REDUCING IRRIGATION AND IMPROVING COTTON YIELD AND PROFITABILITY IN THE SOUTHEAST USA

Duli Zhao
David Wright
Jim Marois
Cheryl Mackowiak
Tawainga W. Katsvairo
University of Florida
Quincy, FL

Abstract

Irrigation is one of important management practices in the US southeast cotton production. However, excess water use with high N rate can negatively influence cotton production, resulting in low economic return. An experiment was conducted in 2002-2007 using two crop rotations with conservation tillage (strip-till) at the University of Florida, North Florida Research and Education Center, Quincy, FL. The major objectives of the study were to (1) determine cotton yield response to irrigation and precipitation and (2) investigate if crop rotation can affect water use efficiency in cotton. The experiment included two cropping systems (sod-based bahiagrass-bahiagrass-peanut-cotton and conventional peanut-cotton-cotton) and two irrigation regimes (irrigated and non-irrigated). In normal and wet years, irrigation did not improve lint yield. In dry years, irrigation increased lint yield. Reducing irrigation significantly improve water use efficiency without any yield reduction even in dry years. Results of this study indicate that there is great potential to reduce amount of irrigation and increase profitability in the southeast cotton production.

Introduction

Cotton is an excellent candidate for irrigation. Irrigation is particularly important in most areas of US cotton belt for high-yielding cotton production. It is well known that the critical period for cotton is during the bloom and boll development. During peak bloom, cotton plants need about 8 mm of water per day in the Southeast US according to Rhoads (2002). Water deficit stress negatively affect cotton growth, development, and physiology (Zhao et al., 1989; Zhao et al., 1992; Gerik et al., 1996), resulting in lower lint yield and poor fiber quality (Zhao et al., 1990; Gerik et al., 1996; Jordan, 1986). On the other hand, excess water with high N application can lead to many issues (such as nutrient leaching, plant rank growth, increases in rick of insects and diseases and input cost), resulting in lower yield and profits. Therefore, water reduction or deficit irrigation based on plant water requirement, soil properties, and weather conditions in a region, can be an important approach for sustainable cotton production. Agricultural scientists have long been conducting research on cotton plant water requirement and irrigation scheduling for the specific regions.

Numerous cotton irrigation studies have focused on irrigation scheduling to optimize yield and water use efficiency. Ajaib and Fowler (1985) reported that reduce irrigation based on soil water potential before flowering can promote the earliness without any significant reductions in cotton yield. Leaf area and leaf photosynthesis are two major physiological parameters for plant growth, accumulation of biomass, and yield development. Stomata on leaf surfaces are major channels for both water moving out (transpiration) and CO_2 moving in (Carbon fixation). Leaf water potential is an important indicator of plant water status and changes greatly from time to time (Oosterhuis, 1991). Studies have suggested that the threshold leaf water potential during cotton squaring and fruiting for plant growth and physiology is about –1.5 MPa (Zhao and Oosterhuis, 1997; Faver et al., 1996; Oosterhuis et al., 1991). Stomatal conductance to water linearly decreases with the decrease in leaf water potential, but cotton leaf photosynthesis response to leaf water potential differs from leaf transpiration (Zhao and Oosterhuis, 1997). When leaf water potential is greater than -1.5 MPa, leaf photosynthetic rate does not change with change in leaf water potential. When leaf water potential was less than -1.5 MPa, Photosynthesis decreases as leaf water potential decreases (Zhao and Oosterhuis, 1997; Kakani et al., 2006). Although water deficits limit cotton yield, using water saving irrigation can considerably reduce amount of water use and increase water use efficiency (WUE) without the reduction in yield (Carmi and Plant, 1988; Zhao et al. 1992; Krieg et al., 1993). In a field study with different irrigation treatments, Carmi and Plant (1988) found that plant height, node number, percentage boll abscission and DM/plant decreased with decreased irrigation rate but seed cotton yield was highest and maturity earliest with the lowest irrigation. The common questions for cotton irrigation are: (1) Do we need to irrigate cotton? (2) When do we have to irrigate crop? and (3) How much water do we have to use? Three major components of climate (i.e. solar radiation, precipitation, temperature, RH, wind speed), soils (i.e. soil texture, soil fertility, land slope), and crops (cultivars, yield potential) have to be considered when trying to answer these questions and scheduling irrigation in crop production.

