

Water Deficit Effects on Growth and Reproductive Performance of Cotton

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Rationale and Objectives

- Cotton (*Gossypium hirsutum* L.), a C_3 crop, is used as a source of fiber for the textile industry worldwide.
- Plants respond continuously to changes in available water, temperature and other abiotic factors. Changes in water balance and the amount of water available in the soil is crucial for plant vegetative and reproductive growth and development (Kramer and Boyer, 1995).
- Cotton plant responses to water stress vary depending on the stage of growth at which the stress occurs, the degree of stress, and the length of time the stress is imposed.
- Water stress at any stage of growth will affect adversely both vegetative growth and major metabolic processes like photosynthesis, stomatal conductance (Pettigrew, 2004) which ultimately results in reduction of biomass production. In addition, water stress affects both the production and distribution of carbohydrates, and thus partitioning of carbohydrates between sources and sinks.
- The impact of water stress on final yield depends on the degree to which each physiological process is affected.
- The process-specific functional algorithms developed in this study can improve the predictive capability of the cotton models for natural resource management in the field.

Objectives

- To study the effects of water stress on growth, development and physiological processes.
- To develop the functional algorithms for water stress effects on various growth and physiological processes.

Experimentation and Measurements

The experiment was conducted in sunlit controlled environment chambers known as SPAR (Soil-Plant-Atmosphere-Research; Plate 1) at the Mississippi State University's Plant Science Research Center, Mississippi State, MS, during the 2009 growing season. Cotton cultivar TM-1 was grown with fine sand as growing medium. Plants were irrigated with automated drip irrigation system.

Treatments

Four levels of water stress treatments of 100, 80, 60 and 40% of evapo-transpiration of control (100%) were imposed from flowering to maturity stage of the crop. Prior to water stress treatments, all chambers were well-watered with full-strength nutrient solution. Day/night temperatures of 30/22 °C and carbon dioxide concentration of 400 ppm were maintained throughout the experiment.

Measurements

- Photosynthesis and stomatal conductance were measured weekly with LI-6400 (LICOR, NE) from 0 to 56 days after water stress treatment.
- Cell membrane thermostability (CMT), chlorophyll stability, leaf wax and pigments were measured at 56 days after water stress treatment.
- Stem length, and node numbers were recorded once a week after emergence to few days after flowering stage.
- Total as well as various plant component biomass and boll numbers per plant and seed numbers per boll were recorded at the end of experiment.

Data analysis

- To test the significance of different water regimes on growth and development and physiological parameters ANOVA analysis was performed using general linear model "PROC GLIMMIX" procedure in SAS.
- Sigma Plot 11.0 was used to fit the curves and regression analysis.

Results and Discussion

Growth and photosynthesis parameters

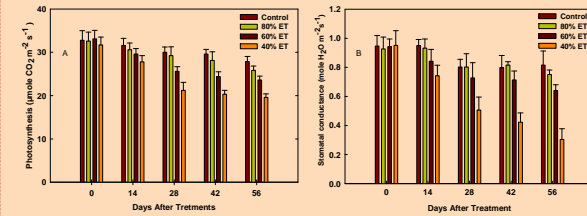


Figure 1. Effect of four water stress regimes on cotton (A) leaf photosynthesis and (B) stomatal conductance.

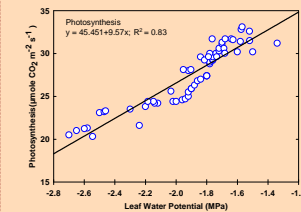


Figure 2. Relationship between cotton leaf water potential and photosynthesis.

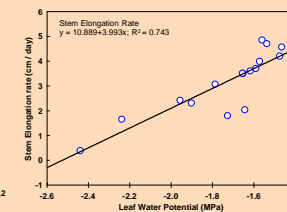


Figure 3. Relationship between cotton leaf water potential and stem elongation rate.

- Photosynthesis and stomatal conductance measured at fixed light level (1500 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PAR) (Figure 1) over time declined with water stress treatments, and the decline in stomatal conductance was greater than the decline observed in photosynthesis.
- Maximum photosynthesis (31 $\mu\text{mol m}^{-2} \text{s}^{-1}$) and stem elongation (4.9 cm d^{-1}) rates were observed at -1.5 MPa midday leaf water potential (Figure 2 and 3).
- Even though, stem elongation and photosynthesis rates declined linearly with increased water deficits, the decline in vegetative growth was steeper than the decline in gas exchange processes (Figure 2 and 3).

Cell membrane thermostability and chlorophyll stability indices

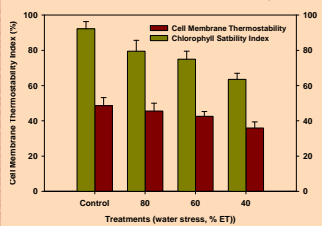


Figure 4. Water stress effects on cell membrane thermostability and chlorophyll stability indices of cotton leaves.

