IMPORTANCE

Potassium (K) deficiency in California vineyards is considered third in overall importance, following that of nitrogen and zinc. This is somewhat surprising, because the potassium needs of the grapevine are relatively high and are comparable to the demand for nitrogen. The reasons are, in part, the greater initial supply of K in most California soils and resistance of K to losses from leaching. K deficiency is usually confined to small areas in a vineyard—seldom larger than 1 to 3 acres. When vines are deficient, however, the poorer vine growth and lower crop yields can be dramatic.

K-deficient areas in San Joaquin Valley vineyards probably total no more than several thousand acres. The deficiency has not been found in Kern County vineyards and is rare in Tulare County, where it may be found only in scattered areas between Kingsburg and Orosi. Fresno County has scattered areas of localized deficiency, mostly east of Dickenson Avenue north of Fresno and east of Highway 41 south of Fresno. In a tissue analysis survey of 120 vineyards throughout Fresno County, only one vineyard was found to be deficient in K, further demonstrating the infrequency and localization of the problem. K deficiency is rare in Madera County. Merced and Stanislaus counties have scattered deficient areas centering around Ballico, Ceres, and Delhi, and around Keyes and Ceres. In San Joaquin County, deficiency is occasionally found in the vineyard areas around Manteca, Ripon, and Escalon.

SOURCES IN THE SOIL

Most K in soils is derived from minerals, notably micas and feldspars. These minerals are only slightly soluble and are usually found as large-size particles. Under the influence of various weathering factors, K is gradually solubilized and becomes available to plants as positively charged ions, which become attached to clay colloids or to organic matter in the soil.

A comparatively large quantity of K is found in soils, but most of it is present in relatively insoluble compounds. Thus, the available K level in the root zone is a more important consideration than the total supply. The ordinary range of total K in minerals ranges from 0.15 percent in sands to 4 percent and higher in clay soils.

When K fertilizer is applied to the soil, part is fixed in slowly available compounds. The extent of fixation is proportional to the amounts and kinds of colloids in the soil, being greatest in clays and clay loams and smallest in sands. K fixation or holding by the soil is important, because it serves as a check against rapid leaching and provides a more continuous supply of available K. Even when K fertilizer dissolves in the soil moisture, it is soon attracted to the surfaces of the colloidal complex and replaces sodium, calcium, or some other element associated with the colloidal soil particles. K so fixed may move slowly in the soil, the rate dependent on the amount and nature of the colloidal complex.

The K cycle is fairly simple. It is fixed by the soil; removed by crops and, to a minor extent, by drainage water; exported by harvested crops; and returned to the land in crop residues, manures, or K fertilizers.

K levels are generally highest in the topsoil. Hence, deficiency is most likely to occur in cut areas from land leveling where the less fertile subsoil is exposed. K deficiency is also more common in sandier soils.

ROLE AND UTILIZATION

Not much is really known about the function of K in grapevines. Much more is known about what happens to vine growth and crop yields when this element is deficient.

Plants need K for the formation of sugars and starches, for the synthesis of proteins, and for cell division. K also neutralizes organic acids, regulates the activity of other mineral nutrients in plants, activates certain enzymes, and helps to adjust water relationships. It increases the oil content of certain fruits, and contributes to cold hardiness. Even though it is considered essential for the formation of carbohydrates and is somehow involved in other processes, it is not usually found as a part of organic compounds. About 1 to 4 percent of a plant by dry weight is K.

The demand for K is highest in midsummer to late summer, when greater amounts accumulate in the ripening fruit. Thus, temporary K deficiencies are sometimes associated with overcropping.
DIAGNOSIS OF DEFICIENCY

The ability to recognize and identify symptoms of K deficiency is extremely important; response to K fertilization has been obtained only in vineyard areas with visible symptoms of deficiency. Fertilizer trials in vineyards with low, but not deficient, levels of K in leaf tissue have not shown a yield or growth response.