Generally long growing season, higher relative humidity and more precipitation in the US southeast region are major climatic characteristics compared to other areas of the United States. In a 4-yr field study of cotton response to irrigation in the north Florida, lint yields did not differ between the irrigated and non-irrigated treatments (Katsvairo et al., 2007). We hypothized that reducing irrigation might benefit resource conservation, reduce input cost, and improve cotton productivity and profitability in the southeast of USA. Field experiment was conducted in last seven years to test our hypothesis. The objective of this study was to determine precipitation and irrigation effects on cotton yield and water use efficiency.

Materials and Methods

A crop rotation and irrigation study was initiated in 2000 at the University of Florida's North Florida Research and Education Center in Quincy, FL (84°33' W, 30°36' N). The soil type at the experimental location is Dothan sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudult). Treatments included two cropping systems (sod-based and conventional peanut/cotton rotations) and two irrigation regimes (irrigated and non-irrigated). The sod-based system was a 4-yr rotation with bahiagrass-bahiagrass-peanut-cotton and the conventional system was a 3-yr rotation with peanut-cotton-cotton. Both systems were used conservation tillage (strip-till for summer crops) with winter oat cover crop following the summer crops. The non-irrigated (i.e. rainfed) treatment was never received any irrigation water during the experiment. The irrigated plots were irrigated using a lateral move irrigation system if needed. In 2000–2006, irrigation was applied based on Florida cotton production guidelines (Rhoads, 2000). In 2007, irrigation was implied when the lowest leaf water potential of uppermost fully expanded mainstem leaves, measured with a plant water status console (Soil Moisture Inc., CA) between 1300 and 1400 h EDT, was about -1.5 MPa during squaring and fruiting (Zhao et al., 1991).

The second year bahiagrass of the sod-based rotation was killed in late October of each year with 3 qts. of Rundup Weather Max per acre for the coming year peanut. In late March of each year, about 3 weeks prior to cotton planting, oat cover crop was killed with Rundup and plot rows were strip-tilled using a Brown Ro-till implement (Brown Manufacturing Co., Ozark, AL). Cotton cultivar Deltapine DP 458 BG (2002-2004) or DP 555 BG/RR (2005-2007) was used for this long-term rotation study. All plantings were made from late April to early May using a Monosem pneumatic planter (ATI Inc., Lenexa, KS) with a row spacing of 0.91 m and about 18 seeds per meter row. Nitrogen (28 kg N ha^{-1}), P (56 kg P ha^{-1}), and K (84 kg K ha^{-1}) from a combination fertilizer (5-10-15) were band applied adjacent to each row at planting. Cotton was sidedressed with additional N of 68 kg ha^{-1} (ammonia nitrite) at first square stage. Details of bahiagrass and peanut management and other cotton crop management practices, including disease and insect control, herbicide use, and chemical defoliation, were done according to standard University of Florida crop production recommendations (Ferrell et al., 2006).

To avoid effect of plot edges (usually with bigger plants) and to reflect the real production conditions, Plants in 2 m long area in each end of all plots were trimmed prior to harvest time in 2007. Then, seedcotton was mechanically harvested from four middle rows in each plot two weeks after defoliation. Seedcotton samples were weighed and seedcotton yield was further determined. Two seedcotton subsamples (1000 g each) in each plot were ginned to determine turnout (lint %). Lint yield was calculated based on seedcotton yield and lint %. Cotton water used efficiency (WUE for the irrigated cotton) or precipitation use efficiency (PUE for non-irrigated cotton) was estimated using lint yield dividing by the sum of precipitation and amount of irrigation for WUE or by only precipitation for PUE during the growing season from April to September.

The experiment was arranged in split-block design with 3 replications. Irrigation was main plot and crop rotation was sub-plot. The sub-plot size was 21 m long and 9.1 m wide with 10 rows of cotton in each plot. The irrigation unit stayed in the same area all seven years of the study. Differences in cotton yield were relatively small between the cropping systems in most test years as compared with year effect. To determine cotton yield variation among years and yield response to irrigation management, therefore, lint yield data were averaged across cropping systems within a year in this paper. All data were analyzed for variances using the GLM procedures (SAS Inc., 2002) and Fisher LSD tests were employed to separate mean differences between the irrigation treatments or among the experimental years (SAS Inc., 2002).

