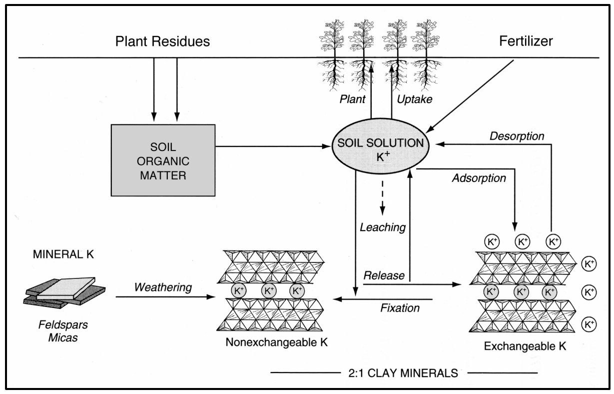

Figure 1 - Potassium slowly becomes available to crops from the weathering of clay minerals but is often deficient in sandy nursery soils. Because of this low availability and because it is so readily leached, growers must supply the potassium needs of their crops as fertilizer (modified from Havlin and others 1999) .

Availability in the soil and growing media. There are 4 classes of soil potassium in soils (Figure 1):

1. Minerals which are very resistant to weathering and release negligible potassium to crops.

Table 1—Potassium is the Second Most Common Mineral Nutrient in Seedling Tissue				
			Average Concentration in Seedling Tissue %	
Element	**Symbol**	**% of Total Mineral Nutrients in Plants**	**Bareroot**	**Container**
Nitrogen	N	37.5	1.20 to 2.0	1.30 to 3.50
Potassium	**K**	**25.0**	**0.40 to 0.80**	**0.70 to 2.50**
Calcium	Ca	12.5	0.20 to 0.50	0.30 to 1.0
Magnesium	Mg	5.0	0.10 to 0.15	0.10 to 0.30
Phosphorus	P	5.0	0.10 to 0.20	0.20 to 0.60
Sulfur	S	2.5	0.10 to 0.20	0.10 to 0.20

2. Slowly available potassium is held tightly between clay minerals and is released only slowly to plants. Vermiculite contains a significant amount of potassium, but potassium fixation can be a concern in clay soils.

3. Exchangeable potassium comprises about 1% of the total soil potassium and is available for plant uptake by the cation exchange process. Because clay soils and growing media components like *Sphagnum* peat moss and vermiculite have high cation exchange capacities (CEC), they retain potassium against leaching.

4. Solution potassium, about 0.5% of the total, is most available to plants but also susceptible to losses from leaching.

Most of the potassium in soils moves very slowly by diffusion and so, without supplemental fertilization, levels may be low in the rhizosphere. This is particular true of sandy nursery soils and organic growing media. Tropical soils, especially those containing kaolinite clays, are typically very low in potassium and heavy rains just exacerbate the problem.

Uptake by plants. Potassium is taken-up by plants as a cation (K^+) and is the only cation that can be transported against an electrochemical gradient into plant cells ("active" uptake). Once inside the roots, potassium is very mobile in plants through the phloem and towards the meristems and young leaves. In the case of a local deficiency, potassium can be quickly transported both acropetally (up) and basipetally (down) which ensures that young metabolically active leaves have enough for their high metabolism and cell growth.

Influences on Plant Growth and Development

Potassium is the only macronutrient that is not a component of any plant structure. However, it is considered the most important cation in plant physiology due to its many important functions:

Seed priming. The first effect that potassium has on the growth of native plants is on seed germination. Soaking seeds of some hard-to-germinate species in potassium hydroxide for only 1 minute was shown to increase germination and seedling emergence. This effect varies significantly by species, however, so tests should be done before using potassium hydroxide operationally.

Regulation of water relations. Because potassium can be accumulated in actively growing tissues like root tips, it enhances uptake and retention of water. This ability is the reason for its most important function - the opening and closing of stomata. During daylight, and using energy from respiration, potassium ions are "pumped" into the guard cells on either side of the stomata. The resulting increase in turgor pressure causes the stomata to open. During dark periods, the potassium is "pumped" out of the guards cells and they lose turgor and close. Also, when the plant is under moisture stress, the turgor pressure in the guard cells drops and the stomata shut down. The effect of the potassium concentration on the transpiration rate of Douglas-fir needles is shown in Figure 2A.

