Potassium Deficiency Increases Specific Leaf Weights and Leaf Glucose Levels in Field-Grown Cotton

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ABSTRACT

Potassium deficiency reduces lint yield and causes fiber quality problems for cotton (Gossypium hirsutum L.) producers throughout the U.S. production regions. This deficiency produces plants exhibiting reduced leaf area but increased specific leaf weights (SLW). The objectives of this research were (i) to determine whether the alterations in leaf growth produced by a K deficiency are associated with changes in leaf carbohydrate levels or leaf water status and (ii) to determine if a K deficiency alters the carbohydrate concentration in root tissue. Field studies were conducted in 1993 and 1994 using four genotypes ('DES 119', 'MD 51 ne', 'Prema', and 'STV 825') and two levels of K fertilization (0 and 112 kg K ha\(^{-1}\)). Glucose, fructose, sucrose, and starch concentrations were quantified for leaves collected at three different dates in both years. Root carbohydrate concentrations were determined once in each growing season. Leaf water potential and its components were determined once each growing season using thermocouple psychrometers. Glucose was the only carbohydrate whose leaf concentration was consistently altered by the K deficiency; it was increased an average of 84% across all leaf harvest dates. Leaf concentrations of starch, sucrose, and fructose were inconsistent in their response to variation in K levels. The K deficiency increased root tissue concentrations of starch by 82%, glucose by 14%, and fructose by 27%, averaged across years. Although leaf water potential (\(\psi_l\)) and leaf osmotic potential (\(\psi_h\)) were unaffected by varying the level of K fertilization, leaf turgor (\(\psi_c\)) averaged across both years was increased 17% in leaves from the K-deficient plants. The elevated carbohydrate concentrations remaining in source tissue, such as leaves, appear to be part of the overall effect of K deficiency in reducing the amount of photosynthate available for reproductive sinks and thereby producing reductions in lint yield and fiber quality seen in cotton.

Potassium deficiencies in upland cotton (Gossypium hirsutum L.) have been reported for a diverse range of environments (consisting of soils possessing varying degrees of native K-supplying capacity) and genotypes. While the detrimental effects that deficient soil K levels can have on lint yield and fiber quality have been well documented (Bennett et al., 1965; Cassman et al., 1990; Minton and Ebelhar, 1991; Pettigrew et al., 1996), the physiological basis for these effects is not completely understood.

A few studies have addressed how whole-plant growth patterns can be altered by varying the level of K fertilization in cotton. When K fertilization was coupled with a subsoiling treatment, Mullins et al. (1994) found an increase in dry matter production. Cassman et al. (1989) reported that the dry weight for the stem, fruit, leaves, and ultimately the total plant was reduced by a K deficiency. Pettigrew and Meredith (1997) did not find significant total plant dry matter differences between control and K-deficient plants, but they did report lower leaf area index (LAI) and plant height for the K-deficient plants. Specific leaf weights (SLW) for the K-deficient plants in the Pettigrew and Meredith (1997) study were greater than the controls which could partly explain the lack of total plant weight differences observed between K treatments.

The basis for this SLW increase observed with cotton under K-deficient conditions is not clear. There would appear to be counteracting forces at work in these plants to affect this trait. On the one hand, the K concentration of these K-deficient leaves would be lower (Pettigrew and Meredith, 1997) and photosynthesis for K-deficient cotton on a leaf area basis has been reported to be lower (Longstreth and Noble, 1980; Bednarz 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 plants that received normal K fertilization. Huber (1985) also demonstrated that maximum leaf area expansion of soybean [Glycine max (L.) Merr.] was reduced under K-deficient conditions. This most likely also happens in cotton and could lead to some of the elevated nutrient concentrations seen in leaves from K-deficient plants (Pettigrew and Meredith, 1997), due to less leaf material being available for dilution of the nutrients (Dibb and Thompson, 1985).

Although not specifically documented in cotton, a deficiency in K often produces an increase in the concentrations of soluble carbohydrates (Evans and Sorger, 1966; Huber, 1985). It is not clear if this accumulation is due to the reduced rate of carbohydrate export or to some other process. As Huber (1985) pointed out, it is generally the reducing sugars (glucose and fructose) rather than sucrose (the carbohydrate involved in translocation) that accumulate in K-deficient leaf tissue. He reported that sucrose concentration can be either reduced or elevated by K deficiencies; the effect was not consistent. Possibly further contributing to increases in the soluble carbohydrate levels is the inhibition of starch synthase in plants growing under K-deficient conditions.

