A Smartphone App for Precision Irrigation Scheduling in Cotton

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Abstract

For farmers to adopt irrigation scheduling tools on a large scale, the tools must be easy-to-use, cheap, provide the users with actionable information when irrigation is required, are accessible from smartphone or tablet platforms, and can be used for conventional or precision irrigation. This study describes a Smartphone App for scheduling irrigation in cotton. The App and the irrigation model which drive it are described in detail. Calibration and evaluation results are also presented. The evaluation of the Smartphone App in commercial cotton fields proved that it can estimate soil water balance accurately during the growing season. Plot studies showed that the App resulted in equal or higher yields while using significantly less water than other irrigation scheduling studies. The App can also be used to schedule irrigation for individual irrigation management zones within a field.

Keywords: crop coefficient, meteorological data, model, yield, root zone

Introduction

One of the most important crops in the USA is cotton. It is grown in 17 states from Virginia to California with the annual production area ranging from 5.1 to 6.3 Mha. Cotton is an intensively managed crop which requires varying amounts of water during its phenological stages to maximize yield. Approximately 40% of U.S cotton is currently produced under irrigated conditions. 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.

Researchers understood that cotton's water needs are a function of phenological stage. For example, McGuckin et al. (1987) optimized irrigation scheduling using accumulated heat units and not a chronological framework. Researchers also realized that evapotranspiration (ET) is an important factor in estimating daily plant water use. Several irrigation scheduling tools have been developed which use estimated crop ET (ETc) to develop irrigation recommendations. These models typically multiply a crop coefficient (Kc) with an estimated reference ET (ETo) to calculate ETc.

Although models which schedule irrigation by using ETc to estimate the volume of water which must be replaced have been used extensively, they do not take into account the moisture available in the soil profile and do not calculate a soil water balance. This

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sometimes leads to over-application of irrigation water. Incorporating soil water balance increases the number of parameters needed as well as the complexity of the model. Dejonge et al. (2012) used ET along with other meteorological, soil, crop management activities, and the crops' phenological stage to simulate environmental stresses, soil water balance, crop growth and yield in a dynamic agroecosystem model. The SiSPAT model (Braud et al, 2013) was created to estimate irrigation needs in southern France. The model estimates the heat and water transfer in the soil while taking into account the water vapor transfer, the soil heterogeneity, the root size, the interception of rainfall by the vegetation and weather variables. Five-Core (Chopart et al, 2007), an irrigation scheduling model for sugarcane, is another model which computes daily water balance. AquaCrop (Steduto et al, 2009) is a more complex model which requires more soil and weather data than the other models in order to estimate crop development and soil water balance.

The crop simulation models described in the previous paragraph are excellent research tools. However, the models are not suited for use by crop consultants, farmers or other professionals making daily irrigation decisions because they are complex, may require calibration, and require the user to collect a variety of input parameters. Migliaccio et al. (2013) described a suite of smartphone apps for scheduling irrigation including apps for citrus, strawberries, urban turf and cotton. The citrus, strawberry and urban turf apps were released in 2013. This paper describes the SmartIrrigation Cotton App and the model behind the app in detail. The Cotton App was released in 2014 and is available at www.smartirrigationapps.org.

Material and Methods

The Cotton App is an interactive ET-based soil water balance model. It uses meteorological data, soil parameters, crop phenology, crop coefficients and irrigation applications to estimate root zone soil water deficits (RZSWD) in terms of depth of soil water and percent of total available soil water. The 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 RZSWD to make appropriate irrigation decisions.

ET and Kc

The model uses meteorological data to calculate reference ET (ETo) using the Penman–Monteith equation (Allen et al, 1998). The model's daily ETo is a five-day running average of calculated ETo. The model then uses a crop coefficient (Kc) to estimate crop ET (ETc). The crop coefficient (Kc) is widely used to estimate crop water use and to schedule irrigation and changes during the life cycle of the plant. A Kc of 1.0 matches the ET of well-watered grass. For annual crops, Kc typically begins with small values after emergence and increases to 1.0 or above when the crop has the greatest water demand. Kc decreases as crops reach maturity and begin to senesce. Perry and Barnes (2012) described crop coefficient functions for cotton in southeastern states. Information from this work and the authors' experience were used for developing a prototype Kc curve for the Cotton App model. Field experiments took place in 2012 and 2013 to calibrate and validate the Kc curve for conditions typical of southern Georgia and northern Florida. Changes in the model's Kc values are driven by accumulated heat units commonly referred to as growing degree days (GDDs). GDDs are calculated using equation 1.

