RESEARCH PPI EDUCATION

BETTER CROPS

with plant food

Fall 1987

Potassium for Agriculture

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Contents

Potassium: An Essential Plant Food Nutrient

POTASSIUM (K) is basic to plant and animal life. It plays many roles in plant nutrition.

Plants readily absorb available soil K. Once inside the plant, K is mobile. It moves readily from older to younger tissue . . . and that is why deficiency symptoms of K appear on older leaves first.

Unlike nitrogen (N) , phosphorus (P) and most other essential nutrients, K does not become a part of the chemical structure of the plant. Rather, it remains unattached as it influences plant growth. A large part of plant K can be found in cell sap in soluble form.

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.

This booklet is about K. It gives some of the reasons why potash should be a part of a well-balanced fertilizer program; why K is essential to MEY crop production. ■

K

Functions of Potassium in Plants

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

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

Enzyme Activation

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

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

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

Water Use

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

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

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

Photosynthesis

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

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

Transport of Sugars

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

Water and Nutrient Transport

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

Protein Synthesis

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

Starch Synthesis

The enzyme responsible for synthesis of starch in leaves is activated by K. Thus, with inadequate K, starch accumulation in the leaves is reduced. The effect of the K level on photosynthesis also affects the amount of sugar available for starch production. Under high K levels, starch is moved from the stems for efficient utilization.

Crop Quality

High levels of available K improve the physical quality, disease resistance, and feeding value of grain and forage crops, as well as crops used for human food. Quality is becoming an increasingly important market factor, so adequate K will become more critical for the value of the crop produced.

Other Functions of K

Volumes have been written on the specific roles of K in plants. And research into this subject is far from complete. This summary can only highlight a few examples of how K is used in plants. Disease resistance, tolerance of water stress, rate of grain development, winterhardiness, and nearly every aspect of growth and development, yield, and quality are dependent upon an adequate K supply.

The effects of K deficiency cause reduced yield potential long before any visible symptoms appear. This "hidden hunger" robs profits from the farmer who fails to keep his soil K levels in the range high enough to supply adequate K at all times during the growing season. ■

How potassium (K) works to increase crop yields:

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

K

Production and Use of Potassium

Potash fertilizers, of which muriate of potash (KCl) is the most important, are mined and refined from underground ore deposits, salt lakes and brines. North America, the Soviet Union and Western and Eastern Europe account for almost 95% of world output. Known potash reserves are estimated to be equivalent to 19 billion tons K_2O.

POTASSIUM IS ESSENTIAL to all forms of plant and animal life. It is a chemically active metal. And because of its highly active characteristics, it is never found in its pure 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 of potassium in an acre furrow slice. However, most of it is chemically bound in insoluble mineral forms and is only slowly available for plant growth. This is especially true on many soils that have been depleted by decades or even centuries of continuous farming with crop removals.

For example, in 1986 it was estimated that 31 major field crops grown in the U.S., including hay and alfalfa, removed 87% more K than was applied.

Potassium is added as a fertilizer in the form of potassium chloride, potassium sulphate, or potassium magnesium sulphate or some other forms which will be discussed later. Any and all of these forms are spoken of as potash.

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

Potash is sold on the basis of its oxide or K_2O equivalent content. For example, chemically pure potassium chloride or muriate of potash (KCl) contains 52.44% potassium (K) or 63.17% K_2O equivalent. Most muriate of potash sold as fertilizer contains 60 to 62% K_2O.

It is frequently necessary to convert from K to K_2O or from K_2O to K. $K \times 1.2 = K_2O$. $K_2O \times 0.83 = K$.

Potash Fertilizer Materials

In North America, muriate of potash (KCl) accounts for approximately 95% of all potash fertilizers. Potassium sulphate and potassium magnesium sulphate are also widely used forms, but they account for less than 5% of the total. Other forms such as potassium nitrate, potassium carbonate, potassium metaphosphate, potassium calcium pyrophosphates, and potassium orthophosphates are used only to a very limited extent. See **Table 1.**

Table 1. Composition of important potash fertilizers.

	Percent K_2O	Percent K
Muriate of Potash	60-62.5	49.8-51.9
Sulphate of Potash	50-52	41.5-43.2
Sulphate of Potash—Magnesia	22	18.3
Potassium Nitrate	44	36.5

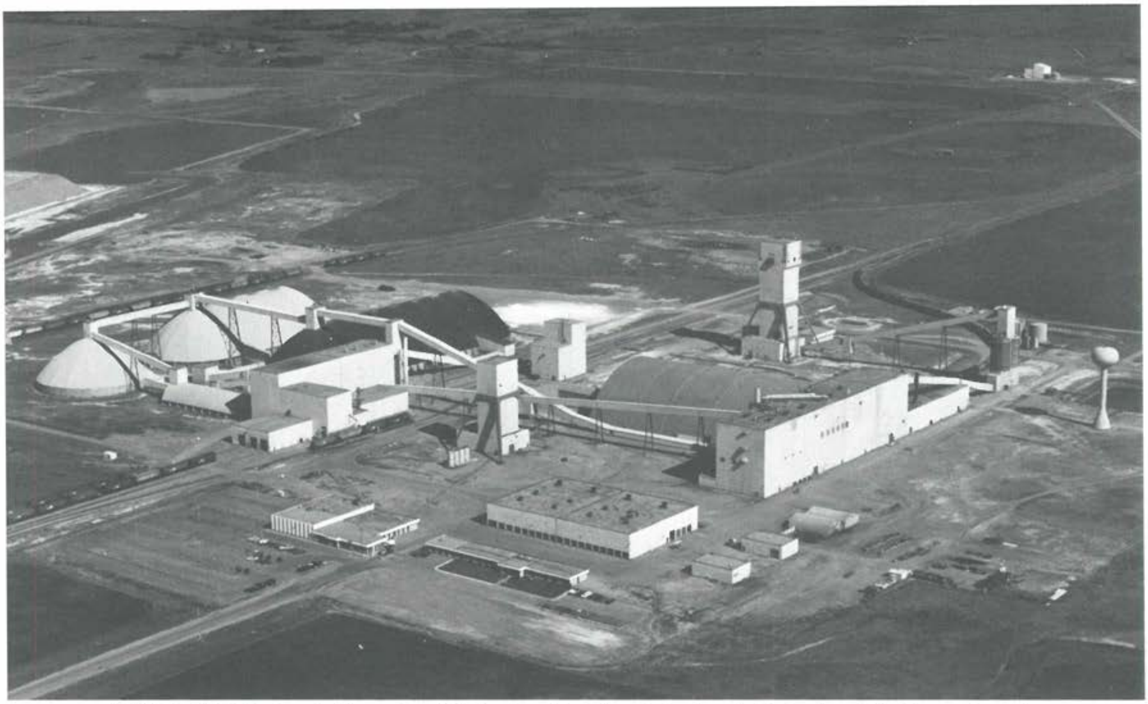
Other Potash Materials

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 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% nitrogen, 20% phosphoric acid (P_2O_5), and 20% potash (K_2O) by weight.



AFTER MILLING of potash ore, the finished product (muriate of potash) is placed in dome-shaped storage areas until shipping at this Saskatchewan facility.

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_2O 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 Carlsbad, New Mexico, area these 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 potassium and sodium 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 which is already near the saturation point in potassium, sodium and magnesium salts is further evaporated in shallow ponds and the different salts are separated.

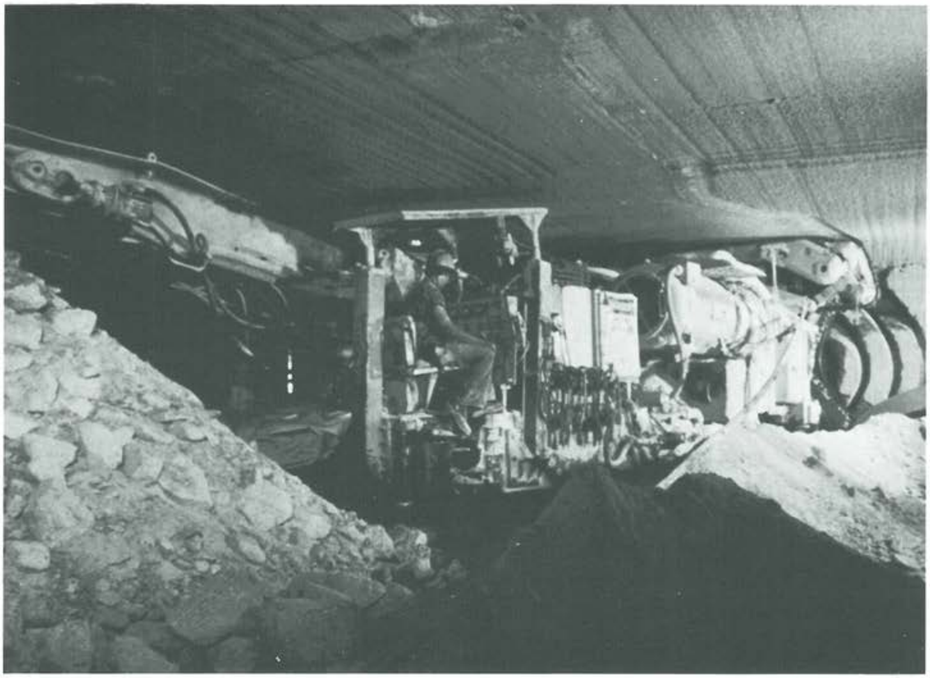
Potash Production and Consumption

Total world production increased from 16.1 million tons K_2O in 1966 to 25.8 in 1976 and 31.1 in 1986.