**Abbreviations:** CDT, central daylight time; DAP, days after planting; \(g_s\), stomatal conductance; LAI, leaf area index; SLW, specific leaf weight; \(\psi_l\), leaf water potential; \(\psi_h\), leaf turgor potential; \(\psi_c\), leaf osmotic potential.

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(Nitsos and Evans, 1969; Hawker et al., 1974). Nonetheless, an increase in soluble carbohydrates may help to explain some degree of the SLW increases observed in K-deficient cotton leaves.

Alterations in leaf nutrient and carbohydrate concentrations may affect leaf water relations of K-deficient cotton plants because K and sugar contents directly affect the osmotic potential ($\psi_s$) of leaf cells (Huber, 1985). The role that K plays at stomatal opening (Fischer, 1968; Fischer and Hsiao, 1968) could also affect leaf water relations. Huber (1985) reported that K-deficient plants typically transpire less than control plants. The permeability of sugar beet ($Beta vulgaris$ L.) roots to water under K deficiency decreased and sugar beet leaf water potential ($\psi_l$) and leaf K concentration were correlated (Graham and Ulrich, 1972). Carroll et al. (1994) also showed that Kentucky bluegrass ($Poa pratensis$ L.) plants grown with low-K nutrient solutions had lower leaf turgor potentials ($\psi_l$) but greater leaf $\psi_s$ than plants grown with higher K nutrient solutions.

Little is known about the effect of K nutrition on cotton root carbohydrates. Alfalfa ($Medicago sativa$ L.), likewise a perennial plant, was found to have lower root starch concentrations when grown in pots and fertilized with low-K nutrient solutions than when fertilized with nutrient solutions adequate in K (Li et al., 1997). Cotton has been shown to store considerable amounts of starch in its rooting system (Wells, 1995). Wells (1995) hypothesized that these carbohydrate reserves might be remobilized at times when carbohydrate demand is greater than production, such as during peak boll filling. High-affinity K uptake by plant roots (at low external K concentrations) against an electrochemical gradient is via an active mechanism requiring chemical energy, while low-affinity uptake (at high external K concentrations) can occur by passive transport (Smart et al., 1996). Considering that K-deficient cotton leaves have reduced photosynthetic rates (Longstreth and Noble, 1980; Bednarz and Oosterhuis, 1999) and decreased export of photosynthetic assimilates (Ashley and Goodson, 1972), and that there is a need for an active mechanism to support the K uptake by the roots at low soil K concentrations, it is not clear what effect K deficiency might have on cotton root carbohydrates.

Plants grown under field conditions would not develop nutrient deficiencies or symptoms of moisture stress as rapidly or severely as the potted plants grown in glasshouses or growth chambers in many of the aforementioned studies. In addition, the timing of the low-K stress imposed upon these pot-grown plants may not be the same as when the soil K levels first become deficient for a developing crop. There is a need for confirmation of the results from these controlled-environment, pot-grown plants with practical field studies. Therefore, the objectives of this research were to determine in the field (i) if there is a measurable alteration in the carbohydrate status of both root and leaf tissue between K-deficient plants and plants receiving adequate K fertilization and (ii) if leaf water potential and its components are altered by varying the rate of K fertilization.

### MATERIALS AND METHODS

Field studies were conducted in 1993 and 1994 on a Beulah fine sandy loam (coarse-loamy, mixed, thermic Typic Dystrochrepts) near Stoneville, MS, using four upland cotton genotypes and two levels of K fertilization. Genotypes used in this study were ‘DES 119’ (early maturity), ‘MD 51 ne’ (medium maturity), ‘STV 825’ (medium maturity), and ‘Prema’ (late maturity) and represented a range of maturity groups and regional adaptations. DES 119, MD 51 ne, and STV 825 were bred for the Mississippi Delta region, while Prema is an Acala-type cotton bred for California. The two rates of annual K fertilization used in this study were 0 and 112 kg K ha$^{-1}$, with KCl as the source of K. Plots, consisting of six rows spaced 1 m apart and 6.1 m long, were planted 28 April in 1993 and 19 April in 1994. The 0 kg K ha$^{-1}$ plots were situated on areas that had not received K fertilization for a number of years and were therefore deficient in soil K levels (Pettigrew et al., 1996; Pettigrew and Meredith, 1997). The experiment design was a split plot with seven replicates in 1993 and eight replicates in 1994. Main plots were the K fertility rates and subplots were the genotypes.

