# COTTON GROWTH AND DEVELOPMENT UNDER DIFFERENT IRRIGATION REGIMES

Cecilia M. Tojo Soler and Gerrit Hoogenboom

Department of Biological and Agricultural Engineering, The University of Georgia, Griffin, Georgia. *E-mail: ctojo@griffin.uga.edu*

## Introduction

Cotton (*Gossypium hirsutum* L.) is one of the most important row crops in Georgia. Currently, the crop accounts for approximately 1,396,000 acres per year. The average yield for the past 10 years has been 660 lb/acre with a high inter-annual variability. Fiber quality is also frequently mentioned as a concern for cotton that has been produced in Georgia. Efforts to solve these problems for cotton have been conducted and new technologies have been adopted. For instance, in recent years farmers have planted mainly genetically modified (GM) cultivars. Within the strategies to improve cotton yields, irrigation scheduling is an important management practice that can help to obtain high and stable yields with adequate fiber quality. There are several, well documented irrigation scheduling methods. A new approach for determining irrigation scheduling consists of using decision systems, such as the Decision Support System for Agrotechnology Transfer (DSSAT) (Tsuji et al., 1994; Jones et al., 2003; Hoogenboom et al., 2004). The DSSAT encompasses models for 27 different crops, including the Cropping System Model CSM-CROPGRO-Cotton model which has been one of the most recently developed models. The main goal of irrigation scheduling is to obtain high and stable yields and to use water efficiently. Most of the irrigation studies have been conducted under rainfed conditions, meaning that supplemental water is provided through irrigation if needed. However, there is insufficient information about the response of cotton to different irrigation scheduling techniques when all water applications are completely controlled throughout the growing season. The objective of this study was to determine the impact of different irrigation scheduling regimes on cotton growth and development under completely dry conditions.

## Material and Methods

Two experiments were conducted in four automatic rainout shelters located on the Griffin Campus of the University of Georgia. The rainout shelters are 39.3 feet long and 13.1 feet wide. Each rainout shelter corresponded to one irrigation treatment and each treatment had 3 replicates. The decision when to irrigate and how much water to apply was determined daily based on simulations with the cotton crop simulation model CSM-CROPGRO-Cotton for each individual treatment. As an example for each treatment when the actual soil water content in the top layer dropped below a specific threshold of the available water content (AWC), irrigation was applied until the soil water reached 100% of AWC. The irrigation treatments corresponded to 40%, 60% and 90% of the irrigation threshold (IT) and 100% ETc in 2004 and 30%, 40%, 60% and 90% of the irrigation threshold in 2005. Due to problems with the electronic control system of the rainout shelters, only the 40% and 60% IT treatments for 2004 and the 40%, 60% and 90% IT treatments for 2005 were analyzed. Experimental errors were one of the main concerns for the treatments that were not analyzed.

For the irrigation scheduling the CSM-CROPGRO cotton model was set to consider the observed weather data until the decision date. For the remainder of the growing season the average daily weather data for the last 10 years (Tmax, Tmin and solar radiation) were used for the 2004 growing season, while for the 2005 growing the daily weather data for the last 10 years were used. Irrigation depth is fixed for the entire growing season in the model but it was modified manually according to development of the crop to be able to have more realistic irrigation scheduling.

The cotton cultivar DP 555 BG/RR was planted on May 19$^{th}$, 2004 and May 17$^{th}$, 2005. The plants population was 45,000 plants per acre. Rows were spaced 3 feet, plant spacing was 3.9 inches and the planting depth was 1.5 inches. Fertilization was conducted following the recommendations based on the results of the soil analysis. Pests were controlled with specific chemical applications. The plant growth regulator Pentia® was applied in the two cotton experiments (2004 and 2005 growing seasons).

Soil physical and chemical analysis was conducted at depths of 2, 6, 12, 24 and 36 inches. The soil was characterized by its high sand content (92%) in the profile. Soil water content was monitored with Time-Domain-Reflectometry (TDR) in both experiments and with a PR2 probe during the 2005 experiment. The TDR probes were 11.8 inches in length and 3 probes were installed in each rainout shelter or treatment. Three access tubes were installed for the PR2 probe within the rows and one access tube between the cotton rows for each treatment. The PR2 measured the volumetric soil water content at depths of 3.9, 7.8, 11.8, 15.6, 23.4, and 39 inches.

