Sprinkler irrigation for site-specific, precision management of cotton

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Abstract. Fluctuations in cotton yield in the Tennessee Valley region in North Alabama are common and are usually due to irregular rainfall or drought. A sprinkler irrigation scheduling study was initiated in 2006 at the Tennessee Valley Research and Extension Center to test cotton yield response to six irrigation treatments ranging from 0% (rainfed) to 125% of calculated pan evaporation adjusted for percent canopy cover. The study was conducted in a randomized block design with eight replications. The 2006 and 2007 growing seasons were the driest growing seasons since 1954 at the research site. Rainfall was less than 7 inches during both 2006 and 2007 seasons, with total pan evaporation exceeding 23 inches each year. All irrigation treatments significantly increased seed cotton yield over rainfed. Irrigation at 100% and 125% gave the highest yields in 2006 (3.0 bales/acre) and in 2007 (4 bales/acre). Average sprinkler irrigated cotton yields were 2.3 bales in 2006 and 3.5 bales in 2007. The increase in yields in 2007 was likely due to change in irrigation management to longer, deeper irrigations compared with 2006. Although the two irrigation managements were not replicated across each season to obtain a verifiable cause-and-effect, the two growing seasons were similar enough to draw strong inferences about the irrigation management used during these two drought years. Results from both years provide clear differences between yield responses to overhead irrigation schedules during drought conditions. These results quantify the benefit of irrigation to increase cotton yield during sporadic periods of drought.

Keywords: cotton yield, rainfall, irrigation, canopy cover, evapotranspiration

Introduction

Water is the main limiting factor in crop production. Limited water resources mandates that agricultural researchers find alternate ways to increase the water use efficiency of irrigation while maintaining optimum economic crop productivity. Excessive application of irrigation water to crops not only worsens water scarcity, but also causes runoff and leaching of fertilizer nutrients and pesticides to ground and surface water, leading to environmental pollution and unnecessary costs in crop production. While the southeastern U.S. has abundant rainfall on an average annual basis, large inter-annual variability in rainfall and frequent dry periods during the growing season make purely rain-fed agriculture a poor competitor to the efficiency of irrigated agriculture (Dougherty et al., 2007). Under such periods of drought, irrigation is critical to avoid potential yield loss.

Steger et al. (1998) reported that water stress caused by delaying post-planting irrigation reduced cotton lint yield. Similarly, in field studies conducted under rainfed and irrigated conditions, Pettigrew (2004) found that moisture deficit reduced cotton lint yield by 25% in rainfed cotton. Other studies have shown that both drip and sprinkler irrigation increased seed cotton yield compared to rainfed treatments (Camp et al., 1994; Camp et al., 1997; Bronson et al., 2001; Pringle and Martin 2003; Sorensen et al., 2004; Curtis el al., 2004; Kalfountzos et al., 2007).

The objective of this study was to test cotton yield response to six overhead sprinkler irrigation treatments ranging from 0% (rainfed) to 125% of calculated pan evaporation adjusted for percent canopy cover.

Materials and Methods

The research presented in this paper was conducted at the Tennessee Valley Research and Extension Center, located in northern Alabama, an area of widespread cotton production. Treatments included five overhead sprinkler irrigation schedules and a non-irrigated, rainfed treatment. These irrigation treatments were 0 (rainfed), 25, 50, 75, 100, and 125% of calculated pan evaporation adjusted for percent canopy cover. The target depth of irrigation water was derived using pan evaporation (PAN) and percent canopy cover (CC) according to the equation:

$$\text{Irrigation (inch)} = \text{PAN (inch)} \times \text{CC\%} \times \text{irrigation treatment \%}.$$

Canopy cover for each treatment was measured on a weekly basis. Pan evaporation for Belle Mina station was downloaded daily from the Alabama Weather Information Service (AWIS, 2008). Treatments were applied to plots arranged in a randomized complete block design and replicated eight times. Each plot was 39 feet x 39 feet and was irrigated with four quarter-throw sprinklers located head to head in each corner of the plot programmed with a "soak-and-cycle" feature to limit runoff. The flow rate of each sprinkler was 3.5 gpm and the application rate in each plot was 0.89 inch/h. According to irrigation equation above, maximum soil water depletion due to evapotranspiration (ET) and before irrigation was set at 0.10 inch in 2006 and at 0.30 inch in 2007. In 2006, sprinklers in each plot were turned on to irrigate for a minimum of 7 minutes, but only after the accumulated ET depletion reached 0.1 inch. In 2007, the threshold for minimum ET depletion was increased to 0.3 inch, resulting in a minimum 21-minute water application.. This change in irrigation management was due to concerns that irrigated water was not adequately wetting the root zone and benefiting plants.

