Effects of soil and foliar potassium status and water deficit on cotton physiology and yield

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ABSTRACT

Limited information exists about the impact of water deficit stress and K deficiency on cotton (Gossypium hirsutum L.) lint yield and mid-season growth. Field studies were conducted over four growing seasons in three locations to test the hypothesis that the physiological response to the onset of K deficiency in cotton, dry matter accumulation, and the efficacy of foliar-applied K were directly affected by the plant water status. Eight treatment combinations of well-watered or dryland conditions, high or low soil K, and with or without foliar-applied K were arranged in a split-split plot design with six replications. Lint yield averaged over four growing seasons in both Mississippi Delta locations in Arkansas tended to respond to soil-applied K only under well-watered conditions. Lint yield increased by a greater margin in response to foliar-applied K under the low versus the high soil K level. No difference was observed in lint yield response to foliar-applied K under irrigated or dryland conditions. In 2002, leaf glucose, fructose and sucrose concentrations responded to foliar K applications in K-deficient and water-stressed plots at three weeks after first flower; whereas, glucose and fructose concentrations in leaves from high K plots were reduced under well-watered conditions. Potassium deficiency increased leaf membrane leakage and reduced photosynthesis under well-watered conditions at the same stage of growth. Although the components of leaf gas exchange responded inconsistently to soil and foliar-applied K across seasons, K deficiency had a more negative impact on lint yield of cotton grown under irrigated as compared to dryland conditions. The use of appropriate pre-plant, soil-applied K fertilizer rates may be particularly important to maximize cotton yields under irrigated conditions. In contrast, foliar-applied K, which can stimulate root uptake of soil K, can be beneficial to cotton-lint yield under dryland or irrigated conditions depending on pre-plant soil test K values.

Introduction

Proper potassium nutrition is essential for optimal crop productivity in cotton and requires that deficiencies be avoided. A review of the literature shows that K is critically needed for maintaining plant water relations (Kramer and Boyer, 1995), activating enzymes, supporting photosynthetic systems (Kerby and Adams, 1985), and translocating sugars and starch out of leaves (Bednarz and Oosterhuis, 1999).

The change to modern cotton cultivars which fruit in a shorter period of time, mature earlier, and have greater total K requirements has placed an emphasis on understanding plant uptake and utilization of K throughout the growing season (Oosterhuis, 1995). Although K may be taken up in luxury amounts by the cotton plant prior to peak demand, sporadic K deficiencies often occur late in the growing season in Arkansas when the large developing boll load becomes the dominant sink for available K and the rate of root growth decreases. Factors that interfere with the strong source-sink relationship of K in cotton will directly influence the efficiency of K use and the potential for high lint yields (Mullins, 1990; Oosterhuis, 1995). Although yield and economic advantages of timely foliar-K applications to supplement soil-applied K have been documented, (Oosterhuis, 1999; Weir, 1999), the impact of mid-season water-deficit stress on the efficiency of foliar-K uptake and yield response to foliar-K fertilization needs further investigation.

We hypothesized that the crop water status would change K partitioning in the plant and directly affect the efficiency or benefit from foliar-applied K. Therefore, our first objective was to determine the effect of water deficit and K deficiency stress on mid-season physiology, adsorption, translocation and general efficacy of foliar-applied K. A second objective was to investigate cotton lint yield response to foliar-applied K under irrigated (well-watered) and dryland (water-stressed) conditions with (high K) or without (low K) pre-plant, soil-applied K fertilizer.

Experimental procedure

Cotton growth, K partitioning, physiology, and lint yield under varying water levels and K fertility were studied in 1999 in field plots located at Rohwer (Coker and Oosterhuis, 1999), in 2000 at Clarkedale and Rohwer (Coker and Oosterhuis, 2000), in 2001 at Clarkedale (Coker *et al.*, 2002) and at Fayetteville in 2002. This report describes the 2002 study with reference to the previously conducted studies (cited above) with identical treatments. Eight treatment combinations of well-watered (irrigated) or dryland (non-irrigated) conditions, high (preplant, soil-applied K) or low-soil K (unfertilized or no preplant K), and with or without foliar K were arranged in a split-split plot design with five or six replications.