Phenology records were obtained on a daily basis. Growth analysis included plant height, Leaf Area Index (LAI), dry matter weight for leaves, stems and roots. For reproductive development, we recorded boll position in the stem, number of squares and bolls, boll weight, and lint weight. Approximately every 18 days destructive samples were collected for 3.3 ft of linear row. All plants were cut at the base, individual plant components were separated and oven dried at 70$^{o}$C until constant weight and then weighed. For the final harvest, 9.8 linear feet was manually cut for each replicate and plants were separated into the different plant components similar to the procedures used for growth analysis.

An analysis of variance was conducted to determine the effect of irrigation treatment on cotton lint yield and yield components using the SAS-GLM procedure. In addition, mixed model procedures were used to analyze the growth variables for the destructive samplings conducted during the cropping season. For the 2005 experiment, an analysis of paired data to determine the differences between the means in soil water content was performed using the t-test at a significance level of $P > 0.05$.

## Results and Discussion

### Irrigation and soil water content

For 2005, the total amount of water applied through irrigation for the entire growing season was 11.4 inches for the 40% IT treatment, 21.7 inches for the 60% IT treatment and 26.4 inches for the 90% IT treatment. The total soil water measured with the PR2 access probe for the entire growing season for 2005 for the main soil profile up to a depth of 47.2 inches was on average 2.7 inches for the 90% IT treatment. This was significantly different from the others which, on average had 2 inches for the 40% IT treatment and 1.9 inches for the 60 % IT treatment. A preliminary analysis indicated that the period in which significant differences in soil water content were observed between the three irrigation treatments was between emergence and July 7$^{th}$, or until 3$^{rd}$ square stage. For this period, the 90% IT treatment had an average of 4.3 inches in the profile, which was significantly different from the 60% IT treatment (3.5 inches) and 40 % IT treatment (3 inches).

### Biomass accumulation

There was a low accumulation of biomass during the first 45 days of the growing season during the months of May and June with a rapid increase in July through middle of September. Water stress was the main cause for the low values for biomass accumulation, especially for 40 % IT treatment, which was significantly different from the 60% and 90% IT treatments (Figure 1).

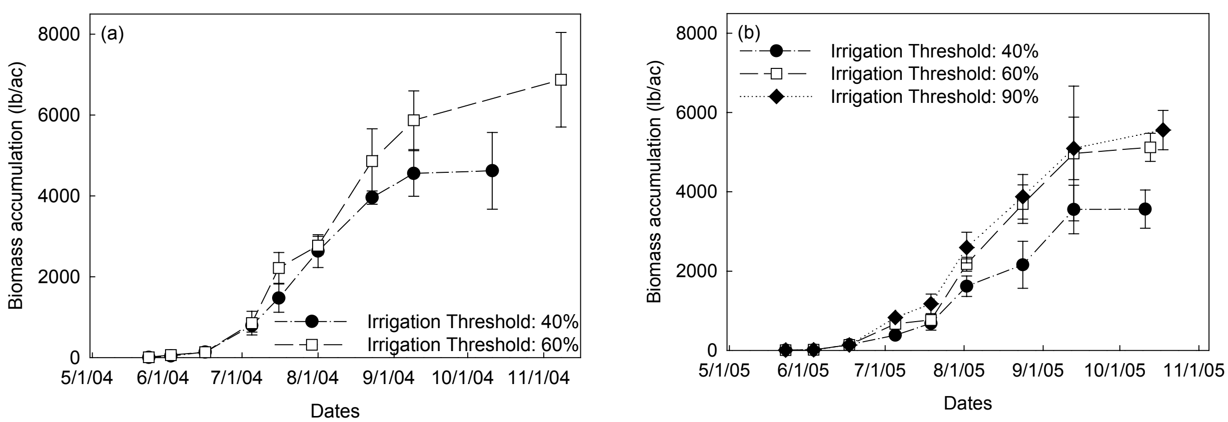


Figure 1. Biomass accumulation for cotton grown under different irrigation treatments for the years 2004 (a) and 2005 (b).

