

Water Relations of Field Grown Cotton and Sorghum: Temporal and Diurnal Changes in Leaf Water, Osmotic, and Turgor Potentials¹

R. C. Ackerson, D. R. Krieg, T. D. Miller, and R. E. Zartman²

ABSTRACT

Trends in leaf water, osmotic, and turgor potentials of cotton (*Gossypium hirsutum* L., cv. 'Dunn 56C') and sorghum (*Sorghum bicolor* L. Moench, cv. 'RS671') were monitored on both a seasonal and diurnal basis. The effects of differential soil water availability on leaf water potential components were examined in order to ascertain the differences in the water relations of these two species.

Decreasing availability of soil water was responsible for decreased morning and afternoon leaf water potentials in sorghum and cotton. The magnitude of depression in leaf water potential was greater in cotton than in sorghum at equivalent soil water potentials. Decreases in osmotic potentials maintained positive turgor in both species when sufficient soil water was available. However, as water stress increased, turgor potentials became zero due to the failure of osmotic potentials to decrease more than water potentials.

Diurnal changes in water potential components were distinctly different for each species. Leaf water potentials of sorghum came into approximate equilibrium with soil water potential in the early morning, whereas leaf water potentials of cotton did not. Concomitant changes in leaf osmotic potentials on a diurnal basis resulted in specific trends of increasing turgor in sorghum, while anomalous fluctuations were evident in cotton leaf turgor potentials.

The relationship between leaf water potential and relative water content was determined for each species. The change in relative water content per unit change in leaf water potential was greater in cotton than in sorghum.

Drought tolerance of these two species appears to be dependent on species specific relationships in leaf water potential components.

Additional index words: Irrigation timing, Soil profile depth.

TEMPORAL water deficits during plant growth and development are known to elicit several morphological, physiological, and biochemical modifications (14). Restriction of root growth and top growth of cotton (*Gossypium hirsutum* L.) due to water stress has been reported (15, 18, 22, 23, 24). Decreased rates of leaf development in sorghum (*Sorghum bicolor* L. Moench) due to water stress has recently been reported (19). Laboratory and greenhouse studies of cotton and sorghum have indicated that water stress was responsible for reductions in photosynthesis (2, 6, 10, 11, 13, 25) and stomatal closure (2, 5, 10, 25, 26, 27). The method of imposing water stress is apparently responsible for determining how decreased plant water potentials are manifested in certain physiological processes. Boyer

(6) observed that osmotically induced water stress reduced photosynthesis but not leaf diffusive resistance in cotton. Water stress, imposed by withholding water, was responsible for decreased rates of transpiration and photosynthesis in cotton and inhibited full recovery of these processes after irrigation (2). Decreased leaf water content induced by decreasing root temperatures reduced photosynthesis and increased leaf diffusive resistance of cotton (25).

Data for water relations of field-grown sorghum and cotton are somewhat limited. Turner (26) and Turner and Begg (27) examined vertical profiles of water, and osmotic and turgor potentials of sorghum, and found that these parameters varied with canopy height. Stomatal closure was evident at -20 bars when concomitant turgor potentials were zero. In field grown cotton, Jordan and Ritchie (16) observed no evidence for stomatal closure when leaf water potentials decreased to -27 bars, whereas, greenhouse grown material was observed to close stomata at -16 bars. Evidence for genotypic differences in leaf water potential, water saturation deficits, and stomatal activity due to water stress has been obtained for sorghum (3, 4, 12).

Since limited data are available with respect to water relations of field-grown sorghum and cotton, studies were undertaken to examine changes in plant water potential components imposed by decreasing availability of soil water. By examination of changes in water, osmotic and turgor potentials of cotton and sorghum during periods of soil water deficits, information regarding drought tolerance mechanisms might be obtained. Since apparent discrepancies exist between data obtained in growth chamber or greenhouse studies and field grown plants, the experiments reported here will further the understanding of water relations of plants grown under field conditions.