In 2002, the cultivar Suregrow 215 BR was planted on a well-drained Captina silt loam (fine-silty, mixed, mesic Typic Fragiudults) on the Main Agricultural Experiment Station Farm located in Fayetteville, AR. Each plot consisted of four, 9 m long rows spaced 1 m apart. Pre-plant granular KCl fertilizer was hand broadcast to designated plots (high soil K) prior to planting at recommended rates based on University of Arkansas fertilizer recommendations for cotton. The average Mehlich 3 extractable soil K was 270 kg K/ha (Table 3). Preplant K fertilizer application rates ranged from 46 to 90 kg K/ha. Foliar KNO_3 was applied (4.9 kg K_2O/ha/week or 11.2 kg KNO_3/ha) for four consecutive weeks starting one week after first flower with a CO_2 backpack sprayer calibrated to deliver 93.5 l/ha. Irrigation events were scheduled in well-watered plots according to the University of Arkansas Irrigation Scheduling Program. An infrared thermometer was used to measure the temperature of the uppermost, full-expanded main-stem node leaves starting at the first flower stage in all plots to monitor plant stress (data not shown). At major phenological stages, measurements were made of photosynthesis, soluble carbohydrates and membrane integrity in the uppermost fully-expanded leaves. Final lint yield and components of yield were determined from each plot by hand picking a 1 m length from each of the two center rows and counting and weighing the bolls. Lint yield and components of yield comparisons were made using the SAS General Linear Model procedure and PDIFF option within LSMEANS statements.

Results

Leaf sugars

At three weeks after first flower, glucose, fructose and sucrose concentrations were lower ($p \leq 0.05$) in leaves from foliar-K treated plots at the low soil K but not the high soil K level (Table 1). Glucose, fructose, and sucrose concentrations were lower ($p \leq 0.05$) in leaves from plots receiving foliar-applied K compared to plots without foliar-applied K under the dryland but not the well-watered condition at first flower plus three weeks. Glucose and fructose concentrations in leaves were lower ($p \leq 0.01$) in high K, irrigated but not rainfed plots at three weeks after first flower. When averaged over water and foliar-K treatments, leaf glucose and fructose concentrations were lower ($p \leq 0.05$) in high K plots at first flower plus three weeks (Table 2).

Leaf membrane integrity

At three weeks after first flower, leaf membrane leakage was reduced under high-soil K, well-watered ($p \leq 0.05$) conditions but not under water-stressed conditions (Figure 1).

Leaf photosynthesis

Leaf photosynthesis responded ($p \leq 0.05$) to foliar-applied K under the low but not the high soil K level at three weeks after first flower (Figure 2). Foliar-applied K increased ($p \leq 0.05$) leaf photosynthesis at three weeks after first flower under irrigated but not dryland conditions (Figure 3). Pre-plant soil-applied K increased photosynthesis ($p \leq 0.05$) under well-watered but not water-stressed conditions at three weeks after first flower (Figure 4).

Lint yield

Although we observed similar yield responses to soil-applied K at Fayetteville in 2002, the yield responses to foliar-applied K were noticeably greater compared to responses observed during previous seasons at Rohwer or Clarkedale (Table 3). Foliar-applied K increased lint yield ($p \leq 0.05$) by 236 kg/ha when preplant K fertilizer was applied (high soil K). When preplant K fertilizer was not applied (low soil K), the mean lint yield response to foliar-applied K was approximately 101 kg/ha, although it was not statistically different from lint yield without foliar applied K. Thus far, our studies have shown a small lint yield increase to foliar-applied K when preplant K was not applied (low soil K) as opposed to when preplant K fertilizer was applied (high soil K) when averaged across all three-test sites during the past four years. In 2002, cotton lint yields were significantly greater ($p \leq 0.05$) when foliar K applications were made to dryland (rainfed or non-irrigated) cotton, but not to irrigated cotton (Table 3). However, when averaged across all three-test sites, dryland-cotton lint yields have tended to show slightly greater response to foliar K application as compared to irrigated-cotton yields. Lint yield response to soil-applied K was significant ($p \leq 0.05$) for irrigated (well-watered) cotton and tended to be positive, although not statistically significant, under dryland conditions in 2002. Across all locations and growing seasons, soil-applied K (high soil K) increased the mean irrigated cotton lint yield by 5.9%, but had no significant effect on dryland-cotton yields in our studies.

