Agricultural Water Management 156 (2015) 63–69

Contents lists available at ScienceDirect

Agricultural Water Management

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

Crop water use and stage-specific crop coefficients for irrigated cotton in the mid-south, United States

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ARTICLE INFO

Article history:
Received 10 September 2014
Accepted 29 March 2015
Available online 22 April 2015

Keywords:
ASCE
Crop evapotranspiration
FAO-56
Reference evapotranspiration
Crop coefficient
Weighing lysimeter

ABSTRACT

Regional variations in environmental conditions, cultivars, and management practices necessitate locally derived tools for crop water use estimation and irrigation scheduling. A study was conducted in northeast Louisiana (mid-south US) aimed at estimating daily crop evapotranspiration (ET_c) and reference evapotranspiration (ET_o) and thus, developing local crop coefficient (K_c) curves for irrigated upland cotton. ET_c was determined using paired weighing lysimeters installed near the middle of a 1-ha cotton field and planted with cotton as in the rest of the surrounding field, while ET_o was calculated using the Standardized Reference Evapotranspiration Equation (SREE) developed by the American Society of Civil Engineers (ASCE), using estimates of weather variables from a nearby standard reference weather station. Stage-specific K_c values averaged over 2 years were 0.42, 1.25 and 0.70 for initial, midseason, and end season stages of cotton, respectively. The initial-stage K_c value was approximately 26% lower than the Food and Agricultural Organization (FAO)-adjusted initial K_c value. The mid- and end-season K_c values obtained in the study were approximately 6% and 11% greater, respectively, than the FAO-adjusted K_c values for the corresponding stages. The observed differences among the local stage-specific K_c values (especially at initial growth stage of cotton) and the FAO-adjusted initial K_c values could be attributed to regional variations in environmental conditions, cultivars, and management practices. The ET_c and K_c values obtained from this study provide research-based information for future studies and the development of K_c-based irrigation tools in this region.

1. Introduction

Cotton (*Gossypium hirsutum* L.) is an important commercial crop grown in the mid-south US, including states such as Missouri, Arkansas, Tennessee, Mississippi, and Louisiana (Vories et al., 2007). In 2012, Louisiana was ranked 11th nationwide among cotton-producing states with a majority of its cotton acreage located in the northeastern part of the state (USDA-NASS, 2013). Recently, the significance of irrigation in attaining and sustaining optimum productivity of major crops in this region has been documented. Vories et al. (2007) reported an increase in irrigated agriculture from 3% in 1975 to 58% in 2005 for three mid-south states including Arkansas, Louisiana, and Mississippi. The increasing need and dependence on irrigation, however, is being challenged by the limited knowledge of crop water use in this region as well as excessive groundwater declines in some regions. Due to limited availability of local data on crop water use, research-based information on proper irrigation scheduling to improve crop productivity and water resource management is lacking in the region.

Building a dependable irrigation scheduling tool requires information on crop evapotranspiration (ET_c), which represents the combined processes of water loss through evaporation from soil surface and transpiration from crop surface (Allen et al., 1998). The crop coefficient (K_c) methodology of ET_c estimation was introduced by Jensen (1968) and was further improved by various researchers

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http://dx.doi.org/10.1016/j.agwat.2015.03.022
0378-3774/

subsequently (Doorenbos and Pruitt, 1977; Allen et al., 1998). In this approach, a single crop coefficient (K_c) algorithm is developed for a crop experimentally, which can be multiplied by reference evapotranspiration (ET_o) computed from local microclimatological data to estimate ET_c. This method of ET_c estimation is widely accepted among researchers and consultants and is considered an inexpensive and practical tool for irrigation scheduling (Allen et al., 1998, 2005; Allen and Pereira, 2009; Ko et al., 2009).

The Food and Agricultural Organization (FAO) of the United Nations has provided details on the development and use of K_c values for different crops in different parts of the world (Allen et al., 1998; hereafter referred to as FAO-56). However, site-specific K_c values determined experimentally for different growth stages of cotton have been considerably different from those listed in the FAO-56 paper (Hunsaker, 1999; Grismer, 2002; Farahani et al., 2008; Bezerra et al., 2012). Thus, the use of generalized K_c values listed in FAO-56 has reportedly resulted in considerable differences between estimated ET_c and actual ET_c (Hunsaker et al., 2003; Farahani et al., 2008). Therefore, the development of local-based K_c curves for a more precise crop ET_c estimation is vital.

Due to limited research-based information on cotton water use in the mid-south US, a research project addressing this topic was initiated in northeastern Louisiana. This study employed the use of paired weighing lysimeters to estimate ET_c in an irrigated cotton field. The key objectives of this study were to (1) estimate daily ET_c (or crop water use) and ET_o experimentally, and (2) construct local straight line K_c curves for irrigated upland cotton. Comparison of local K_c values with FAO-K_c values and findings from other studies was also made.