MATERIALS AND METHODS

Seeds of cotton (*Gossypium hirsutum* L., cv. 'Dunn 56C') and sorghum (*Sorghum bicolor* L. Moench, cv. 'RS671') were planted 14 May 1975 on a Friona coarse sandy loam. Each plot consisted of six rows, spaced 102 cm apart and 6.7 m long oriented in an east to west direction. Pre-plant N fertilizer was applied at a rate of 100 kg N/ha on sorghum. The appropriate herbicide was applied for each crop prior to planting. Plant populations were approximately 175,000 plants/ha for sorghum and 100,000 plants/ha for cotton.

Three irrigation treatments were imposed on each species beginning at panicle initiation for sorghum (27 June) and at first bloom for cotton (4 July). Application of irrigation water was based on leaf water potential measurements. Irrigation water quantity was sufficient to bring the upper 80 to 90 cm of the soil profile back to field capacity. Water was applied when the minimum daily leaf water potentials of the uppermost fully expanded leaves were -17 , -22 , or -27 bars for the high, medium, or low irrigation treatments, respectively.

Leaf water potential was determined using the pressure bomb and osmotic potentials were obtained by freezing leaf tissue in

¹Contribution from Texas Tech Univ., College of Agric. Sciences, Lubbock, TX 79409. Research supported in part by grant 14-31-0001-5225 from the U.S. Dep. of Interior through the Office of Water Research and Technology and Southwestern Public Service Company, Lubbock, Tex. Received 18 Mar. 1976.

²Research assistant, associate professor, research associate, and assistant professor, Dep. of Plant and Soil Science, Texas Tech Univ.

liquid N and thawing at room temperature (25 to 27 C) prior to equilibration in a thermocouple psychrometer. Data was taken throughout the day and minimum values of leaf water potentials usually occurred between 1400 and 1500 hours. Turgor potential was calculated by the standard equation: $\Psi_w = \Psi_\pi + \Psi_p$. In some cases, calculations yielded to 1 to 2 bars negative

turgor but are reported as zero turgor. Relative water content (RWC) was determined according to the method of Weatherly (28, 29) and data were obtained several times during the growing season on both a daily and diurnal basis. Material used for the determination of leaf water, osmotic and turgor potentials, and relative water content of cotton consisted of the uppermost, fully expanded vegetative leaves and fruiting leaves in the lower canopy. Late in August reproductive leaf values were obtained from leaves subtending rapidly developing bolls that were approximately 20 to 25 days old. Values for sorghum were obtained from the flag leaf and the first leaf below the flag leaf.

Determination of soil water content was made by gravimetric methods for the top 15 cm of the profile and by neutron probe analysis for the remaining depths. Soil water potentials were obtained from water characteristic curves previously determined.

Data reported in this paper were collected on several days between 4 August and 4 September coinciding with the period of maximum reproductive development and represent values obtained for the high and low irrigation treatments only. Each data point represents the mean of at least three determinations of different plants.

RESULTS AND DISCUSSION

As soil water depleted, the midday minimum water potential of vegetative leaves of cotton remained essentially constant at -16 to -17 bars until the soil could not supply water to meet the evaporative demand (Fig. 1). At this point (12 August) the midday leaf water potential decreased rapidly to -20 bars. Irrigation water was supplied and the daily minimum returned to approximately pre-stress levels and declined very gradually as soil water again became deficient. Irrigating on 3 September resulted in an increase in leaf water potential but not to levels comparable to pre-stress conditions. The seasonal tendency was for midday leaf water potentials to gradually decline from -16 bars to -20 bars. The trend toward decreasing leaf water potentials as the season progressed could be due to the slight stress prior to irrigation resulting in changes in the internal resistance to water flow, as has been previously suggested, (18) or it could be due to physiological changes associated with plant development (17). The reproductive leaves followed a pattern similar to the vegetative leaves. A gradient in Ψ_w existed between the vegetative and reproductive leaves, the magnitude being dependent on the treatment and time during the growing season. Continued decreases in midday leaf water potentials were observed in both vegetative and reproductive leaves of plants exposed to continued soil water depletion. A minimum leaf water potential of -28 bars was observed on 2 September at which time irrigation water was supplied. The leaf water potential of the stressed plants on 3 September was less than the leaves of non-stressed plants.

