One of the most important crops in the USA is cotton. It is grown in 17 US states from Virginia to California with the annual production acreage ranging from 5.1 to 6.3 million ha. Cotton is an intensively managed crop which requires varying amounts of water during its phenological (growth) stages to maximize yield. Researchers quickly understood that cotton's water needs are a function of phenological stage (Figure 1). Researchers also realized that evapotranspiration (ET) is also 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 use a crop coefficient (Kc) to calculate ETc from a reference ET (ETo) as shown in equation 1. Crop coefficients will be discussed in detail below.

$$ET_c = ETo \times Kc \tag{1}$$

<u>ET and Kc</u>

The model uses meteorological data to calculate reference ET (ETo) using the Penman–Monteith equation (Allen et al. 1998). This method, also known as FAO 56, is commonly accepted for irrigation scheduling. The model's daily ETo is a 5-day running average of calculated ETo. The model then uses a crop coefficient (Kc) to estimate crop ET (ETc) as shown in equation 1. The crop coefficient (Kc) is widely used to estimate crop water use and to schedule irrigation. The concept was introduced by Jensen (1968). Kc changes during the life cycle of the plant. For annual crops, it 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. Figure 1 presents measured water use and crop coefficient functions for cotton in Mississippi and Louisiana (Perry and Barnes, 2012). We used information from these and other studies to develop a prototype Kc curve for southern Georgia and northern Florida conditions. The curve was calibrated and validated with a series of plot and field studies in 2012 and 2013. In the model, changes in Kc are driven by accumulated heat units commonly referred to as growing degree days (GDDs) as shown in Figure 2. GDDs are calculated using equation 2.

$$GDD = \frac{T_{max}+T_{min}}{2} - T_{base} \tag{2}$$

For cotton, T_{base} is 60°F. Any temperature below T_{base} is set to T_{base} before calculating the average. Table 1 presents GDDs used to trigger Kc changes in the model and the corresponding phenological stages. GDDs required for phenological stages are derived from Ritchie et al. (2004).

<u>Soil Water Balance</u>

ETc is used by the model to estimate daily crop water use. ETc, measured precipitation and irrigation are then used to estimate the plant available soil water as shown in Figure 3. Plant available soil water is a function of the soils plant water holding capacity which is determined from USDA-NRCS soils data and current rooting depth. As the plants rooting system grows, the depth of the profile from which the plant can extract water also increases. In the model, the

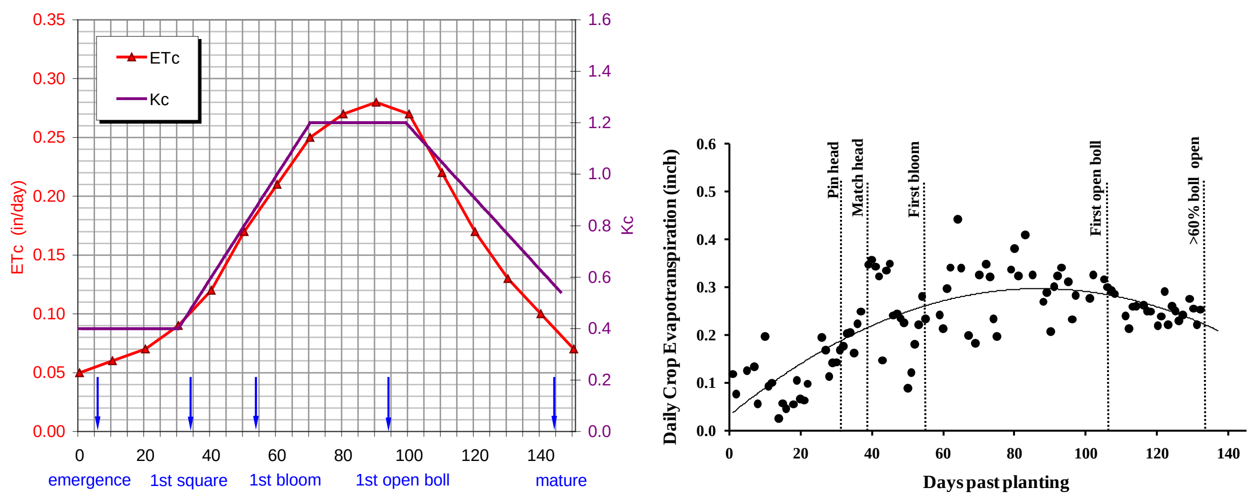

Figure 1. Water use and crop coefficient function for cotton in Stoneville, Mississippi (left) and measured crop water use (ETc) from a cotton field in Louisiana over the growing season (left) (Perry and Barnes, 2012).