Cotton (*Gossypium hirsutm*, L.) variety, DPL 445 BR, was planted in the second and third week of April in 2006 and 2007, respectively, using a 4-row John Deere 1700 vacuum planter set at

40-inch row spacing and a seeding rate of 4-5 seeds per foot. Each irrigation treatment was applied to a plot with eight rows of cotton, using the four middle rows as yield rows. The other four rows in each plot were treated as border or guard rows (two rows on each side). Cultural practices were carried out according to conventional cotton production practices in the Tennessee Valley region. Harvesting was carried out in the third week of September in 2006 and in the first week of October in 2007. Each treatment was harvested individually and then weighed.

Yield data were analyzed statistically with Statistix 8 using Tukey method for means separation at $\alpha \leq 0.05$ (Analytical Software, 2003).

Results and Discussion

The 2006 and 2007 growing seasons were progressively dryer at the Tennessee Valley Research and Extension Center (TVREC), Belle Mina, AL, with decreasing precipitation and increasing evaporation during both years (Figure 1). The most recent 10-year average rainfall at Belle Mina for June through August is 10.5 inches; and the 78-year average is 11.5 inches. Comparable season rainfall in 2006 and 2007 was less than 7 inches. Only four previous years on record had such low rainfall during these months; and only one year on record, 1954, had less rainfall than 2007. Not only was rainfall low, but evapotranspiration (approximated by pan evaporation) was extremely high throughout the growing season of both years (Figure 1), with estimated pan evaporation surpassing 23 inches each year.

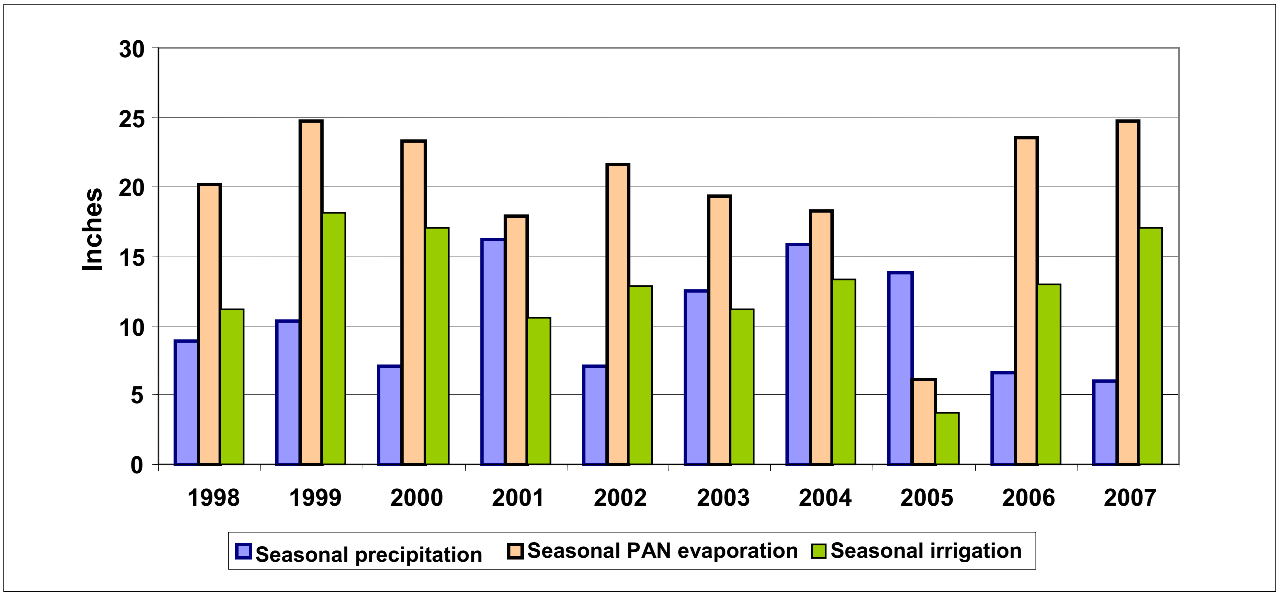

Figure 1. Ten-year seasonal water balance (June through August only), TVREC, Belle Mina, AL. Annual seasonal irrigation is calculated as 90% x seasonal pan evaporation x crop canopy factor.