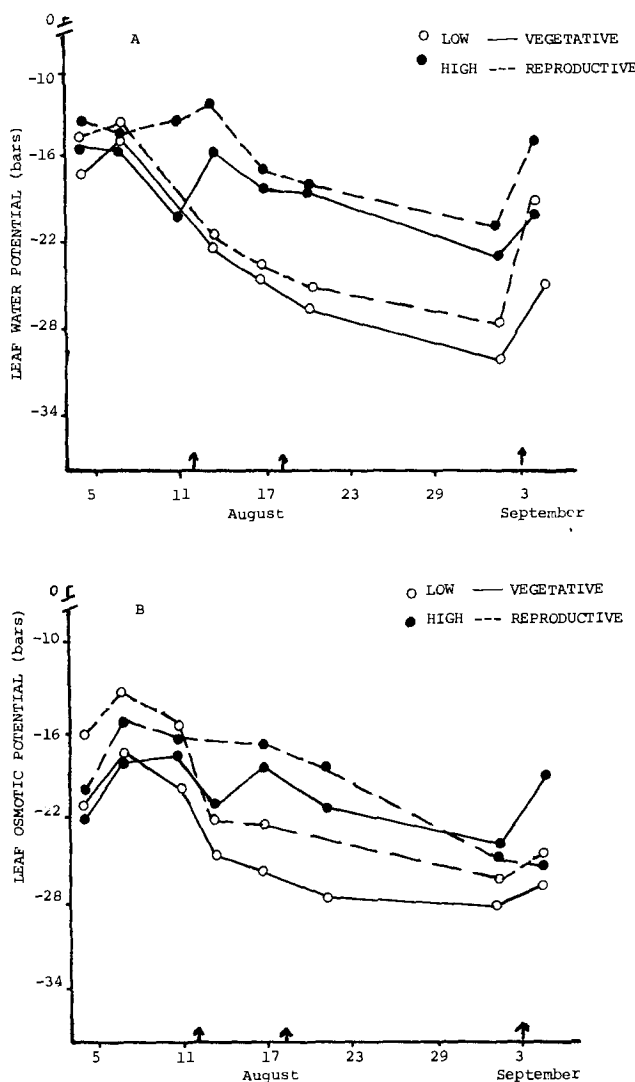


Fig. 1. Midday leaf water potentials (A) and osmotic potentials (B) of cotton leaves during August and early September, 1975. \uparrow indicates when plants were irrigated. Standard deviations for leaf water potentials ranged from ± 0.3 to 1.0 bar and from ± 0.5 to 1.2 bar for osmotic potentials.

Table 1. Sorghum leaf water (Ψ_w), osmotic (Ψ_π), and turgor (Ψ_p) potentials for two days in August, 1975. Values represent means \pm standard deviation.

Irrigation treatment	4 Aug.						18 Aug.					
	1000 (CDT)			1400 (CDT)			1000 (CDT)			1400 (CDT)		
	Ψ_w	Ψ_π	Ψ_p	Ψ_w	Ψ_π	Ψ_p	Ψ_w	Ψ_π	Ψ_p	Ψ_w	Ψ_π	Ψ_p
bars												
High												
Flag	-14 ± 0.5	-23 ± 1.0	9	-16 ± 0.8	-26 ± 1.0	10	-14 ± 0	-17 ± 1.4	3	-20 ± 0.7	-25 ± 1.5	5
First	-14 ± 0.4	-23 ± 1.5	9	-15 ± 0.8	-28 ± 1.0	13	-14 ± 0.4	-18 ± 1.2	4	-16 ± 0.8	-20 ± 1.0	4
Low												
Flag	-14 ± 0.5	-18 ± 1.0	4	-18 ± 0.5	-26 ± 1.5	8	-19 ± 1.0	-19 ± 1.2	0	-21 ± 0.3	-21 ± 1.0	0
First	-14 ± 0	-26 ± 1.6	12	-17 ± 0.5	-28 ± 0.7	11	-17 ± 0.5	-18 ± 0.7	1	-22 ± 0.5	-25 ± 1.0	3