Symptoms

Leaf symptoms usually begin to show in early summer and typically are seen first on leaves on the middle portions of the shoots. A fading or yellowing of leaf color begins at the margin or outer edge of the leaf.

As the season progresses, the yellowing continues to progress into the areas between the main veins, leaving a central island of green extending somewhat along the main veins. (See fig. 3a.) The yellowed leaf areas of colored grape varieties may bronze or redden (fig. 3b). In all varieties, marginal burning and curling, either upward or downward, usually follows. Leaves above and below the mid-shoot section become affected as the season advances, until many of the leaves show some symptoms by harvest time.

When K deficiency is severe, shoot growth is markedly reduced, and symptoms may be present on nearly all of the leaves before blossoming time. Leaves may drop prematurely, especially if the vines are carrying a heavy crop or are stressed for moisture. If leaf drop is extensive, the fruit may fail to develop full color or to ripen normally.

Symptoms of a mild K deficiency do not appear until late summer, approaching harvest. Here, symptoms may appear on many of the leaves on lateral or secondary shoots. In Thompson Seedless, the late symptoms produce a more blotchy or irregular pattern of chlorosis, particularly on the leaves near the ends of lateral shoots.

Vines severely deficient in K tend to have fewer and smaller, tight clusters with unevenly colored, small berries. With Thompson Seedless the lower portion of the bunch may collapse by midsummer, resulting in raised, immature berries by harvest. (See fig. 4.)

Much of the effect of K deficiency on the fruit is the result of reduced vine growth and premature leaf fall, and accounts for lower vine yields and fruit maturity. Fruit symptoms alone are not always distinctive enough to be used in diagnosis; other factors, such as moisture stress, water berry, or red berry, can affect the fruit in a somewhat similar manner.

K deficiency symptoms may be confused with those caused by midsummer moisture stress during hot weather. Moisture stress, however, causes a general leaf burn of an irregular pattern that is most prominent on the older, basal leaves. The gradual fading or yellowing pattern, characteristic of K deficiency, is not seen.

A high water table during the spring and early summer may induce typical K deficiency symptoms. In fact, many other conditions that substantially reduce the effectiveness of the root system may also cause deficiency symptoms to appear. The diagnostic procedure should include digging and careful examination of the vine root system for the presence of phylloxera, nematodes, or unfavorable soil conditions.

Vineyard areas showing deficiency symptoms should be marked during the growing season. This will pinpoint the vines to be treated during the dormant season.

Using laboratory analysis

Even though keen observers may readily identify K deficiency by means of leaf symptoms, laboratory analysis of a properly collected sample of petioles may verify the diagnosis or help clear up confusion with other disorders. Based on fertilizer trials and field observations, tissue potassium values may be interpreted to determine whether the vines have an adequate level.

Soil analysis is not a reliable means of determining whether a vineyard requires K treatment. Too many variables are involved: the wide range of soil depths; the varying concentrations of K in the soil profile; the many different grape varieties and rootstocks used; and the many factors influencing root health and thus K uptake.

A note of caution: the K level in the vines may be influenced by other conditions that reduce the effectiveness of the roots—overcropping, shallow-rooting, high water table, inadequate irrigation, or heavy nematode or phylloxera feeding. The application of K fertilizer cannot be expected to give a positive vine response under such conditions.

FERTILIZER PRACTICE

Research results in California for both fruit trees and vines have shown that, when a deficiency exists, massive rates of K fertilizer are necessary to obtain vine or tree recovery and yield response. Large amounts of fertilizer are needed to overcome the high fixation of K in most California soils. Fertilizer mixes or complete fertilizers are not recommended,
because they have a relatively low K content and hence would be needed in unreasonably large amounts to supply enough K.

### Materials

The symbol “K,” used for the element, is from the Latin word for potassium—Kalium. When expressed as a plant food by the fertilizer industry, potassium is usually reported in terms of the oxide, K₂O, also called potash.

