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CONTENTS

Potassium: An Essential Plant Food Nutrient 3

Functions of Potassium in Plants 4

Production and Use of Potassium 6

Effects of Potassium on Crop Maturity 9

Potassium Interactions with Other Nutrients 12

Potassium Availability and Uptake 14

Yield and Economic Responses to Potassium 16

Potassium Deficiency Symptoms in Some Crops 20

Potassium Application Methods 24

The Influence of Potassium in Crop Quality 28

Influence of Potassium on Nitrogen Fixation 30

Potassium in Animal Nutrition 32

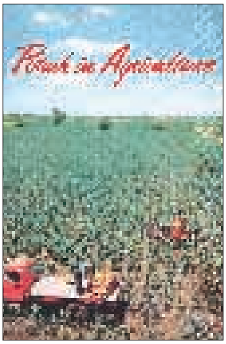
Potassium Reduces Stress from Drought, Cool Soils, and Compaction 34

Effects of Potassium on Plant Diseases 37

Powerful Potassium 40

Note: Reprints of this issue are available under the title of *Potassium for Agriculture*. Contact PPI at the address shown at left.

Potassium: An Essential Plant Food Nutrient



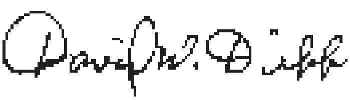
This publication presents current information on the importance of potassium (K) for agriculture. A forerunner booklet on this subject was published by the Institute in the 1950s. During the more than 40 years since then, several editions have been released. Our knowledge of plant nutrition and crop production has greatly increased. Yields have doubled and tripled. Fertilization practices have improved. There are newer and better hybrids and varieties. However, we still have much to learn about nutrient management as it relates to high yield, high profit crop production that is environmentally friendly.

There are still widespread areas of nutrient depletion. Africa is a well known example, but nutrient mining exists everywhere, even in some of the U.S. Corn Belt states. That is, more phosphorus (P) and K are being removed in harvested crops than are being applied in fertilizers and animal manures. Improving the management of P, K and other nutrients is more important now than it has ever been.

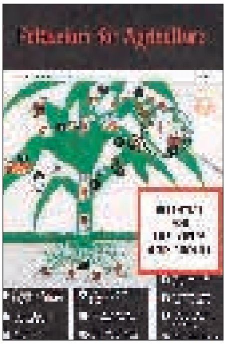
Potassium is basic to plant and animal life. Except for nitrogen (N), plants require more K than any other nutrient. Potassium is the third most abundant mineral in the human body, and it plays many vital roles in plant nutrition.

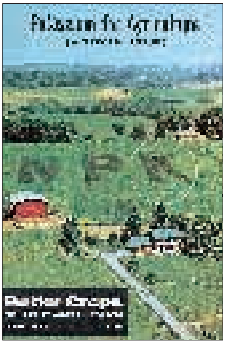
Unlike N, P and most of the other essential nutrients, K does not become a part of the chemical structure of the plant. Thus, its mobility in the plant allows it to influence almost all aspects of plant growth. Potassium encourages root growth, strengthens stalks, activates enzymes, controls plant turgidity, transports sugar and starch, helps in protein formation, controls diseases...and is involved in many other plant functions.

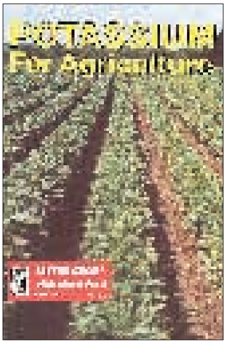
Potash & Phosphate Institute (PPI) scientists have updated and summarized material for use in this booklet. We hope this scientific summary helps contribute to a better understanding of the importance of K in food and fiber production. BC

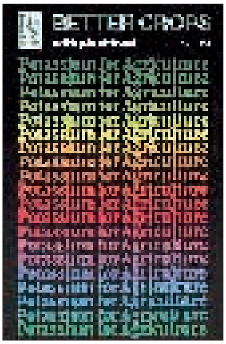


David W. Dibb, President









Functions of Potassium in Plants

Potassium is vital to many plant processes. A review of its role involves understanding the basic biochemical and physiological systems of plants. While K does not become a part of the chemical structure of plants, it plays many important regulatory roles in development.

Potassium (K) increases crop yield and improves quality. It is required for numerous plant growth processes.

Enzyme Activation

Enzymes serve as catalysts for chemical reactions, being utilized but not consumed in the process. They bring together other molecules in such a way that the chemical reaction can take place. Potassium "activates" 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 reaction. Potassium also neutralizes various organic anions and other compounds within the plant, helping to stabilize pH between 7 and 8...optimum for most enzyme reactions.

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

Stomatal Activity (Water Use)

Plants depend upon K to regulate the opening and closing of stomates...the pores through which leaves exchange carbon dioxide (CO_2), water vapor, and oxygen (O_2) with the atmosphere. Proper functioning of stomates is essential for photosynthesis, water and nutrient transport, and plant cooling.

When K moves into the guard cells around the stomates, the cells accumulate water and swell, causing the pores to open and 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 and minimize drought stress to the plant.

If K supply is inadequate, the stomates become sluggish – slow to respond – and water vapor is lost. Closure may take hours rather than minutes and is incomplete. As a result, plants with an insufficient supply of K are much more susceptible to water stress.

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 are more subject to stress when water is in short supply.

Photosynthesis

The role of K in photosynthesis is complex. The activation of enzymes by K and its involvement in adenosine triphosphate (ATP) production is probably more important in regulating the rate of photosynthesis than is the role of K in stomatal activity.

When the sun's energy is used to combine CO_2 and water to form sugars, the initial high-energy product is 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. Conversely, plant respiration increases which also contributes to slower growth and development.

In some plants, leaf blades re-orient toward light sources to increase light interception or away to avoid damage by excess light, in effect assisting to regulate the rate of photosynthesis. These movements of leaves are brought about by reversible changes in turgor pressure through movement of K into and out of specialized tissues similar to that described above for stomata.

How potassium works to increase crop yields:

- Increases root growth and improves drought resistance
- Activates many enzyme systems
- Maintains turgor; reduces water loss and wilting
- Aids in photosynthesis and food formation
- Reduces respiration, preventing energy losses
- Enhances translocation of sugars and starch
- Produces grain rich in starch
- Increases protein content of plants
- Builds cellulose and reduces lodging
- Helps retard crop diseases

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 retarded as a result. An adequate supply of K helps to keep all of these processes and transportation systems 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 (Ca), magnesium (Mg), 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

Potassium is required for every major step of protein synthesis. The "reading" of the genetic code in plant cells to produce proteins and enzymes that regulate all growth processes would be impossible without adequate K. When plants are deficient in K, proteins are not synthesized despite an abundance of available nitrogen (N). Instead, protein "raw materials" (precursors) such as amino acids, amides and nitrate accumulate. The enzyme nitrate reductase catalyzes the formation of proteins, and K is likely responsible for its activation and synthesis.

Starch Synthesis

The enzyme responsible for synthesis of starch (starch synthetase) is activated by K. Thus, with inadequate K, the level of starch declines while soluble carbohydrates and N compounds accumulate. Photosynthetic activity also affects the rate of sugar formation for ultimate starch production. Under high K levels, starch is efficiently moved from sites of production to storage organs.

Crop Quality

Potassium plays significant roles in enhancing crop quality. High levels of available K improve the physical quality, disease resistance, and shelf life of fruits and vegetables used for human consumption and the feeding value of grain and forage crops. Fiber quality of cotton is improved. Quality can also be affected in the field before harvesting such as when K reduces lodging of grains or enhances winterhardiness of many crops.

The effects of K deficiency can cause reduced yield potential and quality long before visible symptoms appear. This "hidden hunger" robs profits from the farmer who fails to keep soil K levels in the range high enough to supply adequate K at all times during the growing season. Even short periods of deficiency, especially during critical developmental stages, can cause serious losses.

Quality factors are addressed in more detail on pages 28 and 29. BC

Production and Use of Potassium

Potassium (K) is essential to all forms of plant and animal life. It is a chemically active metal. Because of its highly active characteristics, K is never found in its pure elemental state in nature. It is always combined with one or more other elements.

Potassium is found widely distributed throughout the Earth's crust. It is the seventh most abundant element in the world. It is not only found in every living plant and animal, but is also found in rocks, minerals, soils, lakes, rivers and oceans.

Agricultural soils may contain from 2 to 30 tons/A of total K in the upper six inches. However, most of this is chemically bound in insoluble mineral forms and is unavailable, or only slowly available to plants.

Many soils have been depleted of available and slowly available K by decades or even centuries of continuous farming with crop removal exceeding inputs. For example, in any given year, the major field crops grown in the U.S. and Canada, including hay and forage, often remove many times more K than is applied.

Potash refers to a variety of K-bearing minerals that are used for fertilizer. It includes potassium chloride [KCl, or muriate of potash (MOP)], potassium sulfate [K_2SO_4, or sulfate of potash (SOP)], potassium-magnesium sulfate (K_2SO_4•$MgSO_4$, or sulfate of potash magnesia), potassium nitrate (KNO_3, or saltpeter), and mixed sodium-potassium nitrate ($NaNO_3$ + KNO_3, or Chilean saltpeter).

The term "potash" comes from "pot ashes" which, in Colonial days in North America, were the primary source of K for fertilizers and for soap, glass, gunpowder, and other industrial uses.

Potash fertilizers are mined and refined from underground ore deposits, salt lakes and brines. North America, the Former Soviet Union, and Europe account for almost 90 percent of world output. Known potash reserves are estimated to be equivalent to 9 billion tons K_2O.

Potash is sold on the basis of its oxide or K_2O equivalent content. For example, chemically pure KCl contains 52.44 percent K or 63.17 percent K_2O equivalent. Converting from K to K_2O or vice versa is a simple calculation: percent K_2O = percent K x 1.2; percent K = percent K_2O x 0.83.

Potash Fertilizer Materials

In North America, MOP accounts for approximately 95 percent of all potash fertilizers. Potassium sulfate and K_2SO_4•$MgSO_4$ are also widely used sources, but account for less than 5 percent of the total. Other forms of potash are used only to a very limited extent. The K content of the most common potash fertilizers is shown in **Table 1**.

Other Potash Materials

Some industrial wastes offer a source of potash. Tobacco stems, wool waste, sugar beet factory waste, flue-dust, and similar wastes from many industries can have limited use.

Mixed Fertilizers

While nearly all the potash fertilizer used comes in one of the forms described above, a considerable proportion of it is applied to the

TABLE 1. Composition of important potash fertilizers.

Form of potash	K_2O (%)	K (%)
KCl	60-62.5	49.8-51.9
K_2SO_4	50-52	41.5-43.2
K_2SO_4•$MgSO_4$	22	18.3
KNO_3	44	36.5

Photo courtesy of Potash Corporation of Saskatchewan Inc.

Giant mining machines cut into the potash ore in underground bedded deposits.

soil as part of a fertilizer which contains one or more other nutrients in addition to potash.

Thus in a 5-20-20 fertilizer, there is 5 percent nitrogen (N), 20 percent P_2O_5, and 20 percent K_2O by weight.

The analyses are always stated in the same order. Blended fertilizers, a physical mixture of such materials as KCl and diammonium phosphate, are widely used. Fluid fertilizers contain relatively small amounts of K in clear solutions but relatively high amounts in suspensions.

Mining of Potash

Most potash fertilizers are mined from **underground bedded deposits**.

In Saskatchewan, Canada, most deposits are more than 3,000 feet below the surface while in New Brunswick the deposits are approximately 2,500 feet below the surface. The Canadian deposits are, however, of high grade, thick, and relatively easy to mine once a shaft is sunk to the level of the bed. In the area of Carlsbad, New Mexico, deposits are located between 700 and 1,800 feet underground.

Solution mining is another method of extracting potash from underground deposits. In this method, water is injected into the deposit through a well to dissolve the salts, and a solution containing the K and sodium (Na) chlorides is withdrawn through another nearby well. This method has advantages when the deposit is irregular in shape or when the depth is too great for conventional mining.

