Computers and Electronics in Agriculture 127 (2016) 249–259

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Development and assessment of a smartphone application for irrigation scheduling in cotton

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ARTICLE INFO

Article history:
Received 4 March 2016
Received in revised form 19 May 2016
Accepted 17 June 2016

Keywords:
Crop coefficient
Soil water balance
Phenology
GDDs

ABSTRACT

The goal of this work was to develop an easy-to-use and engaging irrigation scheduling tool for cotton which operates on a smartphone platform. The model which drives the Cotton SmartIrrigation App (Cotton App) is an interactive ET-based soil water balance model. The Cotton App uses meteorological data from weather station networks, soil parameters, crop phenology, crop coefficients, and irrigation applications to estimate root zone soil water deficits (RZSWD) in terms of percent as well as of inches of water. The Cotton App sends notifications to the user when the RZSWD exceeds 40%, when phenological changes occur, and when rain is recorded at the nearest weather station. It operates on both iOS and Android operating systems and was released during March 2014. The soil water balance model was calibrated and validated during 2012 and 2013 using data from replicated plot experiments and commercial fields. The Cotton App was evaluated in field trials for three years and performed well when compared to other irrigation scheduling tools. Its geographical footprint is currently limited to the states of Georgia and Florida, United States, because it is enabled to use meteorological data only from weather station networks in these states. A new version is currently under development which will use national gridded meteorological data sets and allow the Cotton App to be used in most cotton growing areas of the United States.

1. Introduction

Cotton (*Gossypium hirsutum* L.) is the most important fiber crop in the world and one of the most important agronomic crops in the United States where in 2014 it had a production value in excess of USD 5 billion. It is grown in 17 states across the southern half of the United States with the annual production area ranging from 5.1 to 6.3 million ha. Cotton is an intensively managed crop which requires varying amounts of water during its phenological stages to maximize yield (Vellidis et al., 2009, 2011).

In the United States, the cotton crop under irrigation has increased steadily over the past two decades because irrigation serves both to reduce risk of crop loss but also to build resiliency and yield stability. Approximately 40% of U.S. cotton is currently irrigated but 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. As a result, the organizations representing growers are investing in the development of irrigation scheduling tools which improve irrigation water use efficiency. In response, a significant amount of research has been conducted on this topic.

Cotton's water needs are a function of phenological stage (Fig. 1). Evapotranspiration (ET) is also an important factor in estimating cotton's daily water use and several cotton irrigation scheduling tools have been developed which use estimated crop

Abbreviations: ET, evapotranspiration; ETo, reference evapotranspiration; ETc, crop evapotranspiration; FAWN, Florida Automated Weather Network; FRET, forecast reference evapotranspiration; GAEMN, Georgia Automated Environmental Monitoring Network; GDDs, growing degree days; IMZs, irrigation management zones; Kc, crop coefficient; NOAA NWS, National Oceanic and Atmospheric Administration National Weather Service; RZSWD, root zone soil water deficit; SIRP, University of Georgia's Stripling Irrigation Research Park; UGA SSA, University of Georgia Smart Sensor Array.

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http://dx.doi.org/10.1016/j.compag.2016.06.021
0168-1699/