Yield results from 2006 and 2007 (Table 1; Figure 2) provided benchmarks that clearly indicated the significant ($\alpha = 0.05$) response of various overhead irrigation schedules on seed cotton yield over rainfed treatments. Sprinkler irrigated cotton yields averaged 2.3 bales in 2006 and 3.5 bales in 2007 (Table 1). The highest yielding sprinkler treatments in both seasons were 100 and 125% of pan evaporation (adjusted to crop canopy percent), resulting in approximately 3.0 and 4 bales per acre in 2006 and 2007, respectively. Similar cotton yield responses to irrigation under rainfed conditions were reported in several studies (Camp et al., 1994; Camp et al., 1997; Bronson et al., 2001; Pringle and Martin 2003; Curtis et al., 2004; Sorensen et al., 2004; Balkcom et al. 2006; Kalfountzos et al., 2007; Balkcom et al. 2007). However, other studies reported the absence of response to irrigation in cotton and attributed that to root growth restriction by soil compaction or insufficient irrigation (Bauer et al., 1997; Camp et al., 1997; Camp et al., 1999). The increased sprinkler irrigated yields in 2007 season was most likely due to the change in the irrigation threshold used to trigger irrigation events. In 2007, soil moisture depletion, estimated by daily pan evaporation, was allowed to reach 0.3 inch before an irrigation event was scheduled, while in 2006 irrigation events occurred once estimated soil moisture depletion reached 0.1 inch. The larger soil moisture depletion in 2007 resulted in less frequent, but beneficial deeper irrigations (Figure 3).

Table 1. Effect of different sprinkler irrigation treatments on cotton yield.

	2006		2007	
Treatment	**Seed Cotton (lb/acre)***	**Bales (bales/acre)**	**Seed Cotton (lb/acre)***	**Bales (bales/acre)**
125% pan evaporation x canopy cover factor	**3703.9[a]**	**2.9**	**4612.1[a]**	**3.9**
100% pan evaporation x canopy cover factor	**3520.4[a]**	**2.8**	**4692.1[a]**	**4.0**
75% pan evaporation x canopy cover factor	**2748.2[b]**	**2.2**	**4436.5[a]**	**3.8**
50% pan evaporation x canopy cover factor	**2491.0[cb]**	**2.0**	**3969.6[b]**	**3.4**
25% pan evaporation x canopy cover factor	**2098.0[c]**	**1.7**	**2612.5[c]**	**2.2**
0% pan evaporation (rainfed)	**1492.3[d]**	**1.2**	**1151.3[d]**	**1.0**

***Different superscripts denote statistical difference (α = 0.05). Turnout in 2006 and 2007 were 38% and 41%, respectively.**