So, in summation, plants that are deficient in potassium have impaired stomatal activity which affects 3 important physiological processes;1) carbon dioxide

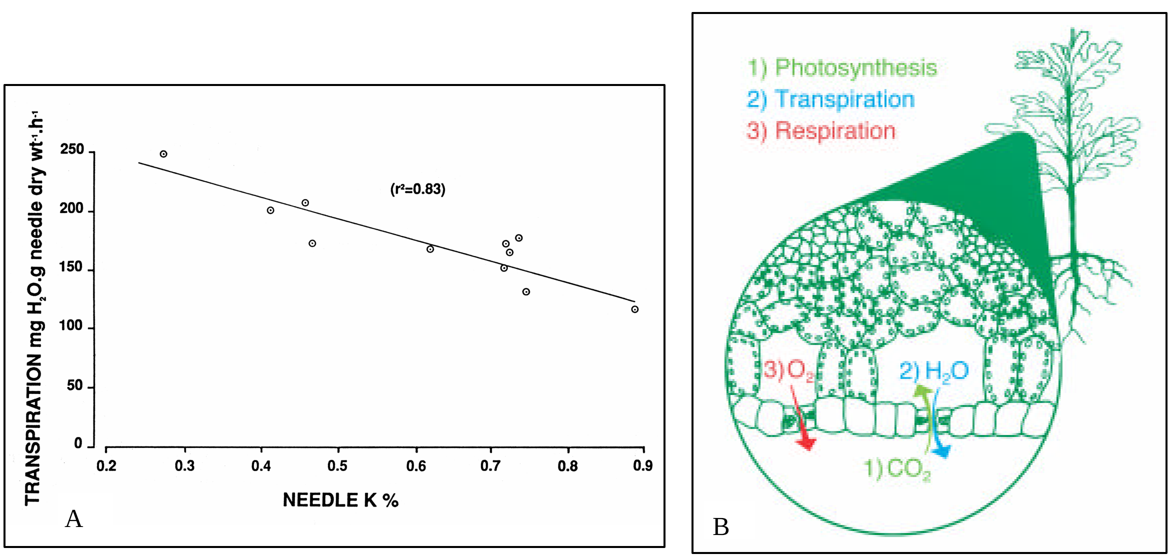

Figure 2 - Because potassium controls stomatal functioning, it has a critical effect on many important physiological process including transpiration (A), and photosynthesis and respiration (B).

uptake for photosynthesis; 2) transpiration which affects turgidity and growth; and 3) oxygen uptake for respiration (Figure 2B).

Energy relations. Plants need potassium for the production of adenosine triphosphate (ATP) which allows energy captured in photosynthesis to fuel all other physiological processes. Numerous studies have shown that potassium stimulates translocation of the products of photosynthesis. While this could be an indirect result of more carbon dioxide uptake, it appears that it is due to synthesis of the energy compound ATP.

Enzyme activation. Potassium has been shown to stimulate the activation of 50 to 80 different enzymes. These enzymes control a wide variety of physiological processes such as synthesis of starch from glucose, allowing energy to be stored for subsequent respiration and growth. Potassium is also involved in several steps in protein synthesis and a deficiency results in an accumulation of soluble nitrogen products.

Cation-anion balance. Potassium is the major cation for balancing anions in plant tissue. For example, potassium is the predominant cation to balance the negative charge of nitrate in long distance transport in the xylem.

Hardening plants against frost and pest resistance. Traditional nursery wisdom has been to apply extra potassium as part of the hardening process. For example, potassium is considered to help plants resist stresses such as cold injury or attack by fungi or insects. This perception may be due to the fact that potassium increases the strength of straw in grasses and helps prevent lodging. Potassium has also been shown to reduce the severity of several diseases of agricultural plants. However, the evidence is much weaker for woody plants. We know that high nitrogen levels stimulate rapid "soft" growth whereas adequate potassium counteracts this by promoting firmer tissues. In addition, potassium, calcium, and magnesium have been shown to increase waxes on the surface of leaves and needles which would help with the hardening process. A thicker cuticle also increases the resistance to insect feeding and penetration by fungi.

The relationship between potassium and frost hardiness has a long history and there are even potassium sprays available for "plant frost protection." However, the ability of high potassium levels to increase the frost resistance of trees was tested on Scots pine (*Pinus sylvestris*) and European birch (*Betula pendula*) seedlings. These experiments actually revealed an inverse relationship: foliage with higher levels of potassium was actually less resistant to cold injury. Because potassium has a major effect on water relations, it may be that adequate potassium fertilization helps prevent overwinter desiccation. Nevertheless, the practice of increasing potassium fertilization during the hardening phase appears to be groundless.

Monitoring Potassium

Because of its many effects on plant physiology and growth and the fact it must be supplied by fertilization, it only makes sense to carefully monitor potassium nutrition in nurseries.

Deficiency symptoms. Foliage that is deficient in potassium looks like it has been burned on the leaf margins or the tips of needles—a condition known as "scorch." Since potassium is so mobile in plants, these deficiency symptoms first occur in older tissues. The relationship between potassium and nitrogen has been mentioned earlier but overfertilization with nitrogen has been shown to induce potassium deficiency in bareroot spruce seedlings in two different studies. Typical tip burn symptoms were shown to occur when foliar potassium concentration was below 0.35% and subsequent potassium treatments did not always alleviate the problem. Experiments have shown that plant growth rate slows considerably ("hidden hunger") before symptoms develop so growers should use other means of monitoring potassium.