Leaf samples were collected at 70, 83, and 104 days after planting (DAP) in 1993 and 72, 85, and 106 DAP in 1994. The leaf sampling procedure on each sample date involved identifying five plants at random per plot and collecting the youngest fully expanded main stem leaf (fourth or fifth leaf from the top) and the main-stem leaf four nodes down from the youngest fully expanded leaf for each of these plants during the morning hours. These 10 leaves per plot were stored on ice, transported to the laboratory, and a total of 25 leaf disks (1.2 cm diam.) were cut from the leaves. The leaf disks were stored at –80°C until subsequent analyses for starch and soluble carbohydrates. Leaf area of the remaining leaf material was determined using a LI-3100 area meter (LI-COR, Lincoln, NE); these leaves were subsequently dried for 48 h at 60°C and used for SLW determinations.

Root samples were collected at 70 DAP in 1993 and 72 DAP in 1994 by uniformly excavating an area under 30 cm of row (two plants) in each plot, to 30 cm in depth, and to 30 cm perpendicular to the row center, similar to the procedure employed by Cook and El-Zik (1992). Once the plants were removed, the roots were washed and all lateral roots were pruned from both plants and placed in a sample bag. In addition, a 4-cm section of taproot, 8 cm beneath the soil surface, was cut from each plant and also placed in the sample bag. The root samples were frozen and stored at –80°C, lyophilized, ground to pass through a 20-mesh screen, and then stored at −20°C until subsequent analyses for starch and soluble carbohydrates.

Soluble carbohydrates were extracted from both leaf (25 leaf disks) and root tissue (100 mg) using three successive 15-mL washes of boiling 800 mL L$^{-1}$ ethanol, followed by incubation in a 60°C water bath and centrifugation at 9400 × g for 10 min. The three supernatants were pooled and evaporated to dryness using a Savant Speed-vac concentrator (Savant Instruments, Farmingdale, NY$^1$); the pellet was saved for starch analyses. Using the procedure previously described by Heitholt and Schmidt (1994), the dried supernatant residue was washed three times with 10 mL of hexane, the supernatants were discarded, and the residue was again evaporated to dryness in a 65°C oven. This residue was then redissolved

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$^1$Trade names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product or service, and the use of the name by the USDA implies no approval of the product or service to the exclusion of others that may also be suitable.
in 10 mL H₂O and passed through a C-18 Sep-Pak (Waters Chromatography Div., Milford, MA) and a 0.45-μm filter. The soluble sugars (sucrose, glucose, and fructose) in this solution were determined and quantified using a Waters HPLC system with a Bio-Rad HPX-87P column (Bio-Rad Laboratories, Hercules, CA) and a Waters Model 410 refractive index detector as described by Heitholt and Schmidt (1994).

Starch in the pellets remaining from the hot ethanol extraction of plant tissue was quantified following digestion with amyloglucosidase for 100 min at 55°C according to the procedures described by Hendrix (1993) and Heitholt and Schmidt (1994). Prior to amyloglucosidase digestion of the ethanol-washed root tissue, an additional starch digestion utilizing heat-tolerant α-amylase for 30 min at 85°C was performed on the root tissue. Starch quantities are reported as anhydroglucose equivalents.

Water relations data were collected at approximately 1330 h CDT on 82 to 86 DAP in 1993 and on 80 to 83 DAP in 1994. Components of ψs for the youngest fully expanded leaf per plant (fourth or fifth leaf from top of the plant) were determined for leaves from three plants per plot using leaf cutter psychrometers (JRD Merrill Specialty Equipment, Logan, UT). After rapidly cutting and inserting the leaf disc into the chamber, the samples were equilibrated for 2 h in a 30°C water bath and then the ψs was measured. Four ψs readings were taken on each leaf disc during a 2.5-h period following equilibration. Stable readings from the three psychrometers per plot were averaged together for subsequent statistical analysis. Following ψs determinations, the samples were frozen overnight in a −20°C freezer, then allowed to reequilibrate for another 2 h in the 30°C water bath; then the ψw was determined. Leaf turgor (ψt) was estimated as the difference between ψs and ψw.