Conclusions

Our studies have shown that mid-season K deficiency stress in cotton inhibits sugar translocation, photosynthesis, and other metabolic processes critical for fiber quality and yield, particularly under well-watered conditions. Strong consideration should be given to the pre-plant soil K status when making decisions about foliar K fertilization. Studies during the past three years show significant responses to foliar-applied K on soils with pre-plant soil test K <280 kg K/ha, which supports our previous findings (Oosterhuis, 1995). Our results also show that the potential for foliar-K feeding to increase cotton lint yield of dryland (non-irrigated) cotton is similar to if not better than that observed for irrigated cotton in the U.S. Mid-South. Physiologically, this was evidenced in part by lower concentrations of glucose, fructose, and sucrose in leaves under water-stressed as compared to well-watered conditions during peak boll development.

Our current studies also show that soil-applied K fertilizer was beneficial to cotton-lint yields produced under irrigated, but not necessarily dryland conditions in plots where the pre-plant soil test K values ranged from medium to high (>280 kg K/ha, Mehlich 3 soil K). Hence, the use of appropriate pre-plant, soil-applied K fertilizer rates may be particularly important to maximize cotton yields under irrigated conditions. In contrast, foliar-applied K, which can stimulate root uptake of soil K, can be beneficial to cotton-lint yield under dryland or irrigated conditions depending on preplant soil test K values.

Acknowledgments

Support for this research was provided by the Arkansas Fertilizer Tonnage Fees, the Potash and Phosphate Institute, and IMC Global. We thank Larry Fowler and support staff at the Delta Branch Station, Clarkedale and Vaughn Skinner and support staff at the Arkansas Agricultural Research Center, Fayetteville for help with field preparation and management. Thanks to Scott Brown and Milenka Arevalo for technical assistance.

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Table 1. *Sugar concentration at three weeks after first flower in uppermost leaves of field-grown cotton cv. 'SG 215 BR' to foliar-applied K averaged over the water and soil K treatments (Fayetteville, 2002).*

	Sugar concentration (μg/cm^2)		
Treatment	Glucose	Fructose	Sucrose
Averaged over water			
High soil K, no foliar K	37.49	43.28	92.43
High soil K, with foliar K	43.25	50.06	103.52
Low soil K, no foliar K	69.3	76.65	134.94
Low soil K, with foliar K	35.96^z	42.48^z	98.34^z
Soil K × foliar K	^{y}	^{y}	^{y}
Averaged over Soil K			
Well-watered, no foliar K	33.77	39.09	83.67
Well-watered, with foliar K	35.16	41.32	90.08
Dryland, no foliar K	73.03	80.84	143.70
Dryland, with foliar K	44.05^z	51.22^z	111.79^z
Water × foliar K	^{y}	^{y}	^{y}

^{z} Significant at p≤0.05 for the paired treatments.

^{y} Significant at p≤0.05 for treatment interaction.

Table 2. *Sugar concentration in uppermost leaves of field-grown cotton cv. 'SG 215 BR' at three weeks after first flower to soil-applied K averaged over the water and foliar-applied K treatments (Fayetteville, 2002).*

	Sugar concentration (μg/cm^2)		
Treatment	Glucose	Fructose	Sucrose
Averaged over foliar K^z			
Well-watered, high soil K	27.71	33.20	77.16
Well-watered, low soil K	41.21^y	47.22^y	96.59
Dryland, high soil K	53.03	60.14	118.79
Dryland, low soil K	64.05	71.92	136.69
Averaged over Water and Foliar K			
High soil K	40.37	46.67	97.98
Low soil K	52.63^x	59.57^x	116.64

^{z} No significant (p≤0.05) interactions observed between main effects.

^{y} Significant at p≤0.1 for the paired treatments.

^{x} Significant at p≤0.05 for the paired treatments.