A third method for mining potash is the **evaporation of water from salt lakes and subsurface brines**. This technique is used in the U.S. at the Great Salt Lake and Bonneville Salt Flats in Utah, in Searles Lake in California, and in Israel and Jordan at the Dead Sea. The water that is already near the saturation point in K, Na and Mg salts is further evaporated in shallow ponds, and the different salts are separated.

TABLE 2. World potash production (1997) and reserves by country.

Country	Mine production (million tons K_2O)	Reserve base (million tons K_2O)
Canada	9.3	10,700
Russia	3.1	2,400
Belarus	2.9	1,100
Germany	3.5	960
Brazil	0.3	660
Israel	1.4	640
Jordan	1.3	640
China	0.1	350
U.S.A.	1.6	260
Others	2.4	340
World total	25.9	18,050

Numbers may be rounded.
Source: U.S. Dept. of Interior, Bureau of Mines.

Potash Production and Consumption

Total world production increased from 15.9 million short tons K_2O in 1966 to 27.2 in 1976 and 31.7 in 1986. Production declined slightly to 25.3 million tons in 1996 and 25.9 million tons in 1997.

Seven countries produced 90 percent of the world's potash in 1997 (**Table 2**). Canada was the largest producer at 36 percent, followed by Germany (14 percent), Russia (12 percent), and Belarus (11 percent). U.S. production represented 6 percent of world output. Other producing countries include Brazil, Chile, China, France, Spain, Ukraine, and the United Kingdom, while very little or no potash is produced on the continents of Africa or Oceania.

Since the initiation of potash mining in Canada in 1962, production in North America has shifted from the U.S. to Canada. The high-grade ore reserves in Saskatchewan and New Brunswick are more economical to mine than the lower grade ore reserves remaining in the Carlsbad, New Mexico, basin.

Europe and the Former Soviet Union accounted for 30 percent of world potash consumption in 1997, followed by Asia at 25 percent, the U.S. at 25 percent, and Latin America at 15 percent.

In the fertilizer year ending June 30, 1997, 86 percent of the 10.8 million tons K_2O produced in North America came from Canada. Saskatchewan produced about 92 percent of Canada's potash. More than half of the Canadian production (60 percent) was shipped to the U.S.

The use of potash in the U.S. and Canada showed phenomenal growth in the three decades preceding 1980. In 1950, 1.5 million tons K_2O were used. By 1960, the figure was 2.2 million, and in 1970, 3.5 million. Consumption in the two countries peaked at more than 6 million tons in 1980 with more than 90 percent used in the U.S.

Since 1980, potash use in North America has fluctuated between 5 and 6 million tons K_2O. Much of this fluctuation is attributable to reduced prices for most crops in recent years, coupled with acreage control programs in the U.S.

Photo courtesy of IMC Global Inc.

Canada is the world's largest producer of potash. Large reserves remain there and in other countries.

Reserves and Resources

Potash reserves are those that can be mined economically under short-term marketing conditions. The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic, and some that are currently subeconomic. Resources include proven, probable and inferred reserves.

In 1997, global reserves were estimated to be 9 billion tons K_2O, while the reserve base was estimated at about 18 billion tons (**Table 2**). Canada and Russia have over 70 percent of the total reserve base.

In addition to those listed in **Table 2**, other producing countries have small reserves (Chile, France, Spain, Ukraine, and the United Kingdom) and undeveloped deposits exist in a number of other countries.

Estimated world resources of potash total about 250 billion tons. Canada's potash resources are estimated at about 48 billion tons, and total U.S. resources are estimated at about 6 billion tons. Most of U.S. resources occur as bedded deposits between 6,000 and 10,000 feet below the surface in Montana and North Dakota. Some 2 billion tons occur 4,000 feet below surface in Utah and at least 25 million tons about 7,000 feet deep in Michigan. At these depths, solution mining is the only recovery method that is feasible. At present production levels, North America has sufficient potash resources for several thousand years. BC

Effects of Potassium on Crop Maturity

Crop stress caused by too little K can exhibit itself in many ways...increased incidence of diseases...lodging in corn and other crops...less winterhardiness in forage legumes and grasses...and premature "cutout" in cotton. Potassium stress on corn, for example, will result in the accumulation of high sugar content in the stalks by midseason. Apparently, the low K levels in the sap prevent the normal translocation of sugar to ears, disrupting the growth cycle and preventing normal grain development. Potassium, then, has a direct influence on crop maturity because the grain never develops.

Potassium (K) influences crop maturity in different ways. It speeds silking in corn, but lengthens time of grain fill, thus increasing yield potential. Higher moisture at harvest in an adequate K environment indicates K stretches the growing season in corn. Potassium deficiency delays maturity in soybeans. With adequate K, cotton yields are increased by extending the boll-filling period and preventing premature senescence or "cutout". The effects of K on maturity of fruits and vegetables are variable.

Research has shown that application of starter fertilizers containing nitrogen (N), phosphorus (P) and K hastens the maturity of corn from a few days to as much as a week. In addition, adding the nutrient that is in shortest supply advances maturity, whether it is applied through the planter or broadcast. The greater the yield and growth response to the nutrient, the more maturity is hastened.

Potassium hastened silking in corn in a Kentucky study. It reduced days from emergence to silk, **but delayed maturity** by as many as five days. The net effect was an increase of seven days in time of grain development...and higher yields. Results are shown in **Table 1**.

Other studies have shown that K hastens silking, but most show that it does not shorten the total production cycle. In other words, there is a longer grain filling period.

The percent of ears silked on a given date can give an exaggerated impression of maturity differences from fertilizer applications. Data in **Table 2** illustrate the point. Results were taken from the northern Corn Belt.

The plot that was only 25 percent silked on August 5 was probably 90 percent silked about three or four days later, approximately the difference in maturity indicated by the moisture contents of 40.9 percent and 39.2 percent.

Illinois research showed that corn silk emerged sooner when K was added to a medium K soil. The conclusions were that the K influence on silking could boost corn yield by lengthening the grain filling time. Adequate K helps prevent pollen shed and silking times from getting mismatched during hot, dry weather when silking is often delayed. Results are shown in **Table 3**.

Even with earlier silking, K can delay maturity if it does influence the length of time for grain fill. In an Ohio study, optimum

Adequate K nutrition offers benefits in development and maturity of corn, soybeans and other crops.

TABLE 1. Potassium increases number of grain development days for corn.

K_2O rate, lb/A	Days from emergence to silk	Days from emergence to maturity	Days of grain development	Yield, bu/A
0	83	138	55	142
60	81	142	61	155
240	80	142	62	170

TABLE 2. Relationship between silking date and corn grain moisture.

Percent silked on August 5	Percent moisture at harvest
25	40.9
80	40.4
90	39.2

TABLE 3. Potassium hastens corn silking.

K_2O rate, lb/A	% of plants silked
0	14
50	34
100	38
200	67

N and K rates increased yields, improved N utilization efficiency, and tended to increase grain moisture at harvest...an indication of an extended period of grain fill and a definite effect on maturity, **Figure 1**.

The tendency for added K to increase moisture content may have an indirect effect on physiological maturity as well. Studies have shown that low K causes early death of corn plant tissue, allowing stalk rot to kill the plant prematurely.

Soybeans can suffer from delayed maturity because of K starvation. When K is low, plants are usually stunted. Leaves show yellowish margins, and both leaves and stems remain green after normal plants have matured and dropped their leaves.

Other Ohio studies comparing combinations of low, medium, and high soil tests of P and K showed no significant interactions between these two nutrients on corn or soybean grain moisture (maturity). High soil test K levels ***reduced*** soybean grain moisture from 14.3 to 13.1 percent at harvest, and yields were increased by almost 10 bu/A (**Figure 2**).

The overall influence of K on cotton maturity ranges from speeding it up to no effect to a delay. Many of these differences can be related to the level of N nutrition and imbalances with K. Similar to disease and K nutrition effects in corn, low K can result in an increase in foliar leaf spot diseases in cotton, premature defoliation, and reduced yields. In Louisiana on a low K, acid soil, K had no effect on first harvest yields without lime. But when dolomitic lime was applied, K increased both first harvest and total yields (**Table 4**).

Proper K fertilization in Mississippi increased lint yield, with proportionately more of the yield developing later in the season. The effect was similar among four varieties which represented a range in earliness (**Table 5**).

Recent soil and foliar K fertilization research with no-till cotton in Tennessee showed that adequate soil-applied K reduced

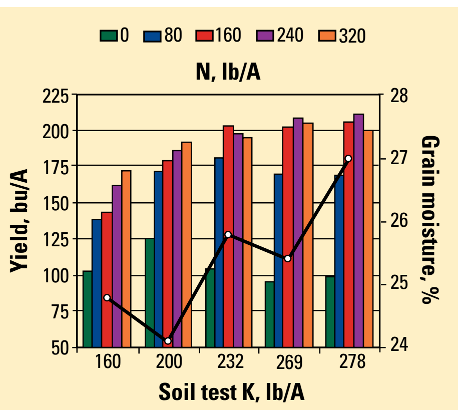


Figure 1. Effect of K and N on corn grain yields and moisture content (4-year average).

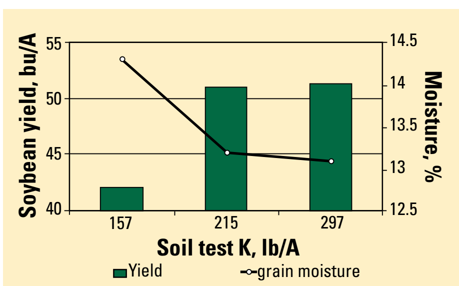


Figure 2. Effect of K levels on soybean grain yields and moisture (4-year average).

the percent first harvest from 80 percent down to 65 percent (**Table 6**), yet increased the first harvest yield by 68 percent and doubled total lint yield on a low K soil. Some cotton producers mistakenly believe that K delays maturity. Instead, K increases the first harvest yields, the second harvest yields, and total lint yields by allowing plants to take full advantage of soil moisture, sunlight and other plant nutrients. Extension of the boll filling period as a result of improved K nutrition would have little potential for negative economic consequence except in the most northern reaches of the cotton production belt in North America.

TABLE 4. Potassium and lime increase first harvest and total yields of seed-cotton.

K_2O rate, lb/A	First harvest yield, lb/A	Total yield, lb/A
No lime		
0	684	1,008
64	685	1,194
Dolomitic lime		
0	1,057	1,283
64	1,400	1,920

TABLE 5. Cotton lint yield and percent harvests at two K fertilization rates, averaged among four varieties (2-year average).

K_2O rate, lb/A	Lint yield, lb/A	% at first harvest	% at 2 weeks after first harvest	% at 4 weeks after first harvest
0	876	34	34	32
100	960	29	34	36

TABLE 6. Potassium effects on earliness of no-till cotton.

K treatment, lb K_2O/A		Lint yield, lb/A			Proportion in 1st harvest, %
Soil-applied	Foliar-applied	1st harvest	2nd harvest	Total	
0	0	411	103	514	80
0	17.6	623	192	815	76
120	0	694	359	1,053	65
120	17.6	648	362	1,010	64

In the more northerly regions with short growing periods, appropriate cultivar selection and timely planting can enhance the ability to capture potential yield benefits from adequate K nutrition, before a killing frost arrests boll development.

The effects of K on maturity of fruit and vegetable crops vary. In one study, K increased early harvest and total yields of tomatoes, but had no effect in another study. Adequate K has been shown to reduce premature drop of tomatoes and citrus fruits. There may be a slight early season advantage from K on cauliflower. But high K rates have delayed maturity of broccoli, **Table 7**.

TABLE 7. Effect of K on the number of broccoli terminals mature by midseason.

K_2O rate, lb/A	Terminals mature by midseason		
	Location 1	Location 2	Location 3
0	147	139	148
85	124	127	130
170	142	116	142
225	102	134	119

In a North Carolina study, K increased yields and hastened the maturity of blueberries. Early maturity of fruits and vegetables almost always offers the advantage of higher prices in the marketplace. BC

Potassium Interactions with Other Nutrients

Potassium affects nitrate (NO_3) absorption and reduction. Rapid NO_3 uptake depends on adequate K in the soil solution. Activity of the enzyme glutamine synthetase in wheat is lower when K is deficient.

