

On Potassium Deficiency in Cotton – Disorder, Cause and Tissue Diagnosis

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SUMMARY

As modern cotton varieties including Bt (*Bacillus thuringiensis*) transgenic cotton are adopted and yield per unit area continues to increase, potassium deficiency is occurring with rising frequency in many cotton-growing countries. Symptoms of K deficiencies used to occur at the bottom of the plant on the older or mature leaves, but more recently described symptoms show up on young leaves near the top of the plant. Potassium deficiency induces numerous disorders in cotton, including decreased leaf area index, photosynthesis and plant biomass, but enhances specific leaf weight and earliness of maturity. Low supply and uptake of K, adoption of modern cotton varieties particularly Bt transgenic cotton, and environmental stress are obvious contributors to potassium deficiency. Single leaf photosynthesis (P_n) reduction results mainly from decreased stomatal conductance, low chlorophyll content, poor chloroplast ultrastructure, restricted saccharide translocation, and decreased synthesis of RuBP carboxylase under K deficient conditions. Canopy photosynthesis reduction in K-deficient plants is mainly attributed to both inhibited single leaf P_n rate and decreased leaf area index. Potassium concentrations in both blade and petiole of top fully expanded leaves on main stem are good indicators of K deficiency.

KEY WORDS

cotton, potassium deficiency, physiological disorder, tissue diagnosis

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INTRODUCTION

Potassium is an essential nutrient for normal plant growth and development. Cotton (*Gossypium hirsutum* L.) appears to be more sensitive to low K availability than other crops (Cassman et al, 1989) and often exhibits deficiency symptoms on soils with or without adequate potassium (Gulick et al, 1989). Signs of emerging K deficiencies in cotton have become more common in recent years, particularly in modern high yielding cotton varieties such as Bt transgenic cotton (Tian et al, 1999; Phipps et al, 2003). The sensitivity of high-yielding cotton to K limitations has led to much research on K nutrition and fertilization with the focus on yield and yield components throughout the world (Howard et al, 1998; Mullins et al, 1999; Howard et al, 2000, 2001; Gormus, 2002; Roslem et al, 2003). Potassium deficiency usually causes numerous physiological disorders, depressed plant growth and development, and reduced cotton yield and fiber quality. This paper presents a summary of recent studies on potassium deficiency and related responses in cotton plants, particularly on physiological disorders, possible causes and tissue diagnosis.

PHYSIOLOGICAL FUNCTIONS OF POTASSIUM

Potassium plays a vital role in plant growth and metabolism, although it is not a constituent of any plant component. Studies with many plant species including cotton for the past 40 years have showed that activation of numerous enzymes (Evans and Sorger, 1966), acting as an osmoticum to maintain tissue turgor pressure (Kaiser, 1982), regulating the opening and closing of stomata (Humble and Raschke, 1971), and balancing the charge of anions (Streeter and Barta, 1984) are physiological functions of K in plant cells. Potassium deficiency decreases photosynthesis through a reduction in both leaf area (Huber, 1985) and in net CO₂ fixation (Ozbun et al, 1965a, 1965b). The K levels also influence the rate of translocation of photo-assimilate from cotton leaves to other plant parts (Ashley and Goodson, 1972). In addition, K and malate are the primary osmotica that produce the turgor pressure essential for cotton fiber elongation (Dhindsa et al, 1975).

Adequate K may be also needed for the efficient use of N fertilizer (Pettigrew and Meredith, 1997; Varco and Fridgen, 2004). On the one hand, potassium has been found to co-transport in the xylem with NO₃⁻ as an accompanying cation from the roots to aerial plant parts and then recycle down the phloem with malate (Blevins, 1985). On the other hand, because NO₃⁻ is taken up by plant roots via an active process (Streeter and Barta, 1984), NO₃⁻ uptake may be affected through the influence of K on the

translocation of photosynthetic assimilates (Ashley and Goodson, 1972).

