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# 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 withexcess and/or deficiencies of potassium in the plant. The availability of potassium to the plant is highlyvariable, due to complex soil dynamics, which are strongly influenced by root–soil interactions. Manyplant physiologists consider potassium second only to nitrogen in importance for plant growth. Potassiumis second to nitrogen in plant tissue levels with ranges of 1 to 3% by weight. Potassium is vital to manyplant processes, its functions are discussed elaborately. Potassium deficiency symptoms are mentionedwithexamples.
**KeyWords:**Potassium,PotassiumDeficiency,PlantGrowth

## I. 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 thewaterwas allowed to evaporate,leaving a residue of potassium salts. People called the residue "potashes" or potash. These salts were boiled with animal fat to produce soap. In 1868, Samuel WilliamJackson, a botanist in Connecticut, burned plants and analyzed the ash. Jackson found plants consisted oflarge amounts of potassium, as well as other minerals. His work led to the use of fertilizers to promote anincreaseincropyields(McAfee,2008).

**POTASSIUMINSOILS**

There are four different sources of potassium in the soil. The largest soil component of potassium, 90 to98%, is the soil minerals such as feldspar and mica. Very little of this potassium source is available forplantuse.The second soil potassium sourceisthenonexchangeable potassium,1to 10%,andisassociated with the 2: 1 clay minerals. The non exchangeable potassium source acts as a reserve source ofpotassium in the soil. The third soil potassium source, 1 to 2%, is called the exchangeable or readilyavailable potassium and is found on the cation exchange sites or in the soil solution (Rehm& Schmitt,2002). The soil solution potassium is readily taken upby the plants root system and is then replaced bythe potassium on the exchange sites. A fourth source of potassium in the soil is the potassium contained inorganic matter and within the soil microbial population. This soil source of potassium provides very littleofthepotassiumneededforplantgrowth.

The total K content of soils frequently exceeds 20,000 ppm (parts per million). Nearly all of this is in thestructural componentof soil minerals and is not available for plant growth. Because of large differencesin soil parent materials and the

effect of weathering of these materials in the United States, the amount ofK 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.Thegeneralrelationshipsoftheseformstoeach otherareillustratedinFigure1.

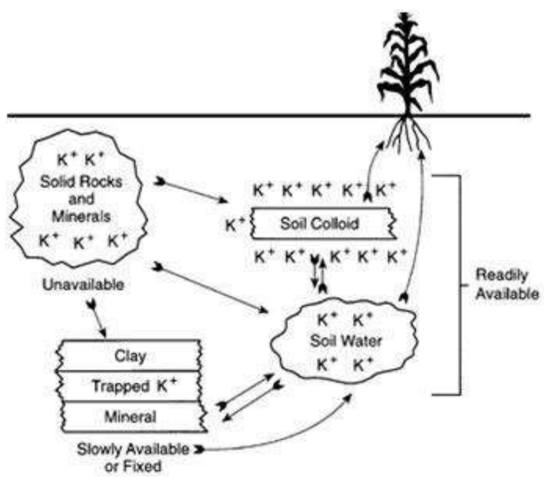


**Figure1: Relationship among unavailable, slowly available and readily available potassium in thesoil-plantsystem(RehmG.& Schmitt M.,2002).**

**UnavailablePotassium**

Depending on soil type, approximately 90-98% of total soil K is found in this form. Feldspars and micasare minerals that contain most of the K. Plants cannot use the K in this crystalline-insoluble form. Overlong periods of time, these minerals weather(break down) and K is released. This process, however, istoo slow to supply the full K needs of field crops. As these minerals weather, some K moves to the slowlyavailablepool.Somealsomovestothereadilyav ailablepool(Figure1).

**SlowlyAvailablePotassium**

This form of K is thought to be trapped between layers of clay minerals and is frequently referred to asbeing fixed. Growing plants cannot use much of the slowly available K during a single growing season.This slowly available K is notmeasured by the routine soil testing procedures. Slowly available K canalso serve as a reservoir for readily available K. While some slowly available K can be released for plantuse during a growing season, some of the readily available K can also be fixed between clay layers andthusconvertedintoslowlyavailableK(Figure1).
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 Kwhen soils become dry because K is trapped between the layers in the clay mineral. This K, however, isreleasedwhen the soil becomeswet.Illite claysaredominantinmostofthe soilsin southeasternMinnesota. These clays also fix K between layers when they become dry, but do not release all of thefixed K when water is added. This fixation without release causes problems for management of potashfertilizersforcropproductionintheregion.

