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Research Article

THE IMPORTANCE OF POTASSIUM IN PLANT GROWTH – A REVIEW

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ABSTRACT
This issue discusses the importance of potassium as a key plant nutrient and problems associated with excess and/or deficiencies of potassium in the plant. The availability of potassium to the plant is highly variable, due to complex soil dynamics, which are strongly influenced by root–soil interactions. Many plant physiologists consider potassium second only to nitrogen in importance for plant growth. Potassium is second to nitrogen in plant tissue levels with ranges of 1 to 3% by weight. Potassium is vital to many plant processes, its functions are discussed elaborately. Potassium deficiency symptoms are mentioned with examples.

Key Words: *Potassium, Potassium Deficiency, Plant Growth*

INTRODUCTION
The letter *K*, used to symbolize potassium, comes from the German word *kalium*. During Colonial times, people burned wood and other organic matter in pots to manufacture soap. The ashes were rinsed and the water was allowed to evaporate, leaving a residue of potassium salts. People called the residue "pot ashes" or potash. These salts were boiled with animal fat to produce soap. In 1868, Samuel William Jackson, a botanist in Connecticut, burned plants and analyzed the ash. Jackson found plants consisted of large amounts of potassium, as well as other minerals. His work led to the use of fertilizers to promote an increase in crop yields (McAfee, 2008).

POTASSIUM IN SOILS
There are four different sources of potassium in the soil. The largest soil component of potassium, 90 to 98%, is the soil minerals such as feldspar and mica. Very little of this potassium source is available for plant use. The second soil potassium source is the non exchangeable potassium, 1 to 10%, and is associated with the 2: 1 clay minerals. The non exchangeable potassium source acts as a reserve source of potassium in the soil. The third soil potassium source, 1 to 2%, is called the exchangeable or readily available potassium and is found on the cation exchange sites or in the soil solution (Rehm & Schmitt, 2002). The soil solution potassium is readily taken up by the plants root system and is then replaced by the potassium on the exchange sites. A fourth source of potassium in the soil is the potassium contained in organic matter and within the soil microbial population. This soil source of potassium provides very little of the potassium needed for plant growth.

The total K content of soils frequently exceeds 20,000 ppm (parts per million). Nearly all of this is in the structural component of soil minerals and is not available for plant growth. Because of large differences in soil parent materials and the effect of weathering of these materials in the United States, the amount of K supplied by soils varies. Therefore, the need for K in a fertilizer program varies across the United States (Slavik, 1974).

Three forms of K (unavailable, slowly available or fixed, readily available or exchangeable) exist in soils. A description of these forms and their relationship to each other is provided in the paragraphs that follow. The general relationships of these forms to each other are illustrated in Figure 1.

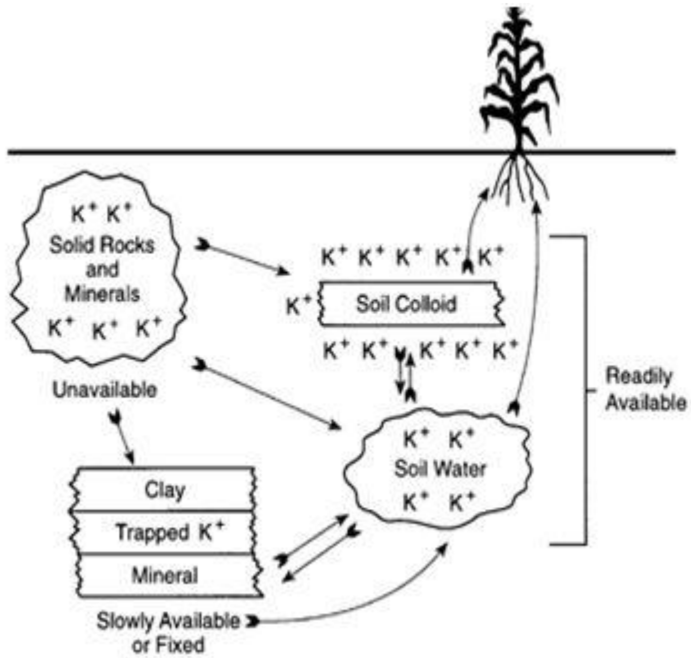

Figure1: Relationship among unavailable, slowly available and readily available potassium in the soil-plant system (Rehm G. & Schmitt M., 2002).

Unavailable Potassium
Depending on soil type, approximately 90-98% of total soil K is found in this form. Feldspars and micas are minerals that contain most of the K. Plants cannot use the K in this crystalline-insoluble form. Over long periods of time, these minerals weather (break down) and K is released. This process, however, is too slow to supply the full K needs of field crops. As these minerals weather, some K moves to the slowly available pool. Some also moves to the readily available pool (Figure 1).