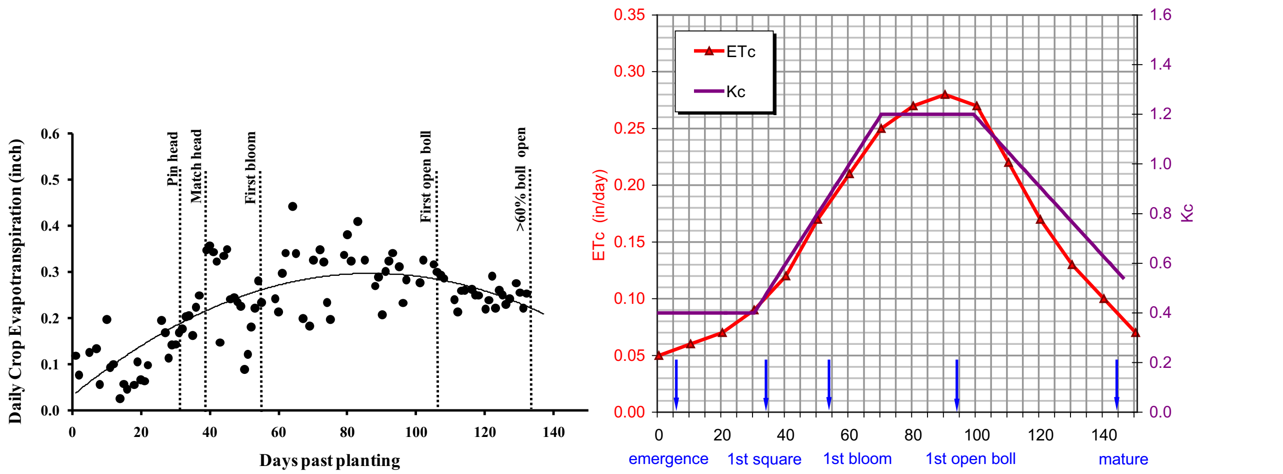

Fig. 1. Measured crop water use (ETc) from a cotton field in Louisiana over the growing season (left) and water use and crop coefficient curve for cotton in Stoneville, Mississippi (right) (Perry and Barnes, 2012).

ET (ETc) to develop irrigation recommendations. These models typically use a crop coefficient (Kc) which represents the crops phonological stage to calculate ETc from a reference ET (ETo) as shown in Eq. (1) (Jensen, 1968; Doorenbos and Pruitt, 1975, 1977; Burman et al., 1980a, 1980b; Allen et al., 1998).

$$ETc = ETo \times Kc \quad (1)$$

Models which use only ETc to estimate irrigation requirements are simple and easy-to-use but they do not consider moisture available in the soil profile which sometimes leads to over-application of irrigation water. Incorporating soil water balance increases accuracy but also increases the number of parameters needed as well as the complexity of the model.

The increasing availability of online environmental measurements required for ET-based irrigation schedules (i.e., temperature, solar radiation, relative humidity, wind speed, and rainfall) published by local, state, and regional weather station networks has facilitated the development of a wide variety of web-based irrigation scheduling tools. The University of Florida's PeanutFARM (Field Agronomic Resource Manager; http://agronomy.ifas.ufl.edu/peanutfarm) is a web-based irrigation scheduling tool for southeastern peanut production. PeanutFARM uses cumulative adjusted growing degree days (aGDD) (Rowland et al., 2006) and ET from weather station networks to estimate crop water use and provides daily irrigation recommendations. Washington State University's AgWeatherNet (http://weather.wsu.edu) uses meteorological data from nine weather station networks in the western United States and Canada to develop irrigation scheduling recommendations for 56 agronomic and horticultural crops. The University of Arkansas Irrigation Scheduler (http://irrigweb.uaex.edu) also develops irrigation scheduling for several agronomic crops including cotton. It has been available in various forms for 20 years and recently became available online. All of these web-based tools require regular, sometimes daily interaction with the user and/or can be accessed effectively only via a desktop or laptop computer which makes them cumbersome to use consistently throughout the growing season.

Recent technological advances that allow for widespread internet access through handheld devices such as tablets and smartphones provide a novel platform on which to deliver sophisticated yet easy-to-use ET-based irrigation scheduling tools. Smartphone tools, typically referred to as smartphone applications or apps, are being developed at exponential rates for every imaginable use. The functionality of an app differs from a web tool in that apps are with the user at all times since they reside on the smartphone, are readily accessible, and engage the user through notifications (Migliaccio et al., 2015, 2016). Some apps use notifications, similar to text messages, to prompt users to respond to critical events and eliminate the need to interact with the tool on a daily basis.

Agricultural researchers and extension specialists are entering the fray and offering apps for a variety of uses ranging from pest identification to irrigation scheduling. Migliaccio et al. (2016) presented a suite of SmartIrrigation apps which were recently released to provide real-time irrigation schedules for avocado, citrus, cotton, peanut, strawberry, turf, and vegetables. Information about and links to download these apps can be found at www.smartirrigationapps.org. This paper describes the Cotton SmartIrrigation App (hereafter referred to as the Cotton App) which was released in 2014. Our objectives were to develop a novel ET-based irrigation scheduling tool for cotton that requires minimal user interaction, is delivered to the user on a smartphone platform, and outperforms many other irrigation scheduling tools.

2. Materials and methods

The model which drives 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 percent and inches of water and provides these two pieces of information to the user. The model does not deliver irrigation application recommendations. However, the user may utilize the RZSWD information to make appropriate irrigation decisions.

2.1. ET and Kc

The model uses meteorological data to calculate ETo using the Penman–Monteith equation (Allen et al., 1998). This method, also known as FAO 56, is widely accepted for irrigation scheduling. The model then uses Kc to estimate ETc as shown in Eq. (1). For annual crops, Kc changes with phenological stage. 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. Fig. 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