Toxicity symptoms. Potassium has no direct toxicity effects but overfertilization can interfere with the uptake of calcium and magnesium, especially the latter. In studies with radiata pine (*Pinus radiata*), the cause of magnesium deficiency was determined to be related to high soil levels of potassium.

Soil tests. Soil analysis is routinely run for potassium and many fertilizer recommendations are made on the basis of such analyses. Because of the many different forms of soil potassium (Figure 1), however, there is no standard extraction method that truly reflects available potassium. And, because of the wide variation in soil properties, it is difficult to develop a potassium test that is good for all soils. Therefore, the ability of soil tests to predict the potassium needs of crops is questionable.

Artificial growing media tests. Although there are several techniques available, forest and conservation nurseries do not typically analyze their growing media for potassium. Instead, most growers have developed their fertilization regimes based on seedling growth response or foliar tests (Figure 3).

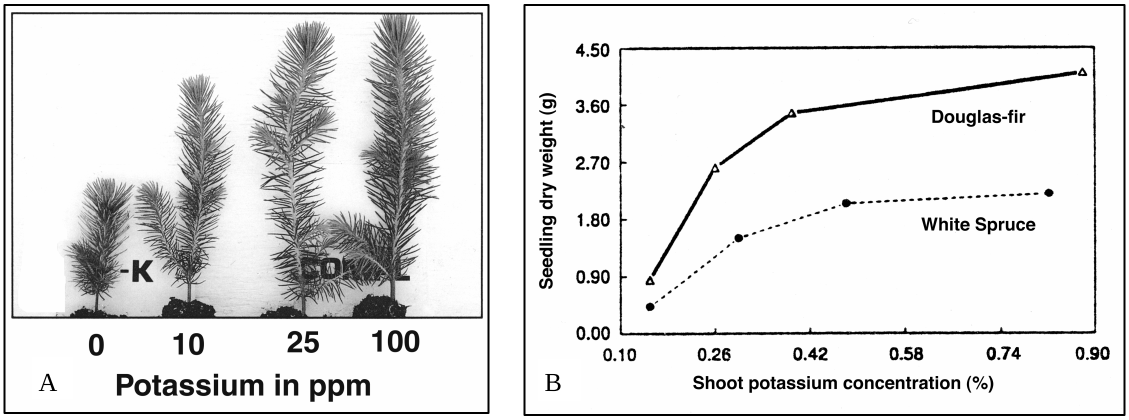

Figure 3 - Although soil tests have been traditionally used, growth trials (A) or tissue tests (B) are the most reliable way to monitor potassium.

Seedling tissue analysis. Tissue tests have the ability to precisely measure how much potassium seedlings have taken-up, and are quick and inexpensive. However, nutrition experiments have shown that foliar potassium concentration can vary considerably between plant species. Apparently, some species like Douglas-fir have a significantly higher demand for potassium than others, like white spruce (Figure 3B). The extreme mobility of potassium within plants is another consideration. Studies with agricultural crops suggest that the ratio of potassium levels between young and old tissue was the best indicator of true potassium status.

Considering the limitations of testing soils or growing media, chemical analysis of plant tissue is one the most useful ways to monitor potassium in forest and native plant nurseries. Typical ranges for potassium in the foliage of bareroot and container plants are given in Table 1. Container plants accumulate higher potassium levels, probably due to higher fertilization rates and greater availability in artificial growing media.

Potassium Management

Plants usually absorb most of their potassium during the active growth and metabolism in the first half of the growing season. Growth curves show a steadily increasing amount of potassium in plant tissue (Figure 3B) so growers should make sure that potassium fertilizers are applied early and then regularly during the entire growing season. This is particularly important for sandy nursery soils where potassium leaching can be significant. Because of its limited availability in nursery soils and growing media, essentially all of the potassium needed for the growth of nursery crops should be supplied by fertilization.

Potassium fertilizers. Fortunately, there are many potassium fertilizers and all of them are soluble (Table 2). Remember that the legal analysis of multinutrient fertilizers will list potassium as % K_2O— to convert to % K, multiply by 0.83. When formulating or applying fertilizers, the nitrogen-to-potassium ratio should be considered. As we have discussed, high nitrogen fertilization can induce potassium deficiency so try to maintain a ratio of 2 parts N to 1 part K. Note that Sul-Po-Mag (K-Mag) is a naturally occurring mineral and therefore is popular with organic growers. Because of its chemical make-up, it serves as a natural slow release source of potassium, magnesium, and sulfur.

