CHARACTERIZATION OF WHOLE-PLANT WATER ECONOMY IN COTTON GENOTYPES

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Abstract

Water deficit is the major abiotic factor curtailing cotton production in drought-prone Texas croplands. The objective of this study is to characterize the water economy in different cotton genotypes by identifying the physiological and anatomical traits controlling their water use, and transfer this information to breeders and geneticists in an effort to accelerate the development of drought-tolerant cultivars. Preliminary data for 3 contrasting genotypes under water-stress conditions, collected in the 2011 cotton-growing season, will be presented in this paper followed by a brief discussion on possible traits affecting their water use.

Introduction

Soil water availability is the most dominant yield-limiting factor in cotton production across drought-prone Texas croplands and curtails the magnitude of its economic impact statewide. Cotton production in Texas could potentially increase and become more stable with the use of improved drought-tolerant cotton genotypes as the negative impacts of water deficit on yield and fiber quality would be reduced. Although cultivar-by-environment interactions have been repeatedly studied in tests conducted under natural or managed soil moisture regimes, differential responses to water-stress among genotypes have not been quantified nor explained by properly identifying responsible plant traits. A plethora of physiological studies have indicated that water economy is controlled by a combination of anatomical and physiological characteristics, but this knowledge has not translated into improved breeding lines. The main objectives of this research is to characterize the water economy of a selected group of cotton genotypes by accurately identifying traits controlling their water use and transfer this information to breeders and geneticists to help advance the development of drought-tolerant cultivars. Preliminary data for 3 genotypes exhibiting contrasting water use patterns will be presented in this paper in an attempt to demonstrate the potential for the methodology used.

Materials and Methods

The study was conducted in the Drought Tolerance Laboratory at the Texas AgriLife Research and Extension Center in Corpus Christi during the 2011 cotton-growing season. This facility consists of two joined modified greenhouse structures housing 128 electronic mini lysimeters capable of measuring continuous whole-plant transpiration under controlled watering regimes. Computerized systems monitored whole-plant water use and controlled watering with a nutrient solution throughout the growing season. Data collected were automatically transferred to a dedicated Web server for archiving and posterior analysis.

Seeds of 16 cotton genotypes supplied by Texas AgriLife Research cotton improvement programs in Lubbock and Monsanto Co. were pre-germinated in wet paper towels at room temperature. After about 4-5 days, germinated seeds showing a healthy 1 ½" long radicle and with cotyledons still covered by the seed coat were hand-planted at the rate of four per pot in a wet soil medium on March 28. The soil medium consisted of fritted clay, which is known by its high water holding capacity (~43 % of volume). Large pots, 3.578–gallon (13.5-L) volume, were uniformly filled

with the soil medium to minimize maximum soil water availability as a variable factor affecting plant growth and plant water economy. Upon planting, the soil surface was covered with aluminum foil to minimize water evaporation from the soil, but leaving a central opening to allow the seedlings to emerge through. Tiny holes were punctured in the aluminum foil to allow infiltration of irrigation water. After seedling establishment, three of the four emerged seedlings were removed. Twenty-four fairly uniform plants of each genotype were grown and spatially arranged to conform a RCB experimental design with eight replications. Each genotype had 3 plants per replication, and one of these three plants permanently sat on the micro lysimeter for continuous water use measurements while one of the other two was subjected to destructive harvest for discrete measurement of various anatomical and physiological attributes before starting the water stress regime. All experimental plants were individually irrigated daily to excess with a modified Hoagland solution made up with purified city water until the start of the water stress regime on June 10 at early flowering stage. Irrigation cycles were performed during the night and the water stress imposed consisted of reducing the time of irrigation events in half, from 4 to 2 minutes, which reduced the amount of water being provided accordingly (from 4 L to 2 L per pot). The destructive plant samples were taken June 8th and 9th before the beginning of the water stress regime, and the final harvest was conducted from July 28th through August 8th to allow proper time for longer cycle genotypes to reach full maturity. The discrete measurements included plant height, number of main-stem nodes, main-stem node of the first-position bloom if present, number of leaves, and total leaf mass. In the second and last plant sampling other measurements included the number of total harvested bolls per plant, the number of harvested first-position bolls per plant, the mass of seed cotton per plant, the mass of seed cotton in first-position bolls and root dry mass. Leaf and petiole samples collected during the water stress period were subjected to dissection for measurements of stomata density, stoma dimensions and xylem properties. Pot weights were measured continuously at 10-min intervals using a computerized automated system. Daily plant water use (daily plant transpiration) was calculated as the 24-hr sum of differences in pot weight between consecutive hours. This method removed almost all interference of plant growth in the calculation of plant transpiration. Environmental conditions inside the laboratory (air temperature and humidity, wind speed, and solar radiation) were also measured continuously at 10-min intervals with the same computerized system to enable calculations of atmospheric potential evaporative demand. Because of an average lower wind speed inside the drought lab when compared to a nearby field weather station and the wind speed effect on the boundary layer resistance to water loss, one can expect transpiration values to be slightly lower than in adjacent field conditions.