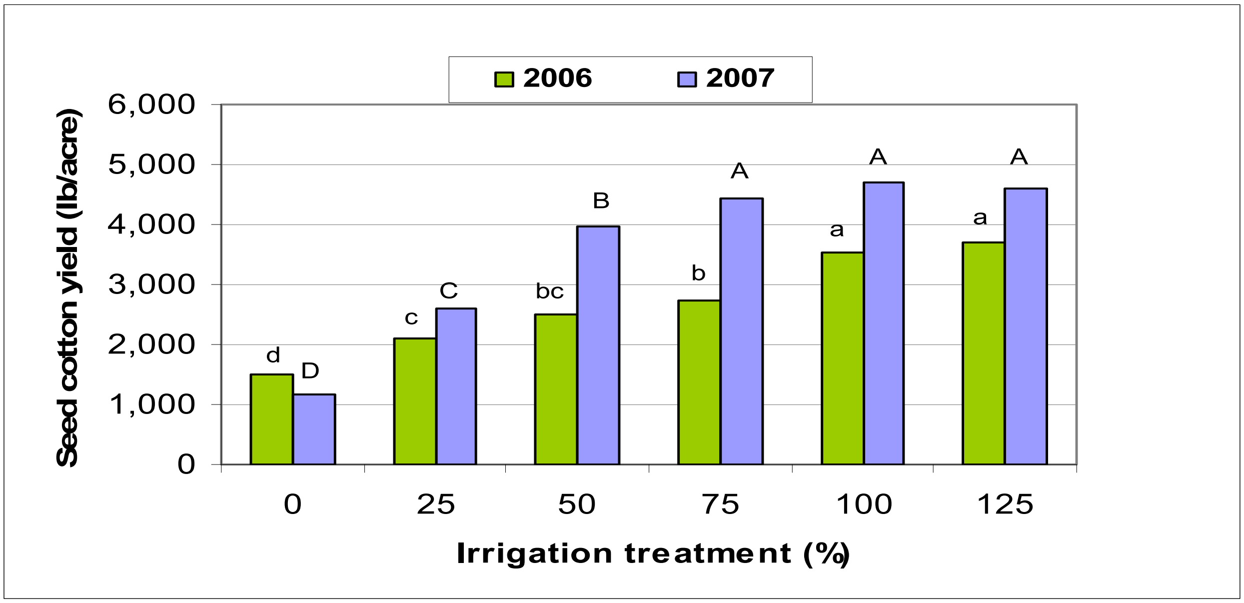

Figure 2. Precision sprinkler irrigation cotton trials, lb/acre, 2006 and 2007. Different letters denote statistical difference ($\alpha = 0.05$) within a year.

Table 2 and Figure 3 revealed that although nearly identical seasonal depths of irrigation were applied in 2006 and 2007 (approximately 20 inches for both 100% irrigation treatments), almost 100 irrigations were required out of the 111-day growing season in 2006 versus only 52 irrigations out of the 97-day growing season in 2007 because of the different irrigation management. Figure 3 shows the resulting irrigation schedule for the 100% treatment using the 2006 and 2007 irrigation set points or thresholds. The observed two-year result was less frequent, but heavier irrigation events in 2007. Marked yield improvement in 2007 suggests the higher allowable depletion management is beneficial because of more efficient water use. Although the two irrigation managements were not replicated across each season to obtain a verifiable cause-and-effect, the two growing seasons were similar enough to draw strong inferences about the irrigation management used during these two drought years.

Table 2. **Total irrigation amounts for 2006 and 2007, sprinkler scheduling trials.**

Treatment	Irrigation depth (inch)	
	2006	**2007**
125% pan evaporation x canopy cover factor	**25.17**	**24.42**
100% pan evaporation x canopy cover factor	**20.44**	**19.31**
75% pan evaporation x canopy cover factor	**15.24**	**14.71**
50% pan evaporation x canopy cover factor	**10.07**	**9.63**
25% pan evaporation x canopy cover factor	**4.87**	**4.29**
0% pan evaporation (rainfed)	**0.00**	**0.00**

