Determining Irrigation Scheduling for Cotton and Peanut using Cropping System Models

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Abstract

Irrigation scheduling is an important management practice for farmers who grow irrigated crops. Effective irrigation is possible by regular monitoring of soil water and crop development conditions in the field. However, this methodology requires frequent field visits and, consequently, it is time consuming. Computer simulation models can be an important aid for irrigation scheduling, as they integrate the soil-plant-atmosphere complex. The main objectives of this study were to determine the impact of different irrigation scheduling regimes on cotton and peanut growth and development and to evaluate the application of a crop simulation model as a tool for irrigation scheduling. Two experiments were conducted in four rainout shelters, located at the Griffin Campus of The University of Georgia, during 2005 and 2006. Cotton was grown in 2005 and peanut was grown in 2006. The CSM-CROPGRO-Cotton and CSM-CROPGRO-Peanut models were used to define the irrigation treatments by estimating the timing of irrigation and the amount of water to apply. The irrigation event was triggered when the actual soil water content in the effective root zone dropped below a specific threshold of the available water content (AWC) and then irrigation was applied until the soil water reached 100% of AWC. The irrigation treatments corresponded to 30%, 40%, 60% and 90% of the irrigation threshold (IT). The models require daily weather data, including maximum and minimum temperature, solar radiation and precipitation as input. Actual weather data were used until the current date and the daily weather data for the past 10 years were used to project until the end of the growing season. The cotton cultivar DP 555 BG/RR was planted on May 17, 2005 and the peanut cultivar Georgia Green was planted on May 22, 2006. For both experiments, the soil water content was monitored with Time-Domain-Reflectometry (TDR) and with a soil profile probe (PR2/6, Delta-T Devices, Ltd.). The TDRs and PR2/6 probe were connected to data loggers. For both

crops, growth analysis, including leaf area index (LAI), plant height and biomass, was conducted approximately every 18 days. Yield and yield components were obtained at final harvest. For cotton, the 30 and 40% IT treatments had significantly less number of bolls/m^2. The statistical analysis for lint yield showed that there were no significant differences between the 60 and 90% IT treatments. For cotton and peanut, low values of aboveground biomass at harvest and yield were found for the 30 and 40% IT treatments. The study showed that the dynamic crop growth models CSM-CROPGRO-Cotton and CSM-CROPGRO-Peanut can be used for irrigation scheduling, but a variable irrigation management depth needs to be incorporated in the model and a correct characterization of the soil properties is needed.

Introduction

Cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.) are important row crops in Georgia and other southeastern states. In Georgia, cotton accounts for approximately 560,000 ha of production per year. The average yield for the past 10 years has been 740 kg ha^{-1} with a high inter-annual variability (Jost, 2006; NASS, 2007). Georgia is the number one peanut producing state in the USA, accounting for over 45% of the acreage and production. In 2006, 580,000 ha were planted and the average obtained yield was 2,970 kg ha^{-1} (NASS, 2007).

Within the strategies to improve cotton yield, irrigation scheduling is an important management practice that can help to obtain high and stable yields. Mert (2005) studied the effects of water stress on cotton cultivars under irrigated and non-irrigated conditions and found that seed cotton yield and other yield related traits varied significantly among cultivars under non-irrigated conditions. Furthermore, growing cotton under non-irrigated conditions resulted in the production of shorter and weaker fibers with reduced micronaire. Pettigrew (2004), in a four year study conducted in Mississippi, reported that irrigation delayed cutout, enabling the plants to prolong flowering later in the growing season compared with dryland plants. During the years when significant moisture deficits occurred, the lint yield of rainfed plants was reduced 25%, primarily because of a 19% reduction in the number of bolls. Irrigated plants produced more bolls at higher plant nodes and at the more distal positions on the sympodial branches than the rainfed plants.

