# IRRIGATION SCHEDULING FOR COTTON USING SOIL MOISTURE SENSORS, SMARTPHONE APPS, AND TRADITIONAL METHODS

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## Abstract

The goal of the work reported here was to compare three different irrigation scheduling strategies in two different tillage systems (conservation and conventional). The three irrigation scheduling strategies were the University of Georgia Checkbook Method for Cotton, the SmartIrrigation Cotton App and the University of Georgia Smart Sensor Array (UGA SSA). The study was conducted during the 2015 growing season at the University of Georgia's Stripling Irrigation Research Park near Camilla. The growing season was unusually wet with more than 23in of rain. Rainfed plots had the highest yields and highest water use efficiency and in this rainy year, irrigation suppressed yield. The major conclusion of the study was that we still have much to learn about the timing of irrigation during wet years.

## Introduction

Cotton is one of the most important crops in the USA. It is grown in 17 US states from Virginia to California with production area ranging from 5.1 to 6.3 million ha. Cotton is an intensively managed crop. It requires careful nitrogen applications to prevent rank growth and plant growth regulators (PGRs) to maintain a balance between vegetative and reproductive growth. Moreover, the use of defoliants at the end of each growing season is necessary to allow the mechanized harvesting (Vellidis et al. 2009; 2011). Approximately 40% of U.S cotton is currently produced under irrigated conditions. In Georgia, approximately half of the cotton acreage is irrigated. Because irrigation water is becoming limited in many cotton growing areas such as the Texas high plains, Arizona, and California, and competition for water is increasing rapidly in areas normally associated with plentiful water resources, many cotton producers and the organizations representing cotton producers are interested in irrigation scheduling strategies which improve water use efficiency.

The most recent National Agricultural Statistical Service Farm and Ranch Survey indicates that fewer than 20% of producers use any type of science-based irrigation scheduling at all. The vast majority of producers still rely either on a fixed schedule or on visual cues of plant stress such as wilting and typically, producers will apply a standard amount (for example 2.5 cm) at each irrigation event. As a result, both the timing and depths of irrigation may be inappropriate and may lead to yield, nutrient, and soil losses. Vories et al. (2006) found that improper timing of irrigation on cotton can result in yield losses of between USD 370/ha to USD 1850/ac.

To address this issue, a large number of techniques and tools have been developed to assist producers to estimate when and how much water to apply to crops. The goal of the work reported here was to compare three different irrigation scheduling strategies developed by the University of Georgia in two different tillage systems (conservation and conventional) with four different cultivars. The three irrigation scheduling strategies were the University of Georgia Checkbook Method for Cotton, the SmartIrrigation Cotton App and the University of Georgia Smart Sensor Array (UGA SSA) and range from low to high technology solutions.

### University of Georgia Checkbook Method for Cotton

The checkbook method is based on extensive irrigation studies and typically tabulates the amount of water a crop needs during each week of its life-cycle. Producers subtract the amount of precipitation received from the weekly requirements and add the remainder via irrigation. Table 1 presents the University of Georgia Extension recommendations for cotton. The Checkbook Method does not account for environmental conditions.

Table 1. University of Georgia Extension cotton irrigation schedule suggested for high yields (UGA Cotton Team, 2015).

| Crop Stage | Inches/Week | Inches/Day |
|---|---|---|
| Week beginning at 1st bloom | 1 | 0.15 |
| 2nd week after 1st bloom | 1.5 | 0.22 |
| 3rd week after 1st bloom | 2 | 0.30 |
| 4th week after 1st bloom | 2 | 0.30 |
| 5th week after 1st bloom | 1.5 | 0.22 |
| 6th week after 1st bloom | 1.5 | 0.22 |
| 7th week and beyond | 1 | 0.15 |

**SmartIrrigation Cotton App**

The SmartIrrigation Cotton App is an interactive ET-based soil water balance model that operates on a smartphone platform (Vellidis et al., 2014; 2015) (Figure 1). It uses meteorological data, soil parameters, crop phenology, crop coefficients, and irrigation applications to estimate root zone soil water deficits in terms of inches of water and percent of total. The Cotton App provides these two pieces of information to the user. The model does not directly deliver irrigation application recommendations. However, the user can utilize the estimated root zone soil water deficits to make appropriate irrigation decisions. In this study, an estimated root zone soil water deficit of 50% was used to trigger irrigation. The Cotton App was released in 2014. During 2015 it was used by 233 users to irrigate 520 unique fields in Georgia and Florida.