Results and Discussion

Physiological Basis of Reducing Irrigation in the Southeast USA

Knowing long-term averages of annual precipitation and potential evapotraspiration (pET) in each specific region can give us important information for crop water consumption and irrigation schedualing. In north Florida region near Quincy, the long-term averaged annual precipitation and pET are 1421 and 1215 mm, respectively (Fig. 1). In growing season from April to September, the pET and precipitation are very comparable and they are 806 and 762 mm, respectively (Fig. 1). Although precipitation in April and May is less than pET, rainfall in January to March can compensate the water shortage in April and May in the normal years. Based on these general climate data, it seems to be that irrigation may not be necessary for cotton production in the region in normal years. Variations in annual precipitation and in other weather parameters are great year by year. The climate information can give us some ideas about water saving, although uncertainty and complexity of weather make irrigation scheduling not as easy as we think.

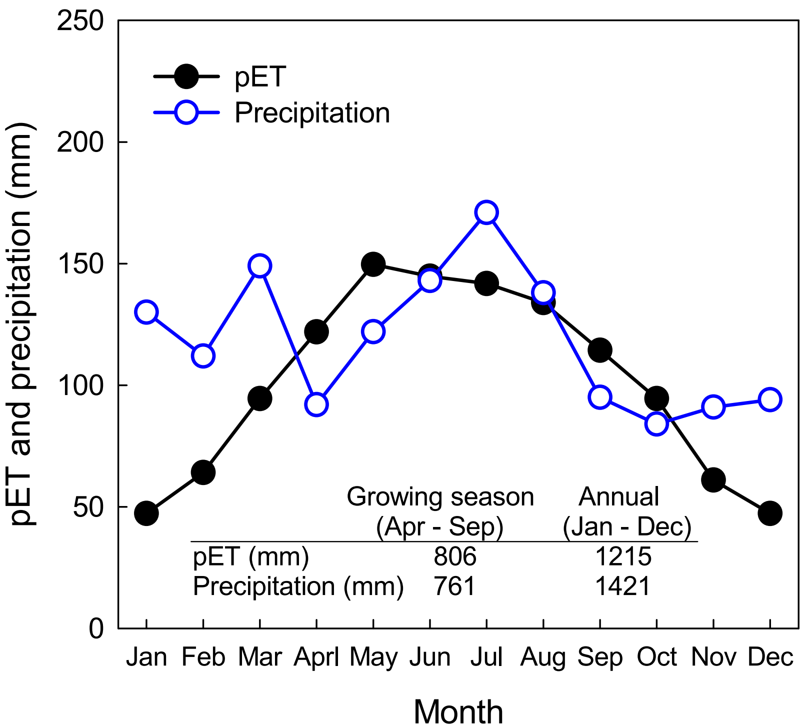

Fig. 1. Long–term monthly potential evapotranspiration (pET) and cumulative precipitation in north Florida. Cumulative pET and precipitation during growing season (from April to September) and at annual level are included.

Precipitation and Irrigation during the Experimental Years

Monthly precipitation and amount of irrigation for irrigated cotton in this study are presented in Table 1. Overall, the 2002 and 2003 growing seasons were close normal with in precipitation of 639 and 730 mm, respectively; the 2004 and 2005 growing seasons were wet with 162-171 mm more precipitation compared to long-term average rainfall

(761 mm); and the 2006 and 2007 growing seasons were dry. Especially year 2007 was extremely dry with only 51% of normal precipitation from April to September (Table 1). The wide range of precipitation year by year during the experiment gave us the opportunity to analyze cotton precipitation use efficiency and lint yield responses to irrigation.

Amount of irrigation in the 2002 to 2007 growing seasons (April – Sept) for the study ranged from 111 to 193 mm). Based on long-term precipitation and pET during the growing season, excess use of irrigation water seemed to be evidence in 2004 and 2005, as well as in 2002 and 2003. The sums of precipitation and irrigation in the growing season were 629 mm in 2006 and 520 mm in 2007 with 178 and 287 mm less than pET, respectively (Table 1).

Table 1. Monthly precipitation (Preci) and amount of irrigation (Irr) in the 2002 to 2007 growing seasons from April to September at Quincy, FL.