Potassium stimulates leaf protein synthesis. Up to 65 percent of the variability in grain quality traits, such as amino acid makeup, is due to non-genetic factors, including K nutrition.

In a nutrient solution study, higher rates of K allowed for the efficient use of more nitrogen (N), which resulted in better early vegetative growth and higher grain and straw yields as K and N rates increased.

In the field, better N uptake and utilization with adequate K mean improved N use and higher yields. Crops respond to higher K levels when N is sufficient, and greater yield response to N fertilizer occurs when K is sufficient. Corn studies in Illinois and Ohio provide examples of this economically and environmentally important interaction (**Figure 1**).

Potassium (K) is unique among the essential nutrients in the diversity and number of roles it plays in plant chemical processes. To perform these varied and multiple roles, K uptake and utilization often interact with the availability and uptake of other nutrients.

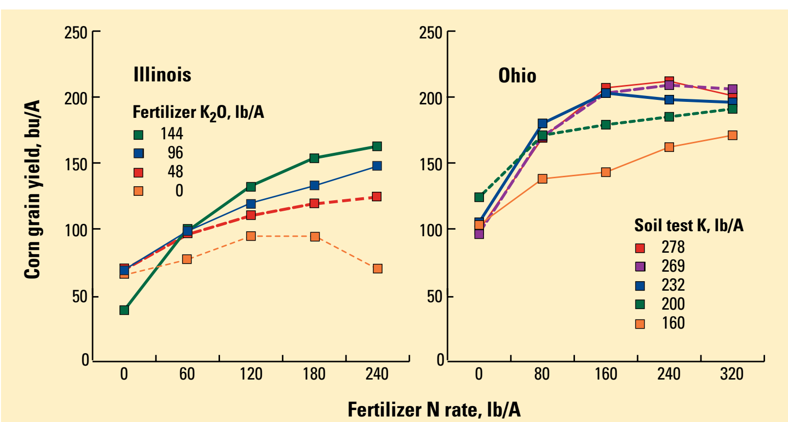


Figure 1. Potassium improves yield response to N fertilizer and N efficiency.

Potassium Uptake

Nitrogen form can affect K absorption. For example, tomatoes grown in nutrient solution with NO_3-N have shown a higher relative growth rate than plants supplied with ammonium-N (NH_4-N). After 4 days, the total K content decreased in NH_4-grown tomato plants and remained constant in those supplied with NO_3.

Similarly, when corn was grown with either NH_4 or NO_3 as the N source, both yield and total N uptake were lower with NH_4-N as the source.

However, when the highest K rate was used, vegetative growth (yield) and N and K uptake were improved with the NH_4-fed plants.

It is clear that K interacts with N and is important in its utilization throughout the crop growth and yield production cycle.

Potassium-Phosphorus Interactions

Research has shown that K interacts with phosphorus (P) and that together they may interact with other nutrients. A good example is the observed reduction of P-induced zinc (Zn) deficiency of corn when available K levels are increased. Manganese (Mn) content of the corn plants also increases,

TABLE 1. Phosphorus and K interact for higher soybean yields.

P_2O_5	K_2O	Yield, bu/A
lb/A		
0	0	25.8
30	0	30.8
0	120	46.2
30	120	54.9

TABLE 2. Positive P-K interaction produces higher Coastal bermudagrass yields.

P_2O_5	K_2O	Yield, tons/A
lb/A		
0	0	2.68
0	360	2.63
230	0	3.26
230	360	4.55

indicating there is some relationship of K, P, Mn, and Zn in this complex effect...resulting in less severe Zn deficiency.

A more simple P-K interaction, but perhaps of more widespread importance, is their synergistic effect on yield (**Tables 1** and **2**).

In these cases, besides their individual effects on yield, P and K together produced an extra 15 percent positive yield interaction for soybeans and 50 percent for Coastal bermudagrass.

Potassium, Calcium and Magnesium Interactions

Low magnesium (Mg) or calcium (Ca) in forages can affect animals by producing low blood serum Mg or Ca (grass tetany).

Incidence of tetany tends to be lower if forage Mg exceeds 0.2 percent and Ca exceeds 0.4 percent. High plant K can have an antagonistic effect on Mg concentrations, particularly when Mg is low in soils.

Seasonal changes in forage composition may be associated with factors such as levels and forms of N absorbed by plants. Absorption of NH_4-N may result in greatly reduced uptake of Ca and Mg while having lesser effects on K.

Large amounts of NH_4-N in the soil would have the same effect on a forage as that of K, causing depressed uptake of Ca and Mg.

Sudden rises in temperature tend to be associated with wider K/(Ca+Mg) ratios, which correspond with a higher grass tetany potential. Higher temperatures tend to increase the K uptake faster than that of Ca and Mg.

Generally, additions of K, Ca or Mg result in a lower concentration of the remaining two cations, regardless of the crop grown.

Research has shown that P fertilization of fescue pastures can significantly increase Mg and Ca contents of leaves early in the spring when the potential for tetany is highest.

Potassium/Sulfur Interactions

Sulfur (S) nutrition of barley plants has an influence on the effect of K on Zn uptake from nutrient solutions. Apparently, good S levels along with adequate K improve Zn uptake.

Potassium/Micronutrient Interactions

Many interactions have been reported between K and micronutrients. Some of those reported with Zn (as they have involved P and S) have already been noted. Interactions with some of the micronutrients...boron (B), iron (Fe) and molybdenum (Mo)...have resulted in decreased uptake when K was added. For others...copper (Cu), Mn and Zn...use of K has increased micronutrient utilization.

An interesting observed interaction is that between K and sodium (Na) on alfalfa. When K is deficient, the classical K deficiency symptom is quite apparent. However, for alfalfa grown on soils high in Na, the K deficiency symptom has a somewhat different appearance. See photos on page 21.

The interactions between K and micronutrients have not yet been well characterized. Further study, especially under field conditions, is necessary.

Summary

Potassium is known to interact with almost all of the essential macronutrients, secondary nutrients, and micronutrients. Future improvements in yield and quality will require a better understanding and management of these interactions.

As livestock feeding operations, industrial uses, and food processors move to special varieties and identity-preserved marketing, nutrient effects on grain quality traits will become even more important. BC

Potassium Availability and Uptake

Plants differ in their ability to take up 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.

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.

Soil Factors

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

The cation exchange capacity (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. Clay minerals and soil organic matter are the two parts of soil that contribute to CEC. In general, the higher the CEC of the soil, the greater the storage capacity and supplying power for K.

The quantity of available K in the soil. This is the value the K soil test reflects. It is the sum of exchangeable K and water soluble K. As the level of soil test K decreases, the crop response to applied K increases.

The nonexchangeable or slowly available K. This is the K that is in equilibrium with 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.

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.

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.

If dense layers (fragipans, etc.) develop in the subsoil, root penetration and rooting volumes are decreased, reducing the availability of K and other nutrients that are there. Root systems are frequently shallow, with roots concentrated in the upper layers where K supply may be adequate, but where shortage of water can make it unavailable to plants.

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 85ºF.

Effects of low temperature can be somewhat offset by increasing soil K levels. Row K can be important with lower soil temperatures, especially for early planted and minimum till crops.

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

Moisture is needed for root growth through the soil to "new" supplies of K. It is needed for mass-flow movement of K to the plant roots with water and for the diffusion of K to the roots to resupply that taken up by the roots. Drought stress or excess moisture reduces K availability and uptake by crops. Increasing soil K levels can help overcome the adverse effects.

Soil tilth. Tilth 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.

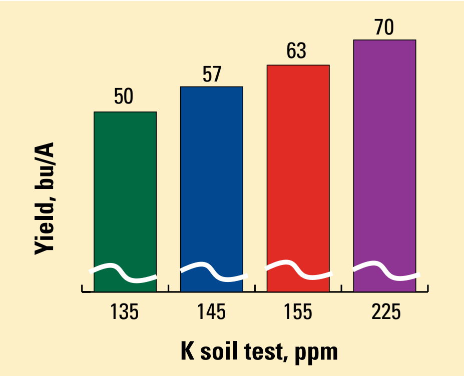


Figure 1. Higher K soil tests can increase soybean yields.

Plant Factors

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

This is associated with the type of root system and surface area of the roots. Grasses, for example, have a much greater capacity to take up K from the plow layer than alfalfa does. Grasses have many more fibrous, branching roots, increasing the K absorbing surface.

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. Plant K content, in turn, has major influence on plant water relations and metabolic processes, often serving as a regulator of physiological processes. Potassium as a nutrient has a very positive effect on root branching and density.

Another factor is that new varieties often have higher yield potentials which increase the demands placed on soil to supply enough K. Additional K will be needed under higher yields.

Plant populations. As plant populations increase, yields 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.

Crop yield. As crop yields increase, total K uptake increases. The uptake per unit of crop yield, such as pounds of K per bushel or ton, may be nearly constant at optimum yield levels.

Fertilizer and Management Practices

Increased use of nitrogen (N) and other limiting nutrients. When adequate K is available, addition of N and/or phosphorus (P) greatly increases 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.

Applications of K in fertilizers, manures or crop residues. The major way to increase K availability is to apply adequate amounts. Potassium is readily available from all these sources, provided they are located where roots can absorb the K. **Figure 1** illustrates how higher soil test levels can increase yields.

Placement of K. Broadcast plow-down applications of K are more available than surface applied disked-in K. Row K at moderate rates and soil test levels is usually twice as available to corn as similar amounts broadcast. Deep placement or drip irrigation helps move K down. Gypsum applied with K also helps move K down in very fine textured soils.

Conservation tillage limits availability of surface applied K. Soil K levels should be built to high levels before shifting to minimum or conservation tillage. This improves K distribution within the plow layer. In many fine textured soils, surface applied K moves very little in the soil and has low availability, particularly under dryland conditions.

Drainage increases K availability. Draining soils of excess moisture helps many soils warm up earlier and improves the aeration of the soil. This improves the availability of soil K.

Weed and insect control. Controlling weeds and insects reduces competition for moisture and nutrients, so that the crop being produced has relatively more K available. BC

Yield and Economic Responses to Potassium

Successful farmers know that they must spend money to make money. They look for income-earning inputs that make their farming operations profitable. However, pessimism and negative talk cause some to try to save money by skimping on or omitting income-earning practices. Cutting costs in the wrong place may reduce profits by lowering yields, which makes the unit costs of production higher.

Farmers must reduce their costs per unit of harvested crop in order to optimize profits during times of depressed crop prices. High yields distribute production costs over more bushels or tons, resulting in lower costs per unit of crop production.

Potassium (K) fertilization is one of the vital income-earning inputs that enables farmers to produce crops at lower unit cost. Not only can K boost yields, but it is also one of the least expensive nutrients to buy. Many experiments clearly show the economic benefits of K fertilization for a wide range of soils and cropping conditions in the U.S. and Canada. Several examples have been selected from such studies to illustrate the substantial impact of K on improving earnings.

In this article, the costs considered for K fertilization were soil sample analyses, fertilizer, application, and harvest costs. Soil samples, taken every 2 years, representing 5 acres, and analyzed for phosphorus (P), K and pH, were assumed to cost \$0.75/A/year for chemical analysis. Potassium fertilizer price was set at \$0.14/lb K_2O. Application costs of \$3.00/A, associated with dry bulk applications, were assumed unless otherwise noted. Harvest costs for grain were \$0.17/bu, which included handling (auger, tractor and labor), hauling from field to farmstead, and hauling from farmstead to market. For corn, an additional harvest cost of \$0.18/bu was incurred for drying, assuming harvested corn was dried to 15.5 percent at \$0.022 per percentage point. This brings the fixed costs of K applications (including sampling) to \$3.75/A and the variable harvest costs to \$0.17/bu (grain crops other than corn) or \$0.35/bu (corn). Base costs for crop production footnoted in each table included direct and overhead expenses.