Supplemental irrigation during drought stress is also critical to produce high yield and top quality peanut in the southeast (Beasley, 2006). Black et al. (1985); Patel and Golakiya (1988); Stirling et al. (1989) and Reddy et al. (2003) reported that peanut is most sensitive to water stress during flowering and pod filling. The flowering rate depends on the irrigation frequency and is reduced when the water frequency is less than once every 6 days (Ishag, 1982). Peg elongation is delayed by drought (Boote and Ketring, 1990); and adequate soil moisture in the pod elongation zone is critical for peg penetration and the formation of pods (Reddy et al., 2003).

Experiences with row-crop farmers in south Georgia indicates that new technologies could be considered as long as they do not take too much time, do not interfere with field operations, are reliable, result in accurate recommendations, and are not too expensive (Thomas et al., 2004). There are several, well-documented irrigation scheduling methods for proper soil water management, e.g., if water is replenished within an appropriate time period before plants are stressed; irrigation has a benefit in crop production. The main goal of irrigation scheduling is to use water efficiently and to obtain high and stable yields. A new approach for determining irrigation scheduling consists of using decision support and information 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 CSM-CROPGRO-Cotton and –Peanut models. There are limited studies conducted using CSM-CROPGRO-Cotton and -Peanut models for irrigation scheduling aiming to obtaining high and stable yields. Most of the irrigation studies have been conducted under rainfed conditions, which means that supplemental water is provided through irrigation, but only if needed and rainfall is inadequate to meet the demands of the crop. However, there is insufficient information about the response of cotton and peanut to different irrigation scheduling techniques when all water applications are completely controlled throughout the growing season. An understanding of the response of the individual cultivars to water deficit is also important to be able to simulate cotton and peanut growth and to estimate water needs for irrigation.

The main goals of this study were to evaluate the application of the CSM-CROPGRO-Cotton and -Peanut models as a tool for irrigation scheduling and to determine the impact of different irrigations treatments on cotton and peanut growth, development and yield.

Materials and Methods

Two experiments were conducted in four rainout shelters, located at the Griffin Campus of The University of Georgia. Cotton was grown in 2005 and peanut was grown in 2006. The cotton cultivar DP 555 BG/RR was planted on May 17, 2005. In each rainout shelter, one irrigation treatment was applied. Each treatment had three replicates, corresponding to three individual rows. The rainout shelters were 12 m long and 4.6 m wide. The CSM-CROPGRO-Cotton model was used to define the treatments by estimating when to irrigate and how much water to apply. The irrigation event was triggered when the actual soil water content in the effective root zone dropped below a specific threshold of the available water content (AWC) and then irrigation was applied until the soil water reached 100% of AWC. The irrigation treatments corresponded to 30%, 40%, 60% and 90% of the irrigation threshold (IT). Thus, the 30% IT was the least irrigated treatment and the 90% IT was the most irrigated treatment. The plant population for cotton was 111,000 plants per hectare. There were 5 rows spaced 0.9 m apart in each rainout shelter, with the two external rows as border rows. Plant spacing was 0.1 m and the planting depth was 0.03 m. Fertilization was conducted following the recommendations based on the results of the soil analysis. Pests were controlled with specific chemical applications. A plant growth regulator (mepiquat pentaborate) was applied at the flowering stage (July 20) with a dose of 1.1 kg ha^{-1}.

The peanut cultivar Georgia Green was planted on May 22, 2006. A similar methodology to the cotton experiment was used for peanut using the CSM-CROPGRO-Peanut model to define the treatments by estimating when to irrigate and the amount of water to apply. The plant population for peanut was 222,000 plants per hectare. The rows were spaced 0.9 m apart, plant spacing was 0.05 m and the planting depth was 0.04

m. Fertilization was conducted following the recommendations based on the results of the soil analysis.

Soil physical and chemical analysis was conducted at depths of 0.05, 0.15, 0.3, 0.6 and 0.9 m. The soil was characterized by its high sand content (92%) in the profile. For both experiments, the soil water content was monitored with Time-Domain-Reflectometry (TDR) and with a soil profile probe (PR2/6, Delta-T Devices, Ltd.). The TDR probes were 0.3 m long and probes were installed vertically while the PR2 probe measured the soil water content at depths of 0.1, 0.2, 0.3, 0.4, 0.6, and 1 m. The TDRs and PR2/6 probe were connected to separate data loggers to allow for continuous monitoring of soil moisture.