$$GDD = \frac{T_{max}+T_{min}}{2} - T_{base} \qquad (1)$$

The GDD calculation for cotton crops considers that T_{base} is equal to 15.5°C. Any temperature below T_{base} is equal to T_{base} and consequently the GDD is equal to zero. Additionally, daily average air temperature higher than 37.7 °C is considered equal to 37.7°C because growth is limited above this temperature. The specific GDDs required for each phenological stage of cotton are derived from Ritchie et al. (2004).

Soil Water Balance

The model calculates ETc to estimate the daily crop water use. ETc, measured precipitation and irrigation are then used to estimate the plant available soil water. Plant available soil water is a function of soil water holding capacity and current rooting depth. In the model, the user can select from one of seven generic soil types ranging from sand to clay. Each soil type has a pre-assigned soil water holding capacity. As the plant rooting system grows, the soil depth from where the plants can extract water also increases. In the model, the initial rooting zone depth is 15.2cm and increases by 0.7cm/day until it reaches a maximum depth of 76.2cm. At emergence, the soil profile from 0cm to 76.2cm is assumed to be at 85% of maximum plant available soil water holding capacity. The daily plant available soil water is calculated by subtracting the previous day's ETc from the previous day's plant available soil water and adding any precipitation or irrigation events. The model uses an effectiveness factor of 85% for all sprinkler irrigation systems to account for evaporation and drift before the water droplets reach the soil. The model assumes that 90% of measured precipitation reaches the soil to account for canopy interception and other possible losses. All these parameters are used to calculate root zone soil water deficit (RZSWD) in inches and % RZSWD.

Description of the Smart Irrigation Cotton App

The Cotton App was designed to provide the most accurate, real-time information that is available without requiring users to collect data for parameterizing the model. The App was also designed to require minimum user input during its operation. When necessary, input is solicited by sending notifications. It is not necessary for the user to check the App regularly. Finally, the App provides ready-to-use output.

Meteorological data, and especially accurate precipitation data, are critical to the Cotton App. In its current version, the Cotton App pulls meteorological data from the Georgia Automated Environmental Monitoring Network (GAEMN) and the Florida Automated Weather Network (FAWN) and can therefore be used effectively in these two states.

The Cotton App recommends irrigation whenever RZSWD exceeds 50% of plant available soil water. Notifications are sent to the user as the 50% threshold approaches. If the user acts upon the recommendation, it is up to the user to add the irrigation event to the Cotton App. This can be a default irrigation depth (supplied by the user upon first use of the model) or the amount irrigated if different from the default depth.

The Cotton App was developed using the official tools and programming language provided by Apple® (Objective C and iOS SDK) and Google® (Java and Android SDK). The Cotton App communicates with servers and databases via specific developed web services that return data in Json (JavaScript Object Notation) format. Moreover code scripts are scheduled in the Crontab program of a UNIX based server to retrieve, process and store observed weather data from FAWN and GAEMN public API's (application programing interface) to run the models needed for the water balance calculation. Critical information is sent to users via push notifications using Apple Push Notification Service (APNS) and Google Cloud Messaging (GCM) protocols. Notifications include those mentioned above and changes in plant phenological stage.

Model Calibration and Validation

We used replicated field plots to calibrate the model and producer fields to validate the model. During 2012 and 2013, we used large plots at the University of Georgia's Stripling Irrigation Research Park (SIRP) and 5 producer fields all of which were located in southwestern Georgia and in close proximity to Florida. Both the plots and fields were instrumented with the University of Georgia Smart Sensor Array (UGA SSA). The UGA SSA is a fully wireless sensing system which measures soil water tension at 0.3, 40.6, and 61 cm using Watermark™ sensors (Vellidis et al., 2013). We used the soil water tension data from the plots in 2012 and 2013 to retroactively calibrate the model's Kc curve so that 50% RZSWD coincided with a weighted root zone average soil water tension of approximately 40 kPa to 50 kPa. Our experience with irrigation scheduling indicates that this range is a good irrigation threshold for cotton. We used the model adjustments made following the 2012 growing season to schedule irrigation in the plots during 2013. Plots were in conservation tillage and conventional tillage. Because the model does not currently account for tillage systems, both types were irrigated in the same way.