Yield was determined by hand-harvesting a 4.6-m section from one of the inside plot rows, previously designated as the harvest row. Plants were hand-harvested on 125, 138, and 162 DAP in 1993 and on 127, 134, 148, and 169 DAP in 1994. Lint yield and lint percentage were determined from the ginned seed cotton. Boll mass was determined by dividing the weight of seed cotton by the number of bolls harvested. Average seed mass was determined from 100 non-delinted seeds per plot. Arealometer, stelometer, and micronaire properties of the fiber samples were determined by Starlab (Knoxville, TN).

Statistical analyses were performed using analysis of variance. Separate analyses were performed on the leaf carbohydrate data for each harvest date. Potassium (main plot) means were averaged across genotypes when the potassium genotype interaction was not significant. Overall potassium or genotype means were separated by a protected LSD at P ≤ 0.05.

**RESULTS AND DISCUSSION**

Presaison soil K levels in 1993 at a depth of 0 to 15 cm were 465 kg ha⁻¹ in the areas receiving K fertilization vs. 289 kg ha⁻¹ in the areas that did not receive K. At a depth of 15 to 30 cm, the soil K levels were 320 and 274 in the areas that received and did not receive K fertilization, respectively. Midseason leaf tissue analyses for both years confirmed the K-deficiency of plants grown in the 0 kg K ha⁻¹ plots. Leaves from the 0 K plots had K concentrations that were 24% lower in 1993 and 29% lower in 1994 (Table 1).

Specific leaf weights were greater in leaves taken from plants that received no additional K fertilization than from plants receiving 112 kg K ha⁻¹ at all harvest dates in both years (Fig. 1). This effect was consistent across all genotypes. These SLW differences confirm previous research documenting greater SLWs in K-deficient cotton leaves (Pettigrew and Meredith, 1997) and justified the need to further investigate potential causes of this phenomenon.

An increase in soluble carbohydrates, which is often seen in leaves from K-deficient plants (Evans and Sorger, 1966; Huber, 1985), may have contributed to the increased SLW in the K-deficient leaves of this study. Results from this field study demonstrate that glucose consistently accumulated to greater concentrations in leaves from plants in the 0 kg K ha⁻¹ treatment than in leaves from the 112 kg K ha⁻¹ (Fig. 2). Averaged across sampling dates, genotypes, and years, the K deficiency increased leaf glucose concentration by approximately 84% relative to plants that received K fertilization. Leaf fructose concentrations were not as consistently affected by the varying levels of K fertilization as were those of glucose. However, on the only sampling date when K fertilization rates significantly altered fructose levels (83 DAP in 1993), leaves from the K-deficient plants had 34% greater fructose concentrations (Fig. 3). Concentrations of sucrose in the leaves were even more erratic than those of fructose. In 1993, varying the rate of K fertilization had no effect on the leaf sucrose concentration for any sampling date (Fig. 4). In 1994, however,
K-deficient leaves had a 16% greater sucrose concentration at 72 DAP, which was reversed at 85 DAP, when the sucrose concentration was 47% lower in leaves from K-deficient plants, compared with plants receiving K fertilization. Leaf starch concentrations of plants that did not receive K fertilization were reduced by 19% at 83 DAP in 1993 and by 14% at 106 DAP in 1994 (Fig. 5). Starch concentrations did not differ between K fertilization treatments for the remaining sampling dates.

The decreases in leaf starch under K deficiency are consistent with starch synthase being inhibited by deficient levels of cellular K (Nitos and Evans, 1969; Hawker et al., 1974) and agree with Ward’s (1959) potato (Solanum tuberosum L.) leaf starch data at varying levels of K fertilization. However, the starch data contrast with the K deficiency induced leaf starch increases reported by Bednarz and Oosterhuis (1999) for greenhouse cotton. The accumulation of the reducing sugars, glucose and fructose, in K-deficient leaves is consistent
with results reported by Huber (1985) and has been credited to decreased in vivo activities of K-dependent enzymes, such as pyruvate kinase (Evans and Sorger, 1966). Huber (1985) also reported that the sucrose concentration was very inconsistent in its response to K deficiencies, which agrees with the data from this study. He speculated that this inconsistency in the response of sucrose to the K status of the leaf may reflect the role of sucrose as the principal phloem transport sugar.