In 1986, developed countries and the centrally planned economy countries of the Soviet Union and Eastern Europe each produced 49% of the world total.

Within these groups the Soviet Union accounted for 37% of world production and Canada 23%. In descending order of size, other producing regions were Western Europe, 19%, Eastern Europe, 12%, and Asia, 6%. U.S. production accounted for 3% of world output while no potash was produced on the continents of Africa, South America or Oceania.

Production in North America has shifted from the United States to Canada



MORE THAN 3,000 feet underground, a powerful continuous mining machine bites off potash ore to be refined.

over the last quarter century since the initiation of Canadian mining in 1962. Part of the shift is due to the exhaustion of high grade ore reserves in the Carlsbad, New Mexico, mining area.

In 1986, 87% of the 8.2 million tons K_2O produced in North America came from Canada. About 37% of total world trade in potash originated in Canada, with shipments to the U.S. accounting for over two-thirds of the volume.

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 of K_2O were used. By 1960, the figure was 2.2 million and in 1970, 3.5 million. In 1980, consumption in the two countries reached 6.6 million tons, over 90% of it in the U.S.

Since 1980, there has been a marked decline in potash use, reaching 5.5 million tons K_2O in 1986. Much of this decrease is attributable to sharply reduced prices for most crops in recent years, coupled with acreage control programs in the U.S.

Reserves and Resources

Potash reserves are those that can be mined economically under short-term marketing conditions. Resources are those that could be recovered with known technology at a future date, usually assuming higher recovery costs.

In 1985, total world reserves were estimated to be 19 billion tons K_2O while resources were estimated to be 163 billion tons. Producing countries with substantial reserves, and percent of known world total, are shown in **Table 2.**

Table 2. World potash reserves by country.

Country	K_2O Reserves (Million tons)	Percent of Total
Canada	11,500	58
U.S.S.R.	5,500	29
Germany, East	880	5
Germany, West	550	3
U.S.A.	330	2
Brazil	220	1

Other potash-producing countries with smaller reserves are France, Italy, Israel, Jordan, Spain, and the United Kingdom. Undeveloped deposits exist in a number of other countries.

Canada and the U.S.S.R. have 40 and 37% of estimated world resources, respectively. U.S. resources are estimated at 6.6 billion tons, most of which occur as bedded deposits between 5,000 and 10,000 feet below the surface in Michigan, North Dakota and Utah. At these depths, solution mining is the only feasible method of recovery. ■

K

Potassium Interactions With Other Nutrients

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

POTASSIUM (K) affects nitrate absorption and reduction. Rapid nitrate 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. Note the effect on barley in **Figure 1.**

Also, in nutrient solution work, higher rates of K allowed for the efficient use of more nitrogen which resulted in better early vegetative growth and higher grain and straw yields as K and nitrogen (N) rates increased **(Figure 2).**

In the field, better N uptake and utilization with adequate K means improved N use and higher yields. Crops need more

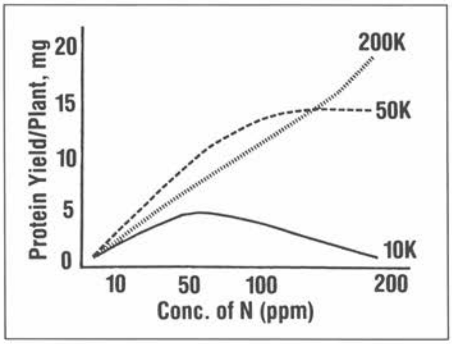


Figure 1. N and K effects on plant protein in barley.

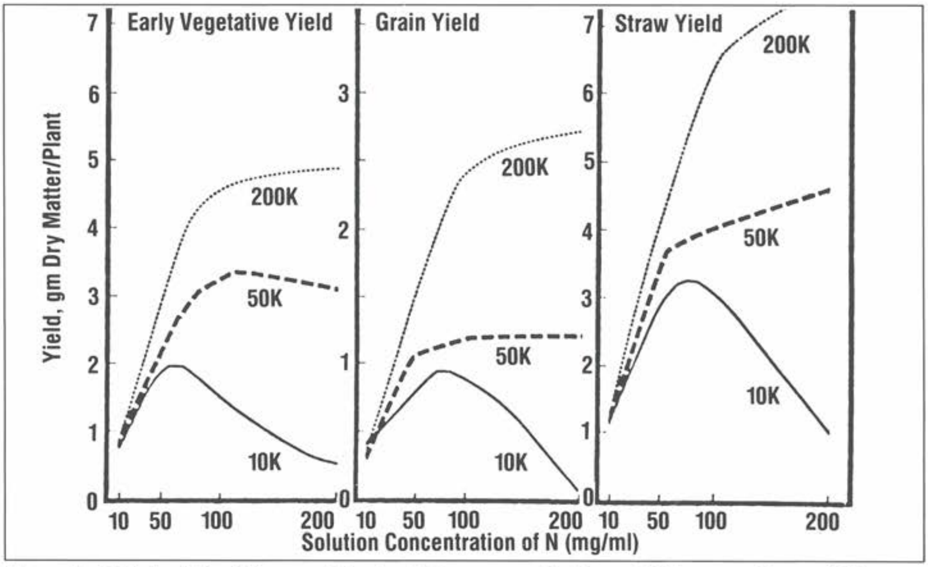


Figure 2. Effect of N at three nutrient solution concentrations of K^+ on early vegetative, grain, and straw yields.

Interactions . . . from page 9

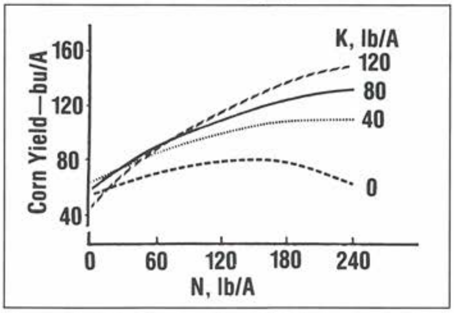


Figure 3. The best rate of N depends on K.

K with higher N rates to take advantage of the extra N. Illinois corn data showed a higher optimum N rate as K applications increased **(Figure 3).**

Potassium Uptake

Nitrogen form can affect K absorption. Tomatoes grown in nutrient solution with nitrate-N have shown a higher relative growth rate than plants supplied with ammonium-N. After 4 days, the total K content decreased in ammonium-grown tomato plants and remained constant in ones supplied with nitrate **(Table 1).**

Table 1. K content of nitrate- and ammonia-grown tomato plants.

Days to harvest	mgm K/gm dry weight	
	Nitrate-grown	Ammonia-grown
0	59.2	59.2
4	59.0	56.7
10	41.8	32.9
21	41.4	25.3
24	41.3	28.1

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 N 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 **(Table 2).**

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 potassium interacts with phosphorus and that together they may interact with other nutrients. A good example is the observed reduction of phosphorus induced zinc deficiency of corn when available K levels are increased. Manganese content of the corn plants also increased, indicating there is some relationship of K, P, Mn, and Zn in this complex effect . . . resulting in less severe zinc deficiency.

A more simple P-K interaction, but perhaps of more widespread importance, is their synergistic effect on yield **(Tables 3 and 4).**

Table 3. Phosphorus and K interact for higher soybean yields.

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

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

Clearly, the interaction of K with P is important in crop production.

Table 2. N form and K rate interact to affect N and K uptake and vegetative yield of corn plants.

Nitrogen Form	K rate ppm	Vegetative Yield* g/pot	Uptake (g/pot) K	Uptake (g/pot) N
NO_3	80	27.7	0.91	0.84
NO_3	160	26.7	1.09	0.84
NO_3	320	28.3	1.29	0.80
NH_4	80	19.2	0.92	0.64
NH_4	160	20.4	1.07	0.68
NH_4	320	33.5	1.83	0.97

*36 days after planting

Table 4. Positive P-K interaction produces higher Coastal bermudagrass yields.