On the whole, potassium plays a key role in assimilation, phloem loading and long distance assimilate transport, in nitrogen metabolism and in storage process. In its role as an osmotically active cation and in controlling the water relationship in plants, K has a vital role in the response of crops to adverse climatic and soil conditions, and is involved in plants resistance and tolerance to pathogens.

SYMPTOMS OF POTASSIUM DEFICIENCY

According to Abaye (1996), potassium deficiency symptoms fall into two categories (Table 1), those that occur at the bottom of the plant on the lower, older or mature leaves (Stromberg, 1960), and the more recently described symptoms that show up near the top of the plant during flowering and boll development (Maples et al, 1988). The K deficiency symptom on leaves appears to be the same for both categories.

Table 1. Difference between traditional K deficiency and recently described K deficiency

Items	Traditional K deficiency	Recently described K deficiency
Season	Late season	Mid and late season
Leaf age	Older leaf	Young leaf
Spreading	From bottom to top	From top to bottom
Soil	K deficient soil	Both K deficient and sufficient soil
Variety	Not specific	Fast fruiting and high yielding

The traditional K deficiency which was first described in 1960s was a yellowish-white mottling of the older foliage that changes the leaf color to light yellowish-green. Yellowish spots begin to appear between the veins, then the center of these spots die and numerous brown specks occur at the leaf tips, around margins and between veins. The tips and margins break down first and begin to curl. These symptoms occur at the bottom of the plant on the lower, older or mature leaves. As the physiological breakdown progresses, the whole leaf becomes reddish-brown, dries, and finally becomes rust colored and brittle. Many leaves are prematurely shed, bolls fail to develop properly and may fail to open or partially open, and the fiber is of poor quality (Abaye, 1996).

Another type of K deficiency usually occurs in young leaves of top canopy and spread from the top to the bottom during flowering and boll development (Maples et al, 1988), differing from the traditional K deficiency occurring mostly in late season and spreading from the bottom to the top (Table 1). Potassium related premature senescence recently described in Australia

(Wright, 1999), USA (Oosterhuis, 2001), and China (Zheng and Dai, 2000) may be a typical K deficiency occurred in top canopy. The first visible sign of premature senescence is a slight yellowing of the veins of the youngest leaf. The third or fourth leaf from the terminal turns yellow then rapidly red or bronze while the underside of the leaf remains green. The bronzing then spreads down the plant and the upper leaves fall from the plant (Bendarz and Oosterhuis, 1996). In severe cases, bronzing occurs in the middle canopy. As the season progresses, premature senescence symptoms can spread and the crop is defoliated. This potassium related premature senescence was initially found in Arkansas in the 1960s and in Alabama in the 1980s (Abaye, 1996), then reported in many other countries including Australia (Wright, 1999) and China (Zheng and Dai, 2000). Studies conducted in Australia (Wright, 1999; Mott, 2003) have indicated that not all fields are showing these symptoms and each field has varying degrees of the symptoms. The symptoms show up more in certain areas of some fields and not all plants in these areas are showing symptoms.

Potassium deficiency symptoms in cotton are quite distinctive with the characteristic of bronzing, and were once termed “cotton rust” before the true cause was known (Kerby and Adams, 1985). The symptoms of K deficiency have been mistaken for Verticillium wilt symptoms because of similar symptom on leaves of affected cotton plants (Weir et al, 1986). Furthermore, the growth and yield of cotton varieties less susceptible to Verticillium wilt are often less affected by K deficiency (Ashworth et al, 1982).