Osmotic potentials were generally less than leaf water potentials when adequate soil water was available, resulting in significant turgor. As soil water became limiting osmotic potentials decreased but not as rapidly as leaf water potentials resulting in loss of

turgor. Significant differences in osmotic potentials existed between stressed and non-stressed plants although the magnitude of the differences was not as great as found for Ψ_w .

Sorghum leaf water, osmotic and turgor potentials exhibited trends similar to those found for cotton with respect to response to available soil moisture (Table 1). On 4 August, morning leaf water potentials were equivalent in both treatments, whereas afternoon values were approximately 2 to 3 bars greater in the high treatment. A notable difference in morning leaf water potentials between treatments was evident on 18 August. In this case, potentials in the low treatment were approximately 4 bars lower than in the high treatment. Although the afternoon leaf water potentials of the flag leaves were almost equivalent on 18 August, a difference of about 6 bars was observed in first leaf water potentials. Turgor potentials

Table 2. Soil water potentials at various depths on selected days in August, 1975.

Profile depth cm	19 Aug.		20 Aug.		25 Aug.	
	Cotton High	Cotton Low	Sorghum High	Sorghum Low	Sorghum High	Sorghum Low
	bars					
22.0	1.9	>15	>15	>15	9.6	>15
37.0	0.8	4.4	1.7	4.2	0.9	4.4
53.0	0.4	1.6	1.0	1.6	0.9	1.6
68.0	0.3	0.8	0.9	1.2	0.9	1.2

