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SCREENING COTTON GERMPLASM FOR VARIATION IN WATER USE EFFICIENCY AND EPIDERMAL CONDUCTANCE

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Abstract

High water use efficiency (WUE) and low minimum leaf epidermal conductance (g_e) are two traits that may enhance productivity of cotton under drought stress conditions. In the present work, a selection of twenty-two commercial cultivars, primitive race stocks and converted lines were screened for variability for these two traits in a greenhouse experiment, under both control (water replete) and cyclic drought stress conditions. WUE was calculated as the ratio of total plant dry matter accumulated to total water used over the period from planting to 40 days after planting. Minimum epidermal conductance was measured for two mainstem leaf positions using leaf gas exchange techniques. Significant genotype differences were found for WUE under drought conditions but not under control conditions. The watering treatment did not affect g_e, but there were significant genotype differences for this trait. Regression analysis revealed a negative correlation between WUE and g_e.

Introduction

Total cotton production in Georgia in 2000 was 1.66 million bales with an estimated value of $458 million, and the total economic impact of the state cotton industry was estimated to be over 3 billion dollars. In 2000 Georgia was second among the states in acres of cotton planted but only fourth in overall production; this difference was largely due to drought (Georgia Cotton Commission, 2001). Also, the increase in competing demands for the state's limited water resources makes it essential that the crop make maximum use of the available water even when irrigation is available. Water use efficiency (WUE = total dry matter produced / water used) has been the subject of much research, and significant variability for WUE has been identified within many crop species, including cotton (e.g., Quisenberry and McMichael, 1991; Saranga et al., 1998).

Under severe drought stress conditions, plants close their stomata to prevent further depletion of soil water and lethal desiccation of leaf tissues. Under these conditions, the amount of water lost through the cuticle becomes a significant fraction of total transpiration. Minimum epidermal conductance to water (g_e) includes both cuticular conductance and conductance through incompletely closed stomata and, along with leaf area, determines the minimum water use rate of a plant under drought stress conditions. The primary importance of minimum g_e to crop survival under severe drought conditions was demonstrated by Sinclair (2000), but it is unknown if there is significant variability for this trait in the available cotton germplasm.

Our objectives were: 1) to screen a selection of cotton varieties, breeding lines and primitive race stocks for vegetative phase dry matter WUE under water replete conditions and under cyclic drought conditions, 2) to determine whether any observed differences in WUE were constitutive in nature, or if they occurred only under drought conditions, 3) to screen the same selection of genotypes for differences in minimum epidermal conductance, and 4) to determine if there is a correlation between minimum g_e and dry matter based WUE.

Materials and Methods

All experiments were conducted between August 2002 and December 2002 in Athens, GA (33.9 °N, 83.3°W). Plants were grown in 2.5-L pots without drainage holes. The soil was a Pacelot sandy loam (a member of the clayey, Kaolinitic, thermic family of Typic Hapludults) amended with sand to a texture of 800 g kg^{-1} sand, 120 g kg^{-1} silt, and 80 g kg^{-1} clay. The pots were filled with 3400 g of soil; the water-holding capacity of the soil was determined in a preliminary experiment. The 22 genotypes used are listed in Table 1. At planting, pots were fertilized with 4 g of 20-20-20 fertilizer and capped at 14 days after planting. Caps had a 1-cm hole for watering and a 1-cm hole for the plant stem. The capping prevented water loss to soil evaporation; thus, all water lost from the soil was via transpiration. On the day that the plants were capped the current soil water content was determined gravimetrically, and all added water was subsequently recorded.

The design was a split plot, with watering treatment (control or cyclic drought stress) as the main factor and genotype as the split factor. The experiment was repeated five times. Each pot was weighed daily to determine the amount of water to be added. Control plants were kept in a water replete condition by maintaining those pots between 55% and 85% relative soil water content (RSWC). Plants assigned to the drought treatment were maintained water replete until 28 days after planting; thereafter, they were exposed to cyclic drought stress by allowing them to dry to below 15% RSWC before being re-watered to 85% RSWC. At 40 days after planting, measurements of g_e were made (see below), and then the plants were harvested and their shoot and root dry weights were determined after drying to constant weight at 80°C. The amount of water used during the course of the experiment and the total plant dry weight was used to determine the integrated WUE .