Corn: Table 1 shows how K fertilization in Ohio increased corn yields and profits on a Crosby soil testing low to medium in K. These data demonstrate that applying needed K can

TABLE 1. Potassium fertilization increases corn yields and return per acre by lowering the unit cost of production (Ohio).

K_2O rate, lb/A	Corn grain yield, bu/A	Total yield income, \$/A	Additional harvest costs from yield response to K, \$/A	Additional input costs from K fertilization, \$/A	Total cost per bushel, \$/bu	Net profit, \$/A
0	146	328.50	–	–	2.05	28.50
50	167	375.75	7.35	9.25	1.90	59.15
100	174	391.50	9.80	16.25	1.87	65.45
200	187	420.75	14.35	30.25	1.84	76.15
400	188	423.00	14.70	58.25	1.98	50.05

Base cost without K = \$300/A; soil test K = 126 to 209 lb/A.
Corn = \$2.25/bu; K applied every other year, so amortized application costs were \$1.50/A/yr.

TABLE 2. Deep banded K boosts yields and profitability on a soil testing 314 lb/A K in a ridge-till system (Minnesota).

Deep banded K_2O rate, lb/A	Corn grain yield, bu/A	Total yield income, $/A	Additional harvest costs from yield response to K, $/A	Additional input costs from K fertilization, $/A	Total cost per bushel, $/bu	Net profit, $/A
0	153	344.25	–	–	1.96	44.25
20	162	364.50	3.15	7.55	1.92	53.80
40	162	364.50	3.15	10.35	1.94	51.00
60	159	357.75	2.10	13.15	1.98	42.50
80	165	371.25	4.20	15.95	1.94	51.10

Base cost without K = $300/A; corn sale price = $2.25/bu; band application = $4.00/A.

result in higher yields, which lowers production costs per unit of crop yield.

Tillage and soil management systems can change the need for fertilizer K. In Minnesota, yield responses to K banded below the seed in ridge-till systems have been observed, even on soils testing high in K (**Table 2**). This response is probably related to lower soil K levels within the ridge. Reduced tillage systems can often have stratified levels of soil K that can reduce the availability of K to the crop under adverse conditions. Other factors which can lead to K responses on high K soils include cool, wet conditions, low soil moisture, compaction, low pH, high amounts of calcium (Ca), magnesium (Mg), and/or sodium (Na), and the presence of K-fixing minerals. Also, some soils may simply lack the capacity to supply K fast enough to satisfy crop needs during critical periods of rapid uptake.

Soybeans: Soybeans respond well to K, giving consistent, profitable increases at many locations. The Ohio data in **Table 3** demonstrate the reduction in costs per bushel resulting from K fertilization. Ohio data have also shown the importance of K fertilization in

TABLE 3. Potassium fertilization increases soybean yields and reduces cost per bushel (Ohio).

K_2O rate, lb/A	Soybean yield, bu/A	Total yield income, $/A	Additional harvest costs from yield response to K, $/A	Additional input costs from K fertilization, $/A	Total cost per bushel, $/bu	Net profit, $/A
0	40	250.00	–	–	5.13	45.00
40	43	268.75	0.51	9.35	4.99	53.89
80	45	281.25	0.85	14.95	4.91	60.45
120	48	300.00	1.36	20.55	4.73	73.09

Base cost without K = $205/A; soybean sale price = $6.25/bu.

TABLE 4. Potassium fertilization increases soybean yields and quality on a low K soil in Virginia.

K_2O rate, lb/A	Soybean yield, bu/A	Total yield income, $/A	Moldy beans, %	Dockage for poor soybean quality, $/A	Additional harvest costs from yield response to K, $/A	Additional input costs from K fertilization, $/A	Total cost per bushel, $/bu	Net profit, $/A
0	38	237.50	31	132.24	–	–	8.87	-99.74
120	47	293.75	12	56.40	1.53	20.55	6.03	10.27

Base cost without K = $205/A; soybean sale price = $6.25/bu; dockage for poor soybean quality = $0.12/pt./bu over 2%.

TABLE 5. Adequate K improves spring wheat yield and grain protein content on a low K soil in northeastern Saskatchewan.

K_2O rate, lb/A	Spring wheat yield, bu/A	Total yield income, $/A	Grain protein, %	Additional harvest costs from yield response to K, $/A	Additional input costs from K fertilization, $/A	Total cost per bushel, $/bu	Net profit, $/A
0	34	119.00	13.3	–	–	4.26	-26.00
30	45	157.50	13.8	1.87	7.95	3.44	2.68
60	43	150.50	13.9	1.53	12.15	3.69	-8.17
120	54	189.00	13.9	3.40	20.55	3.13	20.05
240	60	210.00	14.8	4.42	37.35	3.11	23.23
480	63	220.50	15.0	4.93	70.95	3.51	-0.38

Base cost without K = $145/A; spring wheat sale price = $3.50/bu.

adverse conditions, with the greatest soybean yield and profit increases coming from K in dry years. Yield losses incurred from good years to dry years were also cushioned by the use of K.

Substantial improvements in the economics of soybean production occur from the favorable influence of K on quality. This important aspect of K fertilization is readily apparent in **Table 4**.

Small Grains: Although many of the soils in the heart of the Wheat Belt are high in available K, there are some requiring K fertilization for profitable wheat production. For example, yield increases of at least 4 to 10 bu/A resulted from K additions in six states and provinces. Returns on investments from K applications, usually less than 60 lb/A, were 200 percent or higher approximately 60 percent of the time.

On a low K soil in northeastern Saskatchewan, potassium chloride (KCl) fertilization raised spring wheat yields from 34 to 63 bu/A and greatly increased profit (**Table 5**).

No credit was given for higher grain protein in these calculations. When market demands exist for higher protein content, high protein wheat can sell at a premium, providing additional profits.

Applications of KCl on high K testing soils have frequently increased yields of both hard red winter and hard red spring wheat in the Plains states and Prairie Provinces of Canada. These responses are apparently due to K in some situations and to Cl in others.

Responses of barley and wheat to chloride (Cl) fertilization have been extensively studied, and research continues. Chloride is generally beneficial in high disease environments where soil Cl levels are low. A number of diseases in wheat such as the take-all, common and dryland root rots, leaf and stripe rusts, tan spot, and septoria are suppressed by Cl. Response data from more than 200 responsive and non-responsive trials in Kansas, Manitoba, Minnesota, Montana, North Dakota, South Dakota, Saskatchewan, and Texas have been summarized. These data show that for all sites studied, the average yield increase to Cl fertilization was 2.4 bu/A...the average being 5.2 bu/A on responsive sites. Assuming an application of 30 lb Cl/A, this translates to net returns of $2.34/A and $11.67/A for all sites and responsive sites only, respectively.

Cotton: Potassium is essential for maximizing the profitability of cotton production. **Table 6** shows a cotton yield response to broadcast applications of K. Costs considered for K fertilization were those assumed earlier in this article ($0.14/lb K_2O and fixed input costs of $3.75/A). Using K also improved cotton lint quality properties including micronaire and fiber length and elongation (see page 28).

Foliar applications of K on cotton can be profitable for fast-fruiting cultivars grown on soils low in K. A study in Tennessee showed that foliar applications of K were profitable for at least two years, even when relatively high rates of K were soil-applied each year. In this study, K was soil-applied at rates from zero to 120 lb K_2O/A. In addition, 40 lb/A of potassium nitrate (KNO_3) was foliar applied in 10 lb/A increments on a 9 to 14 day interval starting at or shortly after bloom. The KNO_3 was $0.26/lb, and the foliar application costs were about $9/A. A recent 10-year average Tennessee cotton price of $0.584/lb was used. Net revenue gain from foliar fertilization (**Table 7**) was calculated by subtracting the product and application costs from the additional revenue gained from cotton yield responses.

TABLE 6. Fertilizer K boosts cotton yields (Mississippi).

K_2O rate, lb/A	Lint yield, lb/A	K input costs, $/A	Return to K, $/A
0	1,061	–	–
120	1,169	20.55	42.52

Cotton price = $0.584/lb.

TABLE 7. Economic responses of cotton to foliar applications of K (Tennessee).

Initial soil test K level, ppm[1]	Tillage	Year	Net revenue gained from foliar application of KNO_3, $/A, at various rates of soil applied K, lb K_2O/A: 0	30	60	90	120
45	Conventional	1	-3	27	41	39	21
		2	21	18	14	8	2
		3	15	13	3	-14	-39
		4	40	76	82	58	6
40	No-till	1	16	35	46	49	43
		2	46	27	18	20	33
		3	66	31	7	-6	-9
		4	123	66	20	-14	-36

[1]ppm = parts per million.

Alfalfa: High-yielding alfalfa removes large amounts of K from the soil, usually from 50 to 75 lb of K_2O/ton of dry matter. Most farmers don't apply enough K for their alfalfa, losing yields and profits while draining soil K supplies. The profitability of K fertilization, as in other crops, depends in part on soil test K levels.

TABLE 8. Potassium recommendations and net returns change with soil test levels.

Soil test K	Optimum K rate, lb K_2O/A	K input costs, $/A	Yield response, ton/A	Net return to K, $/A
Very low	335	50.65	1.2	57.35
Low	260	40.15	1.0	49.85
High	90	16.35	0.2	1.65

Hay price = $90/ton.

Normally, less K is required on soils with higher K levels. Some examples of using K at the most economic rate are shown in **Table 8**. Data for **Table 8** came from Wisconsin, New York and Pennsylvania. At lower soil K levels, more K is needed to maximize profitability.

Summary

The most profitable farm operations are not the ones that have the lowest operational costs. Instead, wise investments are the key to financial success. Applications of K can be very profitable when K is in short supply. In such cases, increased returns are achieved only through increased investments. Identifying situations where K is limiting and investing in K fertilizer inputs is a practice that can substantially boost profits. BC

Potassium Deficiency Symptoms in Some Crops

In modern commercial agriculture, symptoms of potassium (K) deficiency are not as commonly seen as in earlier years. However, visual symptoms and "hidden hunger" do still occur in some circumstances. Of course, other conditions can cause poor growth or yield limitation. It's also important to consider possible interactions with other nutrients or treatments.

Following are photos and descriptions of K deficiency for several major crops.

Corn: Firing or scorching appears on outer edge of leaf, while midrib remains green. May be some yellow striping on lower leaves. (Sorghum and most grasses also react this way.) Poor root development, defective nodal tissues, unfilled, chaffy ears, and stalk lodging are other symptoms in corn.

Soybeans: Firing or scorching begins on outer edge of leaf. When leaf tissue dies, leaf edges become broken and ragged...delayed maturity and slow defoliation... shriveled and less uniform beans, many worthless.

Alfalfa: With classical symptoms (shown at top right), first signs of K deficiency are small white or yellowish dots around outer edges of leaves...then edges turn yellow and tissue dies and becomes brown and dry. However, for alfalfa grown on soils high in sodium (Na), the K deficiency symptom has a different appearance, as indicated in the photo at left above.

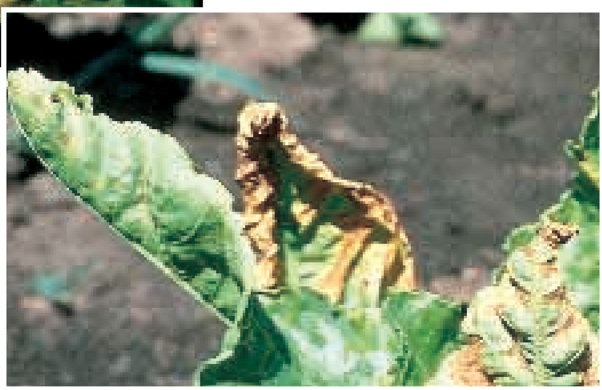
Cotton: Cotton "rust"...first a yellowish or bronze mottling in the leaf. Leaf turns yellowish green, brown specks at tip around margin and between veins. As breakdown progresses, whole leaf becomes reddish brown, dies, sheds prematurely. Short plants with fewer, smaller bolls of short, weak fibers. In the past, K deficiency symptoms have been described as occurring on older, mature leaves at the bottom of the plant. In recent years, symptoms have been observed at the top on young leaves of some heavily fruited cotton varieties.