POTASSIUM-RELATED DISORDERS IN COTTON

Depressed plant growth and development

Potassium deficiency may depress cotton growth and development by affecting roots, leaves, stems and bolls. The overall effect of K deficiency is to produce smaller, stunted plants compared to those receiving full fertilization (Pettigrew and Meredith, 1997). Sensitivity of cotton plants to K deficiency may

vary with genotypes and plant parts. A sequence of increasing sensitivity to K deficiency occurs among plant parts: leaves < roots < stems, suggesting that by the time the K deficiency symptoms are manifested in the leaves, all other plant parts are already affected (Rosolem and Mikklisen, 1991). As a result, different plant parts exhibit a differential range of decline in dry mass being in the order of fruit > stem or root > leaf under K deficient conditions, and severe K-deficiency causes the greatest reduction in fruit dry mass, and the least decrease in leaf dry mass (Zhao et al, 2001). However, Reddy et al (2000) indicated that leaf growth was the most sensitive physiological process to K deficient conditions. They observed that plants grown in a growth chamber and watered with nutritional solution showed reduced rate in leaf area expansion by k deficiency. Leaf growth rates were 14% lower in plants that had only 1.9% K in the leaves compared to fully fertilized plants with 3% K in the leaves. Leaf expansion rates declined even more as K concentration decreased and were only 59% as great in plants that had approximately 1% leaf K. The rates at which main stem leaves and nodes were added were less in plants with lower K concentrations. Leaves were added to the main stem only 90% as fast in plants whose sampled leaves contained 1.9% K compared with plants with higher K concentrations (Table 2).

Joham (1965) reported that K deficiencies in cotton increased the vegetative dry matter production and decreased the fruiting index. In contrast, Cassman et al (1989) reported that K deficiency resulted in reduced plant height, leaf area index, leaf and stem weights, and ultimately the total plant. Pettigrew and Meredith (1997) also found lower leaf area index and plant height for the K-deficient plants. However, specific leaf weights (SLW) for the K deficient plants was much higher than the fully fertilized plants (Pettigrew and Meredith, 1997; Pettigrew, 1999; Zhao et al, 2001). Increased SLW is not attributed to a thicker leaf, but to less intercellular space and higher nonstructural saccharide accumulation in leaves (Zhao, 2001). Pettigrew (1999) reported that a deficiency in K alerted the leaf carbohydrate and water status of cotton plants by increasing the glucose

Table 2. Potassium nutrition and cotton growth- Appearance of cotton leaf K deficiency symptoms, related K levels, and the relative rates of growth or development expressed as a percentage of optimal K ($\geq 3\%$) in the leaves.

Leaf K content (%)	Leaf development (%)	Leaf growth (%)	Stem growth (%)	Photosynthesis (%)
≥ 3.05	100	100	100	100
1.90	90	86	100	93
1.15	88	66	100	85
0.94	85	59	98	80
0.39	83	37	42	45
0.30	82	32	5	25

*According to Reddy et al (2000)



and fructose concentrations and by elevating the leaf O_2 . These increased carbohydrate levels make a minor contribution to the increased SLW in K deficient cotton plants.

Potassium deficiency has been reported to have no effect on earliness of maturity (Joham, 1986; Tupper et al, 1991). However, more reports indicate that potassium deficiency enhances earliness of maturity (Bennett et al, 1965; Gwathmey and Howard, 1998; Pettigrew, 1995). Kerby and Adams (1985) citing California research from the early 1960s, reported that very high K fertilizer rates resulted in 70% of yield produced at first harvest, compared with 85% for no added K. They speculated that lateness with high K levels might be due to plants setting bolls later in the season. Further research indicated that the low K effect on crop maturity was due to a premature termination of reproductive growth and a brief enhancement of the early season flowering rate (Pettigrew, 2003). Early maturity induced by potassium deficiency is also due to the reduction in upper-canopy light interception, while the indeterminate growth habit of cotton may cause a significant portion of this yield potential to develop relatively late in the season if K supply is sufficient (Gwathmey and Howard, 1998).