A deficiency in K caused by the 0 kg K ha\(^{-1}\) treatment consistently increased carbohydrate concentrations of the roots compared with those of plants receiving normal K fertilization (112 kg K ha\(^{-1}\)) in both years of this study (Table 2). Root starch concentration was increased 82%, glucose concentration increased 14%, and fructose concentration increased 27% in K-deficient plants, relative to plants that received 112 kg K ha\(^{-1}\). Sucrose concentration in the root tissue was not affected by varying the level of K fertilization. The increased root starch concentrations under K-deficient conditions is in contrast with findings of Ward (1959), who reported that varying the rate of K fertilization had no effect on root starch concentrations in potato and the work of Li et al. (1997), who found lower root starch concentrations in K-deficient alfalfa plants.

Varying the rate of K fertilization affected the water relations of the plants. Although \(\psi_{w}\) and \(\psi_{e}\) were not affected by varying the K fertilization rate, \(\psi_{e}\) was 17% greater in leaves from plants that received no K fertilization (Table 3). These data contrast with findings of Carroll et al. (1994), who reported lower \(\psi_{e}\); but greater \(\psi_{w}\), for Kentucky bluegrass under low-K growth conditions. Generally, changes in \(\psi_{w}\); are often found in conjunction with opposite changes in \(\psi_{e}\); but that was not the case in our study.

As expected, and as previously documented (Bennett et al., 1965; Cassman et al., 1990; Pettigrew et al., 1996), lint yields were depressed when cotton was grown under K-deficient conditions (Table 4). Genotypes behaved similarly at both K fertilization rates, and so the K fertility treatment means were averaged across genotypes. Increased lint percentage and seed mass were the primary components of yield contributing to the yield increase found with the 112 kg K ha\(^{-1}\) rate; the number of bolls per unit area and boll mass were numerically, but not statistically, greater in this treatment. The K-deficient conditions caused by the 0 kg K ha\(^{-1}\) treatment hastened the termination of the crop’s growth, as seen by an increased percentage of the total lint yield being gathered on the first harvest. This early termination of growth is most likely due to the plants having insufficient K to support further growth and so to prolong the growing season. Accelerated maturity under low-K conditions was also reported by Bennett et al. (1965) and Gwathmey and Howard (1998).

Deficient soil K levels compromised the quality of the fiber produced (Table 5). Fiber micronaire and its components fiber maturity and fiber perimeter were reduced 5, 2, and 2%, respectively in K-deficient plants. Plants grown under the deficient K levels found in the 0 kg K ha\(^{-1}\) treatment also produced fiber that exhibited 4% lower fiber elongation and 1% shorter 50% span length. These fiber quality responses to growth under K-deficient conditions are similar to that found in previous research (Cassman et al., 1990; Pettigrew et al., 1996).

A small part of the SLW increase seen in leaves from K-deficient plants can be explained by increases in the leaf glucose and fructose concentrations. Averaging across harvest dates, the increased glucose concentrations could account for approximately 6.3% of the K deficiency induced SLW increase in 1993 and 4.7% of the SLW increase in 1994. On the only harvest date when fructose levels differed, the higher fructose levels under low-K conditions contributed an additional 0.6% to the SLW increase. Therefore, even though K-deficient conditions increased glucose and fructose levels, they were responsible for only a small part of the SLW change. Assuming a decreased leaf size due to insufficient K conditions, as was documented in soybean (Huber et al., 1985), the concentration of plant nutrients other than K could be elevated due to less leaf material for dilution of the nutrients (Dibb and Thompson, 1985; Pettigrew and Meredith, 1997) and could also contribute to the increased SLW. Both phenomena, and possibly

Table 2. Cotton root carbohydrate concentrations as affected by K fertilization rates averaged across four genotypes and two years at Stoneville, MS.