Table 3. *Yield response of field-grown cotton over four seasons to mid-season foliar K and pre-plant soil-applied K averaged over the water, soil K, and foliar K treatments respectively (Rohwer, 1999 and 2000; Clarkedale 2000 and 2001; Fayetteville 2002).*

	Lint yield (kg ha^{-1})						
	Rohwer	Rohwer	Clark.	Clark.	Fay.	Mean	Change (kg ha^{-1})
Treatment	1999	2000	2000	2001	2002		(%)
Average over water^{z}							
High soil K, no foliar K	1271	1258	1062	1522	1440	1310	
High soil K, with foliar K	1269	1250	1071	1503	1677^{y}	1354	+44 (3.3%)
Low soil K, no foliar K	1247	1219	993	1441	1388	1258	
Low soil K, with foliar K	1291	1203	1103^{y}	1522	1491	1322	+64 (5.1%)
Average over soil K^{z}							
Well watered, no foliar K	1530	1626	1390	1606	1516	1533	
Well watered, with foliar K	1561	1622	1447	1620	1586	1567	+34 (2.2%)
Dryland, no foliar K	988	849	664	1357	1312	1034	
Dryland, with foliar K	1001	831	727	1406	1581^{y}	1109	+75 (7.3%)
Average over water and soil K							
No foliar K	1261	1238	1027	1482	1413	1285	
With foliar K	1280	1225	1086	1512	1584^{y}	1337	+52 (4.1%)
Average over foliar K							
Dryland, high soil K	949	811	717	1375	1496	1070	
Dryland, low soil K	1040	869	674	1388	1397	1072	-2 (0.2%)
Well watered, high soil K	1592	1696	1416	1650	1621	1595	
Well watered, low soil K	1499	1552^{y}	1421	1576	1482^{x}	1506	+89 (5.9%)
Water × Soil K	^{w}	^{w}	-	-	-		
Average over water and foliar K							
High soil K	1270	1253	1066	1512	1558	1332	
Low soil K	1269	1211	1048	1482	1439^{x}	1290	+42 (3.2%)
Pre-plant soil K level (kg ha^{-1})							
Well watered	296	374	279	295	270	302	
Dryland	283	376	279	324	270	307	

^{z} No significant (p≤0.05) interactions observed between main effects.

^{y} Significant at p≤0.05 for the paired treatments.

^{x} Significant at p≤0.10 for the paired treatments.

^{w} Significant at p≤0.05 for treatment interaction ("-" = no interaction).

Figure 1.
Effect of soil K deficiency on leaf membrane integrity under well-watered and water-stressed conditions at three weeks after first flower (Fayetteville, AR 2002).

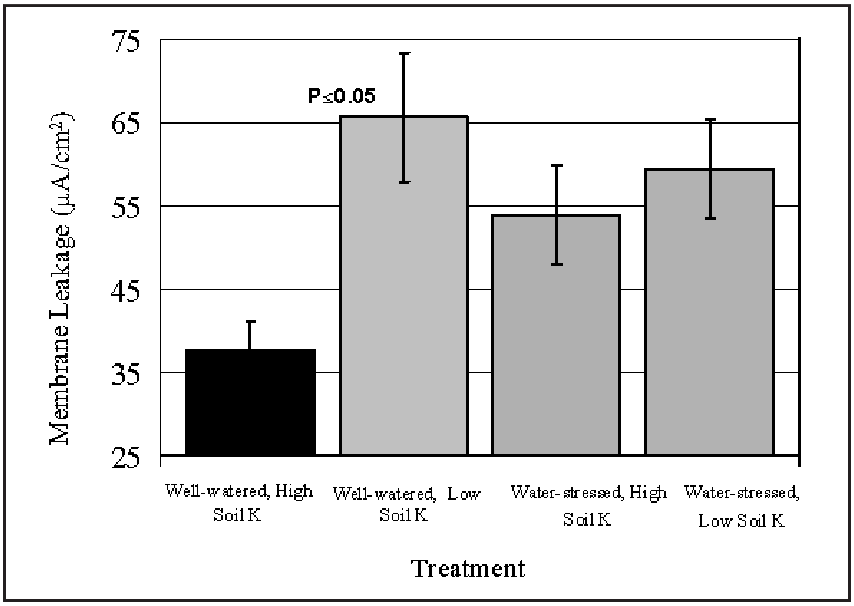

Figure 2.
Photosynthesis response to foliar-applied K under high and low soil K at five weeks after first flower (Fayetteville, AR 2002).