As rapidly growing cotton plants develop more bolls, it becomes progressively more difficult to support their growth. The reproductive parts appear to have a higher priority for available carbon and other nutrient resources. They survive at the expense of roots and other vegetative plant parts. Stem growth becomes incrementally slower. The addition of new leaves slows down, and the leaves also become progressively smaller due to the lack of nutrients. This process is a natural maturing of cotton known as "cutout". The cutout occurs earlier when K or water is limiting, causing fewer young bolls to survive. Excessively hot weather also compounds K-deficit problems in cotton (Reddy et al, 2000). The overall effect of the K deficiency appears to be a reduction in the amount of photosynthate available for the reproductive sinks, which promotes the yield and fiber quality reductions associated with production under K deficiency (Pettigrew, 1999).

Altered Leaf anatomy and chloroplast

Under a light microscope, leaves of K-deficient and control cotton plants have about the same thickness and proportion of palisade cells and spongy mesophyll cells. However, the K deficient leaf has less intercellular air space and fewer chloroplasts in mesophyll cells than the control plants (Zhao et al, 2001). There exist more obvious differences in chloroplast ultrastructure between the control and K-deficient cotton leaves under a transmission electron microscope (Zhao et al, 2001). The chloroplasts of control plant leaves have more well-defined grana stacks and extensive stroma lamellae with very small amounts of starch granules.

The chloroplasts in leaves of K-deficient plants are filled with large starch granules, and contain markedly more and greater plastoglobuli and fewer grana. This result further supports the statement that the K-deficiency decreases translocation of saccharides from cotton leaves to fruit. The poor chloroplast ultrastructure, including starch granule accumulation, low Chl content, fewer grana, disorientation of grana and thylakoids that occurred as they were pushed towards the periphery of the chloroplast, might be one of the causes of low photosynthetic rate in K-deficient cotton.

Reduced photosynthesis

Numerous studies on leaf and canopy photosynthesis of cotton associated with K-fertilization have been taken for the past several decades. Results from these most studies are completely consistent that moderately K-deficiency significantly reduces the photosynthesis (P_n) rate of a single leaf (Bendarz and Oosterhuis, 1999; Bendarz et al, 1998, 1999; Zhao et al, 2001; Wright, 1999) or a canopy (Gwathmey and Howard, 1998; Pettigrew, 1999; Reddy, 2000) of cotton.

The morphologic and physiological basis for the reduced P_n rate by K-deficiency in a single leaf has been investigated since 1960s, but there still exist inconsistent conceptions. Net CO_2 uptake was shown to decrease in K-deficient leaves of *Zea Mays* and may be related to stomatal conductance (Moss and Peaslee, 1965; Peaslee and Moss, 1968). Electron probe analysis has provided convincing evidence that K plays a significant role in stomatal opening and closing (Humble and Raschke, 1971). However, still other studies indicated that reduction in leaf photosynthesis caused by K deficiency was primarily related to decreased mesophyll conductance, and abundant K supply increased the conductance of mesophyll tissue to CO_2 in sugar beet (Terry, 1973) and *Medicago Sativa L* (Peoples and Koch, 1979). Studies on cotton since 1980s have also provided inconsistent results. Xi et al (1989) reported that stomatal conductance of cotton was improved by increasing K rates, and decreased P_n of K-deficient leaves was related to lowered stomatal conductance, while Longstreth and Nobel (1980) stated that increased mesophyll resistance might be the primary factor causing the reduction in photosynthesis. A more recent report by Bendarz et al (1998) indicated that the most limiting resistance to P_n under K-deficiency was stomatal. During a mild K-deficiency, increased stomatal resistance is first to result in a decrease in P_n and, as the deficiency becomes more acute, biological factors also contribute. In contrast, Zhao et al (2001) stated that decreased leaf P_n of K-deficient cotton was mainly associated with dramatically low Chl content, poor chloroplast ultrastructure, and restricted saccharide translocation, rather than

limited stomatal conductance in K-deficient leaves. The differences between documents made by different reporters may be due to the degree of K-deficiency or the age of leaves, since intensity of photosynthetic response and other physiological changes depend on leaf K concentration and leaf age (Reddy et al, 2000; Bendarz and Oosterhuis, 1999). Nevertheless, it can be concluded that leaf photosynthesis reduction induced by K-deficiency are closely associated with decreased stomatal conductance, increased mesophyll resistance, low Chl content, poor chloroplast ultrastructure, restricted saccharide translocation, and decreased synthesis of RuBP carboxylase.