At 40 days after planting all plants were well watered and placed in darkness for 36 h, to ensure that full stomatal closure (minimum g_e) had been achieved. Then, g_e was measured with an open flow gas exchange measurement system (LI-6400, LICOR, Lincoln NE). Humidity in the leaf chamber was not controlled, but chamber CO_2 was maintained at 360 ppm. Once the sample - reference Δ [$H_2 0$] had stabilized, g_e was recorded as the average of 12 readings taken 10 s apart. Two leaves per plant were sampled: the youngest fully expanded mainstem leaf, and the leaf positioned two nodes below the youngest fully expanded. All data were analyzed using the GLM procedure in SAS, and means separation for genotype comparisons was via Duncan's multiple range test.

Results and Discussion

The watering treatments differed significantly for their effects on total plant dry weight and total water used. The mean WUE across genotypes was numerically greater under the drought stress treatment, but this difference was not statistically significant (Table 2).

Genotypes did not differ significantly for WUE when the control and drought treatment data were considered together; however, significant genotype effects were found when the drought treatment data were analyzed alone ($p < 0.05$). This ranking of genotypes for WUE (Table 3) did not always agree with previous work. For example, Saranga et al. (1998) found G-414 and F-177 to have low WUE and Vered to have high WUE under field conditions over an entire season; in the present work (greenhouse conditions, vegetative phase only) G-414 and F-177 had significantly higher WUE than Vered. In other cases, significant genotype differences agreed with those reported previously (e.g., T-80 vs T-141). Also, the WUE rankings for SG-125, DP5415 and DP5690 were consistent with previous observations regarding their leaf internal CO_2 concentrations (c_i) (compare Tables 1 and 3); well-established theory dictates that low c_i directly results in high WUE (Farquhar et al., 1989). Additional replications of this experiment are being conducted to improve the statistical power of these rankings.

There have been no previous investigations of differences in g_e in this germplasm. We found no significant effect of watering treatment on g_e. The mean g_e for youngest fully expanded leaves was significantly less than that for leaves two nodes lower (5.6 and 10.5 mmol m^{-2} s^{-1} respectively; $p < 0.0001$). There were no significant treatment x genotype or genotype x leaf position interactions for g_e. Cultivar main effects were highly significant ($p < 0.0001$). Genotype means for this trait are shown in Table 4. Under severe drought stress, low g_e should enhance the plant's ability to avoid desiccation of leaf tissues, and therefore permit recovery of photosynthetic capacity upon relief of the stress. Interestingly, many of the genotypes with high WUE also had low g_e (compare Tables 3 and 4). Indeed, there was a significant negative correlation between WUE and g_e in this study (Figure 1).

In conclusion, significant genetic variability for both WUE and g_e exists in the available cotton germplasm. Additional experiments are underway to elucidate the physiological basis of observed differences in WUE.

References

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Table 1. Genotypes used in the experiment.

Genotype	Source	Description
T-115 Punctatum T-141 Marie Gal-ante T-169 Latifolium T-185 Latifolium T-461 Richmondi T-80 Latifolium T-256 Richmondi T-15	Primitive (photoperiodic) race stocks from the USDA cotton germplasm collection	Low WUE (Quisenberry & McMichael 1991) High WUE (Quisenberry & McMichael 1991)
MDN– 63	Chiapas, Mexico	Contributed large/positive genetic variation for fiber quality (McCarty et al. 1996)
MDN–101	Jutiapa, Guatemala	Contributed large/positive genetic variation for fiber quality and plant height (McCarty et al. 1996)
MDN–257	Oaxaca, Mexico	Represents the morillii botanical race, positive contributions for fiber length (McCarty et al. 1996)
SG–125	Commercial variety	Maintains low c_i (Earl, unpub.)
DP5415	Commercial variety	Moderate c_i under drought stress (Earl, unpub.)
DP5690	Commercial variety	Maintains high c_i (Earl, unpub.)
Delta Pearl	Commercial variety	High yield commercial variety
H-23	*G. hirsutum*, cv. Israel	'Standard' cv. from Y. Saranga
Vered	*G. hirsutum*, cv. Israel	High WUE (Saranga et al., 1998)
G-414	*G. hirsutum*, cv. Israel	Low WUE (Saranga et al., 1998)
F-177	*G. barbadense*, cv. Israel	Low WUE (Saranga et al., 1998)
195x8	Interspecific hybrid, Israel	Moderate WUE (Saranga et al., 1998)
72-08	Okra-leaf interspecific hybrid, Israel	Suspected unique water relations (Saranga, unpub.)
S-6	*G. barbadense*, cv., U.S.	Commercial Pima variety with high stomatal conductance (Lu et al., 1992)