Potassium fertilizer is commonly available in three forms, each with a different potassium content:

- **Potassium chloride** (KCl, muriate of potash)—52 percent K (62 percent K₂O)
- **Potassium sulfate** (K₂SO₄, sulfate of potash)—44 percent K (53 percent K₂O)
- **Potassium nitrate** (KNO₃)–37 percent K (44 percent K₂O) plus 13 percent total nitrogen

Studies in Fresno County vineyards have shown that one fertilizer form offers no advantage over another in terms of vine response, provided that equal amounts of actual K are used. Thus, the choice will depend on relative cost and availability of the materials and on soil and vine conditions.

Currently, potassium chloride is the most economical source of K. It must be used with caution, however, because its chloride content might contribute to salt injury of vines under some conditions. For example, potassium chloride should not be applied to vineyard soils with an existing salinity condition, nor should it be used on shallow or poorly drained soils. It is best used during the dormant season and should be avoided during spring and summer. Only a low to moderate rate applied during the winter is safe for young vines.

Potassium chloride can be used safely on well-drained soils without a salinity problem. One or two heavy furrow irrigations directly over the area treated are recommended as the best means of reducing the concentration of chloride fertilizer. It is somewhat dangerous to rely on rainfall alone to move the fertilizer, because rainfall amounts are not likely to be adequate. Light rain might be expected to leave a slightly dispersed, but still concentrated fertilizer band in the root zone. To leach the chlorides in sprinkler-irrigated vineyards, one should also provide some irrigation in excess of the grapevines’ water needs.

The relatively high cost of potassium nitrate all but eliminates its use in vineyards as a soil treatment. Potassium sulfate is slightly more expensive than potassium chloride, and is safe to use during the dormant season. However, it should be used with some caution during the growing season, especially on young vines, because experience with this form is limited. Thus, from a practical standpoint, the choice of a potash fertilizer narrows to either potassium sulfate or potassium chloride.

### Rates

A high rate is needed to overcome the high K-fixing power of most San Joaquin Valley soils. (See table 3.) The quickest response by far can be achieved by applying the fertilizer in a single heavy application rather than in small amounts applied annually. In general, the speed and degree of vine recovery, as well as the length of effectiveness, improve as rates are increased.

<table>
<thead>
<tr>
<th>Vine deficiency</th>
<th>Application rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Per vine</td>
</tr>
<tr>
<td></td>
<td>KCI</td>
</tr>
<tr>
<td>Severe</td>
<td>4 - 4½</td>
</tr>
<tr>
<td>Moderate</td>
<td>3½</td>
</tr>
<tr>
<td>Mild</td>
<td>2½</td>
</tr>
</tbody>
</table>

*Pounds per acre equivalent is based on 454 vines per acre (8' X 12' spacing).

### Application methods

Deep placement of K fertilizer in a concentrated band close to the vine is recommended for most soils. This places the fertilizer near the root zone and also is the best means of overcoming soil fixation.

The fertilizer can be applied by hand or banded with a fertilizer applicator into the bottom of 6- to 8-inch-deep furrows opened about 18 to 24 inches from the vine on each side of the row. Many growers have found a 1-pound coffee can a convenient measure for applying K fertilizer by hand. A level, full can holds almost exactly 3 pounds of potassium sulfate.

Open French (row) plow furrows can also be used. In either case, the furrows should be left open to allow rainfall and irrigation water to move the fertilizer. The first irrigation should be made in these furrows to ensure deeper movement.

On sandy soils, surface banding of 2½ pounds of potassium sulfate on each side of the vine row (total of 5 pounds per vine) was successful in limited studies in Fresno County vineyards; movement into the soil depends on winter rainfall. The vines responded fairly rapidly after surface applications, presumably because of a good concentration of actively growing roots near the soil surface in the
spring. Use of this method should be limited until more experience is gained; only high rates of potassium sulfate have been evaluated.

When subsoiling is done reasonably close to the vine rows, K fertilizer may be placed in the subsoiler slots. Good vine responses have been observed following such applications.