Wheat: Frequently, outstanding hunger signs on leaf itself (no discoloration, scorching, or mottling), but sharp difference in plant size and number, length, and condition of roots. Lodging tendency. Smaller kernels. In advanced stages, withering or burn of leaf tips and margins, beginning with older leaves.

Potatoes: Upper leaves usually smaller, crinkled and darker green than normal with small necrotic patches...middle to lower leaves show marginal scorch and yellowing. Early indicator: dark green, crinkled leaves, though varieties differ in normal leaf color and texture.

Apples: Yellowish green leaves curl upward along entire leaf...scorched areas develop along edges that become ragged. Undersized and poorly colored fruit may drop prematurely. Poor storage, shipping and canning qualities in fruit.

Rice: Rice deficient in K may show symptoms as stunted plants, a slight reduction in tillering, and short, droopy, dark green upper leaves. Yellowing may appear in interveinal areas of lower leaves, starting from the top and eventually drying to a light brown. Long, thin panicles and black, deteriorated roots may be related to K deficiency.

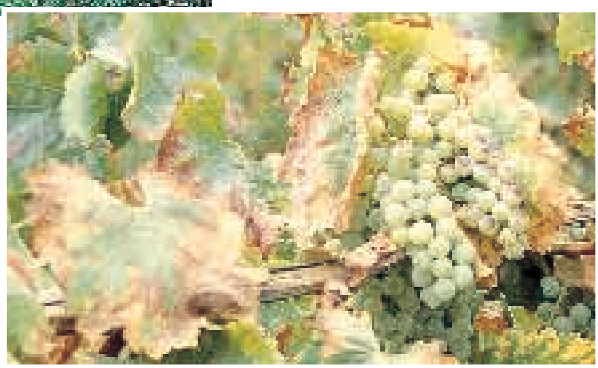


Sugarbeets: The first sign of K deficiency appears as tanning and leathering of the edges of recently matured leaves. When the soil solution is very low in Na, a severe interveinal leaf scorch and crinkling proceeds to the midrib. Under high Na conditions, tanning and leaf scorch lead to a smooth leaf surface.

Canola: Potassium deficiency reduces growth, resulting in smaller leaves and thinner stems. Plants are more easily lodged and may wilt. Under severe deficiency, the edges of older leaves become yellow, or scorched and may die completely, but remain attached to the stem.

Peanuts: Because K is easily redistributed from mature to younger organs, deficiency symptoms are first observable in the older, lower leaves. Deficiency is expressed by chlorosis of the leaves, beginning at the leaf margin. Potassium deficiency occurs frequently in acidic soils, and symptoms usually appear within five weeks of planting.

Coastal Bermudagrass: Potassium plays an important role in heat, drought and cold tolerance of forage grasses. Leafspot diseases may be the first symptom of K deficiency recognized in Coastal and other hybrid bermudagrasses. Yellowing of older leaves, followed by leaf tip and leaf margin chlorosis, can occur with severe deficiency. Reddish-brown to purple spots, caused by fungal infection, may also be scattered over younger leaf blades. Thinning stands and reduced growth, followed by death of older leaves, are frequent symptoms.



Grapes: Potassium deficiency symptoms typically appear in early summer on leaves on the middle portion on the shoots. The leaves fade, becoming chlorotic beginning at the leaf margin, while the center portion of the leaf and veins remain green. The leaves tend to cup downward. In white wine varieties (such as Chardonnay, shown in photo) the leaves become mostly yellow or yellow bronze.

Potassium Application Methods

Potassium is a monovalent cation and is readily adsorbed by the soil's cation exchange sites. It is not generally considered to be mobile in soil. Thus, the K available to plants is that in close proximity to the roots. Placement of supplemental K close to the plant is important for improving uptake and use efficiency under certain conditions. Research is currently focusing on identifying when such placement provides benefits beyond those attained from maintaining higher soil test K levels.

Crop responses to placement of potassium (K) fertilizer are receiving more attention. Current research efforts focus upon identifying soil characteristics or growing conditions that may warrant placement of high concentrations of K in the vicinity of developing plant roots.

Methods

Researchers have explored a number of K application methods including: (1) surface broadcast with and without incorporation; (2) direct seed placement; (3) row placement (banded) – including all combinations of distances below and to the side of the seed; (4) plow sole placement; (5) deep or knife placement; (6) surface strip applications; (7) fertigation; (8) high pressure injection; (9) point injection; and (10) combinations of the various methods.

All of these application methods can be considered variations or combinations of two basic placements: (1) banding in high concentrations with a minimum of soil contact and (2) broadcasting.

Results

Responses to K placement vary among crop types, soil and environmental conditions, and tillage practices.

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 broadcast and banded K. Banded K was more effective on all three soils tested. Even at high rates of application, broadcast K was not as effective as that banded near the seed on two of the three soils.

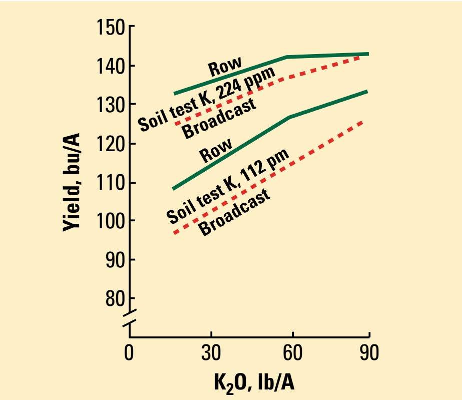


Figure 1. Differences between K application responses are smaller as K test rises (Tennessee); ppm=parts per million.

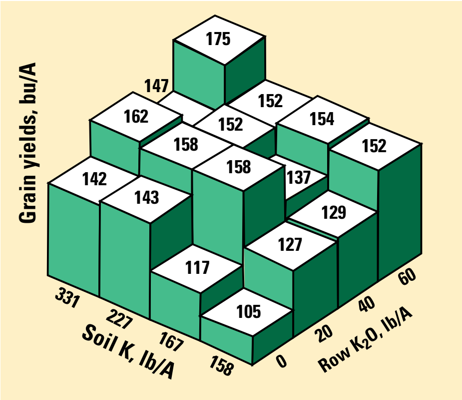


Figure 2. Starter K can be effective even at high soil test levels (Wisconsin).

Differences among the methods of K application usually diminish as K soil test values rise and as rates of application increase (**Figure 1**). 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 2**).

Tillage is an important factor for determining the responsiveness of corn to applied K. Potassium deficiencies are being observed in the upper Midwest on soils testing very high in K. Although all of the causes for this phenomenon have yet to be revealed, stratification of K in soils under reduced tillage is an important factor. Potassium supplies near the surface may be inaccessible by roots under drier conditions, when roots proliferate deeper in soil. Data from Minnesota show that K banded below the seed boosts yields in ridge-till systems even when soil test K levels are high (**Table 1**). Iowa research has recently shown that deep-banded K consistently produces modest yield increases in no-till systems under optimum to very high soil test K levels (**Figure 3**).

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

TABLE 1. Corn responds to banded K in ridge-till systems at a high soil test level of 156 ppm (Minnesota).

K_2O placement	K_2O rate, lb/A	Corn grain yield, bu/A Hybrid A	Hybrid B
—	—	54	59
Fall band	40	92	102
Fall broadcast	40	57	68

TABLE 2. Seed-placed K increased barley yield over band or broadcast on K deficient soils (Alberta).

K_2O, lb/A	Application method	Yield increase, bu/A 6 tests	13 tests
15	Broadcast	8.6	
15	Banded	12.8	6.2
15	With seed	18.8	10.7
30	Broadcast	17.0	
30	Banded	18.8	8.0
30	With seed	21.0	12.2

TABLE 3. Chloride contained in muriate of potash can produce yield and kernel weight increases in small grains (Montana).

Rate of chloride (from muriate of potash), lb/A	WB881 durum wheat yield, bu/A	WB881 durum wheat kernel weight, g/1,000 kernels
0	49.2	38.2
40	60.2	40.4

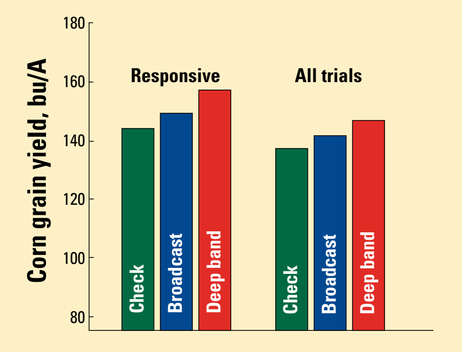


Figure 3. Corn responds to deep band placement of K on soils testing high to very high in K (Iowa).

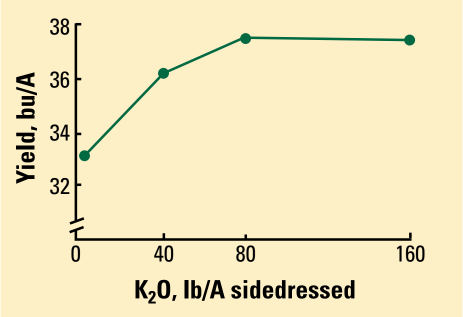


Figure 4. Soybeans respond to K sidedressed at early flower (Alabama).

TABLE 4. Fertilizer K boosts cotton yields (Mississippi).

K_2O rate, lb/A	Lint yield, lb/A	Boll mass, g/boll	Lint, %	Seed mass, mg/seed
0	1,061	4.1	38.6	90
120	1,169	4.4	39.3	94
Increase from K, %	9	7	2	4

TABLE 5. Fertilizer K improves cotton fiber quality (Mississippi).

K_2O rate, lb/A	Strength, g/tex	Elongation, %	Span, 2.5%	Length, 50%	Uniformity ratio	MIC	Maturity, %
			cm	cm			
0	21.1	7.97	2.82	1.35	48.0	3.7	74.1
120	20.7	8.25	2.82	1.37	48.7	4.1	78.3
Increase from K, %	0	3	0	1	1	10	5

for most profitable yields. Starter K significantly increased corn yields on compacted soils in a Wisconsin study and continued to improve yields as K soil tests increased.

Soybeans. Soybeans require high K availability for best yields and profitability. Soybeans generally do not respond differently to broadcast or banded K applications. Responses to applied K have been good on deficient soils, whether broadcast or banded. Banded applications may be appropriate in cool soils or soils with low K fertility. Soybeans are easily injured by contact with salts, so no K fertilizer should be placed in direct contact with the seed. Foliar applications of K have produced modest yield increases in some cases, but predictable increases have not yet been proven.

Potassium should be applied early for soybeans, but research from the Midsouth has shown that K can be applied as late as early pod development and still produce significant yield increases when moisture is adequate (**Figure 4**).

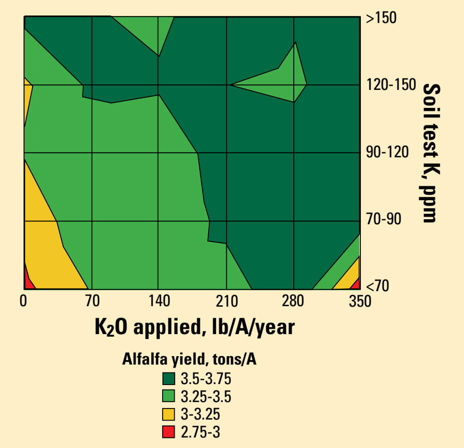


Figure 5. Applications of K to alfalfa become more efficient as soil test K increases (Wisconsin).

Alfalfa. High yield alfalfa has one of the highest K needs of any crop, frequently exceeding 60 lb K_2O per ton of hay. Broadcasting and incorporating K to build nutrient levels before seeding and then topdressing for maintenance is the best approach. This makes K applications more efficient, allowing consistently higher yields to be attained at lower annual application rates (**Figure 5**).