**The University of Georgia Smart Sensor Array (UGA SSA)**

The UGA SSA consists of smart sensor nodes and a base station. The term sensor node refers to the combination of electronics and sensor probes installed within a field including a circuit board, a radio frequency (RF) transmitter, soil moisture sensors and temperature sensors. Each sensor probe includes up to three Watermark® (Irrometer, Riverside, California, USA) soil moisture sensors and up to two thermocouples for measuring soil and/or canopy temperature (Vellidis et al., 2013; Liakos et al., 2015). The three Watermark® sensors are integrated into a probe as shown in Figure 2. In this study, the probes contained sensors at 8, 16, and 24 inches. Soil moisture is measured in terms of


Figure 1. Screen shots of the SmartIrrigation Cotton App which show from left to right the main user interface screen which contains the estimated root zone soil water deficit, one of the setup screens on which the user selects the closest weather station and the soil type, and two notifications. Notifications are pushed to the user whenever action is needed such as irrigation or when there is a phenological change in the crop's growth stage.

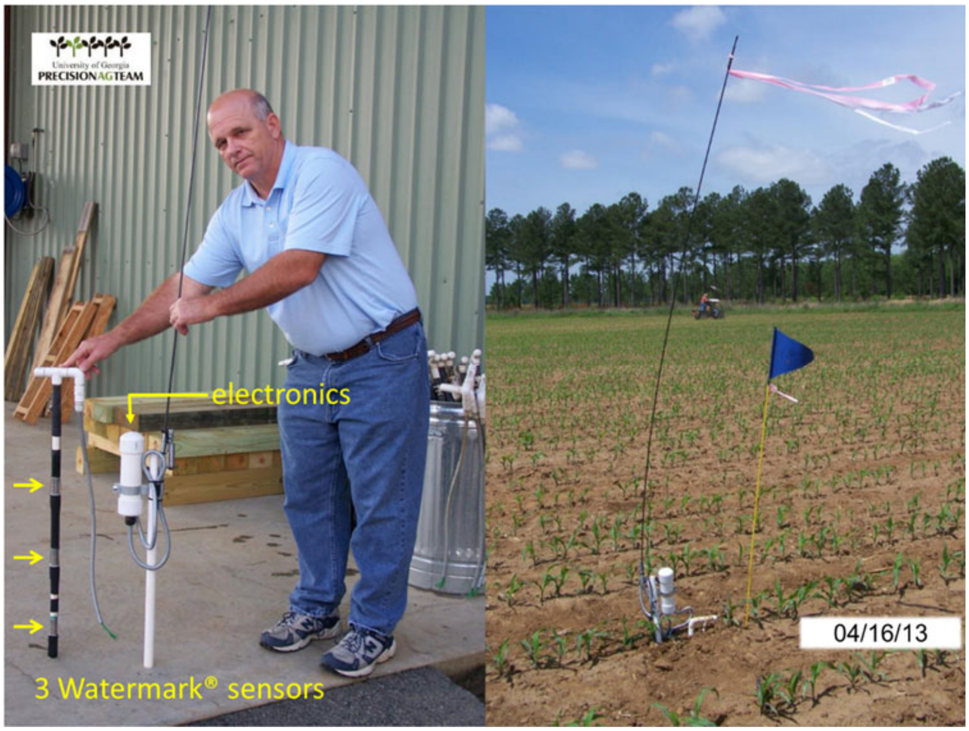


Figure 2. A UGA SSA smart sensor node consists of a sensor probe and an electronics package. Each sensor probe includes up to three Watermark® soil moisture sensors. The data are transmitted from the node wirelessly with a spring loaded antenna which is flexible and allows farm vehicles to pass directly over the sensor node. Each sensor node operates on two AA batteries which typically last about 140 days when sending the data at one hour intervals.