Results and Discussion

In an attempt to demonstrate the potential of the methodology used, only daily transpiration data of three contrasting genotypes are shown (Fig. 1 and 2), namely 06-46-153, 04-22-405 and 08-1-1325. The progressions of daily transpiration for these three genotypes under water stress are compared against the respective averages of all 16 genotypes and displayed on a per unit leaf mass basis to remove part of any variation caused by small differences in leafiness between them (Figs. 3 to 5).

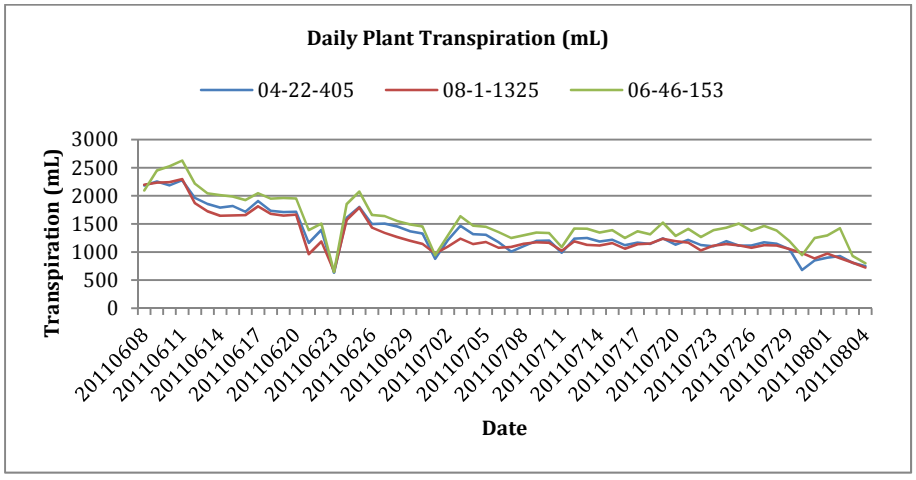

Figure 1. Distinct cotton genotypes' progressions of daily plant transpiration (mL/d) exposed to water-stress conditions.