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

Potassium-Calcium and Magnesium Interactions

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

Incidence of tetany tends to be lower if forage Mg exceeds 0.2%. 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 ammonium-N may result in greatly reduced uptake of calcium (Ca) and Mg while having lesser effects on K.

Large amounts of ammonium-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.

Potassium-Sulphur Interactions

Sulphur (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 improves 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 (B, Fe and Mo) have resulted in decreased uptake when K was added. Others (Cu, Mn and Zn) have increased micronutrient utilization with the use of K.

An interesting observed interaction effect is that between K and sodium (Na) on alfalfa. When K is deficient, the classical K deficiency symptom is quite apparent.

THESE alfalfa leaves show typical symptoms of potassium (K) deficiency.

However, for alfalfa grown on soils high in Na, the K deficiency symptom has a somewhat different appearance.

K DEFICIENCY symptoms look different with alfalfa on high sodium (Na) soils.

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. ■

K

Potassium Availability and Uptake

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

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

Soil Factors...

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

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

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.

3. The quantity of available K in the soil. This is the value the K soil test measures. It is the sum of exchangeable K and water soluble K. As the level of soil test K decreases, the crop response to applied potash increases, shown in **Figure 1**.

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

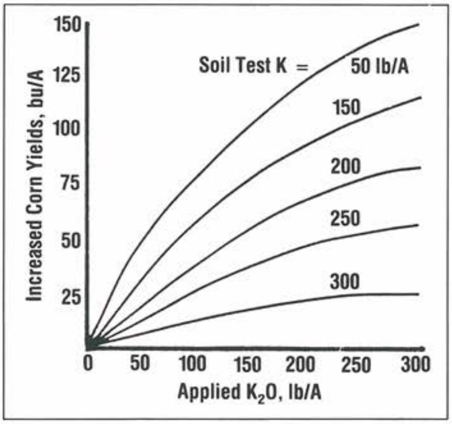


Figure 1. Yield responses to potash are greater on lower K soils, but yields are highest with adequate K.

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

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

If dense layers develop in the subsoil, root penetration and rooting volumes are decreased, reducing the availability of the K and nutrients that are there.

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

Effects of low temperature can be somewhat offset by increasing soil K levels. Row K can be important with

Table 1. Soil test K and row applied K_2O help corn overcome the effects of soil compaction.

Soil Test K	Row Applied K_2O	Soil compaction level, tons <5	9	19	Loss due to compaction
lb/A	lb/A	bu/A			
204	0	151	141	129	22
	45	169	164	164	5
262	0	177	153	157	20
	45	173	168	163	10
469	0	169	162	149	20
	45	169	167	151	18

Wisconsin, 1985-86

lower soil temperatures especially for early planted and minimum till crops.

8. 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 reduced K availability and uptake by crops. Increasing soil K levels can help overcome the adverse effects.

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

Data from Wisconsin in **Table 1** show how the adverse effects of compaction on corn yields can be modified by increasing soil test K levels and by using row-applied K_2O.

Plant Factors...

1. 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.

2. The variety or hybrid. Crop genetics come into play with the differences among varieties or hybrids of a given crop.

Differences are developed through plant breeding. They usually relate back to the type of root system, root density and metabolic activity that affect K uptake and, hence, availability of K for a given K test.

Table 2 shows an interaction between P x K x hybrids. The response of Hybrid B to P and K was independent of the level of the other nutrient. However, the response of Hybrid A to P and K was greatest where both nutrients were at the highest rates.

Potassium as a nutrient has a very positive effect on root branching and density.

Table 2. Corn hybrids may respond differently to applied P and K.

	Hybrid A P_1	Hybrid A P_2	Hybrid A Response to P	Hybrid B P_1	Hybrid B P_2	Hybrid B Response to P
	bu/A					
K_1	129	136	7	120	128	8
K_2	131	147	16	125	133	8
Response to K	2	11		5	5	

The other factor is that new varieties often have higher yield potentials which increase the demands placed on soil K. Additional potash will be needed under higher yields.

3. Plant populations. As plant populations increase yield of some crops are greater and demands on soil K are increased.

Yields often will not increase with higher populations unless adequate levels of K are in the soil, from native or fertilizer sources.

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

Table 3. High yielding crops need more K.

Corn yield	K uptake	K uptake
bu/A	lb/A	lb/bu
110	117	1.06
154	151	0.98
202	223	1.10
231	259	1.12
255*	304*	1.19*

*From a different experiment and location.

Fertilizer and Management Practices...

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

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

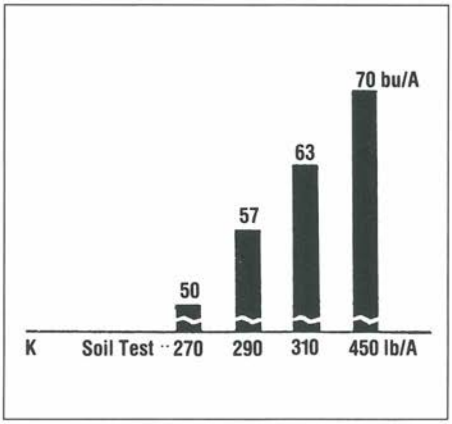


Figure 2. Higher K soil tests can increase soybean yields.

3. Placement of K. Broadcast plowdown applications of K are more available than surface applied disked-in K. Row K at moderate rates is usually twice as available as similar amounts broadcast.

Deep placement or drop irrigation help move K down. Gypsum applied with potash also helps move K down in very fine textured soils.

4. 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 does not move into the soil and has low availability, particularly under dryland conditions.

5. 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.

6. 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. ■

PLANT FOOD UPTAKE

(At various yield levels, per acre)

lb/A	CORN 120	CORN 160	CORN 200 bu	SOYBEANS* 40	SOYBEANS* 60	SOYBEANS* 80 bu	WHEAT 40	WHEAT 80	WHEAT 100 bu
N	160	213	266	224	315	416	75	166	188
P_2O_5	68	91	114	38	58	78	27	54	68
K_2O	160	213	266	144	205	250	81	184	203
Mg	39	52	65	16	24	32	12	24	30
S	20	26	33	14	20	26	10	20	25

lb/A	COTTON (LINT) 750	COTTON (LINT) 1,125	COTTON (LINT) 1,500 lb	GRAIN SORGHUM 6,000	GRAIN SORGHUM 8,000	GRAIN SORGHUM 10,000 lb	POTATOES 300	POTATOES 600	POTATOES 900 cwt
N	105	143	180	178	238	297	150	300	450
P_2O_5	45	54	63	63	84	105	48	96	144
K_2O	65	96	126	180	240	300	270	540	810
Mg	17	26	35	30	40	50	24	40	72
S	15	23	30	28	38	47	14	27	41

lb/A	ALFALFA* 4	ALFALFA* 6	ALFALFA* 8 tons	CLOVER-GRASS 3	CLOVER-GRASS 6	CLOVER-GRASS 7 tons	HYB. BERMUDAGRASS 6	HYB. BERMUDAGRASS 8	HYB. BERMUDAGRASS 10 tons
N	225	338	450	150	300	350	258	368	460
P_2O_5	60	90	120	45	90	105	60	96	120
K_2O	240	360	480	180	360	420	288	400	500
Mg	20	30	40	15	30	35	18	26	34
S	20	30	40	15	30	35	30	44	58

*Legumes get most of their nitrogen from the air.

Figures given are total amounts taken up by the crop in both the harvested and the above-ground unharvested portions. These numbers are estimates for indicated yield levels, taken from research studies, and should be used only as general guidelines.

RESEARCH PPI EDUCATION

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K

Yield and Economic Responses to Potassium

Farmers must reduce their costs per bushel or ton of crop in order to make a profit and survive in times of severely depressed crop prices. High yields distribute production costs over more bushels or tons resulting in lower costs per unit of crop production.

SUCCESSFUL FARMERS know that they must spend money to make money. They look for income-earning inputs which 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 often reduces profits because yields suffer and unit costs of production become higher rather than lower.

Potassium (K) fertilization is one of the vital income earning inputs which enable farmers to produce lower unit cost crops. 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 this work to illustrate the substantial impact of K in improving earnings.

Corn

Table 1 shows how K fertilization in Ohio increased corn yields and profits on a Crosby soil testing low to medium in K. **The principle of lowering production costs per unit of crop when K fertilization results in higher yields is readily apparent.**

Table 1. Potassium fertilization increases corn yields and return per acre by lowering unit cost of production.

K_2O Rate	Yield	Profit From K	Total Cost Per Bu
lb/A	bu/A	$/A	$/bu
0	146	—	2.05
50	167	43	1.85
100	174	56	1.80
200	187	79	1.73
400	188	70	1.78

Base cost without K: $300/A.
Soil Test K, lb/A: 126 to 209.
Corn: $2.50/bu. K_2O: 11¢/lb.
30¢ per added bu harvest cost.
K applied every other year.