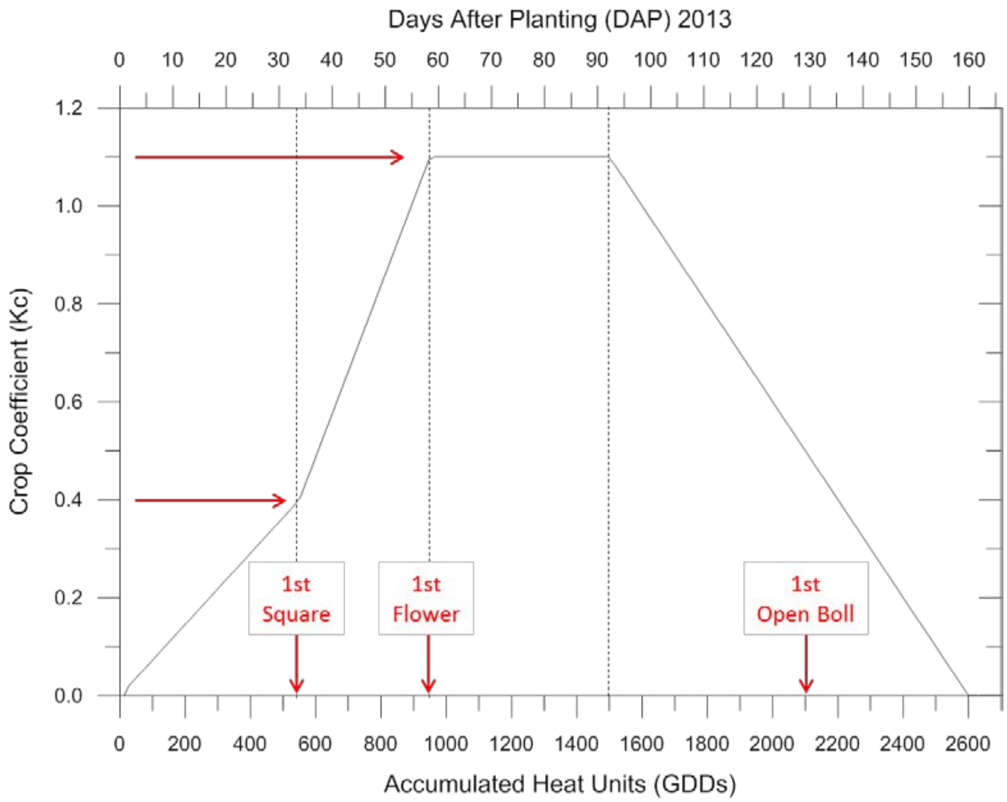

Figure 2. Kc curve used in the model. Maximum Kc is 1.1 which is maintained between 950 and 1500 GDDs. A major inflection point and Kc rate change occurs at 550 GDDs.

initial rooting zone depth is 6in and increases by 0.3in/day until it reaches a maximum depth of 30in. At emergence, the soil profile from 0 to 30in is assumed to be at 90% of maximum plant available soil water holding capacity. Today's plant available soil water is calculated by subtracting yesterday's ETc from yesterday's plant available soil water and adding any precipitation or irrigation measured. The model uses an effectiveness factor of 85% for all sprinkler irrigation events 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 (Figure 3).

Smartphone App Development

Our design principles for the Cotton App were that it should provide the most accurate, site-specific, real-time information we could offer the user. In addition, the App would require minimum user input which, when necessary, we would solicit from the user by sending notifications. It would not be necessary for the user to check the App regularly. Finally the App would provide ready-to-use output and be engaging.

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) (http://www.georgiaweather.net/) and the Florida Automated Weather Network (FAWN) (http://fawn.ifas.ufl.edu/). GAEMN maintains 83 automated meteorological stations while FAWN maintains 35 stations thus limiting the Cotton App's footprint to these two states. We are however evaluating the National Weather Service's 4km grid data as a possible alternative source of information which would greatly increase the Cotton App's footprint.