Each producer field was instrumented with up to 10 nodes of the UGA SSA so we had soil water tension data from 50 or more individual locations. Because of the large soil variability in these fields, soil water tension data within fields was also quite variable. The individual farmers managed irrigation using information from the UGA SSA but they did not always adhere to the 40 kPa to 50 kPa threshold and their soils were occasionally much drier. Our validation process consisted of retroactively running the Cotton App model for each of these 50 locations using local precipitation and irrigation depths as recorded by an onsite tipping bucket rain gage connected to a Hobo™ data logger and observing the pattern of the RZSWD. Our benchmark was for 50% RZSWD to coincide with a weighted root zone average soil water tension of approximately 40 kPa to 50 kPa.

Results and Discussion

Figure 1 presents the calibration results from the conservation and conventional tillage plots at SIRP for 2012 (top) and 2013 (bottom). In 2012, the plots were irrigated with the model containing a cotton Kc curved derived from the literature while in 2013 the irrigation model contained a Kc curve which was calibrated using data from the 2012 plot studies. Figure 2 presents the 2013 validation results from three commercial cotton fields in southern Georgia, USA. Validation was done after the model was further calibrated with the 2013 plot studies.

To quantify the frequency at which the Cotton App RZSWD matched measured soil water tension, we performed a Pearson correlation analysis between these two variables using SPSS v.16 software (SPSS Inc, USA). The results were good with correlation in the 0.7 to 0.8 range. In addition, we measured how many times RZSWD exceeded 50% and weighted soil water tension exceeded 40 kPa and 50 kPa. The results for the fields presented in Figure 2 are shown in Table 1. In 2013, the Cotton App was compared to three other scheduling methods at SIRP; the soil water tension-based Irrigator Pro model (requires sensors), the Crop Water Stress Index method (requires canopy temperatures), and the University of Georgia Cooperative Extension Service Checkbook method. The