### Yield and yield components

Water stress impacted the number of bolls per square meter. Thus, we observed the lowest number of bolls $m^{-2}$ for the 40 % IT treatment, which was significantly different from the other treatments (Table 1). As the irrigation threshold increased, the number of bolls $m^{-2}$ also increased. As the yield is the product of the number of bolls $m^{-2}$ and individual boll weight, we found that lint yield increased as the irrigation threshold increased, e.g. from 40% IT to 90% IT treatment. The regression analysis between yield components and lint yield showed that the number of bolls $m^{-2}$ was the most important yield component in determining the yield ($r^2$= 0.86).

The statistical analysis for lint yield showed that there were no significant differences between the 60 and 90% IT treatments, since the difference between these two treatments was only 2%. However, the 40% treatment was significantly impacted by the low soil water content and the yield for this treatment was on average only 61% of the yield obtained with the 60% IT treatment.

Table 1. Lint yield and yield components for cotton grown under different irrigation treatments for the years 2004 and 2005.

| Year – Irrigation Threshold | Lint (lb/acre) | Seeds and lint (lb/acre) | Bolls number (Nr $m^{-2}$) | Boll weight (g) |
|---|---|---|---|---|
| 2004 - 40% | 831 (b) | 1767 (b) | 59 (c) | 3.4 (a) |
| 2004 - 60% | 1293 (a) | 2643 (a) | 90 (a) | 3.2 (a) |
| 2005 - 40% | 694 (b) | 1550 (b) | 46 (d) | 3.7 (a) |
| 2005 - 60% | 1174 (a) | 2542 (a) | 70 (bc) | 4.1 (a) |
| 2005- 90% | 1258 (a) | 2690 (a) | 73 (b) | 4.1 (a) |

**Boll position**

The analysis of the position of the bolls for the 2005 experiment revealed that when the IT increased, mainly from 40% to 60%, the first bolls were formed on the lower nodes and the final bolls formed on the higher nodes (Figure 2). Thus, a wider range of nodes produced bolls when more water was applied to the crop. This might also explain the high values for the number of bolls per unit land area for the more-frequently irrigated treatments. There was also a high coefficient of determination ($r^2$) between the number of bolls per unit land area and lint yield.

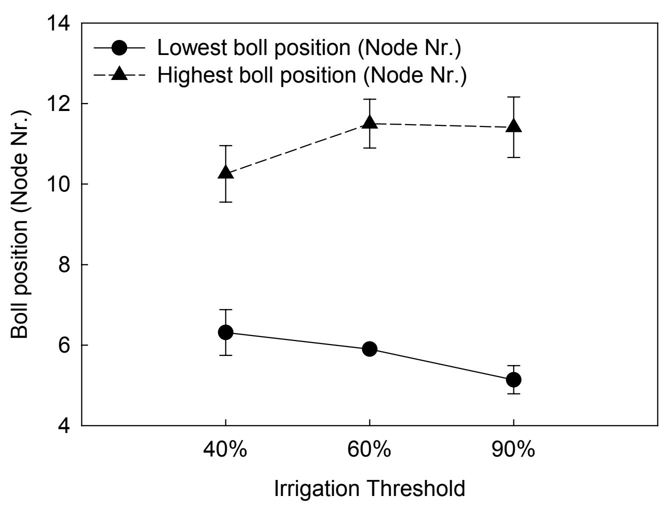


Figure 2. Boll position as a function of the different irrigation treatments for cotton grown in 2005.

**Fiber quality**

The cultivar DP 555 BG/RR is characterized by its high yield and good fiber-quality potential for many cotton growing areas. The results from these two experiments also showed the high quality of fiber for the DP 555 BG/RR cultivar. However, the best values for some of the properties associated with fiber quality were obtained for the 60% IT treatment in 2004, especially with respect to fiber length, uniformity, short fiber index and strength (Table 2). For the experiment conducted in 2005 there was a tendency for lower values for some of the properties related to fiber quality than in 2004, which can be explained in part by environment conditions during the reproductive stage and also by different methods used to gin the cotton in both years. The cotton harvested in 2004 was manually ginned and the 2005 cotton was ginned in a table top gin machine.