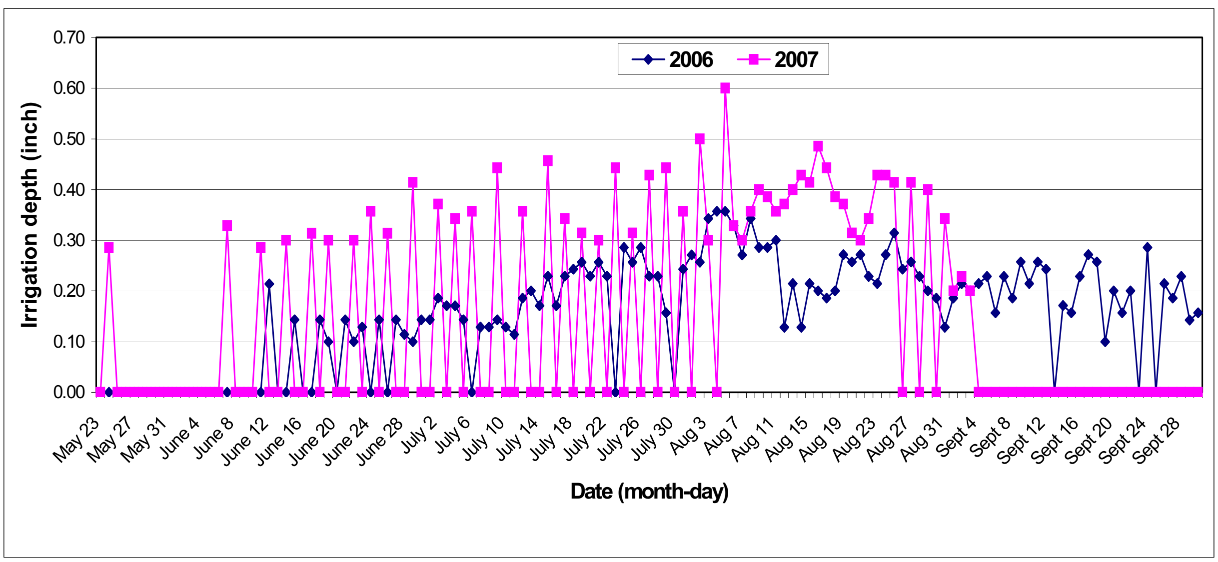

Figure 3. Daily irrigation record for 100% irrigation treatment, sprinkler irrigation trials, TVREC, Belle Mina, AL, 2006-2007.

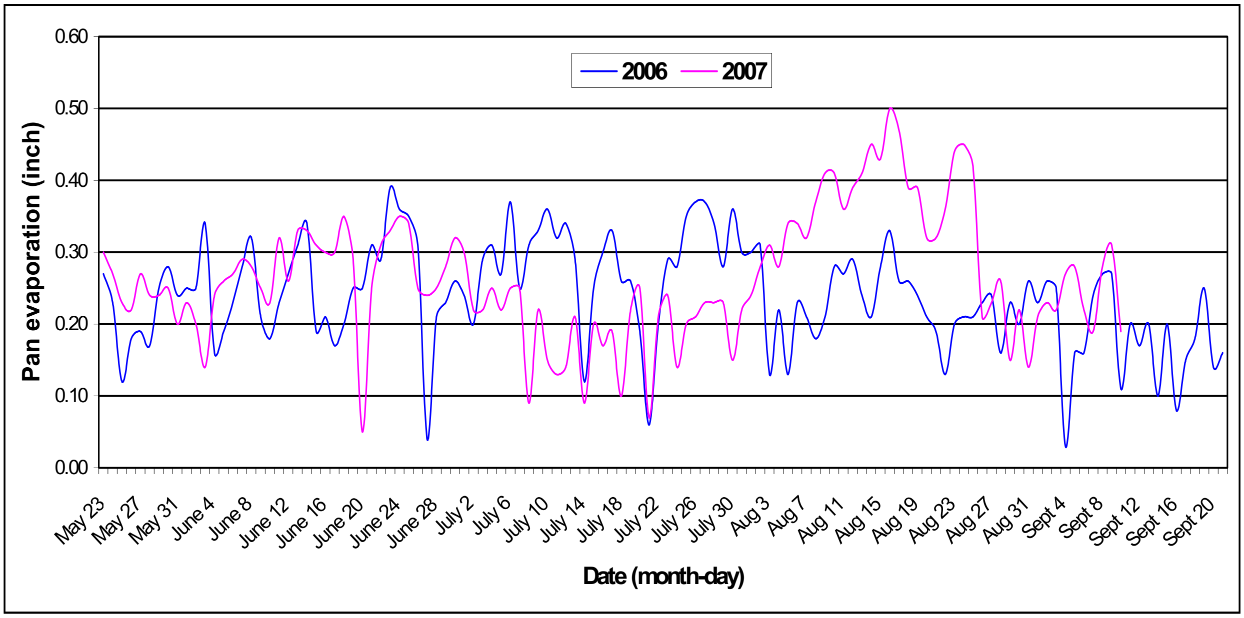

Figure 4. Daily PAN evaporation during growing season, TVREC, Belle Mina, AL, 2006-2007.

Figure 4 illustrates the differences in daily pan evaporation between 2006 and 2007 growing seasons that, along with changes in irrigation management, may also have influenced seasonal yield differences. Daily PAN evaporation was similar in 2006 and 2007, except for the months of July and August. Higher pan evaporation was observed in July 2006 compared to July 2007, with the opposite observed in August of both years. Since July is the peak flowering time in Tennessee Valley, it is possible that the higher evaporation combined with shallow irrigation in 2006 decreased flower setting and thus cotton yield. Guinn and Mauney (1984a, 1984b) reported that water deficit during cotton flowering decreased flower production and yield.