soil water tension (potential) and reported in units of kPa. At the center of each field, a base station receives the data from all nodes at hourly intervals. A base station may support up to 60 nodes. The base station transmits the data via cellular modem hourly to a web-based interface which allow users to visualize their soil moisture data and to make decisions about irrigation. An addition to seeing data from each individual sensor within a probe, users can also view a weighted average of the three sensors on the probe. The weighting function changes over time. By the beginning of the reproductive stage, the weighting function is (0.5×kPa at 8in)+(0.3×kPa at 16in)+(0.2×kPa at 24in). In this study, a weighted average of 50kPa was used to trigger irrigation.

## Material and Methods

### Description of the Study

The study was conducted at the University of Georgia's C.M. Stripling Irrigation Research Park near Camilla in southwestern Georgia using a randomized complete block design. Twenty-seven plots, each 50ft long × 48ft wide (16 rows, 36in spacing) were used (Figure 3). Twelve of the plots were in conventional tillage and 15 in conservation tillage. When the study was designed, we planned to evaluate four different irrigation scheduling strategies (treatments) each with three conventional tillage replicates and three conservation tillage replicates. However, there were technical difficulties with one of the strategies and as mentioned above, we implemented three strategies: the Checkbook Method, the Cotton App, and the UGA SSA. In addition, three conservation tillage plots were used as a control rainfed treatment.

Within each of the plots, only the innermost 8 rows were used for plant growth and yield measurements. The outermost four rows on each side of the plot were buffer rows (Figure 3). During 2015, four different varieties were planted in each plot with each variety occupying two rows. Varietal differences will not be discussed in this paper. Yields and water use efficiencies will be reported only for irrigation scheduling treatments. The plots were irrigated with a variable rate irrigation (VRI) lateral that moved from left to right and right to left in Figure 3. The VRI controls allowed nine individual irrigation zones which were aligned with the plots as shown in Figure 3. This allowed us to irrigate each plot individually if necessary or in any combination. In thus study, 0.75in were applied at each irrigation

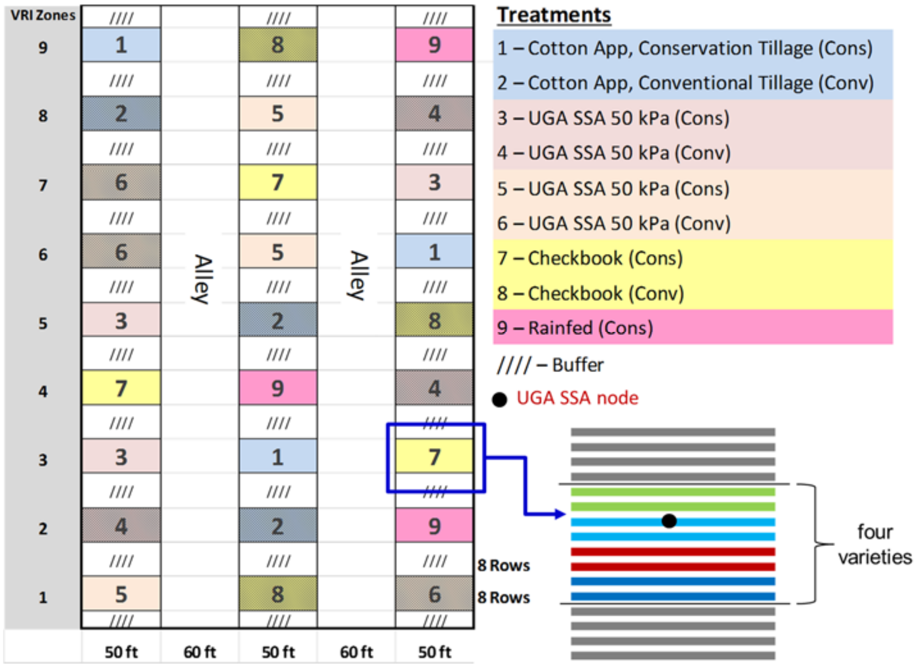


Figure 3. Plot layout and treatments for the 2015 irrigation scheduling study conducted at UGA's Stripling Irrigation Research Park.

event. A UGA SSA sensor node was installed in the same variety in approximately the center of each plot as indicated by the solid black circle in Figure 3 to monitor soil moisture during the growing season.