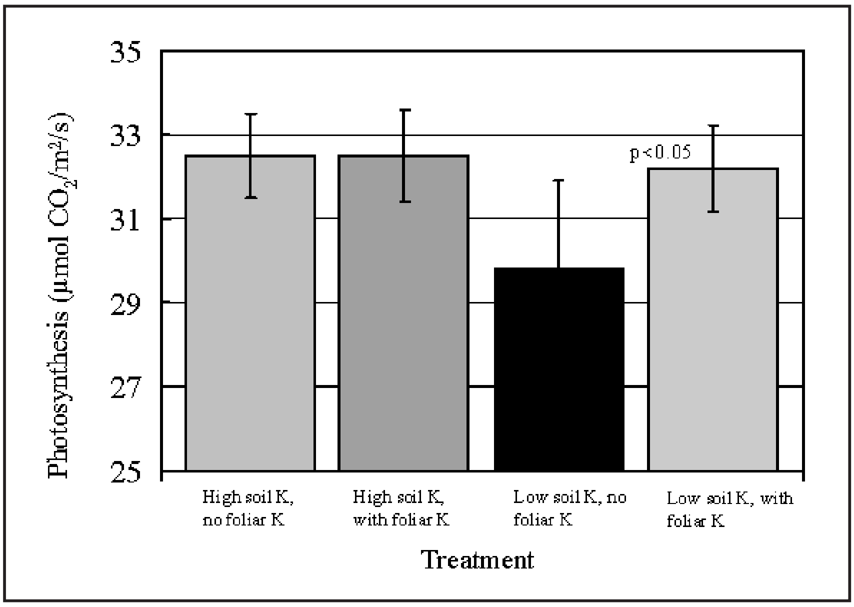

Figure 3.
Effect of foliar-applied K on leaf photosynthesis under well-watered and water-stressed conditions at five weeks after first flower (Fayetteville, AR 2002).

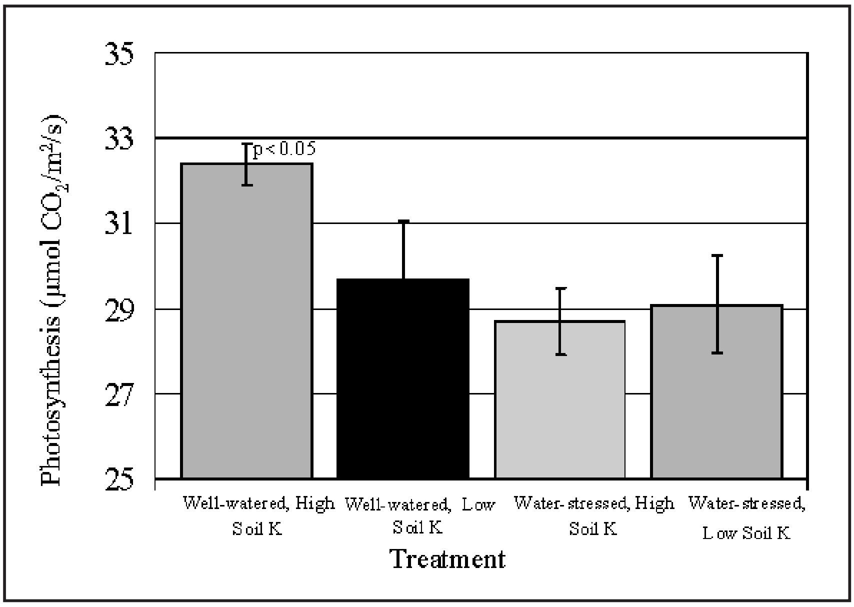

Figure 4.
Effect of soil K level on leaf photosynthesis under well-watered and water-stressed conditions at three weeks after first flower (Fayetteville, AR 2002).