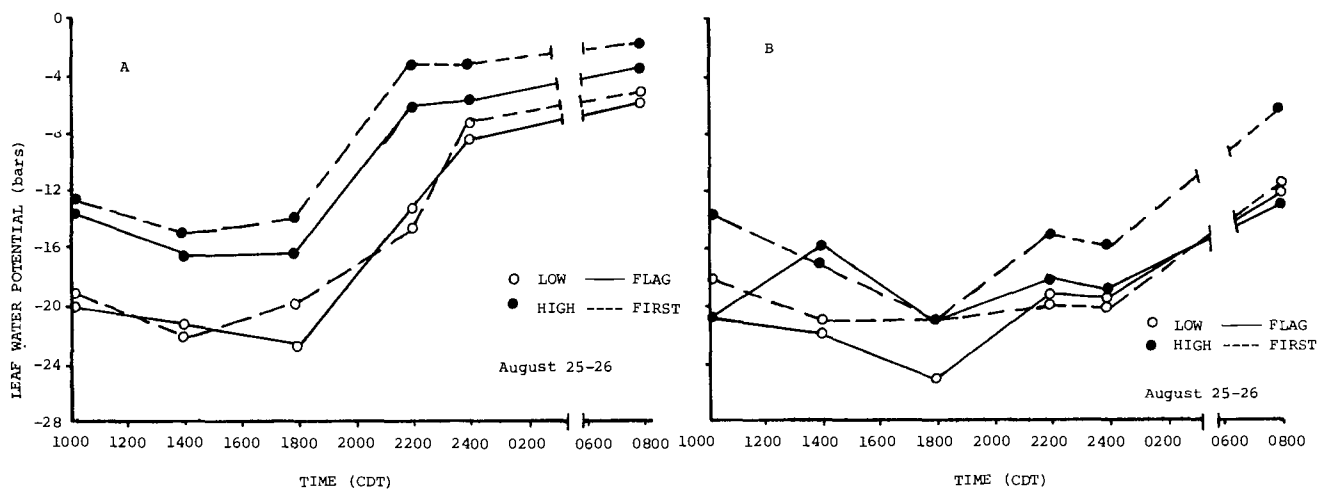


Fig. 2. Diurnal trends in leaf water potentials (A) and osmotic potentials (B) of cotton leaves on 20 and 21 Aug. 1975. Standard deviations for leaf water potentials ranged from ± 0.5 to 1.0 bar and from ± 0.5 to 1.5 bar for osmotic potentials.

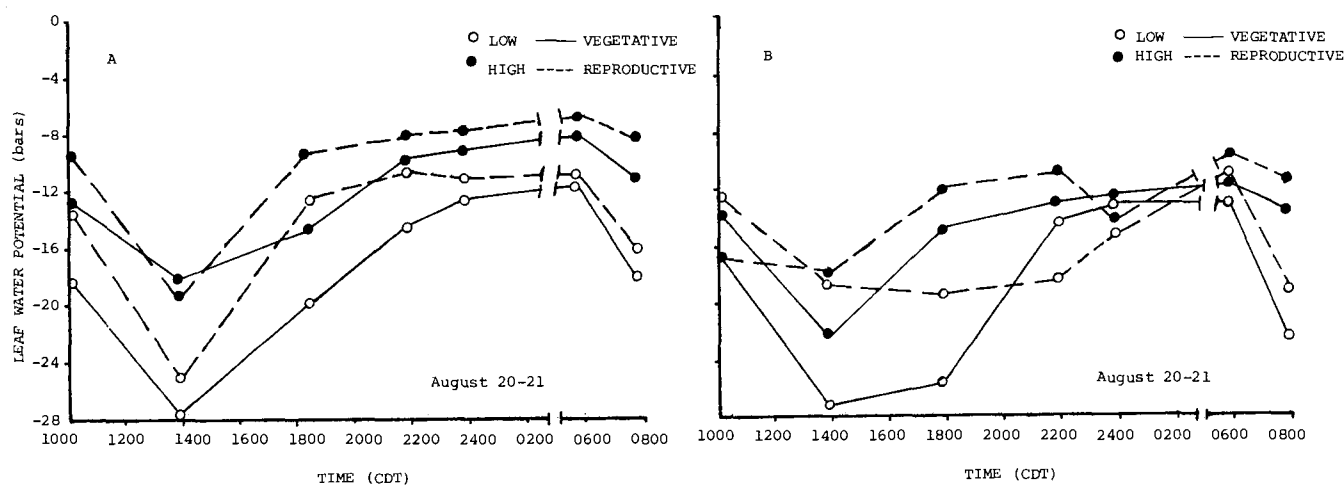


Fig. 3. Diurnal trends in leaf water potentials (A) and osmotic potentials (B) of sorghum leaves on 20 and 21 Aug. 1975. Standard deviations for leaf water potentials ranged from ± 0.1 to 1.0 bar and ± 0.5 to 1.0 bar for osmotic potentials.