**Irrigation Scheduling**

Cotton was planted on 20 May 2015. Half an inch of irrigation water was applied following planting on all 27 plots to ensure germination. There was rain at regular intervals through early July (Figure 4) and the first irrigation event occurred on 13 July. Treatments were irrigated when the corresponding scheduling method indicated that irrigation

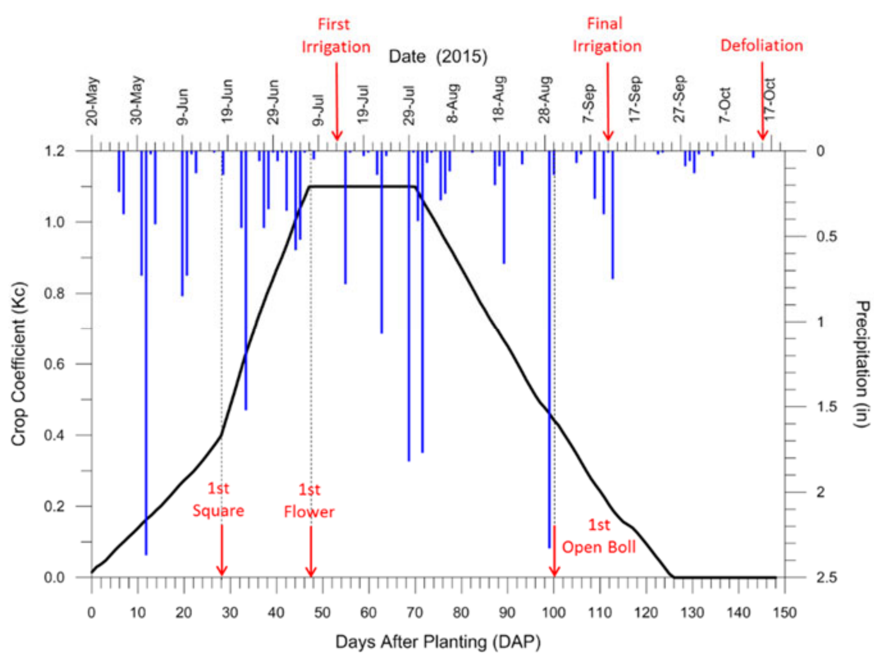


Figure 4. Precipitation during the 2015 growing season superimposed over the cotton crop coefficient curve used by the Cotton App. Much of the precipitation occurred during the period most critical for achieving high yields.

was needed Monday-Friday. Plots were not irrigated on Saturday-Sunday. The final irrigation was applied on 14 September. Checkbook plots, regardless of tillage treatment, were all irrigated at the same time.

The Cotton App does not currently contain an option for conservation tillage. The Cotton App allows the user to select the representative soil type of the field ranging from sand to clay in seven increments (Figure 1). The soil at the site is a Lucy loamy sand. Conservation tillage was simulated within the Cotton App by selecting a sandy loam soil. The conventional tillage plots were simulated by selecting a sand soil. The three Cotton App conventional tillage plots and the three Cotton App conservation tillage plots were represented as different "fields" within the Cotton App and irrigated separately based on the recommendations for each field.

The UGA SSA plots were each irrigated individually when the weighted soil water tension reported by the UGA SSA node in that plot approached 50kPa. Although this is not the traditional way to irrigate replicated plots, the UGA SSA was designed to measure soil moisture conditions in individual irrigation management zones (IMZs) and drive variable rate irrigation. So the purpose of including the UGA SSA in this study was to determine if better overall performance could be achieved by scheduling irrigation using this paradigm.