The physiological basis for canopy photosynthesis reduction induced by K-deficiency in cotton is still not well documented, since the causes for it is more complex than for a single leaf photosynthesis. Canopy photosynthesis can be described as the product of canopy light interception and radiation-use efficiency (Loomis and Connor, 1992). Close relationships have been described between leaf area index and canopy light interception in cotton (Heitholt, 1994). On the one hand, the K concentration of these K-deficient leaves would be lower (Pettigrew and Meredith, 1977) and photosynthesis for K-deficient cotton on a leaf area basis has been reported to be lower (Longstreth and Noble, 1980; Bendarz and Oosterhuis, 1999). On the other hand, Ashley and Goodson (1972) found reduced rates of photosynthetic assimilate export from leaves of K-deficient cotton plants compared with the control that receive normal K fertilization. Huber (1985) also demonstrated that maximum leaf area expansion of soybean was reduced under K deficient conditions. This also happens in K-deficient cotton plants (Pettigrew and Meredith, 1977; Pettigrew, 2003). It appears to conclude that canopy photosynthesis reduction in K-deficient plants results from both inhibited single leaf Pn rate and decreased leaf area index. Feedback inhibition caused by reduced translocation of photosynthate from canopy leaves to bolls and other organs might also be an important reason for canopy photosynthesis reduction under K-deficient conditions.

Cytological response to K deficiency

Insight into the role of K at a cellular level may help further explaining various disorders as described above at different levels of K deficiency. Since the majority of K is located within the central vacuole of plant cells where it functions as an osmoticum, changes in measured tissue K concentrations mostly reflect changes in vacuolar K levels. Vacuolar K concentrations respond rapidly and directly to external K supply and can fall to very low levels under severe deficiency. However, growth and essential plant requirements for K appear to relate more to its role as an activator of biochemical processes in the cytosol (Leigh and Wyn Jones, 1984). Cytosolic K is not replaceable in

its functions by other cations and any decrease in cytosolic K concentration will affect many K-specific processes in the plant, particularly a large number of enzyme reactions that completely depend on K or are stimulated by it. Cytosolic K decreases only slightly under moderate K stress, but may decrease significantly during severe K deficiency (Leigh, 2001). Considering these physiological functions of K, the evolution and location of symptoms of K deficiency within plants depend on the severity of decline in both vacuolar and cytosolic K concentration. Therefore, cotton disorders at a cellular level are closely related to rates of crop K demand for development and growth process at different growth stages, rates of external K supply, the potential reservoir and maximum rate of re-translocation, and possible substitution mechanisms (Dobermann, 2001). Therefore, in a K deficiency situation, cells will first attempt to maintain cytosolic K concentrations at the cost of vacuolar K, particularly in plant parts that are most vital for further crop development. This may then lead to increased root K uptake or, if supply is limiting, relocation of K from other plant parts or increased uptake of cations such as Na, Mg, and Ca or organic solutes to at least partially substitute for possible loss of vascular functions of K. The latter may mainly involves maintenance of osmotic potential of cells. If these resources are insufficient, K deficiency will proceed further, possibly causing a drop in osmotic potential in the vacuole and turgor pressure. In severe cases, cytosolic K concentration may decline as well, decreasing cytosolic pH and the rate of enzyme reactions. Moreover, in K-deficient plants, export rate of photosynthates from source leaves to other organs decline due to a decrease in osmotic potential in sieve tubes.