Table 2. Effect of watering treatment on plant dry weight, water use and WUE. The p-values shown are for the comparison between treatments within a row.

	Treatment		
	Control	**Drought**	**p**
Dry weight (g)	9.75	5.73	< 0.0001
Water used (L)	2.78	1.54	< 0.0001
WUE (g L^{-1})	3.61	3.80	0.14

Table 3. Effect of genotype on water use efficiency under drought stress. Means followed by the same letter do not differ according to Duncan's multiple range test (p = 0.1). n = 5.

Genotype	WUE (g L^{-1})
G-414	4.96 a
F-177	4.58 ab
T-80	4.40 abc
SG-125	4.28 abcd
MDN-101	4.17 abcde
S-6	4.12 abcde
Delta Pearl	4.08 abcde
T-461	3.94 abcde
T-256	3.84 bcde
T-169	3.83 bcde
195x8	3.72 bcde
DP5415	3.60 bcde
MDN-257	3.56 bcde
72-08	3.51 bcde
T-15	3.50 bcde
T-115	3.35 cde
Vered	3.28 cde
T-185	3.25 cde
MDN-63	3.23 cde
H-23	3.20 de
T-141	3.14 de
DP5690	3.03 e

Table 4. Effect of genotype on minimum epidermal conductance. Means followed by the same letter do not differ according to Duncan's multiple range test (p = 0.05). n = 5.

Genotype	g_e (mmol m^{-2} s^{-1})
T-185	20.5 a
T-115	16.4 ab
DP5690	14.7 bc
T-15	13.9 bcd
T-256	12.7 bcde
T-141	12.0 bcde
DP5415	11.6 bcdef
T-169	10.8 bcdef
MDN-101	10.1 cdef
SG-125	10.1 cdef
Vered	9.6 cdef
MDN-63	9.4 cdef
H-23	9.1 cdef
Delta Pearl	9.1 cdef
72-08	8.9 cdef
MDN-257	8.3 cdef
G-414	7.8 def
T-461	7.9 def
195x8	7.8 def
F-177	7.5 def
T-80	7.3 ef
S-6	5.2 f

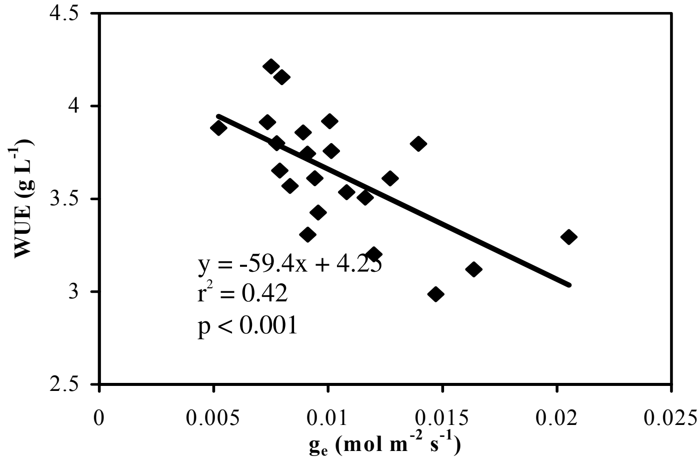

Figure 1. Relationship between mean WUE across treatments and mean minimum epidermal conductance across treatments and leaf positions.