Table 2. Fiber quality properties for cotton grown under different irrigation treatments in 2004 and 2005.

| Year – Irrigation threshold | Length (inches) | Uniformity (%) | Short Fiber Index | Strength (g $tex^{-1}$) | Elongation (%) |
|---|---|---|---|---|---|
| 2004 - 40%IT | 1.1 (b) | 84.0 (b) | 3.4 (b) | 30.3 (ab) | 8.3 (a) |
| 2004 - 60% IT | 1.2 (a) | 86.4 (a) | 2.7 (b) | 33.0 (a) | 7.9 (ab) |
| 2005 - 40% IT | 1.1 (b) | 82.6 (b) | 7.3 (a) | 31.1 (ab) | 7.3 (b) |
| 2005 - 60% IT | 1.1 (b) | 82.2 (b) | 8.1 (a) | 29.4 (b) | 7.5 (b) |
| 2005 - 90% IT | 1.1 (b) | 82.4 (b) | 8.3 (a) | 29.7 (b) | 7.5 (b) |
| | Micronaire | Maturity | Reflectance | Yellow content | Color grade |
| 2004 - 40%IT | 4.9 (a) | 87.0 (a) | 78.3 (a) | 8.1 (a) | 31-2 |
| 2004 - 60% IT | 4.8 (a) | 87.3 (a) | 72.4 (b) | 6.2 (b) | 51-1 |
| 2005 - 40% IT | 4.9 (a) | 88.0 (a) | 73.3 (b) | 6.1 (b) | 51-1 |
| 2005 - 60% IT | 4.5 (a) | 86.7 (a) | 73.6 (b) | 8.6 (a) | 41-5 |
| 2005 - 90% IT | 4.7 (a) | 87.3 (a) | 73.4 (b) | 7.6 (ab) | 41-2 |

## Conclusions

Cotton growth and development was affected by the different irrigation treatments. The method used permitted us to quantify with accuracy the effect of the different irrigation treatments on cotton growth and development, and particularly on lint yield and lint quality. Since the higher biomass accumulation as well as the higher lint and best fiber quality were found with the treatments that had a 60 and 90% irrigation threshold, the 60% irrigation threshold is one of the recommended irrigation practices, as it would conserve water compared to the 90% irrigation threshold level. The treatment with the 40% threshold resulted in a significantly lower lint yield and lowest fiber quality in both 2004 and 2005 and it is not recommended for use under field conditions.

This study showed that the dynamic crop growth model CSM-CROPGRO-Cotton can be a promising tool for irrigation scheduling. However, a variable irrigation management depth should be used and a fairly accurate soil characterization is required. Further work includes the evaluation of the CSM-CROPGRO cotton model with the results obtained from these two experiments and also the evaluation of the model with data from farmer’s field in order to be able to use the model for irrigation scheduling at the field level as well as for yield forecast applications at the state level.

## References

Hoogenboom, G., Jones, J.W., Wilkens, P.W., Porter, C.H., Batchelor, W.D., Hunt, L.A., Boote, K.J., Singh, U., Uryaseva, O., Bowen, W.T., Gijsman, A.J., Du Toit, A.S., White J.W., Tsuji, G.Y., 2004. Decision Support System for Agrotechnology Transfer Version 4.0. [CD-ROM]. University of Hawaii, Honolulu, HI.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J., Ritchie, J.T., 2003. DSSAT Cropping System Model. Eur. J. of Agron. 18, 235-265.

SAS Institute. 2001. SAS system. 8$^{th}$ ed. SAS Inst., Cary, N.C.

Tsuji, G.Y., Jones, J.W., Hoogenboom, G., Hunt, L.A., Thornton, P.K., 1994. Introduction. In: DSSAT v3, Decision support system for agrotechnology transfer. In: Tsuji, G.Y, Uehara, G, Balas, S (Eds.). University of Hawaii, Honolulu, Hawaii. Vol 1.

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