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 of cotton, the boll position on the stem, the number of squares and bolls, and boll and lint weight were recorded. For both crops, growth analysis samples were collected for 1 m of linear row, approximately every 18 days. All plants were cut at the base and the individual plant components were separated and oven dried at 70^{o}C until constant weight and then weighed. For the final harvest, 3 m of linear row was manually cut for each replicate and the 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, seed cotton, the number of bolls at harvest, peanut pod yield, the number of pod, and aboveground biomass at harvest for both crops using the SAS-GLM procedure (SAS Institute, 2001).

Results

Cotton

For 2005, the total amount of water applied through irrigation for the entire growing season, from planting to harvest was 272 mm for the 30% IT, 345 mm for the 40% IT treatment, 610 mm for the 60% IT treatment, and 729 mm for the 90% IT treatment (Figure 1a). The 40% IT was irrigated, on average, every 6 days, while the

World Environmental and Water Resources Congress 2007

60% and 90% were irrigated, on average, every 2.2 and 1.8 days, respectively. The irrigation depth used by the CROPGRO-Cotton model was increased according to the development of the crop, starting with 10 cm at planting and reaching a 40 cm depth at flowering (Figure 1 b).

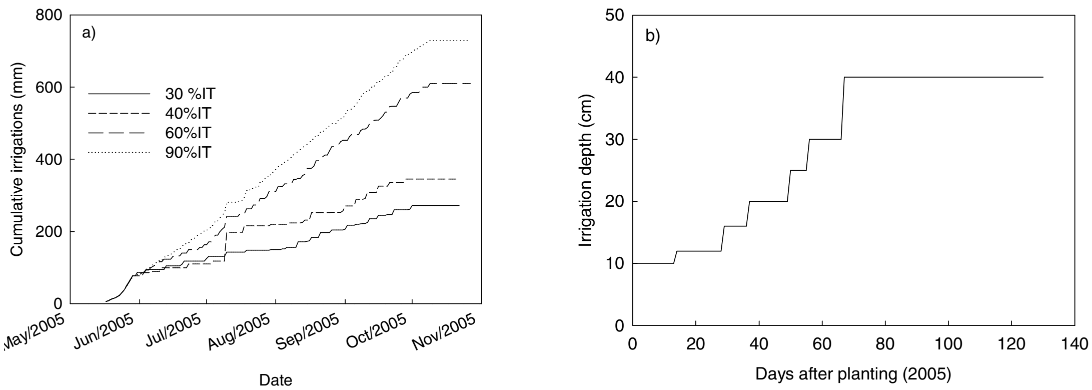

Figure 1. Cumulative irrigation (a) and irrigation management depth (b) for cotton (2005).

The lowest seed cotton yield was obtained with the IT of 30% (453 kg ha^{-1}), followed by the IT of 40% (1738 kg ha^{-1}); these treatments were significantly different from the IT of 60% and 90% (Table 1). 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 6.7% (Table 1). However, the 40% treatment was significantly affected by the low soil water content and the yield for this treatment was, on average, only 60% of the yield obtained with the 60% IT treatment. The aboveground biomass at harvest was significantly low for the 30% and 40% IT.

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Table 1. Lint yield, seed cotton yield, the number of bolls, and aboveground biomass at harvest for cotton grown under different irrigation treatments in 2005.

Irrigation Threshold	Lint yield ($kg\ ha^{-1}$)	Seed cotton yield ($kg\ ha^{-1}$)	Boll number ($\#\ m^{-2}$)	Final Biomass ($kg\ ha^{-1}$)
30% IT	213 (c)	453 (c)	15 (c)	1116 (c)
40% IT	778 (b)	1738 (b)	46 (b)	3996 (b)
60% IT	1316 (a)	2850 (a)	70 (a)	5742 (a)
90% IT	1410 (a)	3016 (a)	73 (a)	6229 (a)

Means followed by a different letter are statistically different ($P \leq 0.05$).