**Foliar sprays.** Potassium nitrate applied in foliar sprays in extensive Fresno County trials has shown no promise in correcting deficiency. During the growing season, repeated sprays at 4 to 5 pounds of potassium nitrate per 100 gallons of water did not measurably increase tissue K levels or reduce deficiency symptoms over a 3-year test period. Higher rates could not be used because of toxicity to young leaves.

**Time of treatment**

The late fall or early winter is a good time to treat, allowing maximum exposure to winter rainfall to help move the fertilizer into the soil. At the latest, the fertilizer should be applied before the first irrigation in early spring, before bud break. Some growers have found that an application in the fall is convenient, because deficient areas can still be defined by the presence of leaf symptoms.

Symptoms are not corrected immediately after fertilizer application in the winter. A partial improvement in leaf color or in vine growth may not appear until midsummer; a full response usually is not attained until the second growing season, or even the third, after fertilizer treatment.

**Treatment longevity**

A single application of K fertilizer at a recommended high rate will sustain an adequate K tissue level and eliminate leaf symptoms for 5 years, at least. Typically, the treatment loses effectiveness after about 8 years. Higher rates than those in table 3 can last for 10 years and beyond. If soil pests, such as nematodes or phylloxera, are causing root problems, the longevity of any treatment can be expected to be shortened.

It would be prudent to observe the treatment area closely for reappearance of foliar symptoms and to monitor the tissue level of K by collecting petiole samples for laboratory analysis. This procedure will be helpful in anticipating the time when a follow-up fertilizer treatment may be necessary.
Clay minerals of the 2:1 type such as illite have the ability to fix ammonium and potassium ions. Smaller ions, such as H⁺, Na⁺, and Ca²⁺, can move in and out of the internal adsorption surface and are thus exchangeable. Potassium and ammonium ions are of such size as to fit snugly between crystals, thereby holding them together. At the same time, these larger ions are rendered at least temporarily non-exchangeable or fixed.

Relative proportions of the total soil potassium in unavailable, slowly available, and readily available forms. Only 1 to 2 percent is rated as readily available. Of this, approximately 90 percent is exchangeable and only 10 percent appears in the soil solution at any time.

Gains and losses in available soil potassium under average field conditions. The approximate magnitude of the changes is represented by the width of the arrows.
<table>
<thead>
<tr>
<th>Potassium</th>
</tr>
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<tbody>
<tr>
<td>Grape varieties ranked by petiole K levels</td>
</tr>
<tr>
<td>Averages of Bloom and Veraison Samples</td>
</tr>
<tr>
<td>U.C. Kearney Agricultural Center</td>
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</tbody>
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<table>
<thead>
<tr>
<th>High, above 1.75%</th>
<th>Zante Currant</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Ribier</td>
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<tr>
<td></td>
<td>Emperor</td>
</tr>
<tr>
<td></td>
<td>Muscat of Alexandria</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Medium, 1.25-1.75%</th>
<th>Thompson Seedless</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exotic</td>
</tr>
<tr>
<td></td>
<td>Calmeria</td>
</tr>
<tr>
<td></td>
<td>Carignane</td>
</tr>
<tr>
<td></td>
<td>Cardinal</td>
</tr>
<tr>
<td></td>
<td>Italia</td>
</tr>
<tr>
<td></td>
<td>Queen</td>
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<td></td>
<td>Rubired</td>
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<tr>
<td></td>
<td>Red Malaga</td>
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<tr>
<td></td>
<td>Perlette</td>
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<tr>
<td></td>
<td>Ruby Cabernet</td>
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<tr>
<td></td>
<td>Chenin blanc</td>
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</table>

<table>
<thead>
<tr>
<th>Medium-Low, 1.0-1.25%</th>
<th>Zinfandel</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Sauvignon blanc</td>
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<tr>
<td></td>
<td>Petite Sirah</td>
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<tr>
<td></td>
<td>Flame Seedless</td>
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<tr>
<td></td>
<td>Barbera</td>
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</table>

<table>
<thead>
<tr>
<th>Low, below 1.0%</th>
<th>Ruby Seedless</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grenache</td>
</tr>
<tr>
<td></td>
<td>French Colombard</td>
</tr>
<tr>
<td></td>
<td>Semillon</td>
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<tr>
<td></td>
<td>Salvador</td>
</tr>
</tbody>
</table>
Functions of Potassium in Plants

Potassium (K) increases crop yield and improves quality because it is needed for several yield-forming processes in plants.