**ReadilyAvailablePotassium**

Potassium that is dissolved in soil water (water soluble) plus that held on the exchange sites on clayparticles (exchangeable K) is considered readily available for plant growth. The exchange sites are foundonthesurfaceof clayparticles.Thisistheformof Kmeasuredbytheroutinesoiltestingprocedure.
Plants readily absorb the K dissolved in the soil water. As soon as the K concentration in soil water drops,moreisreleasedintothissolutionfromtheKattac hedtotheclayminerals.TheKattachedtothe

exchangesitesontheclaymineralsismorereadilyavaila bleforplantgrowththantheKtrappedbetweenthelayer sof theclayminerals.
TherelationshipsamongslowlyavailableK,exchange ableK,andwater-solubleKaresummarizedbelow.

slowlyavailableK

↑↓

exchangeableK

↑↓

water-solubleK

Notice that when the arrows go in both directions, one form of K is converted to another. The rate ofconversionisaffectedbysuchfactorsasrootuptake,f ertilizerKapplied,soilmoisture,andsoiltemperature( Slavik,1974).

**FUNCTIONSOFPOTASSIUM**

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 regulatoryrolesindevelopment.Potassium(K)increas escropyieldandimprovesquality.Itisrequiredfornum erousplantgrowthprocesses.

***I.*** **EnzymeActivation**

Enzymes serve as catalysts for chemical reactions, being utilized but not consumed in the process. Theybring togetherothermoleculesin such away that the chemical reaction can take place.Potassium"activates" at least 60 different enzymes involved in plant growth. The K changes the physical shape oftheenzymemolecule,exposingtheappropriatechem icalactivesitesforreaction.Potassiumalsoneutralizes various organic anions and other compounds within the plant, helping to stabilize pH between7 and 8...optimum for most enzyme reactions. The amount of K present in the cell determines how manyof the enzymes can be activated and the rates at which chemical reactions can proceed. Thus, the rate of agivenreactioniscontrolledbytherateatwhichKenters thecell(VanBruntandSultenfuss,1998)

***II.*** **StomatalActivity(WaterUse)**

Plants depend upon K to regulate the opening and closing of stomata. the pores through which leavesexchange carbon dioxide ($CO_2$), water vapor, and oxygen ($O_2$) with the atmosphere. Proper functioning ofstomata are essential for photosynthesis, water and nutrient transport, and plant cooling. When K movesinto the guard cells around the stomata, the cells accumulate water and swell, causing the pores to openand allowing gases to move freely in and out. When water supply is short, K is pumped out of the guardcells. The pores close tightly to prevent loss of water and minimize drought stress to the plant (Thomasand Thomas,2009).If K supply isinadequate,the stomatabecome sluggish – slow to respond – andwater vapor is lost. Closure may take hours rather than minutes and is incomplete. As a result, plants withan insufficient supply of K are much more susceptible to water stress. Accumulation of K in plant rootsproduces a gradient of osmotic pressure that draws water into the roots. Plants deficient in K are thus lessabletoabsorbwaterandaremoresubjecttostresswhenwaterisinshortsupply.

### *III.* Photosynthesis

The role of K in photosynthesis is complex. The activation of enzymes by K and its involvement inadenosinetriphosphate(ATP)productionisprobablymoreimportantinregulatingtherateofphotosynthesis 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 energysource for many other chemical reactions. The electrical charge balance at the site of ATP production ismaintained with K ions. When plants are K deficient, the rate of photosynthesis and the rate ofATPproductionarereduced,andalloftheprocessesdependentonATParesloweddown.Conversely,plantrespiration increaseswhich also contributes to slower growth and development. In some plants, leafblades re-orient toward light sources to increase light interception or away to avoid damage by excesslight, in effect assisting to regulate the rate of photosynthesis. These movements of leaves are broughtabout by reversible changes in turgor pressure through movement of K into and out of specialized tissuessimilartothatdescribedaboveforstomata(VanBruntandSultenfuss,1998).

### *IV.* TransportofSugars

Sugars produced in photosynthesis must be transported through the phloem to other parts of the plant forutilization 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 theleaves, and the rate of photosynthesis is reduced. Normal development of energy storage organs, such asgrain,isretardedasaresult.AnadequatesupplyofKhelpstokeepalloftheseprocessesandtransportationsystemsfunctioningnormally(VanBruntandSultenfuss,1998).

### *V.* Water and NutrientTransport

Potassium also plays amajor role in thetransport of water and nutrients throughout the plantin thexylem. 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 inxylem transport is often in conjunction with specific enzymes and plant growth hormones. An amplesupply ofK isessentialtoefficientoperationofthesesystems(ThomasandThomas,2009).