Table 2. Corn hybrids respond differently to K fertilization.

K_2O Rate	Hybrid A	Hybrid B
lb/A	Yield, bu/A	
0	146	123
50	165	167
100	170	179
200	170	197
400	169	196
Response to K*	24 bu/A	74 bu/A
Profit from K*	42 $/A	152 $/A

*Corn: $2.50/bu. K_2O: 11¢/lb, 200 lb rate
30¢/bu harvesting cost deducted.
K applied every other year. Medium K soil.

Corn hybrids differ greatly in their need for K. High-yielding hybrids generally need more K as demonstrated in **Table 2.** In this study at Ohio's Western Research Center the additional profit from using K was approximately 3.5 times more for Hybrid B than for the lower yielding Hybrid A.

Table 3. Starter K response on high K soils may be related to cold soil temperature. Kansas.

N Rate	Irrigated Corn Yield, bu/A		Added Earnings from K_2O
lb/A	No K_2O	20 lb K_2O	$/A
0	72	80	15.40
75	128	137	17.60
150	167	182	30.80
225	166	182	33.00

Soil test K level: High. Averaged across P rates.
Spring weather cool and wet.
Corn: $2.50/bu; K_2O: 11¢/lb.
Harvesting cost: 30¢/bu.

Table 4. Potassium fertilization increases profits from soybeans in New Jersey.

K_2O Rate lb/A	Yield bu/A	Added Yield bu/A	Added Return $/A	Added Cost $/A	Cost/Added bu $/bu
0	51	—	—	—	—
100	56	5	22.50	12.00	2.40
200	58	2	9.00	22.40	11.20

$4.50/bu soybean price. This test was run on a very high releasing K soil (about 75 lb K_2O/year).

Tillage and soil management systems can change the need for fertilizer K. In Kansas, starter fertilizer supplying K was beneficial for no-till corn grown on a high K testing soil **(Table 3)**. This response is probably related to lower soil temperatures under no-till or heavy residue conditions. Other soil conditions which can lead to K responses on high K soils include low soil moisture, compaction, low pH, and high amounts of calcium, magnesium, and/or sodium. 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. **Table 4** illustrates the favorable action of K fertilization of soybeans on a very high releasing K soil in New Jersey. The first 100 lb of K_2O/A was a very profitable input.

Even lower costs per added bushel resulting from K fertilization of soybeans in Ohio are evident in **Table 5**. Other research in Ohio revealed that K helps reduce risks of a dry year with the greatest soybean yield and profit increases coming from K in dry years. Yield losses when going from a good year to a dry year were also cushioned by the use of K.

Table 5. Potassium fertilization increases soybean yields and reduces cost per additional bushel in Ohio.

K_2O lb/A	Yield bu/A	Cost/ Added bu $/bu
0	40	—
40	43	1.47
80	45	2.20
120	48	1.47

K_2O: 11¢/lb $4.50/bu soybean price.

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 6**.

Wheat

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 6 states and provinces. Returns on investments in K applications, usually less than 60 lb/A, were 200% or higher approximately 60% of the time.

On a low K soil in northeastern Saskatchewan, KCl fertilization raised spring wheat yields from 34 to 63 bu/A and greatly increased returns **(Table 7)**.

Table 6. Potassium fertilization increases soybean yields and quality on low K soil in Virginia.

K_2O Rate lb/A	Yield bu/A	% Moldy Beans %	Elevator Dockage $/bu	Gross Return $/A	Added Return $/A
0	38	31	.54	150.50	—
120	47	12	.22	201.16	50.66

$4.50/bu soybean price. K_2O: 11¢/lb. Harvesting and hauling: 20¢/bu.

Table 7. Adequate potassium improves spring wheat yield and grain protein content on a low K soil in northeastern Saskatchewan.

K_2O applied lb/A	Yield bu/A	Grain protein percent	Added yield bu/A	Added return $/A	Added cost $/A	Added cost $/bu
0	34	13.3	—	—	—	—
30	45	13.8	11	24.20	4.40	0.40
60	43	13.9	9	19.80	7.50	0.83
120	54	13.9	20	44.00	15.20	0.76
240	60	14.8	26	57.20	29.00	1.12
480	63	15.0	29	63.80	55.70	1.92

Wheat: $2.20/bu; K_2O: 11¢/lb; Harvesting and hauling: 10¢/bu.

No credit was given for higher grain protein in these calculations. High protein wheat frequently sells at a premium and is usually more marketable.

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.

The profitability of KCl fertilization in South Dakota is shown in **Table 8**. With one exception, these responses were due to Cl. 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.

Table 8. Profitability of KCl fertilization in South Dakota.

	Wheat Price, $/bu		
Average for	2.50	3.50	4.50
	$ return per $ invested		
Responsive sites only (15)	3.20	4.48	5.76
All 36 sites	1.24	1.73	2.23

KCl at 7¢/lb; 42% of 36 sites showed response.

Barley

Early seeding usually results in maximum yields of barley. The availability of soil K is depressed by cold, wet soil conditions prevalent in early spring. **Table 9** shows the favorable action of K fertilization on the earnings from early seedings of barley in Montana.

Although the later seedings were unprofitable, K additions helped improve yields. Alberta studies suggest that K fertilization helps late seeded barley withstand stress from diseases such as net blotch and scald.

Cotton

Potassium fertilization of a Mississippi Delta cotton soil testing low in K

Table 9. Potassium fertilization lowers production cost/bu of early seedings of barley over a five-year period on a high K soil in Montana.

Seeding Date	K_2O	Yield	Gross Return	Production Cost	Net Return	Cost of Crop
	lb/A	bu/A	$/A	$/A	$/A	$/bu
April 6	0	48	120	115	5	2.40
	20	55	138	119	19	2.16
May 6	0	36	90	115	-25	3.19
	20	42	105	119	-14	2.83
June 3	0	30	75	115	-40	3.83
	20	33	83	118	-35	3.58

Prices used: Barley = $2.50/bu Harvest = 25¢/bu K_2O = 11¢/lb Applied

Table 10. Lint cotton production costs are lowered by K additions to a low K soil in Mississippi.

K_2O	Cotton Yield	Farmer Savings
lb/A	lb lint/A	$/lb lint
0	1,002	—
60	1,142	$0.05

shaved 5 cents per pound off lint production costs **(Table 10).** In addition to reducing costs, using K also improved cotton lint quality properties including micronaire, fiber length and elongation, and tensile strength. It also helped control diseases such as *Verticillium* and *Fusarium* wilt.

Alfalfa

High-yielding alfalfa removes large amounts of K from the soil, about 60 lb of K_2O/ton. Most farmers don't apply enough K for their alfalfa - losing yields and profits while draining their soil's K supply. During a five-year period in Maryland, alfalfa yields were increased by an average of 1.25 tons/A by adding 430 lb of K_2O/A to high K soils. This yearly investment of $50/A for K resulted in an annual return of $100/A.

Quality

As shown in the preceding discussions, improved crop quality, as well as yields, can add significantly to growers' profits. ■

K

Potassium Reduces Stress from Drought, Cool Soils and Compaction

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

WHY DOES MOISTURE STRESS often cause corn plants to look like they are suffering from potassium (K) deficiency?

A K deficiency (sometimes indicated by early, visible symptoms) can be the most harmful effect of dry weather. In a drought, the films of water surrounding soil particles become very thin. Because most K moves to plant roots through these films of water, droughts make it much more difficult for crops to take up enough K to satisfy their needs.

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.

Higher soil K levels can come from residual amounts left over from prior applications or from direct applications in the year a crop is grown.

Measuring the K content **of the crop** is a common method used by scientists to determine how easily roots can remove K from the soil. In dry years, crops almost always 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 moisture stress. Most agronomists feel that corn leaves must contain at least 1.8% K to allow the crop to produce maximum yields.

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

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

Since drought conditions make it more difficult for plants to get the K

Stress . . . from page 15

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	Good Year	Stress Year	Good Year	Stress Year
lb/A	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 bu	40 bu	4 bu	17 bu
Profit from K ($/A)	0	$90/A	$10/A	$75/A

Corn, $2.50/bu; soybeans, $5.00/bu; K_2O, 10¢/lb; medium K soil.

they need, it would seem logical that fertilizer K requirements would be the greatest in dry years. Research in several states and provinces has indeed shown that the largest yield increases from applied K often occur in dry years.

A good example is a long-term potash 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 moisture stress.

Adding K is similar to buying insurance in that it protects against loss of yield in dry years. Potash cannot protect against extreme droughts, but it does hold up yields in years with moderate water stress, typical of Corn Belt conditions.

An 18-year experiment in Indiana also 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.

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 is expelled to the atmosphere. Closing the stomates is a defense mechanism to preserve water.