POTASSIUM (K) is vital to so many plant processes that a review of its role involves understanding the biochemical and physiological systems of plant growth. While K does not become a part of the chemical structure of plants, it plays many important regulatory roles.

Enzyme Activation

Enzymes serve as catalysts for chemical reactions—they bring together other molecules in such a way that the chemical reaction can take place. Potassium is required to "activate" at least 60 different enzymes involved in plant growth. The K changes the physical shape of the enzyme molecule, exposing the appropriate chemically active sites for the reaction.

The amount of K present in the cell determines how many of the enzymes can be activated and therefore the rate at which the chemical reaction can proceed. Thus the rate of a given reaction is controlled by the rate at which K enters the cell.

Enzyme activation is probably the most important function of potassium in plant growth.

Water Use

The accumulation of K in plant roots produces a gradient of osmotic pressure that draws water into the roots. Plants deficient in K are thus less able to absorb water and more subject to stress when water is in short supply.

Plants also depend upon K to regulate the opening and closing of stomata (the pores through which leaves exchange carbon dioxide, water vapor, and oxygen with the atmosphere). Proper functioning of stomata depends upon an adequate K supply.

When K moves into the guard cells around the stomata, the cells accumulate water and swell, causing the pores to open, allowing gases to move freely in and out. When water supply is short, K is pumped out of the guard cells, the pores close tightly to prevent loss of water. If K supply is inadequate, the stomata become sluggish and, as a result, plants with an adequate supply of K are less susceptible to water stress.

Photosynthesis

When the sun's energy is used to combine carbon dioxide and water to form sugars, the initial high-energy product is adenosine triphosphate (ATP). The ATP is then used as the energy source for many other chemical reactions. The electrical charge balance at the site of ATP production is maintained with K ions. When plants are K deficient, the rate of photosynthesis and the rate of ATP production are reduced, and all of the processes dependent on ATP are slowed down.

The role of K in photosynthesis is complex, but the activation of enzymes and involvement in ATP production is probably more important in regulating photosynthesis than is the role of K in stomatal activity.

Transport of Sugars

Sugars produced in photosynthesis must be transported through the phloem to other parts of the plant for utilization and storage. The plant's transport system uses energy in the form of ATP. If K is inadequate, less ATP is available, and the transport system breaks down. This causes photosynthates to build up in the leaves and the rate of photosynthesis is reduced. Normal development of energy storage organs, such as grain, is also retarded as a result. An adequate supply of K helps to keep all of these processes functioning normally.

Water and Nutrient Transport

Potassium also plays a major role in the transport of water and nutrients throughout the plant in the xylem. When K supply is reduced, translocation of nitrates, phosphates, calcium, magnesium, and amino acids is depressed. As with phloem transport systems, the role of K in xylem transport is often in conjunction with specific enzymes and plant growth hormones. An ample supply of K is essential to efficient operation of these systems.

Protein Synthesis

The role of potassium in protein synthesis is related to several of the functions discussed above. Transport of amino acids to the sites of protein synthesis, enzyme activation, and balancing of electrical charges are among the key roles of K. Research has shown that K is required for every major step of protein synthesis. The "reading" of the genetic code in plant cells to produce the proteins and enzymes that regulate all growth processes would be impossible without adequate K.

Starch Synthesis

The enzyme responsible for synthesis of starch in leaves is activated by K. When K moves into the guard cells, the cells accumulate water and swell, causing the pores to open, allowing gases to move freely in and out. When water supply is short, K is pumped out of the guard cells, the pores close tightly to prevent loss of water. If K supply is inadequate, the stomata become sluggish and, as a result, water vapor is lost. As a result, plants with an adequate supply of K are less susceptible to water stress.
Potassium Availability and Uptake

Availability and uptake of potassium (K) is often complicated by many interacting components. Two factors that have a predominating effect are the soil and plant characteristics involved. A third factor, improved fertilizer and management practices, can be used to modify the inherent characteristics of soils and plants involving K uptake.