Deep and extensive root systems allow alfalfa to make good use of soil K. As the stand ages, large removals of K from past cuttings make alfalfa more dependent upon annual K applications. **Figure 6** shows that alfalfa established for several years can have greater yield responses to applied K than newly established stands.

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

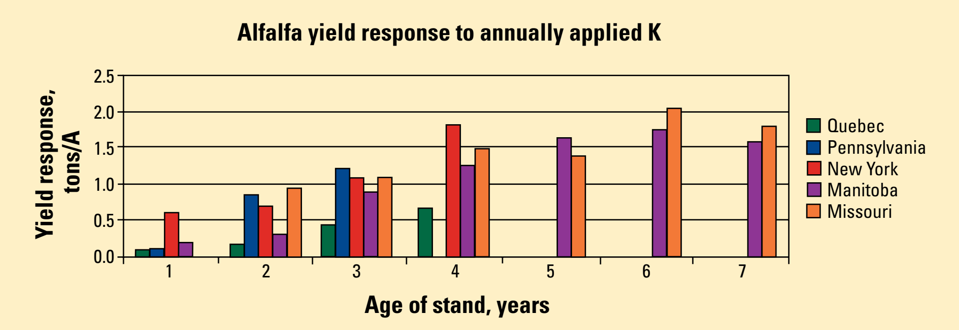


Figure 6. Yield response to K application gets larger as the alfalfa stand ages.

contact may cause germination damage when hoe or disk-opener drills are used.

Much of the wheat in the U.S. is grown in the Great Plains. Soils in this arid environment usually contain high levels of K. Consequently, K-containing fertilizers have not traditionally been applied. In some areas, lack of fertilization has resulted in a depletion of soil chloride (Cl) levels. Chloride is a mobile nutrient and can be leached from soils just like nitrate. Chloride is an essential nutrient and provides small grains with improved disease resistance or an improved ability to withstand disease. Muriate of potash (KCl) broadcast or applied near the seed has produced increases in yield and kernel weight in some cultivars when Cl nutrition has been inadequate (**Table 3**). Caution should be used to avoid salt injury when applying KCl near the seed.

Cotton. Low root length density compared to other major field crops makes cotton particularly sensitive to low soil K supplies. In fact, cotton can exhibit deficiency symptoms on soils not considered K deficient. Potassium is important for maximizing cotton lint yield and quality. Broadcast applications have been commonly used to boost cotton yield and fiber quality (**Tables 4** and **5**). Banded applications of K may be more efficient than broadcast applications in soils that fix large quantities of applied K.

Potassium is required by cotton throughout the growing season, but needs are greatest during boll set and development. Preplant or mid-season sidedress applications of K are commonly used to meet the K needs of cotton. However, even where soil test K levels are considered adequate, late-season K deficiencies have been observed throughout the Cotton Belt. Reasons for this phenomenon are still being investigated, but foliar applications of K have provided yield and quality increases in many cases (**Table 6**). Where appropriate, foliar fertilization should be used to supplement soil applications of K.

TABLE 6. Cotton responds to foliar application of potassium nitrate (California).

Foliar K application applied during the following weeks after first flower:	Lint yield, lb/A	Lint yield response, lb/A
Control	1,291	–
1 & 2	1,360	69
3 & 4	1,411	120
5 & 6	1,367	76
7 & 8	1,313	22

Summary

Potassium placement is receiving increasing attention in modern crop production. Proper placement and timing are essential for getting the most yield response from an application of K. While many issues remain unresolved, research will continue to reveal which management practices provide the most benefits to producers. BC

The Influence of Potassium on Crop Quality

What is the effect of K on crop quality? For some crops, improved quality might be more protein or higher forage feeding value for livestock. It could be improved persistence of alfalfa stands or reduced drying cost of corn grain or less dockage for diseased and shriveled soybean seed. For vegetables, it might be greater consumer acceptance. The economic return from the investment in K can originate from: (1) improvement in total yield; (2) a greater percentage of total yield which is marketable; (3) better crop quality; (4) lower cost per unit of production; (5) disease resistance; (6) stress tolerance; and (7) more effective use of other inputs such as nitrogen (N).

Potassium (K) is often described as the "quality nutrient" for crop production. With a shortage of K, photosynthesis, respiration, translocation, and a number of enzyme systems don't function very well. The result can be a reduction of plant growth and, often, of crop quality.

Potassium requirements for top profit production systems is best determined on a crop-by-crop basis. Inadequate K disrupts plant development in different ways. Plant symptoms or growth irregularities signal a shortage of K. Potassium benefits plant growth in the following ways.

Corn

- Earlier silking and longer grain fill
- Uniform maturity and grain moisture
- Improved stalk quality and reduced lodging
- More kernels per ear and better test weight
- Improved N use effectiveness

Soybeans

- Improved seed size
- Fewer shriveled and moldy beans
- Improved oil and protein content
- More and larger nodules for N fixation
- Better tolerance to pests and improved resistance to disease

Wheat

- Improved grain protein
- Better milling and baking qualities
- More efficient use of N
- Improved disease resistance

Forages

- Increased winter hardiness and stand longevity
- Increased protein quantity and quality
- Better N fixation and nodule activity
- Increased legumes in legume-grass swards
- Increased vitamin and mineral content
- Higher total digestible nutrients
- Improved palatability and digestibility of feed to animals

Fiber Crops

Cotton fiber quality is evaluated in terms of length, strength and fineness of the fiber as well as its color and cleanliness. Research studies show that K improves cotton boll size, micronaire, and strength of cotton fibers. Cloth

TABLE 1. Potassium and N increase marketable yield of tomatoes.

K_2O, lb/A	N, lb/A 120	180	240
	tons/A (% marketable)		
0	7.1 (41)	7.5 (56)	9.3 (55)
300	17.6 (80)	20.8 (85)	26.7 (85)

woven from K deficient cotton fiber resulted in an inferior grade of cloth due to unsatisfactory color dying resulting from the nappiness of the fiber.

Vegetables

Irish and sweet potatoes, cabbage, cassava, and other vegetable crops require K for both yield and quality. Where K is limited, tomatoes, potatoes and cabbage often show discoloration of the internal tissue.

Both tomatoes and potatoes respond well to applied K in terms of total yield and percent of that yield meeting strict market standards. Nitrogen and K interact to help achieve maximum economic yield (MEY) of tomatoes (**Table 1**).

Citrus

Potassium is essential for producing quality citrus. Research with "pineapple" oranges revealed that K influences size of fruit, thickness of the rind, and fruit color. Potassium also improved the acid/sugar ratio, soluble solids, and vitamin C content. The improved yield was due, in part, to reduced fruit fall from the tree and larger fruit size. Under conditions of severe K deficiency, stem end deterioration of fresh fruit results in greater loss during transport and a shorter shelf life in the super market.

Turf

Requirements for K are quality oriented and include grass color, turf density, winter hardiness, resistance to disease, and resilience to traffic. Potassium for improved root growth is believed to be one of the major benefits which allow turf grasses to grow out of stress conditions brought on by insects, disease, and adverse climatic conditions. Producers of sod are interested in how K can improve plant tiller count, rhizome length, and root density. Balancing K with N nutrition is key for maintaining a healthy, vigorous turf.

Tobacco

Plants fertilized with K resulted in increased K content, a reduction in nicotine, and an increase in sugar concentrations.

Grapes

Quality is influenced as K improves yield of marketable grapes and helps prevent cluster tip, uneven ripening, and pre-harvest shattering of fruit.

Sugarcane

Yield and quality are closely tied to K nutrition. This is due in part to K's influence on photosynthesis, total leaf area, drought stress, and disease resistance. A balanced fertilization program with N and K produces high juice quality and the most economical yield level.

Banana

Yield and quality are strongly influenced by K nutrition. It improves fruit weight and number per bunch. In addition, K stimulates earlier fruit shooting and shortens the number of days to fruit maturity. The beneficial effects of K on banana fruit quality continue over and above the level of K required for top fruit yield.

Summary

The role of K in crop quality has been documented throughout the world. The influence exists for crops grown in temperate and humid regions, for legumes and non legume plants, for annual and perennial crops, and for other crops needed for food, fiber or ornamental purposes.

The quantity of K required to obtain MEY plus quality varies with crop requirements for K in the growth environment. In some cases the amount of K required for top yield is adequate for top quality. In other cases, however, the desired level of crop quality and top profit require levels of K exceeding those normally needed for yield alone. This influence has been documented for crops such as tobacco, turf, ornamentals, and some food and fiber crops.

A balanced nutrition program allows K to contribute its best toward highest crop yield, quality and profitability.

Influence of Potassium on Nitrogen Fixation

Nitrogen fixation by trees, shrubs, grasses, and legumes varies widely in economic importance to farmers. The most important involves plants belonging to the family *Leguminosae* and the bacteria genus *Rhizobium*. Crops included within this group are the pea, bean, soybean, alfalfa, clover, cowpea, and lentil. Each crop performs best when provided with its specific strain of *Rhizobium* bacteria through the process of seed inoculation in the top soil or residual from previous crops. The bacteria then enter the seedling by infecting root hair cells and forming a nodule of enlarged plant cells filled with thousands of bacteria. These bacteria derive nutrition from the plant and generate ammonium (NH_4^+) from atmospheric N by a process catalyzed by the enzyme *Nitrogenase*. Conditions favoring N fixation by *Rhizobium* bacteria are similar to those necessary for good growth, vigor and dry matter production of the host plant.

Adequate potassium (K) fertility is important for the symbiotic relationship that enables bacteria to fix nitrogen (N) from the air for use by legumes.

The amount of N generated by a legume varies with the crop species, soil and crop growth conditions, and crop management practices. As the total amount of N fixed by bacteria increases, their need for an energy source to reduce N_2 to NH_4^+ also increases. This energy source is the sugar produced during photosynthesis. Any disruption in the photosynthesis process will also disrupt the N fixation process. The essential role of K in photosynthesis makes K a vital contributor to effective N fixation by legumes.

TABLE 1. Estimated N fixed by selected legumes grown under conditions of optimum production.

	N fixed, lb/A	
	Average yield	**High yield**
Alfalfa	120	350
Clovers	75	250
Soybeans	60	240
Peas, Vetch	50	180

Table 1 provides an estimate of the range in amount of N fixed by several legumes. The total amount of N fixed will usually increase with yield level. Any growth factor, such as K, which is necessary for optimum legume production, would also influence the amount of N fixed.

The N fixation process is influenced by and dependent upon K for very distinct reasons.

- Potassium is the predominant cation in the plant like calcium (Ca) is in the soil. Its high chemical activity and the presence of a water film around the K ion give it special properties. It acts to neutralize organic acid formed during carbohydrate metabolism, to maintain hydration of cellular structures such as membranes and to serve as a cofactor to help enzymes improve the movement of sugars across membranes within the plant.
- Potassium activates more than 60 enzyme systems even though it is not a part of any enzyme structure. The enzyme *Nitrogenase*, for example, is vital for N fixation.
- Potassium is essential for photosynthesis. Carbohydrates generated by photosynthesis provide the energy needed by bacteria in nodules to fix atmospheric N. Potassium allows for photosynthesis to operate at peak capacity for a longer period of time. Basically, it controls the opening and closing of leaf stomates which control the movement of carbon dioxide into the plant and water out into the air. When K is in short supply, photosynthesis and water use efficiency decline. At

TABLE 2. Effect of K on soybean yield, nodulation and protein production.

K_2O rate, lb/A	Yield, bu/A	Nodules number/plant	Nodules weight, g/cu. ft	Seed protein, lb/A
0	26	59	10	662
120	55	114	26	1,289

the same time, the rate of plant respiration remains high, resulting in the excessive consumption of carbohydrates that should be available for root growth and N fixation.

- Potassium contributes to good root growth and has been shown to improve the number and size of nodules on roots. As shown in **Table 2**, the application of K to responsive soils can increase both nodule size and number. This results in improved nodule activity and conversion of atmospheric N into organic forms of N.
- Potassium allows carbohydrates produced in leaves to get to the root system for use by nodules. One function of K is to serve as a cofactor that is required for the action of the enzyme needed to transport carbohydrates across cell membranes and into the phloem. Once in the phloem, these sugars can move quickly into the root system to stimulate growth of new root hairs as well as nodule development and function.