<table>
<thead>
<tr>
<th>K rate</th>
<th>Starch</th>
<th>Sucrose</th>
<th>Glucose</th>
<th>Fructose</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg K ha(^{-1})</td>
<td>33.3</td>
<td>60.4</td>
<td>15.9</td>
<td>1.9</td>
</tr>
<tr>
<td>112 kg K ha(^{-1})</td>
<td>18.3</td>
<td>60.6</td>
<td>14.0</td>
<td>1.5</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>2.6</td>
<td>NS</td>
<td>1.2</td>
<td>0.2</td>
</tr>
<tr>
<td>(P &gt; F)</td>
<td>0.01</td>
<td>0.75</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 3. Cotton leaf water potential, osmotic potential, and turgor as affected by rates of K fertilization averaged across four genotypes and two years at Stoneville, MS.

<table>
<thead>
<tr>
<th>K rate</th>
<th>Leaf water potential (\psi_{w})</th>
<th>Leaf osmotic potential (\psi_{e})</th>
<th>Leaf turgor potential (\psi_{t})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg K ha(^{-1})</td>
<td>-1.93</td>
<td>-2.34</td>
<td>0.41</td>
</tr>
<tr>
<td>112 kg K ha(^{-1})</td>
<td>-1.98</td>
<td>-2.33</td>
<td>0.35</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>NS</td>
<td>NS</td>
<td>0.05</td>
</tr>
<tr>
<td>(P &gt; F)</td>
<td>0.32</td>
<td>0.99</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 4. Cotton lint yield and yield components as affected by rates of K fertilization averaged across four genotypes and two years at Stoneville, MS.

<table>
<thead>
<tr>
<th>K rate</th>
<th>Lint yield</th>
<th>Boll number</th>
<th>Boll mass</th>
<th>Lint percentage</th>
<th>Seed mass</th>
<th>% 1st harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg ha(^{-1})</td>
<td>no. m(^{-2})</td>
<td>g</td>
<td>%</td>
<td>mg</td>
<td>%</td>
</tr>
<tr>
<td>0 kg K ha(^{-1})</td>
<td>982</td>
<td>68.2</td>
<td>3.84</td>
<td>38.1</td>
<td>91</td>
<td>34</td>
</tr>
<tr>
<td>112 kg K ha(^{-1})</td>
<td>1075</td>
<td>70.0</td>
<td>3.90</td>
<td>40.4</td>
<td>95</td>
<td>29</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>56</td>
<td>NS</td>
<td>NS</td>
<td>0.8</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>(P &gt; F)</td>
<td>0.01</td>
<td>0.25</td>
<td>0.06</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>
others, work in conjunction to increase the SLW in leaves from K-deficient plants, but the increased glucose and fructose levels play only a minor role.

Plant tissue carbohydrate pools are transient by nature and therefore caution must be exercised when interpreting changes. For instance, the diurnal changes in pool size, particularly starch, would overshadow any changes induced by varying the K level. However, because all plots were sampled at approximately the same time of day, the diurnal fluctuations would be minimized and thereby allow any treatment differences to manifest themselves. In addition, Bednarz and Oosterhuis (1999) showed that, for the most part, K-fertility-induced leaf carbohydrate differences in greenhouse-grown cotton were consistent between morning and afternoon leaf harvests.

Previous research has indicated that a decrease in the crop’s photosynthetic production, due to reduced leaf area, was associated with the yield and fiber quality reductions found in cotton grown under K-deficient conditions (Pettigrew and Meredith, 1997). When that work is coupled with the results of Longstreth and Noble (1980) and Bednarz and Oosterhuis (1999), who documented photosynthetic reductions on a leaf area basis for K-deficient leaves, a picture emerges of a K-deficient cotton canopy that not only has reduced leaf area, but also is less efficient photosynthetically with the leaves that it does produce. Not only is the canopy of a K-deficient cotton crop less productive photosynthetically, the source leaves appear to keep much of the photosynthetic assimilates and not translocate them to the reproductive sinks. The higher leaf carbohydrate levels detected in this research, coupled with the work of Ashley and Goodson (1972), who documented reduced assimilate translocation rates from K-deficient cotton leaves, support this notion. Reduced photoassimilate production and inhibition of translocation of that photosynthetic to the developing reproductive sinks lowers the yield potential of cotton crops grown on K-deficient soils and compromises the fiber quality of the lint that is produced.