Plants close the stomates by pumping K into the cells surrounding the opening. Swelling of the cells closes the opening and water loss is restricted. Plants with inadequate K can be slower 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.

In cool soils, root growth is less and the roots are less able to absorb nutrients. Crops growing in cool soils often

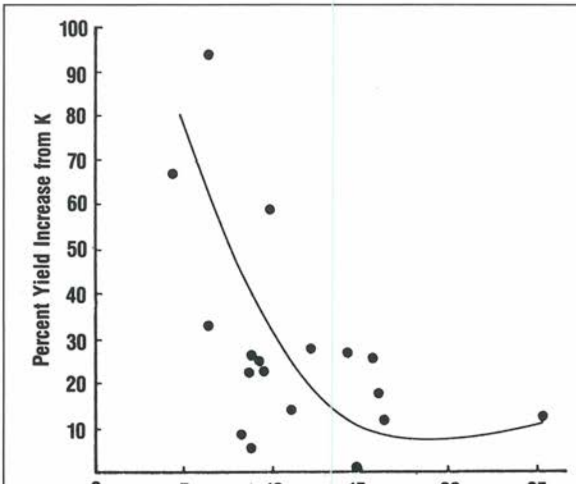


Figure 1. Soybean response to potash was greatest in years with lower rainfall during the critical 12-week period after planting (18-year study, Indiana).

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% higher level of soil K in northern Wisconsin than in southern Wisconsin to obtain a 2% level of K in alfalfa plants.

Management practices such as no-till and early planting cause plants to grow more slowly in cooler soils. Higher K fertility may be required in these situations. Using early planting as an example, 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. 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 harder for the roots to take in adequate amounts of K and other nutrients. This is why plants growing on compacted soils often show K deficiency symptoms.

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 the 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.

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	-------Compaction------- Low	High	Loss
lb/A	------Corn Yield, bu/A------		
0	151	129	22
45	169	164	5
K Response	18	35	
Profit from K	$40/A	$83/A	

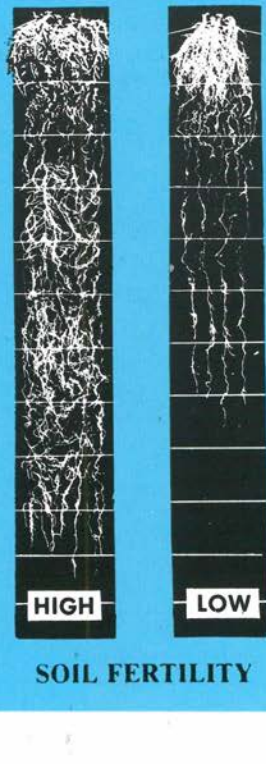
Low compaction: <5 tons/A.
High compaction: 19 tons/A.
Soil test K: 204 lb/A.
Corn $2.50/bu, K_2O 10¢/lb.

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

Effective Moisture Use

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

- **Deeper roots.** Potash helps plant roots penetrate deeper for another inch or two of water.
- **Faster closing of the crop canopy.** Earlier covering of the soil (1) reduces water evaporation and (2) allows more rainfall to enter the soil.
- **Earlier maturity.** Adequate K helps ensure plants will get through the critical pollination period earlier—before drought.



SOIL FERTILITY

Potassium Application Methods

Crop responses to placement of potassium (K) fertilizer are not as likely as for nitrogen (N) or phosphorus (P). However, some soil characteristics or growing conditions may warrant placement of high concentrations of K in the vicinity of developing plant roots.

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

Methods

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

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

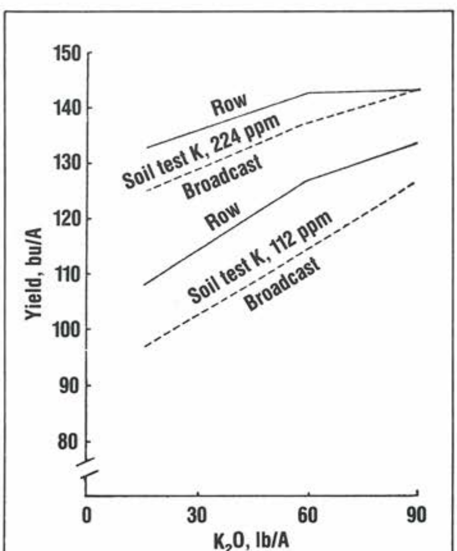


Figure 1. Differences between K application responses are smaller as K test rises (Tennessee).

Results

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

Corn. Soil characteristics can have significant effects on how corn responds to K application methods. Corn on three Illinois soils low to medium in soil test K responded differently to comparisons of broadcast and banded K. Banded K was more effective on all

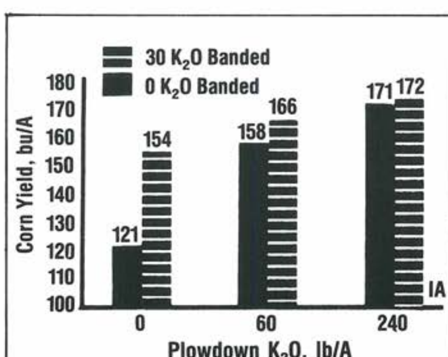


Figure 2. Responses to starter K diminish as soil test K increases (Iowa).

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

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

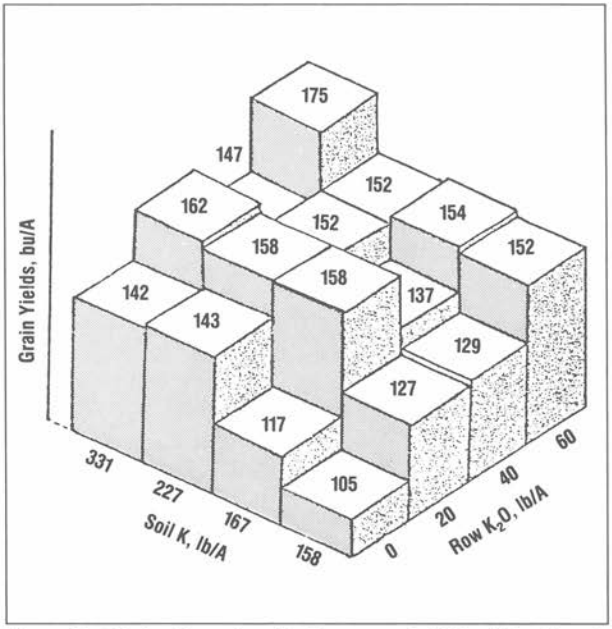


Figure 3. Starter K can be effective even at high soil test levels (Wisconsin).

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

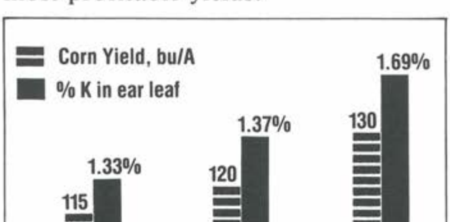


Figure 4. Surface strip applications plowed down are effective for corn (Indiana).

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

Soybeans. Soybeans require high K availability for best yields and profitability. Ohio data show a strong relationship of soil test K to soybean yields

Table 1. Soybeans respond well to K on deficient soils.

Soybean Variety	K_2O applied, lb/A 0	80	160
	-----------Yield, bu/A-----------		
Dare	47	59	70
Bragg	36	45	50

TVA

(**Figure 5**). Responses to applied K have been good on deficient soils, whether broadcast or banded (**Table 1**).

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

Alfalfa. High yield alfalfa has one of the highest K needs of any crop, frequently exceeding 60-70 lb K_2O per ton of hay. Topdressing alfalfa with K is an adequate way of maintaining yield. Building nutrient levels before seeding and then topdressing for maintenance is the best approach.

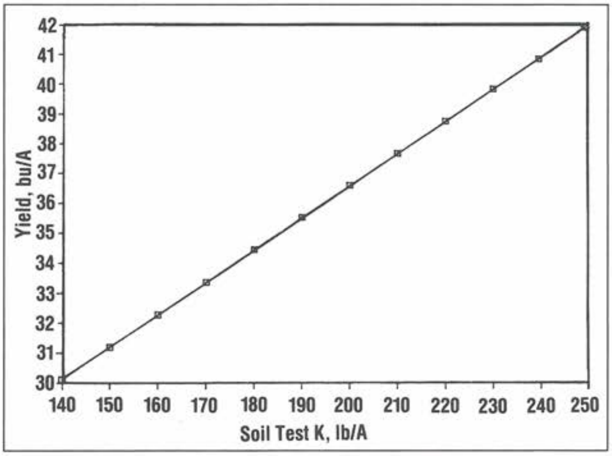


Figure 5. Soybean yields are closely related to soil test K (Ohio).

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

Table 2. Seed-placed K increased barley yield over band or broadcast on K deficient soils.