Peanut

For 2006, the cumulative irrigation for the entire growing season was 254 mm for the 30% IT, 417 mm for the 40% IT, 620 mm for the 60% IT and 682 mm for the 90% IT treatment (Figure 2a). The 40% IT treatment was irrigated, on average, every 4 days, while the 60% and 90% IT treatments were irrigated, on average, every 2.6 and 1.8 days, respectively. The irrigation management depth increased according to the development of the crop in order to improve the irrigation scheduling of the CSM-CROPGRO-Peanut model, starting with 10 cm and reaching a final depth of 40 cm (Figure 2b).

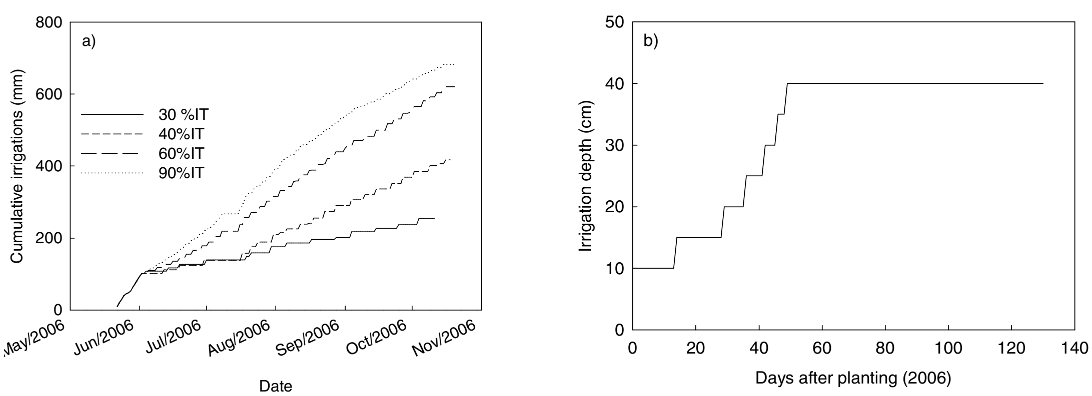

Figure 2. Cumulative irrigation (a) and irrigation management depth (b) for peanut (2006).

The dry weight pod yield (seeds plus shells) for the 30% IT treatment was very low (115 kg ha^{-1}). For the other treatments, the pod yield ranged from 1966 kg ha^{-1} for the IT of 40% to 4899 kg ha^{-1} for the IT of 90% (Table 2). The significantly higher pod yield for the 90% IT treatment could be explained by the high pod number for this treatment. There were no significant difference in aboveground biomass at harvest for the irrigation treatments of 40%, 60% and 90%.

Table 2. Pod yield, pod number, and aboveground biomass at harvest for peanut grown under different irrigation treatments in 2006.

Irrigation Threshold	Pod yield (kg ha^{-1})	Pod number (# m^{-2})	Final Biomass (kg ha^{-1})
30% IT	115 (d)	50 (c)	1084 (b)
40% IT	1966 (c)	425 (b)	3860 (a)
60% IT	3627 (b)	553 (ab)	3874 (a)
90% IT	4899 (a)	622 (a)	4479 (a)

Means followed by a different letter are statistically different ($P \leq 0.05$).

Conclusions

Cotton and peanut growth and development were affected by the different irrigation treatments. The method used permitted us to quantify, with accuracy, the effect of the different irrigation treatments on cotton and peanut growth and development. For cotton, the highest lint yield was found for the treatments of 60 and 90% IT. The 60% IT would conserve water compared to the 90% irrigation threshold level. For peanut, the 90% IT determined the highest pod yield and pod number per unit of land. This study showed that the dynamic crop growth models CSM-CROPGRO-Cotton and -Peanut are promising tools 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 and -Peanut models with the results obtained from these two experiments and also the evaluation of the model with data from farmers' fields 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 and regional level.

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