**Harvest**

The plots were defoliated on 15 October and harvested on 18 November. The cotton was harvested with a two row cotton picker equipped with a bagging mechanism. The yield from the two rows of each variety (Figure 3) was bagged and weighed individually. For this paper, the weights of the four bags/varieties of each plot were added and assigned as the yield of the plot. Ginning data were not available for this paper and a 40% turnout was assumed for all varieties.

## Results and Discussion

**Yields**

The timing and amounts of precipitation received during the growing season appear to have been ideal as the rainfed plots produced the largest mean yields (1760lb lint/ac, 3.67ba/ac) and exceeded the mean yields of all the irrigation scheduling treatments (Figure 5). This occurred with several other irrigation scheduling studies in Georgia and other southeastern states during 2015. The differences between the highest (rainfed) and lowest (Checkbook conservation

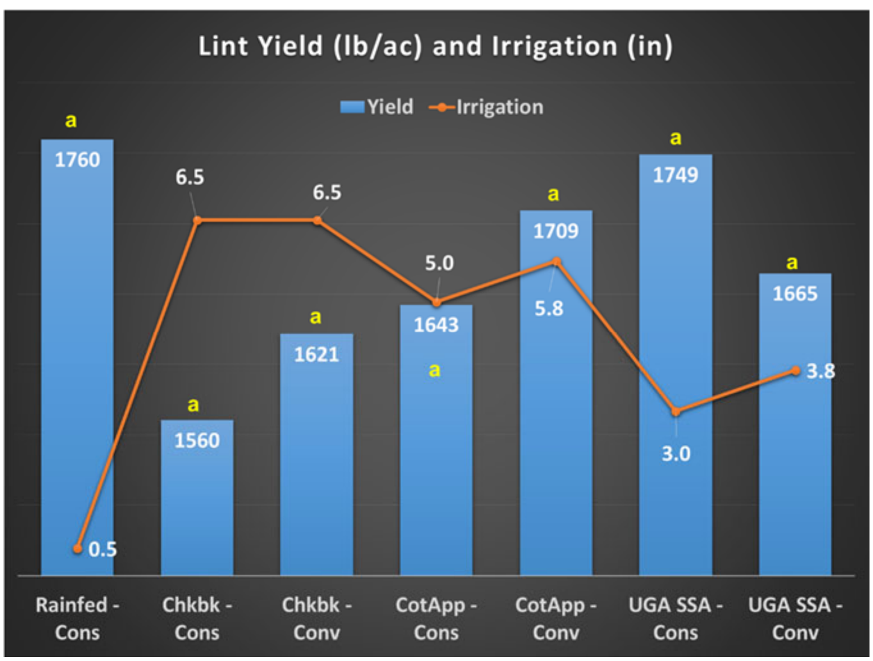


Figure 5. Mean lint yield (blue bars) and irrigation water applied for each of the irrigation scheduling treatments used in the study. A half inch of irrigation water was applied to all treatments after planting to ensure germination. Yellow letters over the bars indicate no statistically significance differences between treatments.

tillage) treatment means was 200lb lint/ac however there were no statistically significant differences between the treatments because of the large variability between plots of each treatment. Table 2 presents yields from the individual

Table 2. Yields from individual plots of the treatments in which the plots within a treatment all received the same amount of irrigation at the same time. The "Difference" column presents the difference between the lowest yielding plot in that treatment and the other two plots of the treatment.