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

Alberta

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

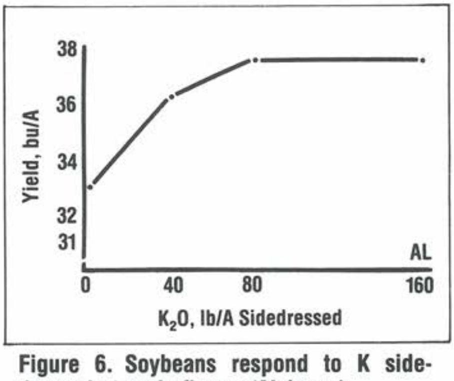


Figure 6. Soybeans respond to K sidedressed at early flower (Alabama).

Summary

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

K

The Role of Potassium in Crop Quality

Potassium (K) is often described as the "quality element" 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.

CROP QUALITY: What is the effect of potassium (K)? 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 . . . or greater consumer

(continued on next page)

Quality . . . from page 25

acceptance of vegetables. Thus, 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; and/or (4) lower cost per unit of production.

The true value of K for maximum economic yield (MEY) production systems is best determined on a crop-by-crop basis.

Grain Crops

Following is a summary of some of the benefits of K for yield and quality of corn, soybeans and wheat.

Corn

- Earlier silking and longer grain fill
- Uniform maturity and grain moisture
- Improved stalk quality and reduced lodging
- Increased kernels per ear and kernel weight
- More efficient use of N.

Soybeans

- Improved seed size
- Fewer shriveled and moldy beans **(Figure 1)**
- Improved oil and protein content
- Better nodule development
- Improved pest and disease resistance
- Increased use efficiency of other inputs.

Potassium Improves Soybean Quality

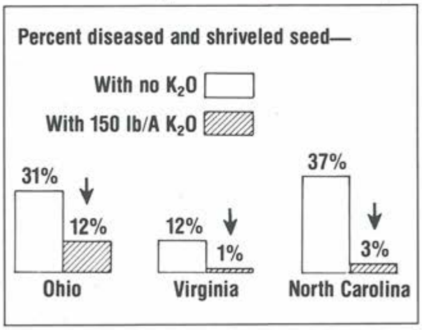


Figure 1. Potash fertilizer for soybeans improves quality by reducing percentage of diseased and shriveled seed.

Wheat

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

Forage Crops

Both legumes and grasses perform best under conditions of adequate potassium nutrition. Potassium plays a key role in the production and utilization of quality livestock feed:

- Winterhardiness and stand longevity
- Protein quantity and quality
- Nitrogen fixation and nodule activity
- Legume-grass composition in the sward
- Vitamin and mineral content
- Total digestible nutrients (TDN)
- Palatability 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 not only cotton boll size, but also micronaire and strength of cotton fibers.

Vegetable Crops

Irish and sweet potatoes, cabbage, cassava, and other vegetable crops require potassium for both yield and quality. Where potassium 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 potassium teamwork helps achieve maximum economic yield of tomatoes **(Table 1)**.

Table 1. Potassium-nitrogen teamwork increases marketable yield of tomatoes.

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

Citrus

For crops such as oranges, potassium improves fruit quality and, specifically, K influences size of fruit, thickness of rind, fruit color, acid/sugar ratio, soluble solids, and the vitamin C content. The influence of K deficiency on "pineapple" orange yield was due, in part, to a high rate of premature fruitfall combined with small 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.

Specialty Crops

Turf requirements for K are quality oriented and include color, turf density, winterhardiness, and resistance to disease. Resilience, regrowth rate, and durability to constant use are turf quality features important for playgrounds, golf courses, and other high traffic areas. Producers of sod are interested in tiller count, rhizome length and root density. Balancing potassium and nitrogen nutrition is key for maintaining a healthy, vigorous turf.

Tobacco fertilized with potassium resulted in an increased K content, a reduction in nicotine and an increase in sugar concentration.

Hybrid tea roses grown under K stress showed reduced growth, fewer flowers, and shorter flower stem length.

Sugarcane yield and quality are closely tied to potassium nutrition. This is due to potassium's influence on photosynthesis rate, total leaf area, and drought and disease resistance. A balanced fertilization program with N and K provides both the highest juice quality and sugarcane yield.

Grape quality is influenced as potassium improves yield of marketable grapes and helps prevent cluster tip, uneven ripening of berries, and preharvest shattering of the fruit.

Banana yield and quality are strongly influenced by K nutrition. It improves fruit weight, number and fingers per bunch. In addition, potassium stimulated earlier fruit shooting and shortened the number of days to fruit maturity. The beneficial effects of K on banana fruit quality continue over and above the levels of K required for top fruit yield **(Table 2).**

Table 2. The effect of K on banana yield and quality.

K_2O	Yield			
lb/ plant	lb/ bunch	hands/ bunch	fruit/ bunch	fruit length inches
0	9.8	7.5	114	7.3
1/3	14.8	8.1	130	7.6
1	16.0	8.9	140	7.8
1-2/3	17.3	9.2	164	8.0

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 nonleguminous plants, for annual and perennial crops, and for other crops for food, fiber, or ornamental purposes.

The quantity of K required to obtain maximum economic yields (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 requires 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. ■

K

Effects of Potassium on Crop Maturity

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. Potash deficiency delays maturity in soybeans. The effects of K on maturity of cotton, fruits and vegetables are variable.

CROP STRESS caused by too little potassium (K) can exhibit itself in many ways . . . increased incidence of diseases . . . lodging in corn and other crops . . . less winterhardiness in forage legumes and grasses. 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.

Research has shown that application of NPK fertilizers as starters 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. Potassium 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 number of days of grain development . . . and higher yields. Results are shown in **Table 1**.

Table 1. Potassium increases grain development days.

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

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.

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

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

Illinois research showed that corn silk emerged sooner when K was added to a medium K soil. The conclusions were that the influence on silking could boost corn yield by lengthening grain filling time and help 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 another Illinois study, summarized in

Table 3. Potassium hastens corn-silking.

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

Table 4, K had a tendency to increase grain moisture at harvest, an indication of an extended period of grain fill, a definite effect on maturity . . . and yield.

Table 4. Potassium increases corn yield and grain moisture.

K_2O rate, lb/A	Moisture in grain, %	Yield, bu/A
0	26.5	248
60	27.1	160
120	27.7	164
240	27.4	164

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. Apparently the real physiological cause is that there are fewer seedpods, and the seeds do not form normally. So, the plant tries to stay alive until more seeds form. The same effect of bean plants remaining green longer can be caused by pulling off the seedpods before maturity.

The overall influence of K on cotton maturity ranges from speeding it up to no effect to a delay. In Louisiana on low K acid soil, K had no effect on first harvest yields on an acid soil without lime. But when dolomitic lime was applied, K increased both first harvest and total yields, **Table 5.** In Arkansas, K did not affect first harvest yield, but it did delay maturity in Alabama.

Table 5. Potassium and lime increase first harvest and total yields of seedcotton.

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

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 6.**

Table 6. Effect of K on the number of broccoli terminals mature by midseason.

K_2O rate,	Terminals mature by midseason		
lb/A	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, **Table 7.**

Table 7. Potassium increases yield and hastens maturity of blueberries.

K rate, lb/A	Yield, lb/bush	Weeks to harvest from fruit set
0	5.14	8.4
43	5.49	8.3
85	5.31	7.7

Early maturity of fruits and vegetables almost always offers the advantage of higher prices in the marketplace. ■

K

Effects of Potassium on Nitrogen Fixation

Adequate potassium (K) fertility is important for symbiosis, the process which enables legumes to fix nitrogen from the air.

IT IS GENERALLY AGREED that factors favoring nitrogen (N) fixation are similar to those necessary for good growth, vigor, and dry matter production of the host plant. Alfalfa, soybeans, and most other legumes require much larger amounts of N and potassium (K) for maximum economic yield (MEY) production than any of the other nutrients. Since legumes have the capacity, through the symbiotic N fixation process, to get most of the N requirement from the air, K is the single most important fertility need.

Most researchers agree that K increases legume N_2 fixation to an equal or greater extent than it increases yield. Thus, the use of adequate K in conjunction with other proven management practices is a vital factor in determining the total N fixed.

Despite the favorable K relationship with N_2 fixation, there are some questions about the involvement of K in the N_2 fixation process because it is often noted that K depresses the percent N in legumes. However, the depressive effect K has on percent N is associated, invariably, with greater yields and greater total N uptake. **Table 1** gives an estimate of the amount of N fixed by several legumes. The amount of N fixed varies widely with yield level. It is obvious that any growth factor, such as K, which is important in good legume production would have a major impact on the amount of N fixed.

Table 1. Estimated N fixation levels for selected legumes.