### *VI.* ProteinSynthesis

Potassium is required for every major step of protein synthesis. The "reading" of the genetic code in plantcells to produce proteins and enzymes that regulate all growth processes would be impossible withoutadequate K.Whenplantsaredeficientin K,proteinsarenotsynthesizeddespite an abundanceofavailable nitrogen (N). Instead, protein "raw materials" (precursors) such as amino acids, amides andnitrate accumulate.Theenzymenitratereductase catalyzes,the formationof proteinsand Kislikelyresponsibleforitsactivationandsynthesis(Patil,2011).

### *VII.* StarchSynthesis

Theenzymeresponsibleforsynthesisofstarch(starchsynthetase)isactivatedbyK.Thus,withinadequate 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 highKlevels,starchisefficientlymovedfromsitesofproductiontostorageorgans(Patil,2011).

### *VIII.* Crop Quality

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

The effects of K deficiency can cause reduced yield potential and quality long before visible symptomsappear. This "hidden hunger" robs profits from the farmerwho failsto keep soil K levels in the rangehighenoughtosupplyadequateKatalltimesduringthegrowingseason.Evenshortperiodsofdeficiency,especiallyduringcriticaldevelopmentalstages,cancauseseriouslosses.

## POTASSIUMUPTAKE

Time of potassium uptake varies with different plants. However, plants generally absorb the majority oftheirpotassiumatanearliergrowthstagethantheydonitrogenandphosphorus.Experimentsonpotassium uptake by corn showed that 70-80 percent was absorbed by silking time, and 100 percent wasabsorbed three to four weeks after silking. Translocation of potassium from the leaves and stems to thegrain was muchless than forphosphorus and nitrogen. The period during grain formation is apparentlynot a critical one for supply of potassium. Cotton takes up about 30 percent of its potassium during thefirsttwelvetofourteendaysofblooming.Sixty-sixpercentofthetotalpotassiumisrapidlytranslocated from the leaves and stems to the bur of the boll during boll fill. Nitrogen and phosphorus are translocatedtotheseed.

**Table1:PotashUptakebyCrops(ThompsonBob,2008)**

| Crop | Uptake($K_2O$) | Yield |
|---|---|---|
| Alfalfa | 600lb/acre | 10ton/acre |
| Banana | 1286lb/acre | 31ton/acre |
| Clover-grassMixture | 360lb/acre | 6ton/acre |
| CoastalBermudagrass | 480lb/acre | 10ton/acre |
| Coffee | 160lb/acre | 2233lb/acre |
| Corn | 266lb/acre | 200bu/acre |
| CornSilage | 266lb/acre | 32ton/acre |
| CottonGrain | 210lb/acre | 1500lb/acrelint |
| Sorghum | 240lb/acre | 8000lb/acre |
| OilPalm | 268lb/acre | 11ton/acre |
| Peanuts | 185lb/acre | 4000lb/acre |
| Soybeans | 205lb/acre | 60bu/acre |
| Wheat | 162lb/acre | 80bu/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 usuallyexpressed in terms of percent potassium (K) but fertilizer recommendations are expressed as $K_2O$. ToconvertfromKto$K_2O$,multiply$K_2O$by0.83.Toconvertfrom$K_2O$toK,multiply$K_2O$byafactorof 1.20.uptake,3-4 lb/acrearetakenup daily)

**PotassiumDeficiencySymptoms**

Plants absorb potassium as the potassium ion (K+). Potassium is a highly mobile element in the plant andis translocated from the older to younger tissue. Consequently, potassium deficiency symptoms usuallyoccur first on the lower leaves of the plant and progress toward the top as the severity of the deficiencyincreases (Hoffer, **1**938).One of the most common signs of potassium deficiency is the yellow scorchingor firing (chlorosis) along the leaf margin. In severe cases of potassium deficiency the fired margin of theleaf may fall out. However, with broadleaf crops, such as soybeans and cotton, the entire leaf may shedresulting in premature defoliation of the crop. Potassium deficient crops grow slowly and have poorlydeveloped root systems. Stalks are weak and lodging of cereal crops such as corn and small grain iscommon. Legumes are not strong competitors for soil potassium and are often crowded out bygrasses ina grass-legume pasture. When potassium is not sufficient, winter-killing of perennial crops such as alfalfaandgrassescanoccur.Seedsfrompotassiumdeficientplantsaresmall,shriveled,andaremoresusceptible to diseases. Fruit is often lacking in normal coloration and is low in sugar content. Vegetablesand fruits deteriorate rapidly when shipped and have a short shelf life in the market (Ashley, Grant andGrabov,2006).