| **Treatment** | **Plot** | **Irrigation (in)** | **Rain+Irrig (in)** | **Seed Cotton (lb/ac)** | **Lint (ba/ac)** | **Difference (lb)** | **Difference (%)** |
|---|---|---|---|---|---|---|---|
| **Rainfed - Cons** | 313-9 | 0.5 | 23.2 | 4320 | 3.60 | 232 | 6% |
| | 328-9 | 0.5 | 23.2 | 4792 | 3.99 | 704 | 17% |
| | 336-9 | 0.5 | 23.2 | 4087 | 3.41 | | |
| | Mean | 0.5 | 23.2 | 4400 | 3.67 | | |
| **Chkbk - Cons** | 318-7 | 6.5 | 29.2 | 4066 | 3.39 | 465 | 13% |
| | 327-7 | 6.5 | 29.2 | 4037 | 3.36 | 436 | 12% |
| | 333-7 | 6.5 | 29.2 | 3601 | 3.00 | | |
| | Mean | 6.5 | 29.2 | 3901 | 3.25 | | |
| **Chkbk - Conv** | 312-7 | 6.5 | 29.2 | 4240 | 3.53 | 552 | 15% |
| | 326-7 | 6.5 | 29.2 | 4233 | 3.53 | 545 | 15% |
| | 338-7 | 6.5 | 29.2 | 3688 | 3.07 | | |
| | Mean | 6.5 | 29.2 | 4054 | 3.38 | | |
| **CotApp - Cons** | 311-1 | 5.0 | 27.7 | 3833 | 3.19 | | |
| | 323-1 | 5.0 | 27.7 | 4283 | 3.57 | 450 | 12% |
| | 332-1 | 5.0 | 27.7 | 4204 | 3.50 | 370 | 10% |
| | Mean | 5.0 | 27.7 | 4107 | 3.42 | | |
| **CotApp - Conv** | 314-2 | 5.8 | 28.4 | 4073 | 3.39 | | |
| | 325-2 | 5.8 | 28.4 | 4523 | 3.77 | 450 | 11% |
| | 335-2 | 5.8 | 28.4 | 4225 | 3.52 | 152 | 4% |
| | Mean | 5.8 | 28.4 | 4274 | 3.56 | | |

plots of the treatments in which the plots within a treatment all received the same amount of irrigation at the same time. The "Difference" column presents the difference between the lowest yielding plot in that treatment and the other two plots of the treatment. Yield differences between plots of the same treatment ranged from 4% (152lb/ac) to 17% (704lb/ac). It is interesting to note that the largest difference between plots of the same treatment occurred in the rainfed treatment which indicates that something other than irrigation water management was the driver of the intra-treatment differences. In general, a drier soil profile resulted in higher yields. Figure 7 compares soil water tension curves as recorded by UGA SSA sensor nodes in the two highest yielding plots and two of the lowest yielding plots. It is interesting to note that even though the UGA SSA-scheduled plot (bottom left in Figure 7) received more irrigation water than the Checkbook plots, it had a drier profile. One explanation for this observation is that a cotton plant or plants immediately around the sensor in this plot were more vigorous or that their root systems affected the sensor more than in other plots.

To better understand the intra-treatment variability we compared the response of individual plots with respect to their location within the field. Figure 8 presents the soil water tension curves of the three rainfed plots. The lowest yielding and wettest plot (plot 313) was in the upper part of the field (Figure 8). All the plots, regardless of irrigation scheduling treatment that were located in the upper part of the field were consistently wetter than the rest of the field. Although we have not investigated transient or perched water tables in this field, it is possible that because of the wetter-than-normal year, perched water tables may have affected these plots.

**Water Use Efficiency (WUE)**

WUE was calculated in terms of pounds of lint produced per acre per inch of water used. Water used is defined as the total of precipitation and irrigation. The rainfed treatment had the highest WUE at 76lb/ac-in because it resulted in the highest yields in addition to using the least amount of water (Figure 9). The lowest WUE efficiency was the Checkbook conservation tillage treatment at 53.5lb/ac-in. There were statistically significant difference between the WUEs of the treatments as indicated in Figure 9.