Type of Legume	Nitrogen fixed, lb/A	
	Avg. Yields	High Yields
Peas, Vetch	50	180
Alfalfa	120	350
Clovers	75	250
Soybeans	60	240

The Roles of Potassium in N Fixation

Several factors are closely associated with N_2 fixation upon which K has a big influence. These factors are: nodule development, photosynthesis and carbohydrate production, root growth, and metabolite translocation.

Nodule Development

Most studies on forage, grain and vegetable legumes strongly suggest that ample K fertilization is required for maximum nodulation and nodule development. **Table 2** provides a good example with soybeans. Potassium fertilization increases nodule number and size. The result is greater nodule productivity (i.e. amount of N fixed per unit time per unit mass).

Photosynthesis and Carbohydrate Supply

The supply of carbohydrates to the nodule is essential for the energy-demanding N_2 fixation process. Potassium increases photosynthesis through larger leaves, more and larger epidermal cells per leaf, more stomata per unit leaf area, and more efficient CO_2 assimilation. The resulting improved carbohydrate levels provide the necessary substrate for nitrogenase activity and the reduction of N.

Root Growth

Rhizobia bacteria infection takes place when a root hair, growing out from active roots, intercepts or is attracted by one of the compatible nodule organisms. Any factor that increases root growth and activity of the host plant will increase nodulation and N_2 fixation potential. Potassium stim-

Table 2. Effects of K on soybean yield, nodulation and protein production.

K_2O Rate	Yield	Nodule Number	Nodule Weight	Seed Protein Production
lb/A	bu/A	/plant	g/cu.ft.	lb/A
0	26.4	59	9.6	662
120	54.8	114	25.7	1,289

ulates growth of the length and mass of legume roots as shown by the comparison in the photo below.

Metabolite Translocation

Sucrose is the main carbohydrate transported to the nodules via the phloem. Potassium is essential as a co-factor for the action of the enzyme needed to transport carbohydrate across cell membranes and into the phloem where it is then taken to other plant parts, including the nodules.

MEY and N_2 Fixation

There have been suggestions that the N_2 fixation capacity of legumes may limit dry matter production when other growth factors are optimal for high yields. For example, high yield soybean research has shown a 20 bu/A yield response to applied N fertilizer when yield potentials are 60 bu/A or more **(Table 3).** The best response to fertilizer N was obtained when applications were made at later stages of growth.

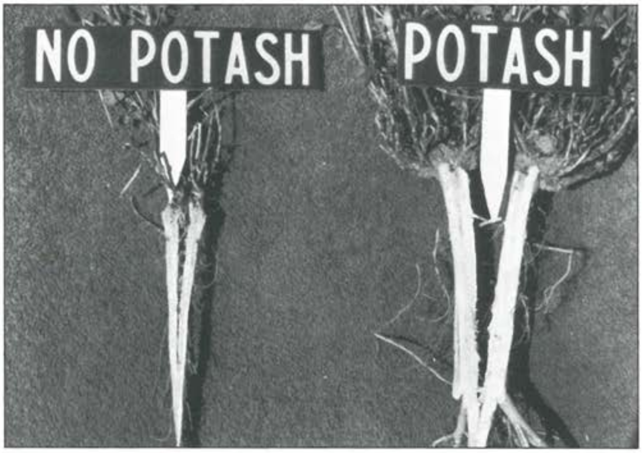
Table 3. Nitrogen (N) fertilization of intensively managed soybeans.

Preplant	Early Flower	Early Pod-Fill	Two-Year Avg. Yields
— — — N Applied, lb/A — — —			bu/A
0	0	0	60
50	0	0	71
0	50	0	76
0	0	50	81

Flannery, New Jersey

Summary

The determination of a direct role for K in N_2 fixation is primarily of scientific interest. The real value to production agriculture is in the combined, interactive effects of all growth factors on the process. Research would indicate that the N_2 fixation process is no different than all other plant functions where an optimum level of all essential nutrients in conjunction with top crop management is needed for optimum activity. ■



POTASSIUM stimulates growth of legume roots and enhances nodulation and nitrogen fixation potential. Alfalfa plant at left in photo received no potash.

K

Effects of Potassium on Plant Diseases

Potassium (K) is regarded as the "disease fighter" among the plant nutrients. The USDA Yearbook on Plant Diseases says, "More plant diseases have been retarded by the use of potassium fertilizer than any other substance . . . " It should be recognized, however, that K does not work alone. The healthiest, most profitable crops will be produced with balanced nutrition that minimizes nutrient stress throughout the growing season.

DISEASE RESISTANCE is genetically controlled. However, it is mediated by the nutritional status of both the plant and the pathogen as that nutritional status affects their life processes. Since one function of K within the plant is as a regulator of enzyme activity, it is involved in essentially all cellular functions that influence disease severity.

Many factors will influence the effectiveness of potassium fertilizer in reducing crop disease: 1) K status of the soil, 2) K rate, 3) K source, 4) nutrient balance, 5) variety/hybrid susceptibility, and 6) disease organism virulence and population. The following are examples of common and well-documented benefits of potassium fertilizer management increasing crop yield and quality through reducing disease.

High N Needs Adequate K

More disease has been "encouraged" over the past few decades by increasing nitrogen rates without supplying adequate K than any other fertilizer practice. As production levels are pushed higher, striving for maximum economic yields, the penalties from this and other nutrient imbalances will become even more severe.

An Illinois study illustrates 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 1.**

A properly fertilized crop such as corn will also have better standability because the plants will develop strong cell walls adding to disease resistance and increasing the opportunity for the crop to maintain firm, healthy stalks until natural maturity, **Table 2.**

Table 1. Potassium increased corn yields and reduced lodging.

	Yield, bu/A		Stalk Lodging, %	
Year	**Control**	**120 lb/A K_2O**	**Control**	**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

Avail. soil K - high

Table 2. Potassium helps develop strong cell walls.

K_2O Rate	Rind Thickness	Stalk Crushing Strength
lb/A	mm	kg
0	91	254
60	97	349
120	100	374

The same benefit from K was observed for sorghum in Kansas. Lodging, caused by stalk rot, was reduced from 88% down to only 2% with 320 lb/A of K_2O, while yield increased by 11 bu/A, **Table 3.**

Balanced Nutrition Important

The need for balanced fertility is widely recognized. This principle can be illustrated with many crops, including turf grass. A smut caused by *Ustilago striiformis* is a problem with high

CORN LODGING can occur when stalks are weakened by potash deficiency and stalk rots invade.

Table 3. Added K reduced lodging and increased dryland grain sorghum yields.

K_2O rate	Stalk rot	Grain yield
lb/A	percent	bu/A
0	88	95
40	71	105
80	45	108
320	2	106

Avail. soil K - low

Table 4. High rates of NPK reduced disease severity in bluegrass.

	NPK Rates, grams/m^2		
	12-2-4	24-4-8	48-8-16
	(% smutted tillers)		
N	8	13	40
NP	1	5	30
NK	1	6	26
NPK	2	2	11

Rhode Island

rates of N applied to "Merion" Kentucky Bluegrass. The percentage of smutted tillers was reduced to the lowest levels using NPK versus N alone or combinations of NP or NK, **Table 4.**

A mixed result was obtained in California, when pistachio trees were fertilized with potassium, without needed phosphorus. Verticillium wilt *(Verticillium dahliae)* was sharply reduced as was tree loss. However, P deficiency was accentuated, resulting in a lower yield per tree, **Table 5.**

Crop Quality Benefits from Less Disease

Low fertility soils often respond to proper fertilizer use and top management in three ways . . . higher yields . . . lower disease susceptibility . . . and **higher crop quality.** Soybeans illustrate how building soil fertility in K and P (another balanced fertility example) pays in a bigger and better crop. Less shriveled and diseased seed also means less dockage at the elevator, **Table 6.**

Similarly, food crops such as potatoes often respond to K by producing a higher quality product. Research in

Table 5. K reduced infection of Verticillium wilt, intensified P deficiency in pistachio trees.

Potassium treatments	Verticillium wilt		Yield	Severe P deficiency
	Infection	Tree losses		
lb/tree	%	No./row	lb/tree	% of trees
2.2	12.7	22	29.0	47
3.0	8.3	17	25.5	65
6.6	7.5	12	23.1	69
LSD.P = 0.05	3.3	-	1.8	10

Avail. soil K - high in surface, low in subsoil. Avail. soil P - low to medium.

STAND LOSS of Coastal bermudagrass is associated with potassium deficiency and leaf spot disease.

Oregon has shown that a well-managed K program resulted in increased total yields, increased No. 1 and No. 2 tubers, and reduced incidence of diseases such as stem soft rot, tuber hollow heart and brown center. Benefits to keeping-quality in storage (less rot and decay) and to market quality of fresh fruits and vegetables are numerous.

Table 6. Soybeans respond to P-K fertilization.