Slowly Available Potassium
This form of K is thought to be trapped between layers of clay minerals and is frequently referred to as being fixed. Growing plants cannot use much of the slowly available K during a single growing season. This slowly available K is not measured by the routine soil testing procedures. Slowly available K can also serve as a reservoir for readily available K. While some slowly available K can be released for plant use during a growing season, some of the readily available K can also be fixed between clay layers and thus converted into slowly available K (Figure 1).

The amount of K fixed in the slowly available form varies with the type of clay that dominates in the soil. Montmorillonite clays are dominant in many of central and western Minnesota soils. These clays fix K when soils become dry because K is trapped between the layers in the clay mineral. This K, however, is released when the soil becomes wet. Illite clays are dominant in most of the soils in southeastern Minnesota. These clays also fix K between layers when they become dry, but do not release all of the fixed K when water is added. This fixation without release causes problems for management of potash fertilizers for crop production in the region.

Readily Available Potassium
Potassium that is dissolved in soil water (water soluble) plus that held on the exchange sites on clay particles (exchangeable K) is considered readily available for plant growth. The exchange sites are found on the surface of clay particles. This is the form of K measured by the routine soil testing procedure.

Plants readily absorb the K dissolved in the soil water. As soon as the K concentration in soil water drops, more is released into this solution from the K attached to the clay minerals. The K attached to the exchange sites on the clay minerals is more readily available for plant growth than the K trapped between the layers of the clay minerals.

The relationships among slowly available K, exchangeable K, and water-soluble K are summarized below.

slowly available K

↑↓

exchangeable K

↑↓

water-soluble K

Notice that when the arrows go in both directions, one form of K is converted to another. The rate of conversion is affected by such factors as root uptake, fertilizer K applied, soil moisture, and soil temperature (Slavik, 1974).

FUNCTIONS OF POTASSIUM

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.

I. 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 chemical 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 (Van Brunt and Sultenfuss, 1998)

II. Stomatal Activity (Water Use)

Plants depend upon K to regulate the opening and closing of stomata. the pores through which leaves exchange carbon dioxide (CO_2), water vapor, and oxygen (O_2) with the atmosphere. Proper functioning of stomata are essential for photosynthesis, water and nutrient transport, and plant cooling. When K moves into the guard cells around the stomata, 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 (Thomas and Thomas, 2009). If K supply is inadequate, the stomata 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.

III. 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 (Van Brunt and Sultenfuss, 1998).

IV. 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 (Van Brunt and Sultenfuss, 1998).

V. 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 (Schwartzkopf, 1972). 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 (Thomas and Thomas, 2009).

VI. 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. Theenzymenitrate reductase catalyzes, the formation of proteins and K is likely responsible for its activation and synthesis (Patil, 2011).

VII. 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 (Patil, 2011).

VIII. 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 winter hardiness 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.

POTASSIUM UPTAKE

Time of potassium uptake varies with different plants. However, plants generally absorb the majority of their potassium at an earlier growth stage than they do nitrogen and phosphorus. Experiments on potassium uptake by corn showed that 70-80 percent was absorbed by silking time, and 100 percent was absorbed three to four weeks after silking. Translocation of potassium from the leaves and stems to the grain was much less than for phosphorus and nitrogen. The period during grain formation is apparently not a critical one for supply of potassium. Cotton takes up about 30 percent of its potassium during the first twelve to fourteen days of blooming. Sixty-six percent of the total potassium is rapidly translocated from the leaves and stems to the bur of the boll during boll fill. Nitrogen and phosphorus are translocated to the seed.

Table 1: Potash Uptake by Crops (Thompson Bob, 2008)

Crop	Uptake(K_2O)	Yield
Alfalfa	600 lb/acre	10 ton/acre
Banana	1286 lb/acre	31 ton/acre
Clover-grass Mixture	360 lb/acre	6 ton/acre
Coastal Bermudagrass	480 lb/acre	10 ton/acre
Coffee	160 lb/acre	2233 lb/acre
Corn	266 lb/acre	200 bu/acre
Corn Silage	266 lb/acre	32 ton/acre
Cotton Grain	210 lb/acre	1500 lb/acre lint
Sorghum	240 lb/acre	8000 lb/acre
Oil Palm	268 lb/acre	11 ton/acre
Peanuts	185 lb/acre	4000 lb/acre
Soybeans	205 lb/acre	60 bu/acre
Wheat	162 lb/acre	80 bu/acre

(Potassium content of fertilizers is expressed as K_2O, although there is no such compound in fertilizers, nor is it absorbed by or found in the plant in that form. Soil and plant tissue analyses values are usually expressed in terms of percent potassium (K) but fertilizer recommendations are expressed as K_2O. To convert from K to K_2O, multiply K_2O by 0.83. To convert from K_2O to K, multiply K_2O by a factor of 1.20. uptake, 3-4 lb/acre are taken up daily)