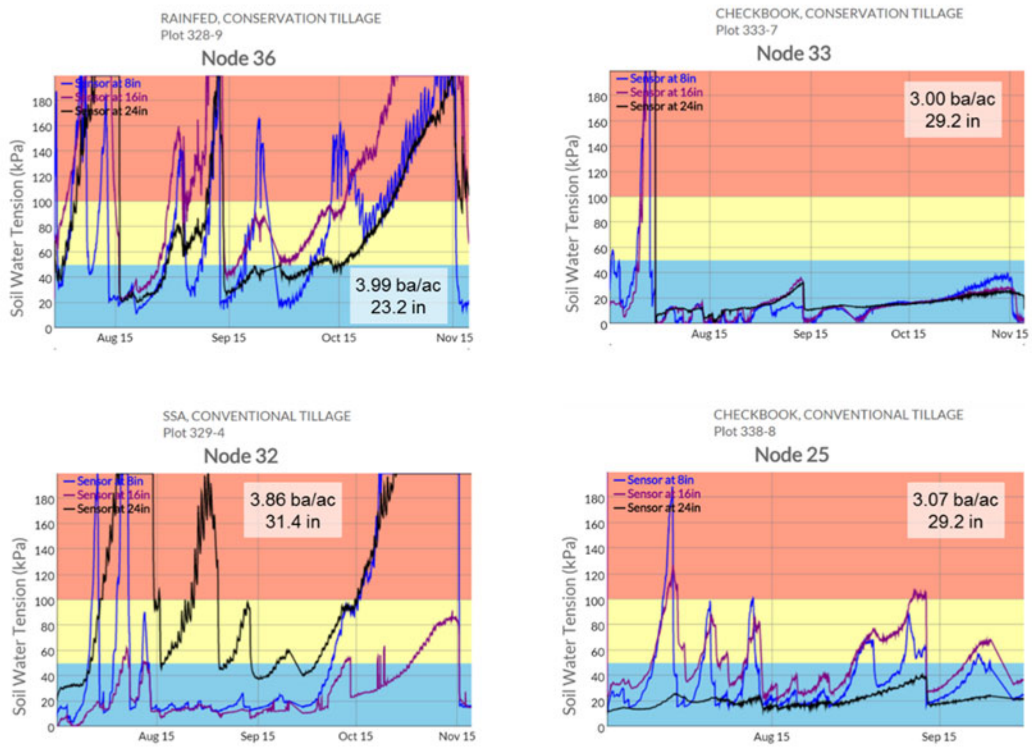


Figure 7. Comparison of soil water tension curves as recorded by UGA SSA sensor nodes in the two highest yielding plots and two of the lowest yielding plots.