2. Materials and methods

2.1. Project location and study site characteristics

The study site (31° 56′ N and 91° 14′ W) is located at the Louisiana State University Agricultural Center, Northeast Research Station near St. Joseph, Tensas Parish, LA. It is approximately 1.5 km from the Mississippi River at an elevation of approximately 23 m above sea level. The climate of this region is considered humid according to the Thornthwaite classification system (Feddema, 2005); characterized by hot and humid summers and mild winters with the maximum and minimum air temperatures occurring in July and January, respectively, while maximum rainfall occurs in January and March. The study site is within the Upper Mississippi River Alluvial Plain ecoregion (east of the Ouachita River) and common soils include Sharkey clay, Tensas silty clay, Tensas-Sharkey complex, Tunica clay, and Commerce silt loam (LDEQ, 2004, 2011). Agriculture is the primary land use of this region, with cotton, corn, and soybean production accounting for the majority of agricultural land use.

2.2. Weighing lysimeters (installation and calibration)

A description of the weighing lysimeters, including their location, soil, mechanical operation, drainage, and expected suitability for ET_c measurement on Sharkey clay was provided by Clawson et al. (2009). The system consists of paired weighing lysimeters (with inner tanks of 1.5 m long, 1.5 m deep, and 1.0 m wide, resting on load cells within the outer tanks) centered 0.8 m apart on same cotton row. The four load cells of each lysimeter were connected to a Campbell Scientific data logger (CR 3000, Campbell Scientific, Inc., Logan, UT) for measuring changes in lysimeter weights. The same lysimeters used by Clawson et al. (2009) were used in the current study. The lysimeters were transferred to a new location approximately 200 m from the original site in 2008. The field at the new site has a similar soil and soil water regime to the original site. In addition, it has advantages of increased uninterrupted fetch (at least 50 m in all direction) and a consistent near-level slope laser leveled for furrow irrigation. The soil inside the lysimeters was left intact from the original installation. The lysimeters were installed on a crop row approximately 1.0 m wide in the middle of 1-ha field. The lysimeters were calibrated annually at the beginning of each growing season. Calibration was accomplished following the method of Howell et al. (1995) as described by Clawson et al. (2009). The offset and slope of the equation obtained by regressing lysimeter mass against the sum of the output from the four load cells were determined for each lysimeter using best fit regression equation. These were used in the data logger programming to convert raw outputs of load cells (mV V^{-1}) into equivalent masses (kg) during the course of each growing season.

2.3. Reference weather station

Following the procedures set by the American Society of Civil Engineers (ASCE) for the estimation of ET_o from measured weather variables (Allen et al., 2005), all parameters needed for the computation of ET_o were obtained from a reference weather station located approximately 0.25 km from the experimental cotton field. The weather station is located in the middle of a 2-ha Bermuda grass (*Cynodon dactylon* L.) field, with a grass fetch of at least 50 m in all directions. A weather tower was instrumented with all sensors needed for the measurement of wind direction and speed (RM Young, 05103.5 wind monitor), air temperature, and relative humidity (Vaisala, HMP 45 AC), solar radiation (Li-COR, LI200SZ), and net all-wave radiation (Kipp and Zonen, NR lite), all recorded by a data logger (Campbell Scientific, CR 3000). All sensors and instruments were obtained from Campbell Scientific, Inc., Logan, UT. Instruments were calibrated and maintained following the recommendations provided by the manufacturers. The grass reference surface was treated annually with herbicides to reduce the infestation of broadleaf weeds. The field was mowed and flood irrigated periodically.

2.4. Cotton establishment

Lysimeters and the surrounding field were planted with cotton (Stoneville ST 5458 B2RF) on May 11 and May 10, respectively, for the 2010 and 2011 growing seasons. In both years, lysimeters and the immediate surrounding area (four rows on each side of the lysimeters) were hand planted with cotton seed and later thinned to match the field plant density of approximately 130,000 plants ha^{-1}. The rest of the field was planted with a John Deere vacuum planter. In both growing seasons, cotton field was fertilized approximately 3 weeks after emergence with urea ammonium nitrate (UAN) at a rate of 136 kg N ha^{-1}. The immediate area surrounding the lysimeters was fertilized at the rate of 91 kg N ha^{-1}. In 2010, the lysimeters themselves were not fertilized due to a history of vigorous growth consistent with N accumulation. The cotton plants in the surrounding field (laser leveled) were irrigated by furrow method. In conjunction with furrow irrigation, the approximate accumulated ET_c (~80 l of water based on 5 cm water depth for each irrigation event) was replaced manually in each lysimeter using plastic buckets. Irrigation scheduling was accomplished with the aid of tensiometers installed at 30 and 60-cm depths within the field and on the lysimeters. Irrigation was generally applied when soil water potential at 30 cm reached −60 kPa or less, especially within the lysimeters. Pest management was conducted as per Louisiana State University Agricultural Center (LSU AgCenter) recommendations, and all other management practices were typical of those used in northeast Louisiana cotton production.