Potassium Deficiency Symptoms

Plants absorb potassium as the potassium ion (K+). Potassium is a highly mobile element in the plant and is translocated from the older to younger tissue. Consequently, potassium deficiency symptoms usually occur first on the lower leaves of the plant and progress toward the top as the severity of the deficiency increases (Hoffer, 1938).One of the most common signs of potassium deficiency is the yellow scorching or firing (chlorosis) along the leaf margin. In severe cases of potassium deficiency the fired margin of the leaf may fall out. However, with broadleaf crops, such as soybeans and cotton, the entire leaf may shed resulting in premature defoliation of the crop. Potassium deficient crops grow slowly and have poorly developed root systems. Stalks are weak and lodging of cereal crops such as corn and small grain is common. Legumes are not strong competitors for soil potassium and are often crowded out by grasses in a grass-legume pasture. When potassium is not sufficient, winter-killing of perennial crops such as alfalfa and grasses can occur. Seeds from potassium deficient plants are small, shriveled, and are more susceptible to diseases. Fruit is often lacking in normal coloration and is low in sugar content. Vegetables and fruits deteriorate rapidly when shipped and have a short shelf life in the market (Ashley, Grant and Grabov, 2006).

Corn

Firing or scorching appears on outer edge of leaf, while midrib remains green. May be some yellow striping appear on lower leaves (Figure-2) (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.

Figure 2: Potassium deficiency symptoms in corn

Soybeans

Firing or scorching begins on outer edge of leaf. When leaf tissue dies, leaf edges become broken and ragged (Figure-3) delayed maturity and slow defoliation shriveled and less uniform beans, many worthless.

Figure 3: Potassium deficiency symptoms in soybeans

Alfalfa

With classical symptoms (shown at top right), first signs of K deficiency are small white or yellowish dots around outer edges of leaves (Figure-4) 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 symptoms has a different appearance, as indicated in the photo at left above.

Figure 4: Potassium deficiency symptoms in alfalfa

Cotton

Cotton "rust" …first a yellowish or bronze mottling in the leaf (Figure-5). 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 appear with fewer, smaller bolls or 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.

Figure 5: Potassium deficiency symptoms in cotton

Wheat

Frequently, no outstanding hunger signs on leaf itself (no discoloration, scorching, or mottling), but sharp difference in plant size (Figure-6) 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.

Figure 6: Potassium deficiency symptoms in wheat

Potatoes

Upper leaves, usually smaller, crinkled and darker green (Figure-7) 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.

Figure 7: Potassium deficiency symptoms in potatoes

Apples

Yellowish green leaves curl upward along entire leaf, scorched areas develop along edges that become ragged (Figure-8). Undersized and poorly colored fruit may drop prematurely.

Figure 8: Potassium deficiency symptoms in Apples

Predicting the Need for Potash

The K status of soils can be monitored with either plant analysis or routine soil testing procedures. Plant analysis can be used to either confirm a suspected deficiency indicated by visual symptoms or routinely monitor the effects of a chosen fertilizer program (Thompson and Bob, 2008). An interpretation for K levels in plant tissue is provided in (Table 2).

Table 2: Interpretation of plant analysis for K for major agronomic crops grown in Minnesota. (Rehm G. & Schmitt M., 2002)

Crop	**Part Sampled**	**Time of Sampling**	**Deficient**	**Low**	**Sufficient**	**High**	**Excessive**
			---------------------K%-----------------------------				
Alfalfa	to 6 inches	bud	<1.8	1.8-2.4	2.5-3.8	3.9-4.5	>4.5
Barley	whole plant	head emergence	<1.25	1.25-1.49	1.50-3.00	>3.00	-
Corn	ear leaf	silking	<1.30	1.30-1.70	1.80-2.30	2.40-2.90	>2.90
Soybean	most recently matured trifoliate	early flower	<1.30	1.30-1.70	1.80-2.50	2.60-4.50	>4.50
Wheat	whole plant	head emergence	<1.25	1.25-1.49	1.50-3.00	>3.00	-

CONCLUSION

Potassium is extremely important in many ways to the productivity of plant. It not only performs the important physiological functions as discussed in the review, but it improves nitrogen use efficiency. As we know, nitrogen is directly related to yield. However, if potassium is the limiting nutrient, forage production will decrease. It has re-confirmed the subtle role of potassium in the modulation of plant stomata apertures; by inference, the latter would be linked to potassium deficiency in plants. If potassium is deficient for a plant, it probably activates a signaling mechanism which leads to the translocation of mobile K^+ ions from old to new leaves to support stomata aperture osmo-modulation in the latter.

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