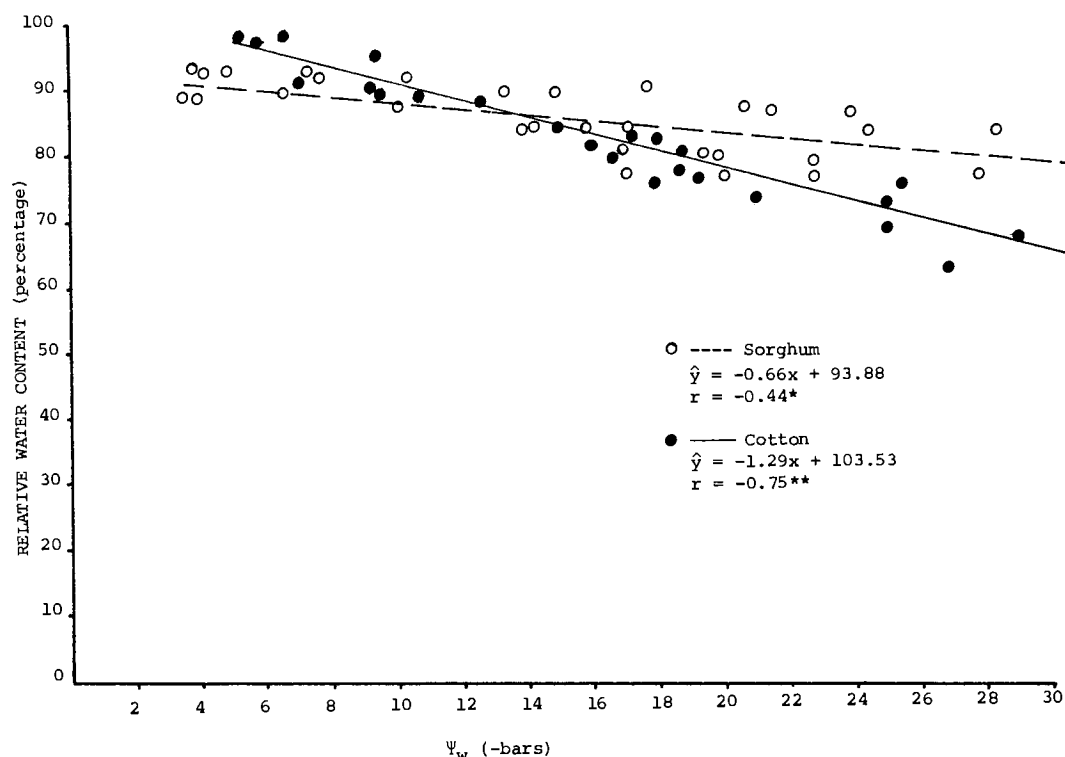


Fig. 4. Relationship between relative water content and leaf water potential for cotton and sorghum.

of sorghum leaves were substantially greater on 4 August compared with 18 August in both treatments. However, on 18 August, turgor potentials of plants in the high treatment were somewhat greater than those observed in the low treatment. The turgor potential changes with time in both treatments are clearly the result of a different relationship between osmotic and water potentials, although the nature of this relationship is difficult to establish. Although only two dates are presented to establish water relations trends in sorghum, the observations in this study are similar in nature to those previously established under similar conditions (1).

Distinct differences between high and low sorghum plots in soil water potential on 20 August are apparent (Table 2). Well irrigated plots exhibited higher soil water potential at all but the 22 cm profile depth when compared with the low treatment. These differences are apparently responsible for the differences in leaf water potential. After irrigation of the high plots (21 August) soil water potentials increased at all profile depths. A specific relationship between soil water potential and leaf water potential is difficult to establish since root distribution data were not obtained. In order to fully elucidate this relationship, it would be necessary to determine at what profile depth the greatest amount of water extraction occurs and the changes in root distribution as affected by water stress (2).

Diurnal changes in cotton leaf water potentials during water stress are shown in Fig. 2. Both the high and low irrigation treatments exhibited similar trends, although the values were more negative in the low treatments. Minimum leaf water potentials occurred

at 1400, thereafter a gradual increase in water potential occurred until 0600. Values obtained at 0800 indicate that leaf water potentials were either similar or slightly more negative than those observed at 1000 the previous morning.