The Cotton App recommends irrigation whenever RZSWD exceeds 50%. Notifications are pushed to the user when the 50% threshold is exceeded. The user is notified that an irrigation event was added. The user is required to "add" the irrigation event to the App. The App then credits the default irrigation amount (entered by the user during setup).

DATE	DAP	Crop Coefficient based on GDD (Kc)	ETo (from GAEMN) (in/day)	ETo 5-Day Moving Avg (in/day)	ETc (Kc*ETo avg) (in/day)	Rooting Depth (in)	Available Soil Water (in)	Irrigation Applied (in)	Effective Irrigation (in)	Rain (in)	Effective Rain (in)	Irrigation + Rain (in)	Root Zone Water Deficit (in)	Root Zone Water Deficit (%) (Keep Under 50% to Avoid Stress)
12-Jun-13	27	0.34	0.23	0.17	0.06	14.10	1.55	-	-	-	-	-	0.05	3%
13-Jun-13	28	0.36	0.24	0.18	0.06	14.40	1.58	-	-	-	-	-	0.11	7%
14-Jun-13	29	0.37	0.21	0.20	0.08	14.70	1.62	-	-	-	-	-	0.17	11%
15-Jun-13	30	0.39	0.24	0.23	0.09	15.00	1.65	-	-	-	-	-	0.25	15%
16-Jun-13	31	0.40	0.22	0.23	0.09	15.30	1.68	-	-	-	-	-	0.34	20%
17-Jun-13	32	0.43	0.22	0.23	0.10	15.60	1.72	-	-	-	-	-	0.43	25%
18-Jun-13	33	0.46	0.22	0.22	0.10	15.90	1.75	-	-	-	-	-	0.53	30%
19-Jun-13	34	0.48	0.17	0.22	0.10	16.20	1.78	-	-	-	-	-	0.63	35%
20-Jun-13	35	0.50	0.19	0.21	0.10	16.50	1.82	-	-	-	-	-	0.74	41%
21-Jun-13	36	0.53	0.24	0.21	0.11	16.80	1.85	-	-	-	-	-	0.84	45%
22-Jun-13	37	0.55	0.18	0.20	0.11	17.10	1.88	-	-	-	-	-	0.95	51%
23-Jun-13	38	0.57	0.15	0.18	0.11	17.40	1.91	0.75	0.64	-	-	0.64	1.06	55%
24-Jun-13	39	0.59	0.14	0.18	0.10	17.70	1.95	-	-	-	-	-	0.53	27%
25-Jun-13	40	0.61	0.23	0.19	0.11	18.00	1.98	-	-	-	-	-	0.63	32%
26-Jun-13	41	0.64	0.24	0.19	0.12	18.30	2.01	-	-	-	-	-	0.75	37%
27-Jun-13	42	0.66	0.14	0.18	0.12	18.60	2.05	-	-	0.20	0.18	0.18	0.87	42%
28-Jun-13	43	0.68	0.10	0.17	0.12	18.90	2.08	-	-	1.37	1.23	1.23	0.80	39%
29-Jun-13	44	0.71	0.14	0.17	0.12	19.20	2.11	-	-	0.12	0.11	0.11	0.00	0%
30-Jun-13	45	0.72	0.09	0.14	0.10	19.50	2.15	-	-	1.76	1.59	1.59	0.01	1%

Figure 3. Snapshot of a spreadsheet segment showing several of the model's parameters. Kc is increasing linearly with GDDs. ETo is calculated from the meteorological parameters retrieved from GAEMN. ETc is calculated by multiplying the 5-day moving average of ETo by Kc. Rooting depth is increasing at a rate of 0.3in/day. Root Zone Soil Water Deficit (RZSWD) is increasing steadily until an irrigation event was applied on 23 June when %RZSWD exceeded 50%.

If the user irrigated a different amount than the default value, the user can easily change the irrigation value.

The Cotton App, as well as the companion Citrus, Strawberry, and Urban Turf apps, were designed to operate on the iOS and Android platforms and are available through the Apple and Google stores. Links to the stores are provided at the project website – www.smartirrigationapps.org.

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Click here to Dow nload a PDF of a 2014 Beltwide Cotton Conference paper describing the SmartIrrigation Cotton App.

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