FACTORS RELATED TO K DEFICIENCY

Although insufficient soil K is implicated as a main contributing factor of K-deficiency in cotton crops (Kerby and Adams, 1985), the relationship between the amount of K in the soil and the occurrence of K deficiency is not straightforward (Bedrossian et al, 2000). While it appears to be connected with the supply of K, the reasons for it are not simple, and it can occur on soils with high or low K levels (Cassman et al, 1989; Wright, 1999). Nutrient supply from soil to roots occurs through a combination of mass flow, diffusion and root interception. Diffusion is usually the main mechanism supplying K to plant roots when the soil has high amounts of available K, but the K diffusion coefficient will be low if K concentration in the soil solution and exchangeable K are low. Besides K diffusion in soil, root growth rate, root length and surface have been associated with K acquisition efficiency of root systems. The rate of K uptake by cotton depends on root length density and total

surface area. Anything that restricts root growth, such as disease, insect damage, nematodes, root pruning, poor drainage, soil acidity, or compaction, reduces nutrient uptake and may increase K deficiency (Abaye, 1996).

Adoption of modern cotton varieties is another important factor for K deficiency, since sensitivity of cotton to potassium varies with genotypes. Many reports have indicated that modern cotton varieties with fast fruiting, high yielding or heavy boll load, and early maturity seem to be more susceptible to K limitation than traditional varieties (Oosterhuis, 1990; Tupper et al, 1996; Wright, 1999). Transgenic cotton varieties with Bt gene seem to be more susceptible than the conventional varieties because of their higher retention of early fruit (Wright, 1998). These transgenic cotton varieties hold a smaller source and a large sink for assimilates than non-Bt cotton, which results in an unbalanced source and sink (Tian et al, 1999). Potassium deficiencies occur easily in these cultivars because bolls are set over a shorter period of time and more nutrients including K should be needed per unit time during boll development. High boll loads may be not a direct cause of potassium deficiency in cotton, but it may contribute to the stress placed upon a crop, which combined with other stresses, may allow plants to succumb to the syndrome (Wright, 1999).

In addition to above-mentioned, soils that “fix” potassium in non-available forms, an unidentified disease, mild to moderate drought stress following heavy fruit set (Edmisten et al, 2003), the relative inefficiency of cotton in absorbing K from the soils compared to other crop species (Cassman et al, 1989) are also important factors inducing potassium deficiency. Under field conditions, potassium deficiency may be caused by a combination of numerous factors, such as K susceptible variety, low K supply or uptake, and environmental stresses. As Oosterhuis (1990, 2001) has indicated, planting cotton on soils having low K availability and inefficient K absorption by earlier-maturing, high-yielding, fast-fruiting cultivars, reduced root growth and ion uptake during reproductive development, and depressed available soil K levels might be the major contributors to K deficiency.

TISSUE DIAGNOSIS OF POTASSIUM DEFICIENCY

Potassium deficiency in cotton can be determined by analysis of plant tissues. Tissue tests not only assay the nutrient status of a cotton crop, but they can also determine fertilizer recommendations during the growing season. Since plant structure vary in the amounts of K they contain, selecting an appropriate tissue for analysis is an important issue. Generally, young mature leaves have higher K concentrations

than old leaves or leaves that are still growing. As plants grow and the amount of roots relative to above-ground parts decreases, the percentage of K in the above-ground parts increases. If the available K is high, the concentration in above-ground parts may remain about constant as plants age. The interpretation of plant analysis results depends on both the time of testing the samples and the parts analyzed. Since the leaves are so important to light interception and dry matter production, it is believed that leaf nutritional status and function are of primary concern. Therefore, young mature leaves near the top of the plant should be sampled to represent the nutritional health of the crop. The fourth or fifth leaf from the main stem terminal is usually the youngest fully expanded leaf, is physiologically the most active leaf, and is therefore the appropriate leaf to sample (Reddy et al, 2000). Although many people think that the uppermost main-stem leaf petiole is a more sensitive indicator of plant K status than leaf blade (Baker et al, 1992), and use petiole sample to determine the K nutritional status of their crops, indeed, there is a close correlation between leaf petiole K and leaf blade K concentrations (Reddy et al, 2000).