PLANTS DIFFER in their ability to take up potassium (K) depending on several factors. The factors that affect availability of K in the soil and resulting plant uptake are soil factors, plant factors and fertilizer and management practices.

Soil Factors...

1. The soil itself. This includes the material from which the soil was formed, the amount and type of clay minerals in it, the vegetation under which it was formed, the topography and drainage, the climate under which it was formed and the length of time it has been forming.

2. The cation exchange capacity or CEC of the soil. This reflects the soil's ability to hold K and other cations and store them in the soil for crop uptake.

3. The nonexchangeable or slowly available K. This is the K that is in equilibrium with the available K and renews the soil's supply of exchangeable K. For most soils, the more crops depend on nonexchangeable K, the lower the yields.

4. The cation exchange capacity or CEC of the soil. This reflects the soil's ability to hold K and other cations and store them in the soil for crop uptake.

5. The K fixation capacity of the soil. Some soils have clay types that can fix large amounts of K from fertilizers or other sources. This reduces the availability of K to the crop.

6. The amount of K in the subsoil and the density or consistency of subsoil layers. Some subsoils are high in K available to roots. Others, such as those formed under grass in the central Corn Belt have low K availability.

7. Soil temperature. Low soil temperatures reduce K availability and uptake rate by crops. The optimum soil temperature for K uptake for a crop such as corn is about 85°F.

8. Soil moisture. Moisture is needed for K to move to plant roots for uptake.

9. Soil tilth. This is related to the friability and ability to get air into the soil. Air is needed for root respiration for K uptake. Tillage when soils are too wet leads to compaction.

Plant Factors...

1. The crop. Crops differ in their ability to take up K from a given soil.

2. The variety or hybrid. Crop genetics come into play with the differences among varieties or hybrids of a given crop. Differences are developed through plant breeding. They usually relate back to the type of root system, root density and metabolic activity that affect K uptake and, hence, availability of K for a given K test.

Potassium as a nutrient has a very positive effect on root branching and density.
The other factor is that new varieties often have higher yield potentials which increase the demands placed on soil K. Additional potash will be needed under higher yields.

3. Plant populations. As plant populations increase yield of some crops are greater and demands on soil K are increased. Yields often will not increase with higher populations unless adequate levels of K are in the soil, from native or fertilizer sources.

4. The crop yield level. As crop yield levels increase, total K uptake increases, Table 3. But the uptake per unit of crop yield, such as pounds of K per bushel or ton, may be nearly constant at optimum yield levels.

Table 3. High yielding crops need more K.

<table>
<thead>
<tr>
<th>Corn yield</th>
<th>K uptake</th>
<th>K uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>bu/A</td>
<td>lb/A</td>
<td>lb/bu</td>
</tr>
<tr>
<td>110</td>
<td>117</td>
<td>1.06</td>
</tr>
<tr>
<td>154</td>
<td>151</td>
<td>0.98</td>
</tr>
<tr>
<td>202</td>
<td>223</td>
<td>1.10</td>
</tr>
<tr>
<td>231</td>
<td>259</td>
<td>1.12</td>
</tr>
<tr>
<td>255*</td>
<td>304*</td>
<td>1.19*</td>
</tr>
</tbody>
</table>

*From a different experiment and location.

Fertilizer and Management Practices...

1. Increased use of N, and other limiting nutrients. When adequate K is available, additions of N and/or P greatly increase K uptake, as yields are increased. Usually the uptake of K by crops closely parallels N uptake, and may be greater. So, as limiting nutrients are added, the demands on soil K increase.

2. Applications of K in fertilizers, manures or crop residues. The major way to increase K availability is to apply adequate amounts. K is readily available for all sources, provided they are mixed deeply enough into the soil where roots can absorb the K, Figure 2.