Month	2002		2003		2004		2005		2006		2007		Long-term	
	Preci	Irr	Preci	Irr	Preci	Irr	Preci	Irr	Preci	Irr	Preci	Irr	Preci	pET
	(mm)													
Apr	53	0	79	25	76	13	127	13	41	34	24	17	92	122
May	45	78	92	28	3	38	80	38	128	25	25	0	122	150
Jun	103	46	200	13	256	0	166	25	52	30	78	41	143	145
Jul	152	15	205	15	131	25	202	25	58	46	116	28	171	142
Aug	56	30	126	15	236	50	297	13	133	30	82	46	138	134
Sep	231	19	28	15	221	0	60	76	24	28	65	0	95	114
Total	639	188	730	111	923	126	932	190	436	193	390	130	761	807

Lint Yield

Year and irrigation significantly affected lint yield with $P < 0.0001$ and 0.01, respectively. The interaction effect of year and irrigation on lint yield was also significant ($P < 0.01$) (Table 2). Among the six experimental years, lint yield ranged from 838 to 1627 kg ha^{-1} for irrigated cotton and from 831 to 1634 kg ha^{-1} for non-irrigated cotton (Fig. 2). Lint yields in 2002, 2003 and 2004 were significantly less than that in other years for both the irrigated and non-irrigated cotton ($P < 0.05 – 0.01$). Averaged across years, lint yields of the irrigated and non-irrigated cotton were 1218 and 1142 kg ha^{-1}. Lint yield did not differ between irrigated and non-irrigated cotton in either normal years (2002 and 2003) or wet years (2004 and 2005). In Mississippi in normal years, lint yield also did not differ between the irrigated and non-irrigated treatments (Zhao et al., 2003, Personal communication). In 2006 and 2007 (dry years), irrigated cotton had significantly greater lint yield ($P < 0.01$) than non-irrigated cotton (Fig. 2). These results clearly indicate that irrigation may not always be necessary for cotton production in the southeast USA and eliminating rank growth by PIX application and by adjusting N rate may be more important than irrigation in both normal and wet years. In dry years, irrigation is required for high-yielding cotton production in the region.

Table 2. Significance of each source of variation for lint yield and water use efficiency (WUE for irrigated cotton) or precipitation use efficiency (PUE for non-irrigated cotton).

Source	df	*Pr > F*	
		Lint yield	WUE or PUE
Year (Y)	5	< 0.0001	<0.0001
Irrigation (I)	1	0.0043	0.0044
Y × I	5	0.0055	0.0001