Results from previous studies on the threshold of K deficiency are inconsistent. It was reported that the critical leaf K concentration is in the range of 1.2%-0.8% (Baker et al, 1992; Hill, 1980), 0.5%-2.0% (Leigh and Wyn Jones, 1984), or 0.95% in leaf and 0.88% in leaf petiole on the dry matter basis (Bednarz and Oosterhuis, 1999). Howard et al (2001) reported that leaf petiole K concentration of over 1.11% was sufficient, while leaf K concentration less than 1.04 was insufficient in one week after flowering. Scientists at the University of Arkansas have used plant analysis data to develop a sufficiency-deficiency range for all levels of K in cotton. At first flower or early bloom, the K sufficiency level is 4%; at peak flower, 3%; at first open boll, 2%; and prior to harvest, 1% (Abaye, 1996). With this information, K deficiency can be predicated as early as the week before first bloom. Weir et al (1997) indicated that critical petiole levels at first bloom, two weeks after bloom, and 10 days after bloom are 3.5%, 2.7% and 1.5% respectively (Table 3). Nevertheless, it can be concluded that both critical K concentration in blade or petiole of top fully expanded leaves on main stem are good indicators. Critical value of K concentration depends on leaf age, growing season, soil type, and possible environmental stresses. All these factors should be taken into consideration before use these critical values for diagnoses of potassium deficiency.

CONCLUSIONS

As yield increases, potassium deficiency in cotton is occurring with rising frequency and intensity in

Table 3. Cotton petiole K critical ranges for three stages of plant growth.

Growth stage	K critical range (%)					
	Very low	Low	Medium	High	Very high	Deficiency
1st flower	<2.5	2.3–3.0	3.0–3.5	3.5–4.0	>4.0	3.5%
14d post 1st flower	<1.8	1.8–2.4	2.4–2.8	2.8–3.2	>3.2	2.7%
10d post cutout	<1.0	1.0–1.4	1.4–1.8	1.8–2.4	>2.4	1.5%

*According to Weir et al (1997)

large cotton production countries throughout the world. Potassium deficiencies fall into two categories, those that occur at the bottom of the plant on the lower, older or mature leaves, and the more recently described symptoms that show up near the top of the plant. The K deficiency symptom in leaves is the same for these two categories. Potassium concentrations in both blade and petiole of top fully expanded leaves on main stem are good, but not adequate indicators of K deficiency. Leaf age and position, growing season, soil type, and possible environmental stresses should be taken into account when use tissue K concentration for diagnosis of potassium deficiency. The overall effect of K deficiency is to reduce plant height, leaf area index, leaf and stem weights, and ultimately the total plant, but increase specific leaf weights and enhance earliness of maturity. Although the relationship between the amount of K in the soil and the occurrence of K deficiency is not straightforward, it appears to consider that low K supply and uptake, modern cotton variety particularly Bt transgenic cotton (early-maturing, fast-fruited, and heavy boll loading or high-yielding cotton), and environmental stress are major contributors to potassium deficiency. Reduction in single leaf photosynthesis induced by K-deficiency is closely associated with the decreased stomatal conductance, increased mesophyll resistance, low chlorophyll content, poor chloroplast ultrastructure, restricted saccharide translocation, and decreased synthesis of RuBP carboxylase, although inconsistent observations and statements still exist. Canopy photosynthesis reduction in K-deficient plants mainly results from both inhibited single leaf Pn rate and decreased leaf area index. It is concluded that the potassium-caused disorders in cotton can be expressed at morphological, physiological and cytological levels. Profound studies into a molecular level in the future may improve understanding of K nutrition in cotton, which would help to better manage cotton technologically and genetically.

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