BECAUSE POTASSIUM (K) is a monovalent cation and readily adsorbed by the soil's cation exchange capacity, it is not considered to be mobile in the soil. Thus, the K available to plants is that in close proximity to the roots. This raises the question of whether placement of supplemental K close to the plant might improve uptake and use efficiency in addition to the beneficial effects of high K soil tests on K availability.

Methods

Researchers have explored a number of K application methods including: (1) surface broadcast without incorporation; (2) broadcast and disced; (3) broadcast and plowed down; (4) direct seed placement; (5) row placement (banded)—including all combinations of distances below and to the side of the seed; (6) plow sole placement; (7) deep placement or knifed; (8) surface strip; (9) fertigation; (10) combinations of the various methods.

All of these application methods can be considered as a variation or combination of the two extremes: (1) banding in high concentrations with a minimum of soil contact, and (2) broadcast and more or less uniformly incorporated into the tillage layer.

Results

Responses to K placement vary among crop types, specific environmental conditions that exist during the growing season, and soil type.

Corn. Soil characteristics can have significant effects on how corn responds to K application methods. Corn on three Illinois soils low to medium in soil test K responded differently to comparisons of broadcast and banded K. Banded K was more effective on all
three soils. Even at high rates of application, broadcast K was not as effective as that banded near the seed on two of the three soils.

Differences among the methods of K application usually diminish as K soil test values rise and as rates of application increase (Figure 1). Iowa studies showed less response to starter (banded) K as rates of plowdown K increased (Figure 2). But the relationship of starter K response to soil test K can vary with soil type and with year. Starter K continued to increase corn yields even at the highest soil test level in a Wisconsin experiment (Figure 3).

Starter K can be effective even at high soil test levels (Wisconsin) (Figure 3).

Starter K significantly increased corn yields on compacted soils in a Wisconsin study and continued to improve yields as K soil tests increased. Compacted, cold or extremely dry soil conditions may favor K starter responses due to slowed diffusion of soil K to plant roots even on high K soils. Large amounts of surface residue leading to lower soil temperatures and higher soil bulk density under reduced till conditions may require starter K for most profitable yields.

Surface band (strip) applications of K plowed down on a low medium K soil in Indiana were significantly more effective than either starter (row)- broadcast and plowed down K (Figure 4). Researchers concluded that optimum K application methods probably are somewhere between broadcast and banding near the row. Higher concentrations of K in a limited amount of soil may produce the best balance between lowered K fixation and greater root-nutrient contact.

Soybeans. Soybeans require high availability for best yields and profitability. Ohio data show a strong relationship of soil test K to soybean yield. (Figure 5). Responses to applied K have been good on deficient soils, whether broadcast or banded (Table 1).

Potassium should be applied early for soybeans, but sidedress rescue applications can have beneficial effects (Figure 6).

Alfalfa. High yield alfalfa has one of the highest K needs of any crop, frequently exceeding 60-70 lb K₂O per ton of hay. Top-dressing alfalfa with K is an adequate way of maintaining yield. Building nutrient levels before seeding and then topdressing for maintenance is the best approach.

Small Grains. Limited root systems, shorter growing seasons, and cooler temperatures enhance yield advantages of seed-placed over broadcast K for small grains. Barley data from Alberta showed a considerable advantage for K placed in direct seed contact at fairly low rates of application (Table 2). High rates of K in direct seed contact may cause germination damage when hoe or disc-opener drills are used.

Montana studies of K application methods have shown some advantages of knifed placement versus surface band or direct seed applications for spring wheat, winter wheat and spring barley but results varied with location. Knifed applications may have resulted in better utilization because of K placement in soil that remained moist longer.

Summary

In general, crop responses to different methods of K application are not nearly as large nor as consistent as responses to methods of application of N or P. However, cold, compacted or dry soil conditions tend to place more stress on K absorption and may warrant placement of high concentrations of K in the vicinity of developing plant roots.