- Cell membrane thermostability and chlorophyll stability indices showed a significant difference ($P = 0.014$ and $P = 0.001$, respectively) between control, moderately and severely water stressed plants (Figure 4).

Leaf surface waxes

Figure 5. Cotton leaf wax content for four different water stress regimes.

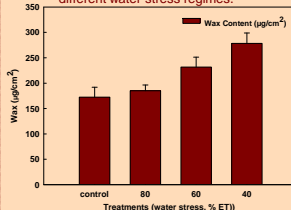
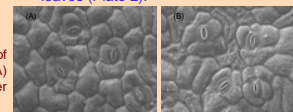


Plate 2. Electron microscopic images of cotton leaf surface wax deposition for (A) control (100% ET) and (B) severely water stress (40% ET) treatments.

- Leaf surface wax content increased with increase water stress, and amounts were significantly ($P = 0.001$) different among control (100% ET), moderately (60% ET) and severely stressed (40% ET) treatments (Figure 5).

- Increased surface wax content was evident the leaf surface scanning electron microscopic images with greater deposition under stressed plant leaves (Plate 2).



Biomass and reproductive parameters

Table 1. Mean and least square difference (LSD) for cotton plant parameters and boll components.

Parameters	Water stress treatments				LSD
	Control	80% ET	60% ET	40% ET	
Plant Parameters					
Plant height (cm/plant)	210.2 ^a	212.9 ^a	211.2 ^a	186.1 ^b	7.59
Main-stem nodes (no./plant)	21.17 ^a	21.50 ^a	21.08 ^a	19.58 ^b	0.58
Total biomass (g/plant)	241.4 ^a	228.4 ^a	180.1 ^{ab}	160.6 ^{bc}	40.0
Total bolls (no./ plant)	20.9 ^a	17.8 ^a	13.2 ^{ab}	11.8 ^{bc}	4.49
Open bolls (no./ plant)	13.25 ^a	13.00 ^a	11.67 ^a	10.58 ^b	1.79
Total boll wt. (g/plant)	83.64	86.52	75.64	69.04	NS
Seed cotton wt (g/plant)	62.15	63.94	56.91	51.73	NS
Lint wt. (g/plant)	19.00	19.81	17.79	16.33	NS
Seed wt. (g/plant)	42.68 ^a	43.49 ^a	38.68 ^{ab}	34.9 ^{abc}	7.20
Reproductive potential (g boll wt./kg dry wt.)	346.44	378.66	419.78	429.90	--
Harvest index (%)	25.74	27.98	31.58	32.21	--
Boll Components					
Boll wt. (g/boll)	6.31 ^a	6.66 ^a	6.44 ^a	6.58 ^a	0.32
Burr wt. (g/boll)	1.62 ^{ab}	1.76 ^a	1.59 ^a	1.65 ^{ab}	0.10
Seed cotton wt. (g/boll)	4.69 ^a	4.92 ^a	4.84 ^a	4.93 ^a	0.28
Lint wt. (g/boll)	1.43 ^a	1.52 ^a	1.51 ^a	1.56 ^{bc}	0.09
Seed wt. (g/boll)	3.22 ^a	3.35 ^a	3.29 ^a	3.33 ^a	0.20
Seeds (no./boll)	28.37 ^a	28.08 ^a	28.59 ^a	28.46 ^a	1.06

- Plant parameters including plant height, number of nodes, total biomass, total retained bolls and open bolls showed a significant difference among the treatments, and declined with severity of stress treatments.

- Individual boll component weight parameters were not different among the water stress treatments except for lint and burr weight.

Summary and Conclusions

- Leaf photosynthesis and stomatal conductance declined under water deficit conditions, and among the gas exchange processes, stomatal conductance declined faster than photosynthesis with increased water deficits.
- Vegetative growth such as stem elongation was more sensitive to water deficits conditions than gas exchange processes.
- Leaf surface wax content and relative injury to cell membranes and chloroplasts increased with water deficits treatments.
- The decreased photosynthesis resulted in fewer numbers of bolls retained per plant under water deficit conditions.
- By regulating vegetative growth, cotton plants partitioned the available carbohydrates to support the bolls that were retained and thus the individual boll component parameters of retained bolls were not much different among water stressed treatments.
- The functional algorithms developed in this study would be useful to improve the predictive capability of cotton models for natural resource management in the field.

References

- Kramer, J. K. and J. S. Boyer, (1995). Water Relations of Plants and Soils. Academic Press, California, pp1-495.
- Pettigrew, W. T. (2004). Physiological consequences of moisture deficit stress in cotton. *Crop. Sci.* 44: 1265-1272.