Photo source: Runk/Schoenberger from Grant Heilman.

Potassium in balance with other nutrients encourages N fixation by bacteria in nodules on roots of soybeans and other legumes.

A highly fertile soil is essential for optimum N fixation. During the first few days after germination, seedlings must rely upon energy from the seed for initial growth. Then, nutrients absorbed by an immature and developing root system plus photosynthesis occurring in a limited leaf area are expected to nourish the plant for the next 10 days to two weeks or until nodulation occurs and the N fixing process begins.

The legume's inability to fix much N during the first two weeks of growth is one reason growers follow the practice of applying 25 to 30 lb of N at planting. This is especially important for stimulating rapid growth of soybeans planted immediately after the harvest of a small grain crop.

Phosphorus (P) and K speed the process of seedling use of N which allows for the earliest possible development of an effective nodulation system.

In summary, the primary importance of K to N fixation by legumes is to assure rapid seedling development, earliest date of N generation by nodules, and then the formation and delivery of carbohydrates required for optimum nodule performance. BC

Potassium in Animal Nutrition

Potassium has been recognized as an essential nutrient in animal nutrition since its importance was pointed out by Sidney Ringer in 1883. Potassium is essential for life. Young animals will fail to grow and will die within a few days when the diet is extremely deficient in K.

Potassium is the third most abundant mineral element in the animal body, surpassed only by calcium (Ca) and phosphorus (P). Potassium concentrations in cells exceed the concentration of sodium (Na) by 20 to 30 times. Outside the cell the reverse is true. Potassium comprises about 5 percent of the total mineral content of the body.

Muscle contains most of the total K in the bodies of animals (**Table 1**).

Potassium is contained almost entirely within the cells and is the most plentiful ion of the intracellular fluids. Potassium is found in every cell. It is present in tissues and cells only in ionic form (K^+).

Potassium (K) is essential for human and animal life. Potassium is involved in many body functions and is required for proper muscle development. Adequate K is also important for good heart function. The recommended daily allowance (RDA) of K varies depending on species, stage of growth, and level of other dietary minerals.

Functions of Potassium

Potassium functions in the intracellular fluids the same as Na does in the extracellular fluids. The major functions of K in the human and animal body are to:

- maintain water balance
- maintain osmotic pressure
- maintain acid-base balance
- activate enzymes
- help metabolize carbohydrates and proteins
- regulate neuromuscular activity (along with Ca)
- help regulate heartbeat.

Potassium Deficiency

There are several causes of K deficiency: inadequate amounts of K in diet, K losses in digestive secretions caused by vomiting and diarrhea, high intake of Na, increased urination, and stress conditions.

Potassium deficiency may commonly be manifested by depressed growth, muscular weakness, stiffness, decreased feed intake, intracellular acidosis, nervous disorders, reduced heart rate, and abnormal electrocardiograms.

The first sign of K deficiency is reduced feed intake. Many of the other signs stem from reduced feed intake. Potassium must be supplied in the daily ration because it is a mobile nutrient and there are not any appreciable reserves.

Potassium Uptake and Control

Potassium is absorbed in the small intestine. Its availability in digestion is nearly 100 percent. Most K is lost or excreted in urine.

TABLE 1. Concentration and distribution of K in animal body.

Tissue or organ	K, meq/kg	K, %
Muscle	110.0	56.0
Skin	58.6	11.1
Digestive tract	96.6	5.6
Liver	95.0	5.3
Red blood cells	106.0	4.2
Blood plasma	4.2	2.2
Brain	98.6	1.4
Kidney	77.6	0.9
Lung	79.3	0.5
Spleen	130.0	0.4
Heart	77.8	0.4
Bones and other	—	12.6

There is a small amount lost in perspiration. Kidneys play the most important role in maintenance and control of K. Under stress conditions the kidneys tend to excrete more K and conserve more Na.

Proper level of K in the diet is important for all types of animals. Lactating dairy cattle have a high K requirement.

Potassium in Human Nutrition

The usual American diet normally contains adequate K. The RDA is 2,500 milligrams (mg). The usual intake is 2,000 to 4,000 mg per day.

Problems with K intake can occur. Diets low in carbohydrates lower blood K and can cause an irregular heartbeat. Potassium deficiency can become serious due to K depletion in cases of cirrhosis of the liver, diarrhea, vomiting, diabetic acidosis, body burns, and severe protein-calorie malnutrition.

Potassium plays important functions in good cardiac health. Blood pressure is influenced by K. It helps overcome the adverse effect of Na on blood pressure. Sodium can be balanced with K to maintain normal blood pressure.

Potassium in Animal Nutrition

Potassium is especially important in diets of chickens and turkeys during the first 8 weeks. During heat stress, or if there is any diarrhea, the needed levels may be higher. Adequate K in the ration of laying hens assures good egg production, egg weight, and shell thickness. In starter chicks and turkey poults, adequate K increases weight gain, improves feed efficiency, and reduces mortality.

Swine K requirement is higher for young pigs than for older ones. It ranges from about 0.33 percent (dry matter basis) in rations of small pigs weighing up to 8 lb, to 0.19 percent in rations of pigs weighing more than 180 lb (**Table 2**). The K requirement for gestating and lactating sows is 0.20 percent. Potassium requirement increases in diets with higher Na and chloride (Cl) levels.

Ruminants have a higher K requirement than nonruminants. Potassium is essential for rumen microorganisms. The single most consistent effect of suboptimal K in the ration of ruminants is decreased feed intake.

Lactating dairy cattle, particularly high-producing cows, require the highest levels of dietary K. Under heat stress, their optimal level of dietary K can be as high as 1.9 percent, but the normal National Research Council (NRC) recommendation is 1.0 percent of dietary dry matter (**Table 2**).

Less K (0.65 percent) is recommended for dry cows, calves and heifers. During the last three to four weeks before calving, excessive K in the dry cow diet can increase the incidence of milk fever and retained placentas. This can lead to reduced milk production during the subsequent lactation. The maximum amount of K desirable in the dry cow diet depends on the use of anionic salts and

(continued on page 36)

TABLE 2. Recommended K level, % in dry ration.

Animal	Recommended level[1]
Beef cattle	0.6-0.7
Dairy cattle	0.65-1.0
Sheep	0.5
Swine	0.19-0.33
Horses	0.25-0.45
Poultry:	
Starting chicks	0.30
Laying or breeding hens	0.40
Turkeys	0.6-0.8

[1]National Research Council of National Academy of Science.

Potassium Reduces Stress from Drought, Cool Soils, and Compaction

Why does water stress often cause plants to look like they are suffering from K deficiency?

Potassium deficiency can be the most harmful effect of dry weather. In a drought, water films surrounding soil particles become very thin. Because most K moves to plant roots through these films, drought makes it much more difficult for crops to take up enough K to satisfy their needs.

Higher levels of potassium (K) in the soil help crops withstand stress conditions.

Higher K concentrations in the soil solution help to speed K delivery to the root. This is why it is so important to have high levels of K fertility in dry years. With higher levels of K in the soil, the crop doesn't have to work as hard to take up the K it needs.

In dry years, crops often contain lower amounts of K than in years with adequate rainfall. For example, Iowa scientists measured sharply lower amounts of K in corn leaves under drought conditions (**Table 1**). Applying 160 lb/A of K_2O raised leaf K concentrations in the dry year but did not entirely compensate for the harmful effects of water stress. Most agronomists feel that corn leaves must contain at least 1.7 percent K in the ear leaf at tasseling to allow the crop to produce maximum yields.

Research in several states and provinces has shown that the largest yield increases from applied K often occur in dry years.

One example is a long-term K study in Ohio (**Table 2**). A good weather year was followed by a dry year on two occasions. Corn was the test crop over the first two-year period and soybeans over the second period. For both crops, yields and profits from adding K were greatest in the year with water stress.

Another 18-year experiment in Indiana showed soybean response to K to be greater in dry years. **Figure 1** shows a higher yield increase from K in years with the lowest rainfall during the critical 12-week period after planting.

Potassium cannot protect against extreme droughts, but it does help maintain yields in years with moderate water stress, typical of Corn Belt conditions.

Another way that K helps drought-stressed plants is to lower the amount of water lost through the leaves. Plants have tiny openings in their leaves called stomates through which water transpires to the atmosphere. Closing the stomates is a defense mechanism

TABLE 1. Stress caused by dry weather reduces the amount of K taken up by corn (Iowa).

K_2O rate, lb/A	K in corn leaves, % No stress	K in corn leaves, % Stress
0	1.1	0.7
160	1.6	1.2

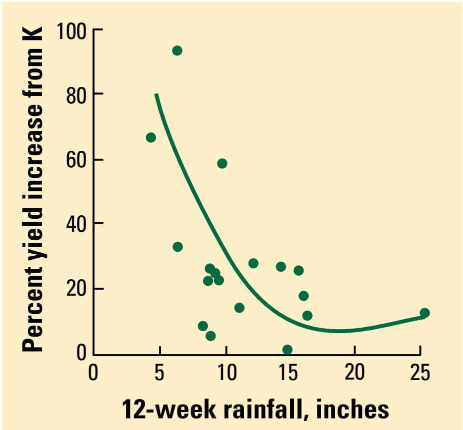


Figure 1. Soybean response to potash was greatest in years with lower rainfall during the critical 12-week period after planting (18-year study, Indiana).

to conserve water. Plants with inadequate K can be slower (and incomplete) in closing their stomates. For example, a Montana experiment showed that barley plants exposed to hot, windy conditions were able to slow water loss within 5 minutes when they had adequate K. But without adequate K, about 45 minutes were required for water loss to be reduced.

TABLE 2. The greatest profits and the biggest yield responses to K occurred in the stress years of this long-term experiment (Ohio).

K_2O rate, lb/A	Good year	Stress year	Good year	Stress year
	Corn yield, bu/A		Soybean yield, bu/A	
0	163	81	56	35
50	163	113	59	44
100	167	121	60	52
Response to K, bu	4	40	4	17
Profit from K, $/A	-5	76	11	92

Corn, $2.25/bu; soybeans, $6.25/bu; K_2O, 14¢/lb; medium K soil.

Additionally, K in plant cells helps keep photosynthesis going. Plant cells that lose too much water slow down in photosynthesis because of distortion of their internal parts. Potassium within plant cells has an osmotic effect that helps retain water. For this reason, tissue K concentrations that are above optimum for normal conditions can be necessary for stress conditions.

In cool soils, root growth is less, and roots are less able to absorb nutrients. Crops growing in cool soils often have reduced K uptake. If the K shortage is too severe, yields can be reduced. Higher K soil tests may be necessary in cooler climates. For example, it required a 50 percent higher level of soil K in northern Wisconsin than in southern Wisconsin to obtain a 2 percent level of K in alfalfa plants.

Early planting situations, where the crop grows in cooler soils, may require higher K fertility. Extra K increased corn yields 26 bu/A when planted April 26, but only 12 bu/A when planted June 2 on a low-K soil in Indiana. Plants receiving inadequate K are also more susceptible to frost damage. A higher yield potential is another factor that may increase K need with earlier planting.

Soil compaction stresses plants by restricting root growth and making it more difficult for the roots to take in adequate amounts of K and other nutrients.

On soils that are low to medium in K, some of the yield loss from compaction may be reduced by added K. In a Wisconsin experiment, 45 lb/A of row-applied K_2O reduced corn yield lost to compaction to 5 bu/A from 22 bu/A without K (**Table 3**). Yield response to K and profits were greater on the compacted soil.

Compaction is one of the reasons why responses to K occur more frequently in no-till and ridge-till cropping systems. Other reasons include stratification of K near the soil surface, cooler soil temperatures, and greater likelihood of anaerobic soil conditions. Anaerobic conditions can increase the fixation of K by soil minerals, making it less available to plants. Roots also depend on oxygen and are less active in taking up K when soils become anaerobic.