Summary and conclusions

Five sprinkler irrigation treatments significantly increased seed cotton yield in the Tennessee Valley region during two years of drought. The highest yields were obtained at 100 and 125% irrigation treatments in both seasons, resulting in approximately 3.0 and 4 bales per acre in 2006 and 2007, respectively. Although irrigation management was changed over the two-year study, the two back-to-back growing seasons were similar enough to draw strong inferences regarding the yield benefits of less frequent, deeper irrigations during low rainfall years. Overall results indicate that cotton producers in this region with adequate irrigation facilities have the potential to realize significant yield gains over rainfed cotton. A third season of this study is currently underway to corroborate these findings across a wider range of seasonal rainfall and temperature conditions.

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References

Analytical Software. 2003. Statistix 8. Analytical Software, Tallahassee, FL.

AWIS. 2008. Weather Services, Inc., P.O. Box 3267, Auburn, AL 36831-3267; http://www.awis.com/contact.htm, (verified 15 September 2008).

Balkcom, K. S., J. N. Shaw, D. W. Reeves, C. H. Burmester, and L. M. Curtis. 2007. Irrigated cotton response to tillage systems in the Tennessee Valley. J. Cotton Sci. 11: 2-11.

Balkcom, K.S., D.W. Reeves, J. N. Shaw, C. H. Burmester, and L. M. Curtis. 2006. Cotton yield and fiber quality from irrigated tillage systems in the Tennessee Valley**.** Agron. J. 98: 596-602

Bauer, P. J., P. G. Hunt, and C. R. Camp. 1997. In-season evaluation of subsurface drip and nitrogen-application method for supplying nitrogen and water to cotton. J. Cotton Sci. 1:29-37.

Bronson, K.F., A.B. Onken, J.W. Keeling, J.D. Booker, and H.A. Torbert. 2001. Nitrogen response in cotton as affected by tillage system and irrigation level. Soil Sci. Soc. Am. J. 65: 1153-1163.

Camp, C.R., W. M. Thomas, and C.W. Doty. 1994. Drainage and irrigation effects on cotton. Trans. ASAE: 37:823-830.

Camp, C.R., P.J. Bauer, and P.G. Hunt. 1997. Subsurface drip irrigation lateral spacing and management for cotton in the southeastern coastal plain. Trans. ASAE. 40: 993-999.

Camp, C.R., P.J. Bauer, and W.J. Busscher. 1999. Evaluation of no-tillage crop production with subsurface drip irrigation on soils with compacted layers. Trans. ASAE: 42:911-917.

Curtis, L., C.H. Burmester, D.H. Harkins, and B.E. Norris. (2004). Subsurface drip irrigation (SDI) tape products and fertigation, Tennessee Valley Research Extension Center. Alabama Agric. Exp. Station. Cotton Research Report, Research Report No. 26:22-23.

Dougherty, M., D. Bayne, L.M. Curtis, E. Reutebuch, and W. Seesock. 2007. Water quality in non traditional off-stream polyethylene-lined reservoir. J. Environ. Manage. 85:1015-1023.

Guinn, G., and J.R. Mauney. 1984a. Fruiting of cotton. I. Effects of moisture status on flowering. Agron. J. 76: 90-94.

Guinn, G., and J.R. Mauney. 1984b. Fruiting of cotton. II. Effects of plant moisture status and active boll load on boll retention. Agron. J. 76: 94-98.

Kalfountzos, D., I. Alexiou, S. Kotsopoulos, G. Zavakos, and P. Vyrlas. 2007. Effect of subsurface drip irrigation on cotton plantations. Water Resour. Manage. 21:1341-1351.

Pettigrew, W.T. 2004. Moisture deficit effects on cotton lint yield, yield components, and boll distribution. Agron. J. 96: 377-383.

Pringle III, H.C., and S.W. Martin. 2003. Cotton yield response and economic implications to in-row subsoil tillage and sprinkler irrigation. J. Cotton Sci. 7:185-193.

Sorensen, R.B., M.J. Bader, and E.H. Wilson. 2004. Cotton yield and grade response to nitrogen applied daily through a subsurface drip irrigation system. Appl. Eng. Agric. 20:13-16

Steger, A.J., J.C Silvertooth, and P.W Brown. 1998. Upland cotton growth and yield response to timing the initial postplant irrigation. Agron. J. 90: 455-461.