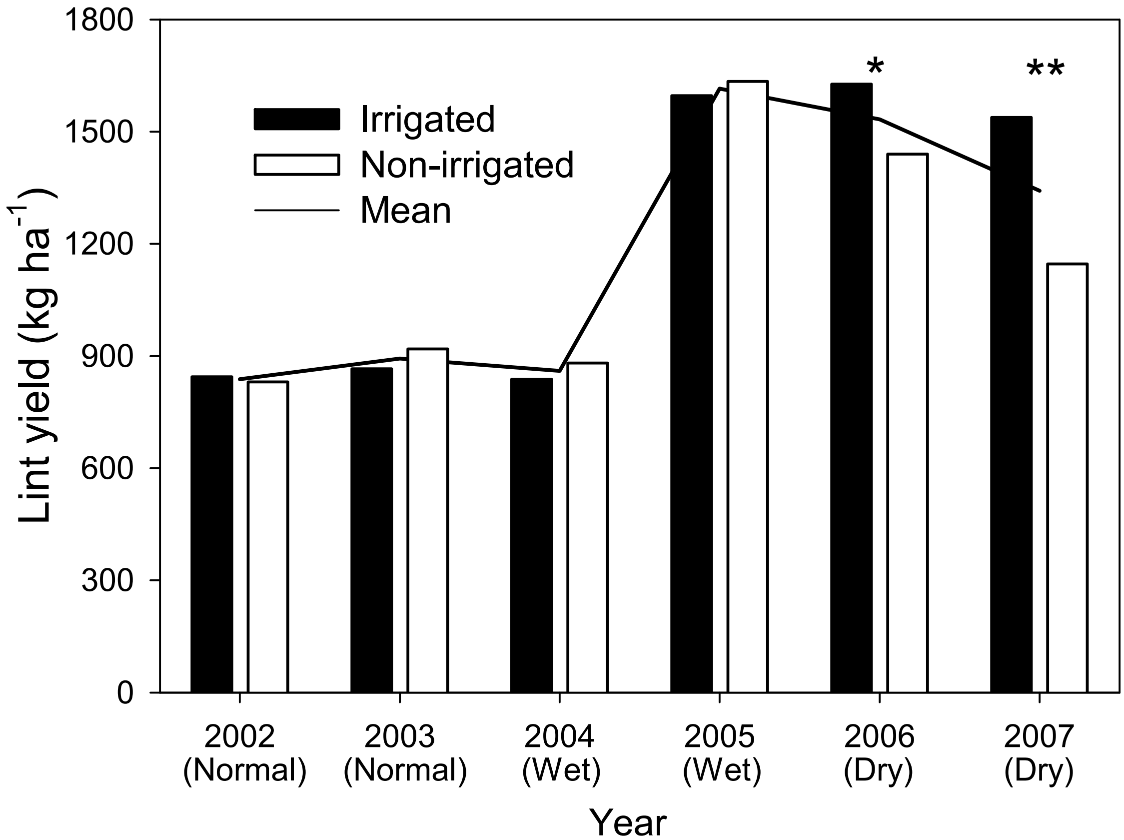

Fig. 2. Lint yields of irrigated cotton, non-irrigated cotton, and their means from 2002 to 2007 at Quincy, FL. The LSD values for the irrigated, non-irrigated, and means across years are 193, 208, and 178 kg ha^{-1}, respectively. The * and ** indicate that lint yield is significantly different between the irrigated and non-irrigated cotton within a year at $P < 0.05$ and 0.01 level, respectively.

Although irrigation is necessary for high-yielding cotton for dry years, it is possible to use water less irrigation and thus reduce production cost in the southeast. For instance, in 2007, an extremely dry year, irrigation was scheduled based on leaf water potential measurements. When lowest leaf water potential dropped to -1.5 MPa, irrigation was provided in the irrigated plots. Compared to 2006 (a dry year), 2007 had 46 mm less precipitation and 63 mm less irrigation (Table 1) during the growing season, but lint yield of irrigated cotton was equivalent (Fig. 2). Therefore, there is a great potential to reduce the amount of irrigation and to improve cotton production profitability even in dry years.

Water Use Efficiency

Similar to lint yield response to precipitation and irrigation, water use efficiency (WUE) for irrigated cotton and precipitation use efficiency (PUE) for non-irrigated cotton were affected significantly by both year ($P < 0.0001$) and irrigation ($P < 0.01$). The year × irrigation interaction was also significant ($P = 0.0001$) (Table 2). Water use efficiency of irrigated cotton varied greatly among years and ranged from 0.80 to 2.96 kg lint mm^{-1} water. Precipitation use efficiency of non-irrigated cotton ranged from 0.84 to 2.29 kg lint mm^{-1} water with the greatest WUE and PUE in 2006 and 2007 among years (Table 3). There was no difference in WUE/PUE between irrigated and non-irrigated cotton in either normal (2002 and 2003) or wet (2004 and 2005) years. In dry years (2006 and 2007), however, irrigation significantly ($P < 0.05$ to 0.01) improved cotton WUE as compared with non-irrigated cotton (Table 3). Benefits of water-saving irrigation for cotton production in the southeast region are to reduce not only irrigation cost, but also PIX application and the pressure of diseases and insects.

Table 3. Water use efficiency (WUE) for the irrigated cotton or precipitation use efficiency (PUE) for non-irrigated cotton in the 2002 to 2007 growing seasons in Quincy, FL.

Year	WUE for Irrigated cotton	PUE for Non-irrigated cotton	Mean	Type of year
	-------------------- (kg lint mm^{-1} water)	---------------------		
2002	1.00	1.30	1.15	Normal
2003	1.03	1.12	1.06	Normal
2004	0.80	0.84	0.82	Wet
2005	1.42	1.46	1.44	Wet
2006	2.59*	2.29	2.44	Dry
2007	2.96**	2.20	2.58	Dry
$LSD_{0.05}$	**0.27**	**0.31**	**0.25**	

† WUE = lint yield/(precipitation + irrigation accumulated in the growing season) for irrigated cotton; PUE = lint yield/(precipitation in growing season) for non-irrigated cotton. Data of precipitation and irrigation during the growing seasons and lint yield are in Tables 1 and Fig. 2, respectively.

The * and ** indicate that WUE is significantly different between the irrigated and non-irrigated cotton within year at $P < 0.05$ and 0.01 level, respectively.

Conclusions

Results of our six-year irrigation study in the two cropping systems and a wide range of precipitation and amount of irrigation indicated that irrigation in normal or wet years in the southeast USA did not improve cotton yield because the long-term precipitation during the growing season is almost equivalent to potential evapotranspiration in the region. Even in dry years, there is great potential to reduce amount of irrigation water, conserve regional water resource, improve cotton WUE and production profitability, and obtain high lint yield. In normal and wet years, there is no need to irrigate cotton in the southeast, but preventing cotton rank growth by applying PIX and adjusting N rate may be necessary for maintaining high yield and sustainability. In dry years, leaf water potential is a useful indicator of scheduling irrigation. When lowest leaf water potential, measured between 1300 and 1400 h, drops to -1.5 MPa (visually canopy leaves show slight wilt or lost tension), irrigation should be considered.