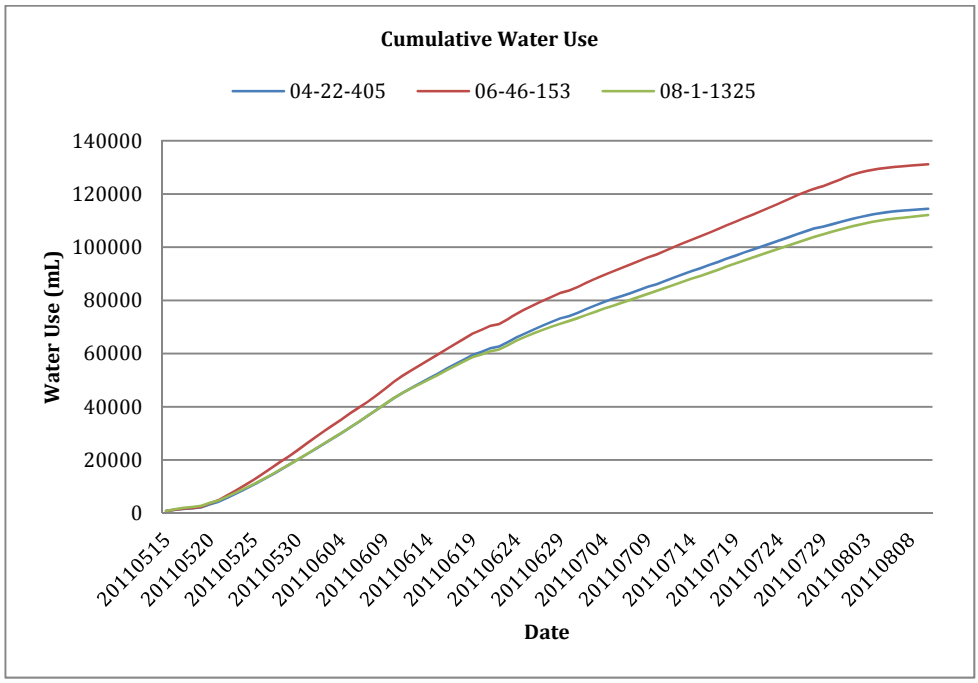

Figure 2. Distinct cumulative cotton genotypes' progressions of daily plant water use (mL/d) exposed to water-stress conditions.

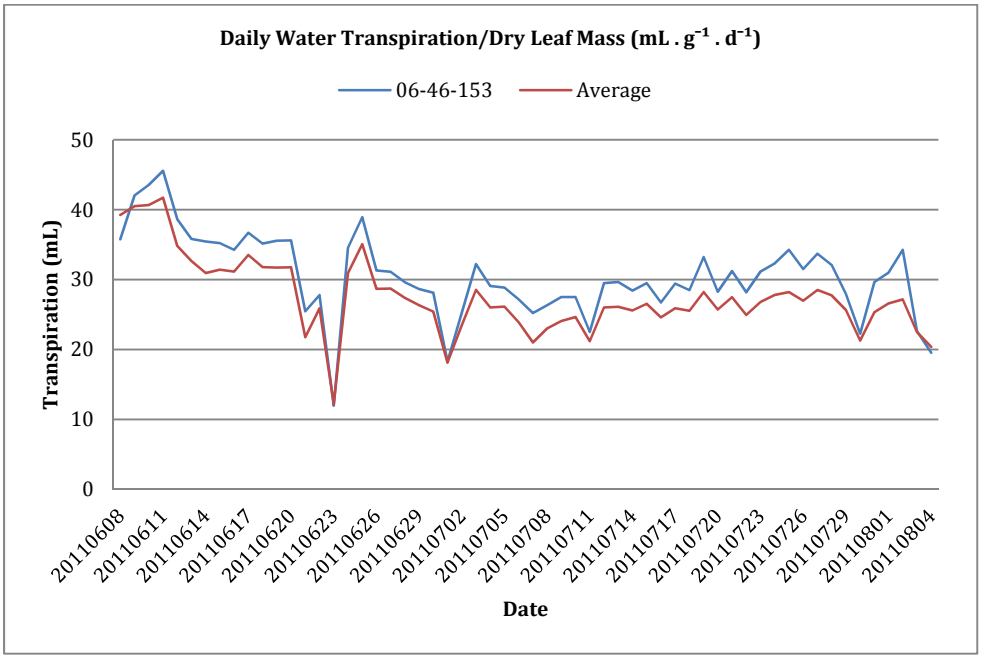

Figure 3. Progression of water-stressed daily plant transpiration per unit leaf dry mass (mL/g/d) of genotype 06-46-153 compared to the progression of the genotypes' average.