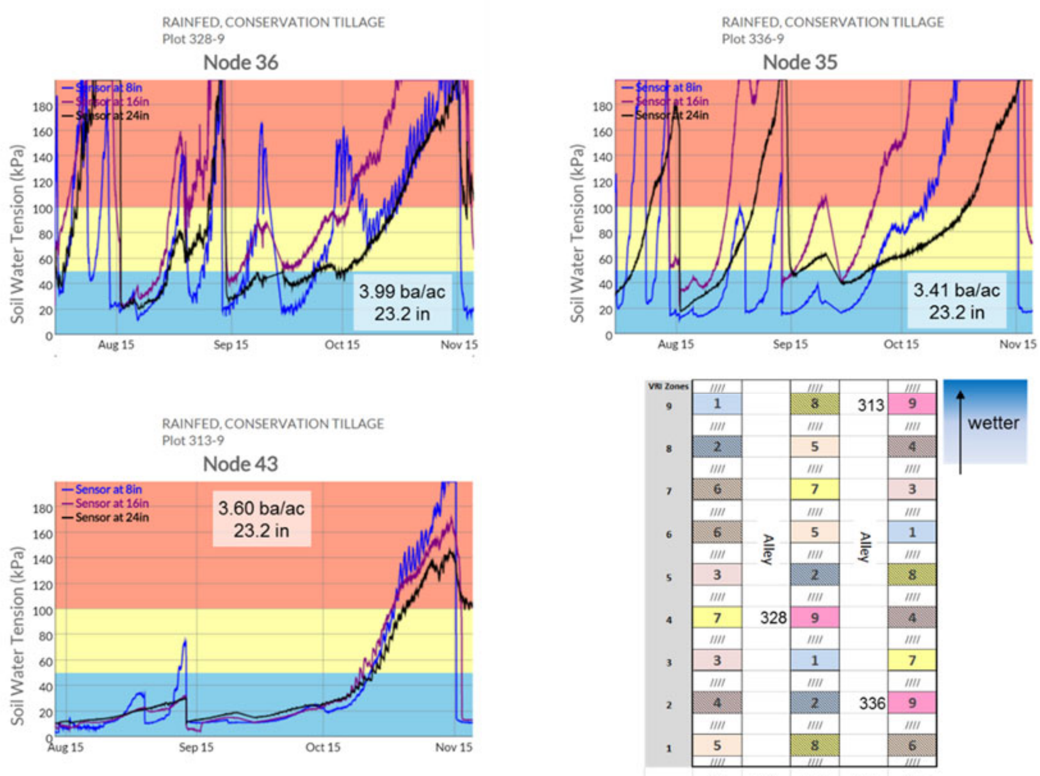


Figure 8. Soil water tension curves of the three rainfed plots. The lowest yielding and wettest plot (plot 313) was in the upper part of the field. All plots, regardless of irrigation scheduling treatment that were located in the upper part of the field were consistently wetter than the rest of the field

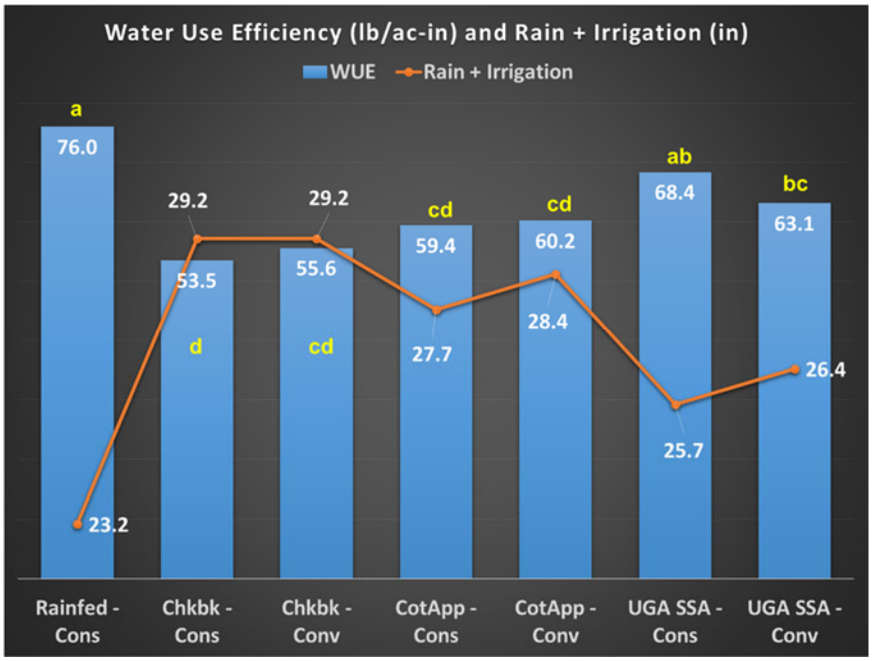


Figure 9. Water use efficiency (blue bars) and total water applied (line) for each of the irrigation scheduling treatments used in the study. Yellow letters over the bars indicate statistically significance differences between treatments.

## Conclusions

The data from this study and other irrigation scheduling studies in southeastern states during 2015 showed that rainfed cotton outperformed all irrigation scheduling methods. This was also observed by producers with both irrigated and rainfed fields. These observations indicate that additional research is needed to better understand the timing and benefit of irrigation during wet years. In this study, the variability of soil moisture and yields within plots of the same treatment prevented statistically significant differences between the mean yields of the different irrigation scheduling treatments. However, general observations indicated that during 2015, drier soil profiles resulted in higher yields.

Because we were able to install soil moisture sensors in all 27 of our plots, we were able to carefully evaluate soil water tension patterns for the entire growing season. Soil water tension patterns are quite different for plots of the same treatment. At this point, the reasons are not clear but could be related to subsurface hydrology and/or vigor of plants surrounding the sensors. More research is needed to understand how placement of sensors, particularly in commercial production settings, drive irrigation scheduling decisions.

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