Osmotic potential changes in cotton leaves on a diurnal basis were similar to changes in water potential. However, since the values of osmotic potential and water potential did not change correspondingly, anomalous fluctuations in turgor potential were evident. Turgor potentials were generally well above zero for the high treatment. In contrast, plants in the low treatments were at or near zero turgor (visibly wilted) most of the day. Subsequently, turgor potentials increased rapidly between 1400 and 1800 and then decreased again. The relationship between leaf osmotic potential and water potential as affected by the irrigation treatment is of significance. Although leaf water potentials increased similarly in both treatments between 1400 and 1800, osmotic potentials increased much more rapidly in the non-stressed plants as compared with the stressed plants (Fig. 2). Since this phenomena was observed in both vegetative and reproductive leaves, the distinct differences in turgor potentials could be due to numerous mechanisms including transport of photosynthate or water between leaves and bolls. If these processes are altered by water stress, the differences between high and low irrigation treatments with respect to daily and diurnal changes in turgor may be the result of transport of osmotica and water between bolls and leaves or synthesis of osmoregulatory compounds by the boll as has been observed (9). If water stress affects transport, as is suspected (8), the observed fluctuations in turgor

would be dependent on the degree of water stress imposed. Clearly, further work is necessary to establish the relationship between water stress and transport of osmotica or water between leaves and bolls.

Diurnal changes in sorghum water potential components are shown in Fig. 3. Characteristic midday depression in leaf water potential are evident in both flag and first leaves. However, leaf water potential of the flag leaf remained at a minimum value until later in the day as compared with the first leaf. This was true under both stressed and non-stressed conditions. A rapid increase in leaf water potential occurs between 1800 and 2000 with a subsequent gradual increase until early morning. Sorghum leaf turgor potentials exhibit a much more distinctive and constant pattern than is characteristic of cotton. This is the result of a rapid increase in leaf water potential coupled with a relatively small change in osmotic potential (Fig. 3B). Maximum turgor occurs at 2400, followed by a gradual decrease in osmotic potential.

The relationship between relative water content and leaf water potential is distinctly different between sorghum and cotton (Fig. 4). Values obtained in this experiment are in close association with those previously reported for cotton (20), but slightly different for sorghum (4, 21). The change in relative water content per unit change in leaf water potential is substantially greater in cotton than sorghum. It might be suggested that the changes in leaf water potential are more dependent on the leaf bulk water status in cotton than in sorghum. It then follows that cotton requires more water to recover from water stress than does sorghum. Under similar soil water conditions, midday and early morning leaf water potentials in cotton are 3 to 4 bars lower than sorghum, suggesting that the relationship between relative water content and leaf water potential may account for differences in water utilization and drought tolerance.

Although sorghum and cotton are recognized as drought tolerant species, mechanisms accounting for this tolerance appear to be distinctly different. Changes in temporal and diurnal patterns in leaf water and osmotic potentials are clearly different in sorghum and cotton. Sorghum turgor potentials are generally greater in magnitude than those observed in cotton. Although some level of turgor is required for cell growth (7), the threshold value of turgor necessary may be species specific. Thus, comparison of turgor potentials with respect to magnitude may be unwarranted. Nonetheless, the distinct species differences in internal water potential components may help elucidate the nature of drought tolerance in many crop plants.