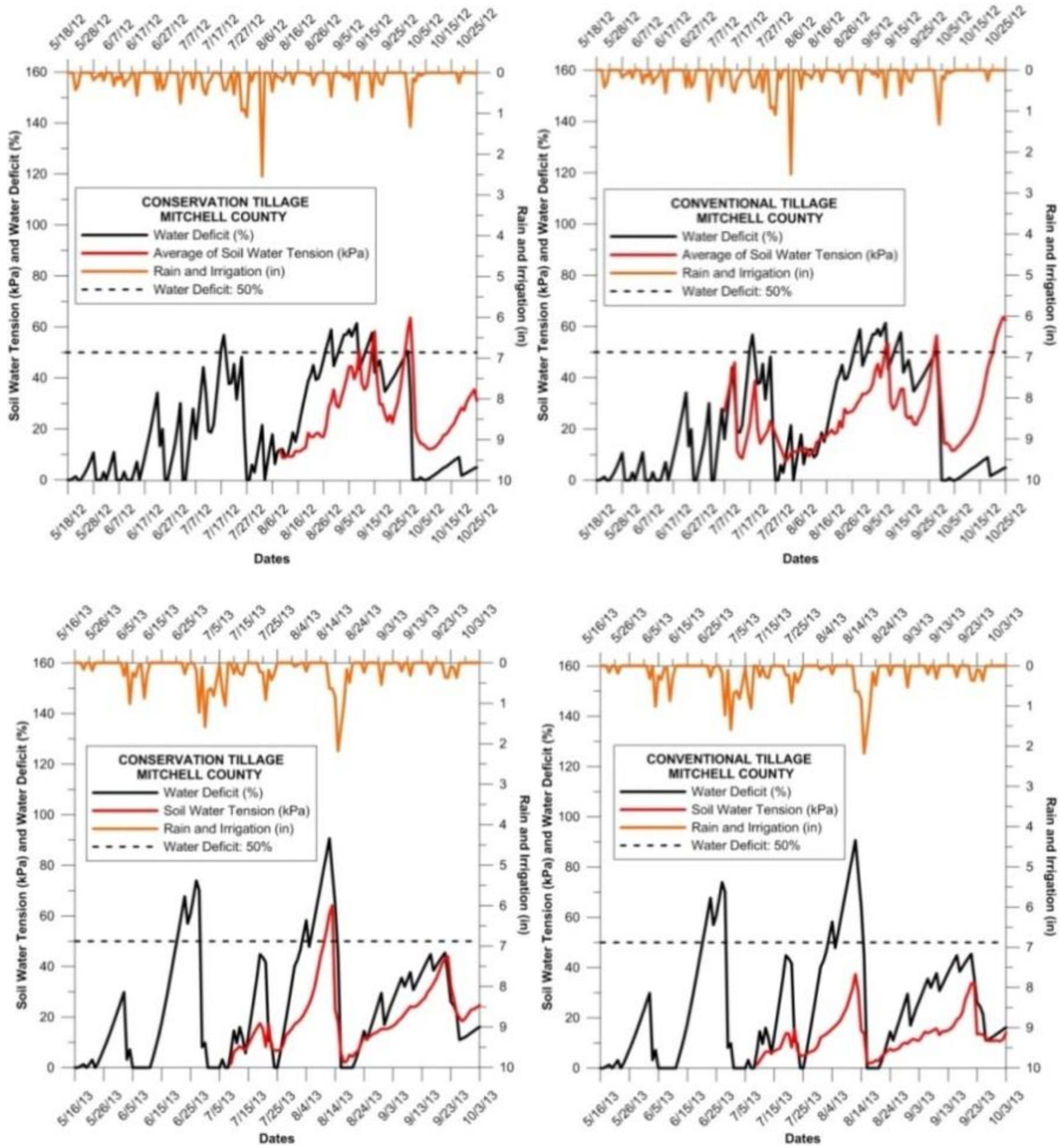
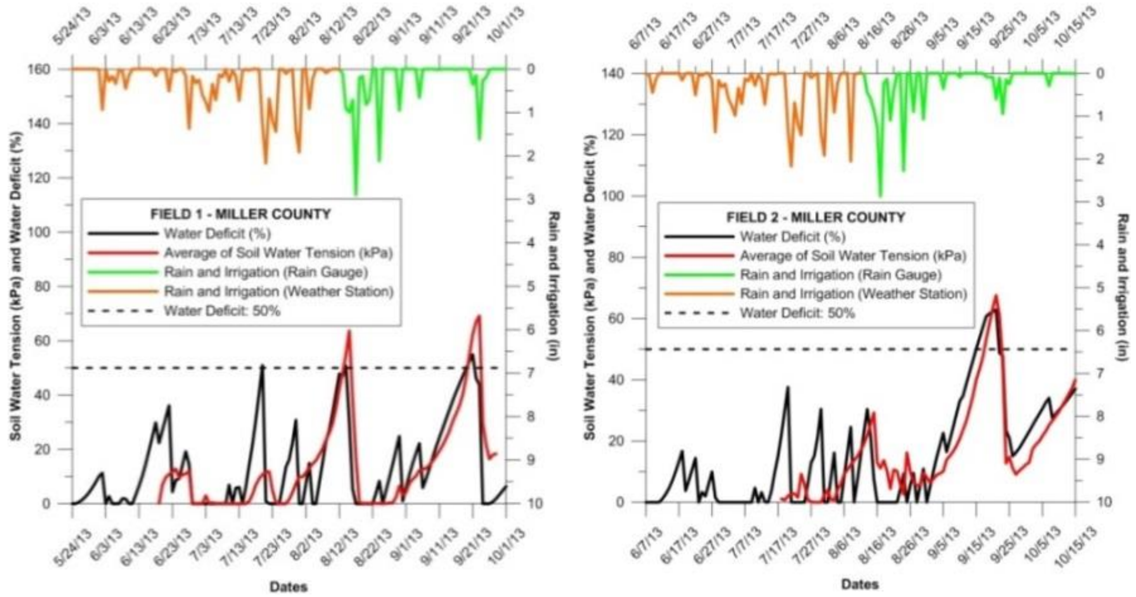


Figure 1. Comparison of weighted soil water tension and % RZSWD in conservation and conventional tillage plots at SIRP in 2012 (top) and 2013(bottom). The soil water tension curves are the weighted average of measured soil water tension at 20.3cm (50% weighting factor), 40.6cm (30% weighting factor), and 61cm (20% weighting factor).

Table 1. Correlation between %RZSWD and weighted soil water tension. Frequency of observed %RZSWD values higher than 50% and soil water tension values higher than 40kPa and 50kPa.