Fertilization in Bareroot Nurseries. The potential fixation of potassium in field soils and its high leaching potential are challenges to fertilization in bareroot nurseries. Two materials are most commonly used: potassium sulfate and potassium chloride. Although potassium sulfate is more expensive and has lower analysis (Table 2), it is more popular with growers because of concerns about the excess chloride. Potassium fertilizers are usually broadcast and incorporated into the seedbeds prior to sowing but banding may be recommended in sandy soils with high leaching potential. Based on crop response or foliar tests, another top-dressing may be required in mid-season. As mentioned earlier, high nitrogen fertilization can induce potassium deficiencies so this should be monitored.

Fertilization in Container Nurseries. Because all granular potassium fertilizers are highly soluble (Table 2), there are many choices when formulating custom fertilizer solutions. Potassium carbonate has appeal because it is a single-nutrient source but, because the carbonate ion also increases solution pH, extra acid may be required. Fertigation solutions typically contain from 150 to 200 ppm potassium. This may be excessive, however, as growth trials with container white spruce seedlings in growing media showed that between 50 and

Table 2—Types of Potassium Fertilizers Commonly Used in Forest and Native Plant Nurseries						
Fertilizer	**Nutrient Analysis**			**Nursery Type**	**Application Method**	**Remarks**
	% N	**% P_2O_5**	**% K_2O**			
Potassium chloride	0	0	60 to 62	BR or C	Top dressing or fertigation	Water soluble with moderate salt index
Potassium sulfate	0	0	50 to 62	BR or C	Top dressing or fertigation	Water soluble with low salt index; also contains sulfur
Potassium magnesium sulfate "Sul-Po-Mag" or "K-Mag"	0	0	22	BR or C	Top dressing or fertigation	Naturally occurring mineral so good for organic growers
Potassium phosphates	0	41 to 51	35 to 54	BR or C	Fertigation	Water soluble with low salt index
Potassium nitrate	13	0	44	C	Fertigation or foliar	Water soluble with low salt index
Potassium carbonate	0	0	56	C	Fertigation	Single nutrient fertilizer but raises pH of solution
Plant Products 20-20-20	20	20	20	C	Fertigation	Completely soluble with micronutrients
Scotts Excel Cal-Mag 15-5-15	15	5	15	C	Fertigation	Completely soluble, with calcium, magnesium, sulfur and micronutrients
Scotts Peters Plant Starter 9-45-15	9	45	15	C	Fertigation	Completely soluble, with high P for young plants
Scotts Peters Foliar Feed 27-15-12	27	15	12	C	Fertigation	Completely soluble
Controlled-Release Formulations						
Osmocote Fast Start; 8 to 9 month release	18	6	12	C	Incorporation	Polymeric resin-coated prills
Osmocote High N; 8 to 9 month release	24	4	8	C	Incorporation	Polymeric resin-coated prills
Polyon 25-4-12; 8 to 9 month release	25	4	12	C	Incorporation	Polyurethane-coated prills
Nutricote 270; 8 to 9 month release	18	6	8	C	Incorporation	Thermoplastic resin-coated prills

100 ppm potassium gave the best response (Figure 3A). This is probably due to the fact the potassium ions can be held against leaching in these high CEC growing media and so less needs to be added in each fertigation. Being a type of clay mineral, vermiculite also contains a significant amount of potassium.

Foliar Fertilization. Because soil applications are more economical and provide a greater amount of available potassium, foliar fertilization is not common. If needed, however, potassium nitrate is the fertilizer of choice.

Environmental Affects of Overfertilization.
Although potassium can quickly leach from nursery soils or growing media, there are no serious environmental consequences of potassium fertilization. Nevertheless, growers should carefully plan and monitor potassium fertilization in their nurseries.

Conclusions and Recommendations

The availability of potassium in sandy nursery soils and organic growing media is naturally low. It is actively absorbed by roots and moves freely throughout the plant. Potassium is the only macronutrient that is not a component of any plant structure but has many important metabolic functions. Potassium is needed for numerous enzymatic reactions including the synthesis of starches and proteins. Perhaps its most important role is the opening and closing of stomata which controls water loss, carbon dioxide uptake, and gas exchange from respiration. Potassium has traditionally been thought to increase plant hardiness and resistance to pests but this has not been proven experimentally, at least for conifers.

Because of its critical metabolic importance, potassium should be carefully monitored in nurseries, and plant tissue analysis is most practical. Nurseries should plan to supply most of the potassium needed for seedling growth with fertilization. Bareroot nurseries should apply potassium as a preplant incorporation and then as top dressings. Because potassium fertilizers are so soluble, container growers can maintain adequate potassium throughout the growing season. High nitrogen fertilization can induce potassium deficiency so growers should consider a nitrogen to potassium ratio of 2 parts N to 1 part K. Unlike nitrogen and phosphorus, potassium fertilization does not have any potentially negative environmental consequences.

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