REFERENCES

- Bennett, J. M. 1975. The effect of light and water stress on yield and yield components of grain sorghum. M.S. Thesis. Texas Tech Univ.
- Bielorai, H., and P. A. M. Hopmans. 1975. Recovery of leaf water potential, transpiration, and photosynthesis of cotton during irrigation cycles. *Agron. J.* 67:629-632.
- Blum, A. 1974. Genotypic responses in sorghum to drought stress I. Response to soil moisture stress. *Crop Sci.* 14: 361-364.
- . 1974. Genotypic responses in sorghum to drought stress. II. Leaf tissue water relations. *Crop Sci.* 14:361-392.
- , and C. Y. Sullivan. 1974. Leaf water potential and stomatal activity in sorghum as influenced by water stress. *Isr. J. Bot.* 23:14-19.
- Boyer, J. S. 1965. Effects of osmotic water stress on metabolic rates of cotton plants with open stomata. *Plant Physiol.* 40:229-234.
- Cleland, R. 1971. Cell wall extension. *Ann. Rev. Plant Physiol.* 22:197-222.
- Crafts, A. S., and C. E. Crisp. 1971. Phloem transport in plants. Freeman, San Francisco.
- Dhindsa, R. S., C. A. Beasley, and I. P. Ting. 1975. Osmoregulation in cotton fiber. Accumulation of potassium and malate during growth. *Plant Physiol.* 56:394-398.
- El-Sharkawy, M., and J. D. Hesketh. 1964. Effects of temperature and water deficit on leaf photosynthetic rates of different species. *Crop Sci.* 4:514-518.
- Harris, D. G. 1973. Photosynthesis, diffusion resistance and relative water content of cotton as influenced by induced water stress. *Crop Sci.* 13:570-572.
- Henzell, R. G., K. J. McCree, C. H. M. van Bavel, and K. F. Schertz. 1975. Method for screening sorghum genotypes for stomatal sensitivity to water deficits. *Crop Sci.* 15:516-518.
- Hoffman, G. J., S. L. Rawlins, M. J. Garber, and E. M. Cullen. 1971. Water relations and growth of cotton as influenced by salinity and relative humidity. *Agron. J.* 63:822-826.
- Hsiao, T. C. 1973. Plant responses to water stress. *Ann. Rev. Plant Physiol.* 24:519-570.
- Jordan, W. R. 1970. Growth of cotton seedlings in relation to maximum daily water potential. *Agron. J.* 62:699-701.
- , and J. T. Ritchie. 1971. Influence of soil water stress on evaporation, root absorption and internal water status of cotton. *Plant Physiol.* 48:783-788.
- , K. W. Brown, and J. C. Thomas. 1975. Leaf age as a determinant in stomatal control of water loss from cotton during water stress. *Plant Physiol.* 56:595-599.
- Klepper, Betty, H. M. Taylor, M. G. Huck, and E. L. Fiscus. 1973. Water relations and growth of cotton in drying soil. *Agron. J.* 65:307-310.
- McCree, K. J., and S. D. Davis. 1974. Effect of water stress and temperature on leaf size and number of epidermal cells in grain sorghum. *Crop Sci.* 14:751-755.
- Namken, L. N. 1964. The influence of crop environment on the internal water balance of cotton. *Soil Sci. Soc. Am. Proc.* 28:12-15.
- Sanchez-Diaz, M. F., and P. J. Kramer. 1971. Behavior of corn and sorghum under water stress and during recovery. *Plant Physiol.* 48:613-616.
- Slatyer, R. O. 1957. The influence of progressive increases in total soil moisture stress on transpiration, growth and internal water relations of plants. *Aust. J. Biol. Sci.* 10:320-336.
- Taylor, H. M., and B. Klepper. 1971. Water uptake by cotton roots during an irrigation cycle. *Aust. J. Biol. Sci.* 24:853-859.
- , and ———. 1974. Water relations of cotton. I. Root growth and water use as related to top growth and soil water content. *Agron. J.* 66:584-588.
- Troughton, J. H. 1969. Plant water status and carbon dioxide exchange of cotton leaves. *Aust. J. Biol. Sci.* 22:289-302.
- Turner, N. C. 1974. Stomatal behavior and water status of maize, sorghum and tobacco under field conditions. II. At low soil water potential. *Plant Physiol.* 53:360-365.
- , and J. E. Begg. 1973. Stomatal behavior and water status of maize, sorghum and tobacco under field conditions. I. At high soil water potential. *Plant Physiol.* 51:31-36.
- Weatherly, P. E. 1950. Studies on the water relations of the cotton plant. I. The field measurement of water deficits in leaves. *New Phytol.* 49:81-97.
- . 1951. Studies on the water relations of the cotton plant. II. Diurnal and seasonal variations in relative turgidity and environmental factors. *New Phytol.* 50:36-51.