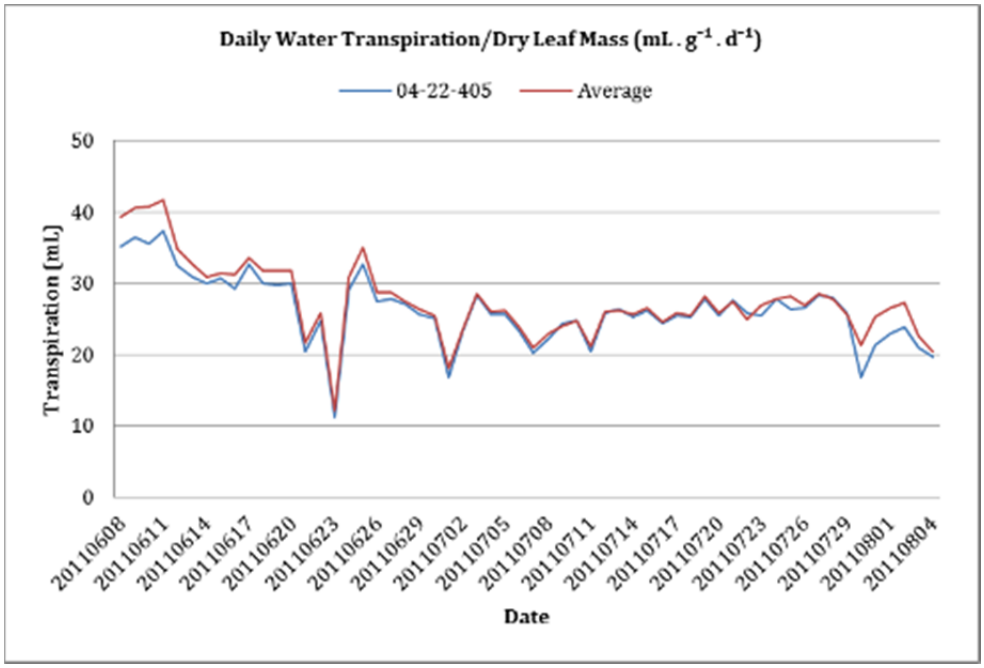

Figure 4. Progression of water-stressed daily plant transpiration per unit leaf dry mass (mL/g/d) of genotype 04-22-405 compared to the progression of the genotypes' average.