Fertilizer*, lb/A P_2O_5	K_2O	Soybean Yield, bu/A	Shriveled & Diseased Seed, %	Dockage $/bu
0	0	35	20.8	1.18
400	0	29	12.5	.54
0	400	38	1.8	none
400	400	52	1.3	none

*Applied only in first of the five-year study. Wisconsin
Avail. soil K and P - low and medium, respectively.

Forage yield, digestibility, and stand longevity can all be increased by potassium fertilization when poor nutrition and disease are problems. Coastal bermudagrass production benefited in all three areas where leaf-spot disease was evident and forage was infected with the toxin-producing variant of the fungus, *Helminthosporium cynodontis*, **Table 7.**

Potassium plus chloride offer two opportunities to reduce disease. In recent years chloride has become recognized as also reducing a number of diseases. Its effect appears to be as a nitrification inhibitor, delaying the amount of nitrate available for uptake by the plant from ammonium and urea based fertilizers. Nitrate accumulation in plant sap is frequently associated with more disease.

The crops known to benefit from Cl fertilization are listed in **Table 8.**

Table 7. Potassium improves yield, quality and longevity of Coastal bermudagrass.

K_2O (annual)	Spring stand density estimates: Year Initial	2nd	3rd	Total change	Yield (Two-year average)	IVDMD (Two-year average)
lb/A	%				tons/A	%
0	57	46	39	- 18	5.9	52.7
100	24	55	50	+ 26	6.6	53.6
200	35	60	72	+ 37	7.1	53.7
400	42	67	83	+ 41	7.3	53.9
600	36	60	81	+ 45	7.6	54.0

Avail. soil K - low
Louisiana

Note: Stand densities for single annual K_2O application; yield and IVDMD averaged across application frequencies (NS between frequencies).

POTASSIUM helps soybeans resist attack from soybean cyst nematode. In the inset photo, the row at left received potash, row at right did not.

Table 8. Crops benefiting from chloride fertilization and their associated diseases.

Crop	Suppressed disease
Winter wheat	Take-all, tan spot, Septoria,leaf rust, stripe rust
Spring wheat	Leaf rust, tan spot, Septoria
Barley	Common root rot, spot blotch, Fusarium root rot
Durum wheat	Common root rot
Corn	Stalk rot, northern leaf blight
Potatoes	Hollow heart, brown center
Celery	Fusarium yellows
Pearl millet	Downy mildew
Coconut palm	Gray leaf spot

Summary

The list of crops which benefit from K fertilization through disease reduction is too extensive to attempt a listing here as was done for chloride.

The International Potash Institute has summarized nearly 1,000 experiments dealing with K and plant disease relationships by the type of pathogenic organism. Crops threatened by fungal and bacterial diseases were benefited most frequently, about 3 out of 4 times. In the case of viral diseases and nematodes, the positive and negative effects were similar, **Table 9.**

As yield goals continue to increase in striving for maximum economic yields, more and more attention will be focused on the management of fertilizers for "non-nutrient benefits" such as yield enhancement through disease reduction. The specific roles of potassium and nutrient balance will become better understood and they in turn will become even more effective as tools to combat crop diseases. ■

Table 9. Effects of K on plant health.

Type of disease	Total number	Beneficial No.	Beneficial %	No effect No.	No effect %	Negative No.	Negative %
Fungal	740	526	71	80	11	134	18
Bacterial	68	51	75	8	12	9	13
Viral	116	48	41	16	14	52	45
Nematode	54	23	42	2	4	29	54

K Potassium in Animal Nutrition

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 for different classes of animals.

POTASSIUM (K) has been recognized as an essential nutrient in animal nutrition since the importance of K was pointed out by Sidney Ringer in 1883. Potassium is absolutely 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 composes about 5% of the total mineral content of the body.

Muscle contains more than 55% of the total K in the bodies of animals, **Table 1.**

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

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 as the K ion.

Concentrations of electrolytes differ markedly between the intra- and extracellular spaces. Sodium and chlorine (Cl) are mostly extracellular, whereas K, P, and sulphur (S) are mostly intracellular. This remarkable segregation of Na and K in body fluids is one of the real "mysteries of life".

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:

1. **Helps maintain water balance;**
2. **Helps maintain osmotic pressure;**
3. **Helps maintain acid-base balance;**
4. **Activates several enzymes of metabolic functions;**
5. **Functions in carbohydrate and protein metabolism and protein synthesis;**
6. **Functions in irritability of muscles. Important with Ca in regulation of neuromuscular activity. K helps 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.

K must be supplied in the daily ration because it is a mobile nutrient and there are not any appreciable reserves.

K Uptake and Control

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

Potassium in Human Nutrition

The usual American diet normally contains adequate K. The recommended daily allowance (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. The desirable Na to K ratio is 1:1.

Potassium in Animal Nutrition

Potassium is especially important in diets of chickens and turkeys during the first 8 weeks. The RDA for starting chicks is 0.3 to 0.4% of ration. The RDA for laying hens is 0.15%. During heat stress, the needed levels may be 0.4% to 0.6% to insure against imbalance at elevated temperatures.

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 in the first 4 weeks.

Swine RDA is higher for young pigs than for older ones. It ranges from 0.27% to 0.39% in rations of pigs weighing up to 8 lb and about 0.2% in rations of pigs weighing 40 to 80 lb.

Ruminants have a higher K requirement than do nonruminants. In ruminants the RDA is about 0.5% of the ration. Ruminants are able to metabolize large amounts of K from the ration. Potassium is also essential for rumen microorganisms.

The single most consistent effect of suboptimal K in the ration of ruminants is decreased feed intake.

Dairy cattle have a RDA of 0.8% K of dry ration. High K in ration is especially needed during early to mid-lactation of high producing dairy cows, **Table 2.** Other dairy classes have a similar requirement.

Table 2. Effects of ration K on dairy cows, early lactation.

	Ration K, %		
	0.51	0.75	0.99
Adjusted feed intake, kg/day	17.8	19.9	20.7
Adjusted milk production, kg/day	28.5	29.9	29.2
Body weight change, kg	-55.7	-35.1	-46.8

The RDA of beef cattle is about 0.5 to 0.7% of dry ration, **Table 3.** Several studies have been reported with weight gains of steers on rations containing optimum levels of K.

Table 3. Recommended K level, % in dry ration.

Animal	Recommended level[1]
Beef cattle	0.5-0.7
Dairy cattle	0.8
Sheep	0.5
Swine	0.2-0.3
Horses	0.4-0.5
Poultry:	
Starting chicks	0.3-0.4
Laying or breeding hens	0.15
Turkeys	0.4-0.7

[1]National Research Council of National Academy of Science

In Texas and Tennessee, elevated K levels in the diets of calves and lambs being shipped to feedlots or market helped reduce the shock and stress of shipping.

Calves on winter native range in Nebraska that were fed supplemental K did not have a depression in weight gains. Dry cows were also helped by supplemental K.

Hypomagnesia grass tetany is a pathological situation in ruminants related to high K intake, and the relationships are not clear. Hypomagnesia grass tetany results from either a deficiency or poor utilization of Mg. A high Mg level in the diet accompanied with high intake offers some protection to grass tetany. The involvement of K is inconclusive. ■

POTASSIUM HUNGER SIGNS IN SOME CROPS	
CORN	• Firing or scorching 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, stalk lodging.
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, much less uniform beans, many worthless.
COTTON	• Cotton "rust" . . . first a yellowish white mottling in the leaf, clearest between veins. 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.
WHEAT	• No 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.
ALFALFA	• First signs small white or yellowish dots around outer edges of leaves . . . then edges turn yellow and tissue dies and becomes brown and dry.
CLOVERS	• First signs white spots size of small pinheads near the border of leaves . . . later toward center . . . while border turns yellow, curls up, and dies. The spots appear first on the older leaves. Slower regrowth.
FRUIT TREE CROPS	• Yellowish green leaves curl upward along entire leaf . . . scorched areas develop along edges that become ragged. Undersized fruit dropping prematurely. Poor storage, shipping, and canning qualities in fruit.
POTATOES	• Upper leaves usually smaller, crinkled, and darker green than normal . . . middle to lower leaves marginal scorch and yellowing. Early indicator: dark green, crinkled leaves, though varieties differ in normal leaf color-texture.
TOMATOES	• Stunted plants, slow growth, older leaves ashen gray green with yellowish brown margins . . . small fruit, darkened stem ends from poor attachments to the plant, cracking of flesh around stems, poor uneven color externally and internally.

POTASSIUM HUNGER signs in corn may appear as "edge scorch", a firing or drying along the tips and edges of lowest leaves. (Photography by Grant Heilman.)

IN SOYBEANS, potassium hunger signs begin as scorching on outer leaf edges. When leaf tissue dies, leaf edges become broken or ragged, with delayed maturity and slow defoliation. (Auburn University photo.)

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