The increased cotton root carbohydrate concentration under low-K fertility conditions might be perplexing in lieu of the fact that varying K fertility levels had no effect on the root starch concentrations in potato (Ward, 1959) and that decreased starch concentrations were found in roots from K-deficient alfalfa plants (Li et al., 1997). When the perennial nature of cotton is taken into account, however, the increased root carbohydrate levels are more easily understood. Assuming that the cotton plant adopts a growth strategy for long-term survival, lack of adequate K during the growing seasons for the K-deficient plots may have predisposed these plants to partition more of their photosynthetic energy into nonstructural storage carbohydrates in the roots and stems. This adaptation could provide additional carbohydrates for growth during the next season for this perennial plant, enabling it to achieve more reproductive success during that growing season, assuming favorable conditions. Since cotton is cultured as an annual, however, it may not be able to fully utilize additional nonstructural carbohydrates stored in the stems and roots during that single season.

The increased levels of leaf $\psi_t$ found in the K-deficient plants are difficult explain without a corresponding decrease in leaf $\psi_m$. It may be related to decreased transpiration associated with K deficiencies in plants, although reduced stomatal conductances ($g_s$) are generally only seen under extreme K deficiencies (Huber, 1985). In addition, if the low-K treatment resulted in smaller leaves, as was documented in soybean (Huber, 1985), this might also result in the plant water being distributed throughout less biomass, which supports a greater leaf $\psi_m$. For as the lack of an effect upon $\psi_m$, there may well be counteracting forces. Carroll et al. (1994) reported that K fertilization increased the $\psi_m$ in Kentucky bluegrass, but the increased glucose and fructose found in nonstructural carbohydrates stored in the cotton leaves, as was documented in soybean (Huber, 1985), this might also result in the plant water being distributed throughout less biomass, which supports a greater leaf $\psi_m$. For as the lack of an effect upon $\psi_m$, there may well be counteracting forces. Carroll et al. (1994) reported that K fertilization increased the $\psi_m$ in Kentucky bluegrass, but the increased glucose and fructose found in the K-deficient plants in this study, combined with increased concentrations of other plant nutrients (Pettigrew and Meredith, 1997), would serve to reduce the $\psi_m$ in K-deficient plants. These two counteracting phenomena probably resulted in the lack of a significant difference in $\psi_m$ between the K fertility levels.

In conclusion, a deficiency in K alters the leaf carbohydrate and water status of cotton plants by increasing the glucose and fructose concentrations and by elevating the leaf $\psi_t$. These increased carbohydrate levels make only a minor contribution to the increased SLW associated with K-deficient cotton plants. The K deficiency also appears to promote more partitioning of the carbohydrate into root tissue, which could be related to its perennial nature. 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.

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Table 5. Cotton fiber quality characteristics as affected by K fertilization rates averaged across four genotypes and two years at Stoneville, MS.

<table>
<thead>
<tr>
<th>K rate</th>
<th>Fiber strength</th>
<th>Fiber elongation</th>
<th>Span length</th>
<th>MIC†</th>
<th>Fiber maturity</th>
<th>Fiber perimeter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kN m kg⁻¹</td>
<td>%</td>
<td>2.5%</td>
<td>50%</td>
<td>%</td>
<td>µm</td>
</tr>
<tr>
<td>0 kg K ha⁻¹</td>
<td>218</td>
<td>7.10</td>
<td>2.82</td>
<td>1.39</td>
<td>3.84</td>
<td>78.5</td>
</tr>
<tr>
<td>112 kg K ha⁻¹</td>
<td>214</td>
<td>7.42</td>
<td>2.83</td>
<td>1.41</td>
<td>4.05</td>
<td>80.5</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>3</td>
<td>0.09</td>
<td>NS</td>
<td>0.01</td>
<td>0.07</td>
<td>1.2</td>
</tr>
<tr>
<td>$P &gt; F$</td>
<td>0.02</td>
<td>0.01</td>
<td>0.11</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

† MIC, micronaire value.
drate analyses and water potential measurements is greatly appreciated.

REFERENCES