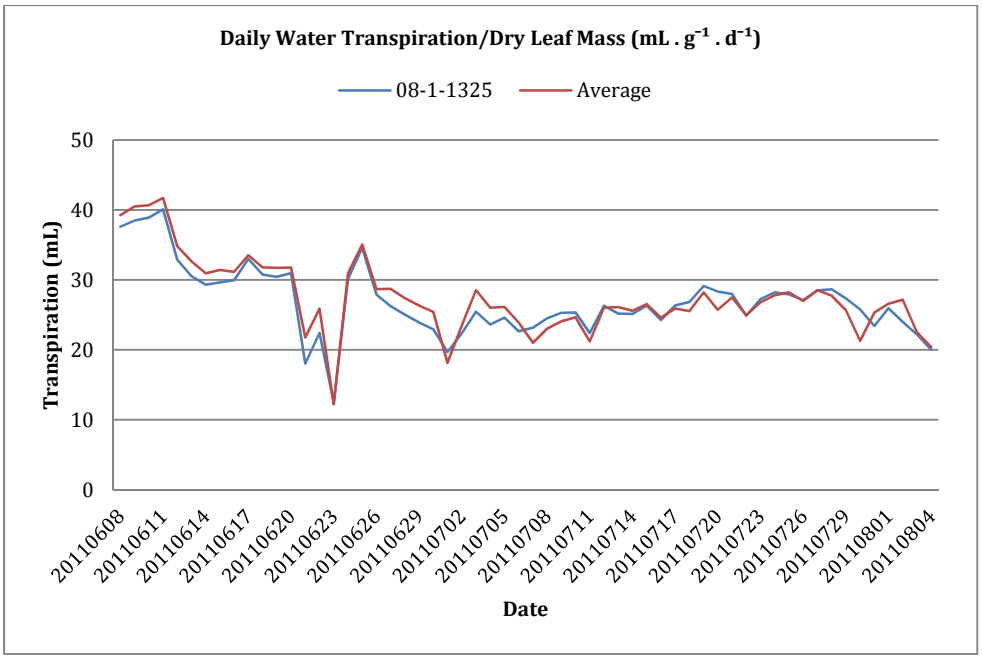

Figure 5. Progression of water-stressed daily plant transpiration per unit leaf dry mass (mL/g/d) of genotype 08-1-1325 compared to the progression of the genotypes' average.

The overall decline through time in daily transpiration per unit leaf mass is caused by an increase in leaf shading as plants get older, increase in leaf production and also due to decreases in leaf conductance following stomata closure. The variation in plant transpiration within days can be attributed to the change in evaporative demand (e.g. day and night, sunny and cloudy days).

Based on the daily plant transpiration data collected, when compared to the genotypes' average, 06-46-153 was identified as a water spender, 04-22-405 as an average water user and 08-1-1325 as a water saver. Interestingly,

when applying the correction for leaf dry mass, genotypes showed different levels of response, with 08-1-1325 exhibiting the greatest response. Before applying the correction, 08-1-1325 exhibited below average daily transpiration throughout most of the growing season and this response leads us to believe that leaf mass may play an important role in controlling the plants' water use for this particular genotype. At this point, the correction for dry leaf mass on daily water transpiration does not take into account characteristics such as the specific leaf area (SLA), leaf mass ratio (LMR), leaf format or the plants' leaf spatial distribution (plant architecture). As demonstrated on Table 1, apart from the estimated number of remaining leaves, no other traits showed significant difference at the 5% level of probability, but it is important to notice that when comparing 08-1-1325 with 06-46-153 in regards to stomata density on the adaxial leaf surface, the p-value is 0.0546. Also, comparing the estimated total number of leaves between 06-46-153 and 08-1-1325 resulted in a p-value of 0.0516, which may indicate that the water saver (08-1-1325) genotype has a higher stomata density on the adaxial leaf surface but presents a lower total number of leaves when contrasted with the water spender (06-46-153) genotype.

Table 1. Means comparisons for all pairs using Tukey-Kramer HSD. Means not connected with the same letter are significantly different at the 0.05 level of probability.

Trait / Genotype	*n*	06-46-153	04-22-405	08-1-1325
Stomata Density (Adaxial)	18	20.11[a]	24.28[a]	29.56[a]
Stomata Density (Abaxial)	18	48.47[a]	51.38[a]	46.46[a]
Estimated Total Number of Leaves	15	65.18[a]	58.57[a]	50.42[a]
Estimated Number of Remaining Leaves	15	55.58[a]	49.37[ab]	41.82[b]

The study indicates that water economy in cotton is likely to be controlled by a combination of plant traits rather than a single trait, and that this combination could be different among genotypes. Additionally, data supports the idea that different traits have distinct impact on plants' water use pattern, varying with genotype.

Leaf type, leaf spatial distribution, xylem's dimensions, stomata density and stoma size have been measured in this study but their effects on whole-plant transpiration have not been analyzed yet. A mechanistic simulation model, such as the models *McStress* (McCree and Fernandez (1989) and *PlantWaterDynamics* (Fernandez and McCree, 1991), capable of integrating these various measured plant traits, along with primary physiological and physical processes controlling plant water economy and the environmental conditions during the study will serve as a useful tool to identify the traits conferring the water economy characteristics of the various genotypes included in this study.

Acknowledgements

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