Acknowledgement

This research was supported in part by cooperative research agreements with Cotton Incorporated and USDA-ARS. We thank Brain Kidd and all other support staff at the Research Center for their excellent field work and technical assistance.

References

Ajaib, S.B., and J.L. Fowler. 1985. Preconditioning cotton to improve water use efficiency and conserve irrigation water. Technical Completion Report. Project No. 1345655 (http://wrri.nmsu.edu/publish/techrpt/tr192/tr192.pdf).

Carmi, A, and Z. Plant. 1988. Double-cropping system (cotton-wheat) based on frequent drip irrigation and control of the root zone system. *In* D. Rymon, (ed) Optimal Yield Management. Aldershot, UK: Gower Publishing Company Ltd. pp. 165-173.

Ferrell, J.A., G.E. MacDonald, and B. J. Brecke. 2006. Weed management in cotton. [Online] Available at http://edis.ifas.ufl.edu/WG003. (accessed 14 Oct. 2006; verified 20 Dec. 2007).University of Florida IFAS. Gainesville, FL.

Faver, K.L., T.J. Gerik, P.M. Thaxton, and K.M. El-Zik. 1996. Late season water stress in cotton: II. Leaf gas exchange and assimilation capacity. Crop Sci. 36:922-928.

Gerik, T.J., K.L. Faver, P.M. Thaxton, and K.M. El-Zik. 1996. Late season water stress in cotton: I. plant growth, water use, and yield. Crop Sci. 39: 914-921.

Jordan, W.R. 1986. Water deficits and reproduction. Pages 63-72 *in* J.R. Mauney and J.M. Stewart (eds). Cotton Physiology. The Cotton Foundation, Memphis, TN.

Kakani, V.G., K.R. Reddy, and D. Zhao. 2006. Deriving a simple spectral reflectance ratio for predicting water status of cotton (*Gossypium hirsutum* L.). J. New Seeds. 8:11-27.

Katsvairo, T.W., D.L. Wright, J.J. Marois, D.L. Hartzog, J.R. Rich, and P.P. Wiatrak. 2007. Cotton roots, earthworms and infiltration characteristics in sod/livestock peanut/cotton cropping systems. Agron. J. 99:390–398.

Katsvairo, T.W., D.L. Wright, J.J. Marois, D.L. Hartzon, K.B. Balkcom, P.P. Wiatrak, and J.R. Rich. 2007. Performance of peanut and cotton in a bahiagrass cropping system. Agron. J. 99:1245–1251.

Krieg D.R., J.L., Hatfield, A.C. Gertsis, and S.A. Staggenburg. 1993. Plant monitoring: Water stress and water management. Pages 1191-1193 in D.J. Herber and D.A. Richter, eds. Proc. of the Beltwide Cotton Prod. Res. Conf. National Cotton Council of America, Memphis, TN.

Oosterhuis D.M., R.A. Ball, and R.E. Hampton. 1991. Plant indicators of water stress for improved irrigation scheduling. P. 33-43 in D.M. Oosterhuis, ed. Proc. 1991 Cotton Res. Meeting. University of Arkansas Agricultural Experiment Station, Special Report 144.

Rhoads, F. 2002. Florida cotton production guidelines: water requirements for cotton. University of Florida, Institute of Food and Agricultural Sciences Extension. NFREC9 (http://edis.ifas.ufl.edu).

SAS Institute. 2002. The SAS system for Windows. Version 9.00. SAS Inst., Cary, NC.

Zhao, D., and D.M. Oosterhuis. 1997. Physiological responses of growth chamber-grown cotton plants to the plant growth regulator PGR-IV under water-deficit stress. Environ. Exp. Bot. 38:7-14.

Zhao, D., Y.Z. Xu, and X. Xu. 1989. Effects of water stress during flowering and fruiting on the development and physiological characteristics of cotton plants. J. Northwestern Agric. Univ. Sci. 17:79-85.

Zhao, D., Y.Z. Xu, and X. Xu. 1990. Effects of water stress during flowering and fruiting on yield and quality of cotton. J. Northwestern Agric. Univ. Sci. 18:42-47.

Zhao, D., Y.Z. Xu, and X. Xu. 1992. Effects of water deficiency on dry matter accumulation and distribution in cotton plants. J. Arid Area Agric. Res. 10:7-11.