Field No.	Correlation %RZSWD with Soil Water Tension*	RZSWD >50%	Soil Water Tension >50kPa	Soil Water Tension >40kPa
Field 1 (2013)	0.708	2	6	10
Field 2 (2013)	0.822	7	5	10
Field 3 (2013)	0.871	11	12	27

*Significant at the 0.01 level.



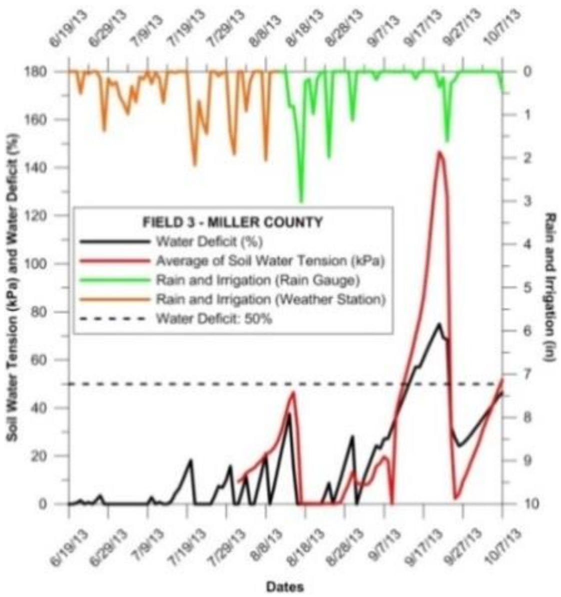


Figure 2. Comparison of weighted soil water tension and percent Root Zone Soil Water Deficit (% RZSWD) in three commercial cotton fields during 2013. The % RZSWD curve shown here reflects changes made in the Kc and rooting depth to better calibrate the model based upon data collected from plot studies at SIRP during the 2013 growing season.

Checkbook method does not take ET into account. It schedules irrigation by replacing the maximum expected weekly crop water use (a function of weeks after planting) minus measured precipitation and is thus a very conservative scheduling tool. Table 2 present the yield and the amount of irrigation water used for each method. The 2013 growing season was unusually rainy so even the rainfed treatments performed well.

Use of the Cotton App for precision irrigation

For precision or variable rate irrigation (VRI) to be fully enabled, irrigation scheduling information must be available for each irrigation management zone (IMZ) delineated within a field. Although VRI has not been widely adopted yet, it has been evaluated and demonstrated in conjunction with center pivot irrigation systems at several locations by researchers and growers in the USA including southwestern Georgia (Vellidis et al., 2013). In these cases, soil moisture sensors have been used to develop irrigation recommendations for IMZs. The need for many sensors within a field to characterize soil moisture variability has been an inhibiting factor for the adoption of VRI because of the

Table 2. Yield and water use results from irrigation scheduling experiment at the Stripling Irrigation Research Park during 2013. Variety = DP 1252 B2RF, Planting Date = 16 May 2013, Harvest Date = 15 Nov 2013, Rainfall = 696 mm.

Method	Conservation Tillage		Conventional Tillage	
	Lint Yield (kg/ha)	Water Use (mm)	Lint Yield (kg/ha)	Water Use (mm)
Checkbook	1513	323	1289	310
Cotton App	1664	76	1411	76
CWSI*	1603	127	1463	58
Irrigator Pro	1631	71	1345	109
Rainfed	1625	38	-	-

*Crop Water Stress Index

expense involved but also because sensors must be installed after planting and removed prior to harvest. The Cotton App provides an opportunity to implement VRI without using sensors.

Under conventional use, the Cotton App provides recommendations for an unlimited number of fields. To register a field, the user provides the geographic co-ordinates, selects one of the seven available generic soil types and identifies the operational characteristics of the irrigation system. This is done only once. In a similar fashion, a user can register individual IMZs within a field provided that the IMZs have different soil types. The Cotton App treats the IMZs as individual fields and provides notifications as each IMZ approaches a RZSWD of 50%. However, farmers will not operate a center pivot irrigation system to irrigate each IMZ individually and at different times from the others. Instead, the farmer prefers to initiate irrigation when the first notification is received and apply varying amounts of water to each of the IMZs so as to replenish soil moisture to a predetermined level. To achieve this using the Cotton App, the user must retrieve the current RZSWD for each IMZ. This is easily done in less than a minute as the architecture of the Cotton App allows users to view individual fields/IMZs with the swipe of a finger across the touchscreen of the smartphone (Figure 3). The user can then convert the RZSWD of each IMZ into an irrigation application amount which can in turn be programmed into the irrigation system's VRI controller.