**Corn**

Firing or scorching appears on outer edge of leaf, while midrib remains green. May be some yellowstriping appear on lower leaves (Figure-2) (Sorghum and most grasses also react this way). Poor rootdevelopment, defectivenodaltissues,unfilled,chaffyears,andstalklodgingareothersymptomsincorn.

**Figure2:**Potassiumdeficiencysymptomsincorn

**Soybeans**

Firing or scorching begins on outer edge of leaf. When leaf tissue dies, leaf edges become broken andragged(Figure-3)delayedmaturityandslowdefoliationshriveledandlessuniformbeans,manyworthless.

**Figure3:**Potassiumdeficiencysymptomsinsoybeans

**Alfalfa**

With classical symptoms (shown at top right), first signs of Kdeficiency are small white or yellowishdots around outer edges of leaves (Figure-4) then edges turn yellow and tissue dies and becomes brownand dry. However, for alfalfa grown on soils high in sodium (Na), the K deficiency symptoms has adifferentappearance,asindicatedinthephotoatleftabove.

**Figure4:**Potassiumdeficiencysymptomsinalfalfa

**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 becomesreddish brown, dies, sheds prematurely. Short plantsappear with fewer, smaller bolls or short, weakfibers. In the past, K deficiency symptoms have been described as occurring on older, mature leaves at thebottom of the plant. In recent years, symptoms have been observed at the top on young leaves of someheavilyfruitedcottonvarieties.

**Figure5:** Potassiumdeficiencysymptomsincotton

**Wheat**

Frequently, no outstanding hunger signs on leaf itself (no discoloration, scorching, or mottling), but sharpdifference in plant size (Figure-6) and number, length, and condition of roots, lodging tendency. Smallerkernels.Inadvancedstages,witheringorburno fleaftips andmargins,beginningwitholderleaves.

**Figure6:**Potassiumdeficiencysymptomsinwheat

**Potatoes**

Upper leaves, usually smaller, crinkled and darker green (Figure-7) than normal with small necroticpatches…middle tolowerleavesshowmarginal scorch and yellowing.Early indicator:dark green,crinkledleaves,thoughvarietiesdifferinnormalleaf colorandtexture.

**Figure7:**Potassiumdeficiencysymptomsinpotatoes

**Apples**

Yellowishgreenleavescurlupwardalongentireleaf,scorchedareasdevelopalongedgesthatbecomeragged(Figure-8).Undersizedandpoorlycoloredfruitmaydroppremeturely.

**Figure8:**PotassiumdeficiencysymptomsinApples

**PredictingtheNeed for Potash**

The K status of soils can be monitored with either plant analysis or routine soil testing procedures. Plantanalysis can be used to either confirm a suspected deficiency indicated by visual symptoms or routinelymonitor the effects of a chosen fertilizer program (Thompson and Bob, 2008). An interpretation for Klevelsinplanttissueisprovidedin(Table2).

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

| Crop | Part Sampled | Timeof Sampling | Deficient | Low | Sufficient | High | Excessive |
|---|---|---|---|---|---|---|---|
| ---------------------K%----------------------------- | | | | | | | |
| Alfalfa | to6 inches | bud | <1.8 | 1.8-2.4 | 2.5-3.8 | 3.9-4.5 | >4.5 |
| Barley | wholeplant | head emergence | <1.25 | 1.25-1.49 | 1.50-3.00 | >3.00 | - |
| Corn | earleaf | silking | <1.30 | 1.30-1.70 | 1.80-2.30 | 2.40-2.90 | >2.90 |
| Soybean | mostrecentlymatured trifoliate | earlyflower | <1.30 | 1.30-1.70 | 1.80-2.50 | 2.60-4.50 | >4.50 |
| Wheat | wholeplant | heademergence | <1.25 | 1.25-1.49 | 1.50-3.00 | >3.00 | - |

## II. CONCLUSION

Potassium is extremely important in many ways to the productivity of plant. It not only performs theimportant physiological functions as discussed in the review, but it improves nitrogen use efficiency. Aswe know, nitrogen is directly related to yield. However, if potassium is the limiting nutrient, forageproduction will decrease. It has re-confirmed the subtle role of potassium in the modulation of plantstomata apertures; by inference, the latter would be linked to potassium deficiency in plants. If potassiumis deficient for a plant, it probably activates a signaling mechanism which leads to the translocation ofmobile$K^+$ ionsfromoldtonew leavestosupportstomata apertureosmo-modulationinthelatter.

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