TABLE 3. Row-applied K partially reduced yield losses due to compaction on a soil testing low to medium in K (2-year average, Wisconsin).

Row K_2O, lb/A	Compaction Low	High	Loss
	Corn yield, bu/A		
0	151	129	22
45	169	164	5
Response to K, bu/A	18	35	
Profit from K, $/A	39	81	

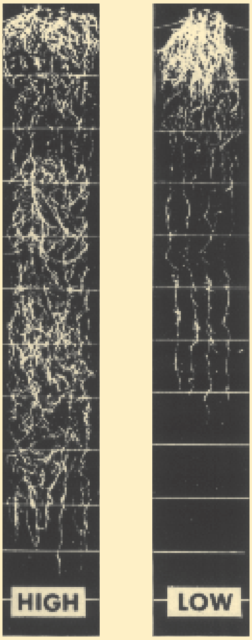
Low compaction: < 5 tons/A. High compaction: 19 tons/A.
Soil test K: 204 lb/A. Corn, $2.50/bu; K_2O, 14¢/lb.

Higher K levels clearly help get crops through periods of stress. Many observations show the need to plan a strong K soil fertility program to make crop yields more certain in an uncertain environment. BC

Effective Water Use

Potassium helps crops use water more effectively. The positive benefits of adequate K fertility are:

- **Deeper roots.** Potash helps plant roots penetrate to access deeper soil water, as illustrated at right.
- **Faster closing of the crop canopy**. When the crop canopy closes, the ratio of transpiration to evaporation increases, which means more of the water available is used by the crop.
- **Greater osmotic gradient**. The more K inside the plant cell, the more strongly it can attract water from the soil – and better control its water loss.
- **Earlier maturity**. Adequate K helps ensure plants will get through the critical pollination period earlier – before drought.



Soil Fertility

Potassium in Animal Nutrition... *(continued from page 33)*

other factors, but generally forage K should be less than 2.5 percent. Cool-season forages tend to contain more K than warm-season grasses. Thus, problems of excess occur less frequently in southern than in northern regions.

The RDA of beef cattle is about 0.5 to 0.7 percent of dry ration (**Table 2**). Several studies have been reported with weight gains of steers on rations containing optimum levels of K. In Texas and Tennessee, elevating K levels to 1.4 percent of dietary dry matter helped reduce the stress of shipping calves and lambs to feedlots.

Grass tetany and wheat pasture poisoning are metabolic diseases of lactating cattle. These occur most frequently in animals grazing cool-season forages in which magnesium (Mg) concentration or availability is low (less than 0.2 percent). High levels of K, unbalanced with Mg, can increase risk of grass tetany. Milliequivalent ratios of K/(Ca+Mg) above 2.2 in forage dry matter are considered hazardous. Grass tetany risk is reduced by feeding Mg supplements. Also, fertilizing with phosphorus (P) can enhance plant uptake of Mg. BC

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Effects of Potassium on Plant Diseases

Disease resistance in crops is genetically controlled. However, natural disease resistance mechanisms can be enhanced by plant nutrients. Potassium deficiency symptoms such as thin cell walls, weakened stalks and stems, smaller and shorter roots, sugar accumulation in the leaves, and accumulation of unused nitrogen (N) encourage disease infection. Each of these reduces the ability of the plant to resist entry and infection by fungal, bacterial and viral disease organisms. A healthy plant, free from stress, is much more resistant to disease attack. Sound fertility management and fertilization practices provide assurance that stress induced by K deficiency is not a factor in crop production.

Of all the nutrients essential for plant growth and function, potassium (K) is most often associated with reducing disease severity. It should be recognized, however, that K does not work alone. The healthiest, most profitable crops are produced with balanced fertility management practices that minimize nutrient stress throughout the growing season.

Several factors influence the effectiveness of K fertilizer in reducing crop stress and disease incidence. These factors include K status of the soil, K rate and source, nutrient balance, variety/hybrid susceptibility, and disease organism virulence and population. The following are examples of K fertilization reducing disease pressure on various crops and the corresponding increases in crop yield and quality.

The incidence of leaf spot disease caused by *Cercospora*, *Stemphylium* and *Alternaria* in cotton has been related to K fertility. A Tennessee study demonstrated the importance of K fertilization in reducing the severity of *Alternaria* leaf spot disease in cotton on a soil testing low in K. This disease organism can cause significant yield reduction where premature plant defoliation is extensive. Potassium was broadcast and incorporated at the rate of 0, 30, 60, and 120 lb K_2O/A. There was also a foliar application component in this experiment. Partial results from this study are listed in **Table 1**.

Disease occurrence may be encouraged by an imbalance between N and K. As production levels are pushed higher, striving for maximum economic yields, K must be balanced with increased additions of N. The penalties from this and other nutrient imbalances can be rather severe. An Illinois study showed the benefits of K fertilization on a soil testing high in available K with 300 lb/A of N applied. Potassium increased yields over four growing seasons by an average of 21 bu/A. Lodging, frequently associated with stalk rot, was reduced in 3 of 4 years (**Table 2**).

Good K fertility is associated with strong cell walls that enhance disease resistance and the ability of the crop to maintain firm, healthy stalks. Therefore, a

TABLE 1. Effect of K fertilization on *Alternaria* leaf spot, defoliation, and cotton lint yields under conventional tillage and no-till conditions.

K_2O, lb/A	*Alternaria*[1]	Defoliation	Lint yield, lb/A
	Conventional tillage		
0	7.7	6.9	350
30	5.8	4.5	556
60	5.5	2.9	621
120	4.7	1.3	760
	No-tillage		
0	7.5	5.8	360
30	6.1	4.2	531
60	5.1	1.6	528
120	4.5	0.6	669

[1]*Alternaria* leaf spot and defoliation ratings, 0=none, 10=highest.

properly fertilized crop such as corn will have better standability until natural maturity is achieved. The data in **Table 3** illustrate the influence of K fertilization on corn stalk strength and rind thickness.

TABLE 2. Potassium fertilization effect on corn yields and lodging.

Year	Yield, bu/A Control	Yield, bu/A 120 lb/A K_2O	Stalk lodging, % Control	Stalk lodging, % 120 lb/A K_2O
1st	148	164	56	60
2nd	148	164	30	25
3rd	151	187	30	16
4th	104	120	52	27

The incidence of stalk rot and lodging in grain sorghum may also be influenced by K fertilization. Two sources of K fertilizer increased grain yield and reduced severity of stalk rot at the higher levels of fertilization in a Kansas study (**Table 4**). In addition, a separate Kansas study showed that 75 lb/A K_2O increased grain sorghum yield by 11 bu/A and reduced visual signs of stalk rot from 6 to 5 nodes affected per plant.

TABLE 3. Effect of K fertilization on corn stalk crushing strength and rind thickness.

K_2O rate, lb/A	Rind thickness, mm	Crushing strength, kg
0	0.91	254
60	0.97	349
120	1.00	374

In addition to higher yields and reduced disease susceptibility, good K fertility management often results in improved crop quality. A Wisconsin soybean study illustrated how building soil fertility in K and phosphorus (P) pays in higher crop yield, with less shriveled and diseased seed that results in less dockage at the elevator (**Table 5**).

TABLE 4. Effect of K fertilization on sorghum grain yield and stalk rot infection.

K_2O, lb/A	Grain yield, bu/A KCl	Grain yield, bu/A K_2SO_4	Plants with stalk rot, % KCl	Plants with stalk rot, % K_2SO_4
0	52	52	22	22
40	61	75	20	35
80	72	74	26	19
160	76	78	16	20
320	83	86	4	9

The effect of soil K status on soybean stem canker infection and plant K concentration was demonstrated in a Mississippi study (**Table 6**). High fertility status (125 lb P/A and 250 lb K/A) was maintained on one half of the plots at each of 6 sites. The remaining low fertility plots were not fertilized.

TABLE 5. Effect of P and K fertilization on soybean yield and quality.

Fertilization*, lb/A P_2O_5	Fertilization*, lb/A K_2O	Soybean yield, bu/A	Shriveled & diseased seed, %
0	0	35	20.8
400	0	29	12.5
0	400	38	1.8
400	400	52	1.3

*Applied only in first year of the five-year study. Soil test P and K levels - medium and low, respectively.

Potassium fertilization can increase forage yield, stand longevity, and disease resistance. A Texas study demonstrated the influence of K fertilization on the occurrence of *Helminthosporium cynodontis* in Coastal bermudagrass at 2 sites (**Table 7**). Coastal bermudagrass production in Louisiana benefited where leaf-spot disease was evident and forage was infected with the fungus *Helminthosporium cynodontis* (**Table 8**).

Potassium fertilization reduces disease infection, increases yields, and enhances the quality of many other crops. For example, foliar application of K from several sources to the first true leaf of cucumber, before inoculation with powdery mildew, induced up to 94 percent systemic protection from this disease organism in a greenhouse study. Research in Oregon has shown that a well-managed K program resulted in increased total yields and reduced incidence of diseases such as stem soft rot, hollow heart, and brown center in potatoes. Potassium benefits the market quality of fresh fruits and vegetables and helps maintain quality in storage, with less rot and decay. In turfgrasses, K is associated with the

TABLE 6. The influence of reduced levels of soil P and K on soybean plant K concentration and stem canker infection level.

Site	Infection increase due to low fertility, %	Plant K decrease due to low fertility, %
1	16.6	23.0
2	36.5	33.0
3	34.1	33.1
4	20.7	15.6
5	41.1	37.8
6	0	11.8

TABLE 7. Influence of P and K fertilization on disease severity on Coastal bermudagrass.

P_2O_5 rate, lb/A			Disease scale[1]	
Site 1	Site 2	K_2O rate	Site 1	Site 2
0	0	0	2.7	3.8
282	241	0	3.1	3.9
0	0	120	1.1	1.4
0	0	240	1.0	1.0
141	120	120	1.3	1.5
282	241	240	1.0	1.1

[1]Disease scale: 1=trace of leaf spot, 5=2 or more leaves dead from disease.

TABLE 8. Potassium fertilization improves yield and stand longevity of Coastal bermudagrass.

Annual K_2O rate, lb/A	Spring stand density estimates, %			Total change, %	Two year average yield, tons/A
	1st year	2nd year	3rd year		
0	57	46	39	-18	5.9
100	24	55	50	26	6.6
200	35	60	72	37	7.1
400	42	67	83	41	7.3
600	36	60	81	45	7.6

Soil test K level - low.

TABLE 9. Diseases suppressed by chloride.

Crop	Disease
Wheat	Take-all and common root rot, tan spot, Septoria, leaf rust, stripe rust
Barley	Common root rot, spot blotch, Fusarium root rot
Corn	Stalk rot
Rice	Stem rot, sheath blight
Potatoes	Hollow heart, brown center
Celery	Fusarium yellows
Pearl millet	Downy mildew
Coconut palm	Gray leaf spot

TABLE 10. Chloride decreases leaf rust and increases wheat yield.

Source	Cl rate, lb/A	Rust rating, %	Yield, bu/A
Check	0	67.5	35.4
NH_4Cl	40	26.3	41.7
KCl	40	27.5	42.0
$MgCl_2$	40	28.8	40.9

Rust rating-flag leaf coverage.

suppression of several disease organisms and also increases tolerance to stress and traffic.

Chloride (Cl), like K, is important in reducing the incidence of plant diseases in many crops (**Table 9**). Chloride interactions with crop diseases are well documented. However, the mechanisms involved are not well defined. Proposed mechanisms involve suppression of the pathogen or increased host tolerance.

Researchers in Texas found that Cl fertilization increases wheat yields in years with high leaf rust and *Septoria* pressure. The data in **Table 10** demonstrate the effect of Cl topdress application on leaf rust severity and yield of winter wheat. Several Cl sources are available, and research has generally found that the various sources are equally effective.

Summary

A well-planned fertility program is essential to the production of healthy crops that produce optimum yields and maximize profits. Potassium is a critical component of any fertility program. Increasing the crop's ability to resist disease infection is only one of many important practical functions that K performs. The number of crops and associated diseases affected by K is extensive and not practical to list here. BC

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