Conclusions

The goal of the work described here was to develop an interactive ET-based irrigation scheduling tool for cotton that can be used for conventional and precision irrigation. The model variables include soil type, meteorological data, irrigation events, phenological stage of the crop and a crop coefficient. Extensive validation of the model in commercial fields proved that root zone soil water deficit is estimated accurately by the model. Perhaps more importantly, Figures 1 and 2 show that the pattern of % RZSWD closely follows the pattern of measured soil water tension. Fields located near weather stations and/or equipped with rain gauges had considerably higher Pearson correlation r values as an accurate estimate of precipitation is critical to estimating the RZSWD well.

The comparison of yields resulting from different irrigation treatments were used to assess the performance of the Cotton App in ways that matter the most to farmers. 2013 was unusually wet with 696 mm of rainfall during the growing season. Nevertheless, the results indicate that scheduling irrigation with the Cotton App compared very favorably to sensor-based scheduling tools and significantly outperformed the Checkbook method

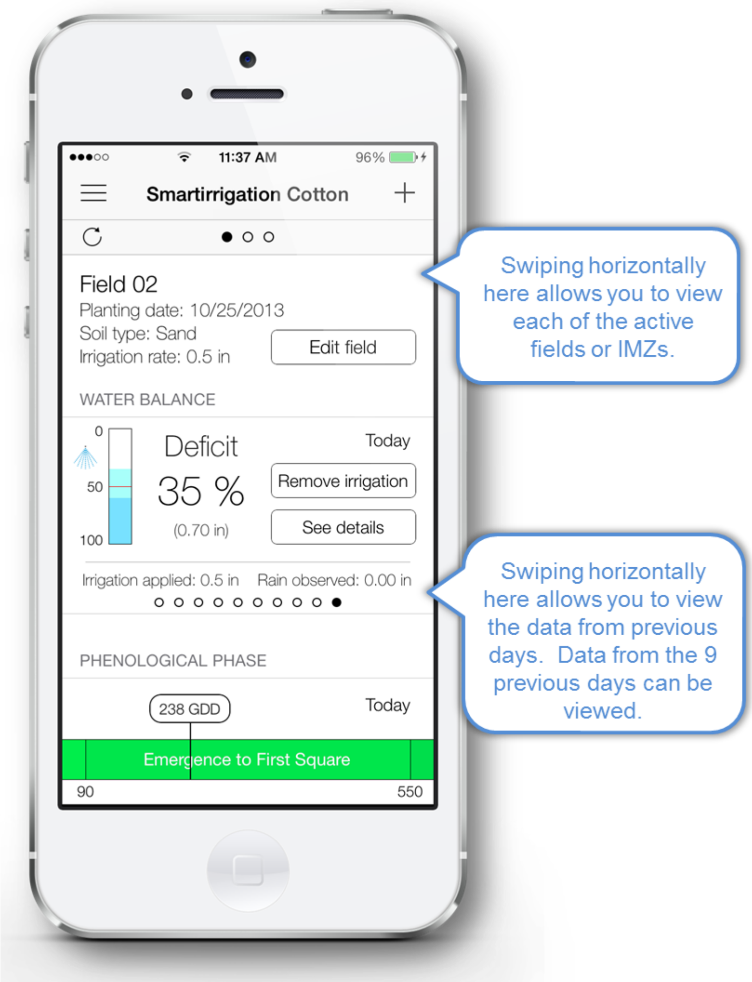


Figure 3. Screenshot of the SmartIrrigation Cotton App indicating how users can view data from multiple fields or zones as well as from up to nine previous days. The RZSWD is displayed both graphically

recommended by the University of Georgia Cooperative Extension Service in both yield and water used. This is an indicator that irrigation scheduling tools can also be effective in years with ample precipitation.

The SmartIrrigation Cotton App can be used to determine how much water to apply to individual IMZs within a field by registering each zone as a field. The user can easily read the RZSWD for each zone from the Cotton App but must then manually enter the corresponding irrigation amount in the irrigation system's VRI controller.

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