Cotton Water Requirements in Humid Areas

Daniel K. Fisher
USDA Agricultural Research Service, Stoneville, Mississippi

In the humid Mid-South U.S., cotton irrigation is a challenge because of the variations in rainfall, temperature, and cloudiness during the growing season. Cotton crop characteristics, as well as environmental conditions, determine daily cotton water use. Water use increases gradually from the initial stage and peaks at the mid-season stage. This peak water-use stage coincides with a stage of full canopy and maximum boll load of the cotton plant which is normally in August (a month typically characterized by high air temperature and solar radiation) in the Mid-South.

Evapotranspiration

Cotton uses water throughout its lifecycle through the combined processes of evaporation and transpiration, often referred to as evapotranspiration (ET). Water is removed from the soil when it evaporates from the surface. Significant amounts of evaporation can occur early in the season when plants are small and much of the soil surface is exposed. Water is also removed by the plant as it grows and transpires. This amount increases as the plant increases in size and begins putting on fruit. Since plant growth is dependent on energy from the sun, ET is a function of weather variables (mainly solar radiation, air temperature, humidity, and wind). Other factors influence water use, including soil and crop characteristics, and cultural practices.

ET can vary greatly on a daily basis and throughout the growing season. A hot, windy day places a high environmental demand on the crop, resulting in more transpiration from the plants. If the soil is wet, from a rain or irrigation event, significant amounts of water are evaporated from the soil surface. In contrast, a cloudy day, with cool temperatures and calm winds, provides less energy for the plants to grow, and transpiration and evaporation are reduced.

Daily reference ET, or ETo, is a measure of the evaporative demand of the atmosphere. It represents the amount of water used by a well-watered grass crop, and was devised as a standard method of quantifying environmental demand. Daily ETo values for a growing season at Stoneville, MS, are shown in Figure 1. Daily ETo varied from less than 0.1 in/day early in the season to almost 0.3 in/day at mid-season. Large fluctuations can be observed on a daily basis.

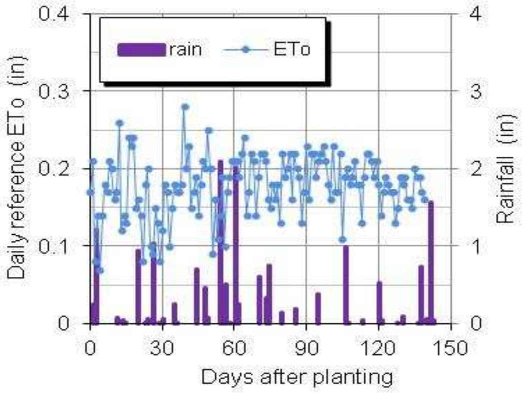

Figure 1. Reference evapotranspiration (ETo) at Stoneville, MS.

While ETo represents the evaporative power of the environment, water use of the crop is of more interest to cotton producers. Crop evapotranspiration, or ETc, consists of the amount of water used by the cotton cropping system, which includes evaporation from the soil surface and transpiration from the cotton plants. ETc, also referred to as crop water use, represents the amount of water needed by the crop growing in the field under the given climatic conditions, which must be supplied by rainfall and/or irrigation.

Measuring Evapotranspiration

ETc, or crop water use, can be measured by several methods, one of which involves growing plants in a weighing lysimeter. The lysimeter, basically a big steel box filled with soil and planted to the crop of interest, is weighed continuously with electronic loadcells. As water is used through the ET process, the weight decreases. The lysimeter measures the weight of water lost during the day, quantifying the daily ETc. Lysimeters have been installed at St. Joseph, LA (Louisiana State University), Stoneville, MS (USDA ARS), and Blackwell, SC (Clemson University) to measure ETc of cotton in the humid southeastern US region.

ETc measurements from the three lysimeter locations are shown in Figures 2, 3, 4, and 5. ETc patterns were similar in the different locations: low rates of water use early in the season, rising to peak water-use 60 - 90 days after planting, then decreasing steadily until harvest. Daily peak water use was slightly higher at St. Joseph and Blackwell, reaching close to 0.4 in/day at times, while remaining less than 0.35 in/day at Stoneville. Average peak water use was approximately 0.28 - 0.35 in/day at the three locations.

Weather can greatly affect crop growth, as shown by comparing Figure 3, showing ETc for the 2003 season, and Figure 5, for 2004. Heavy rain early in the 2004 season delayed crop development and caused excessive soil evaporation. Continued rain and cloudy, cool days then delayed growth and maturity. The crop did develop and produce a good yield, but water-use patterns were different between the two years.

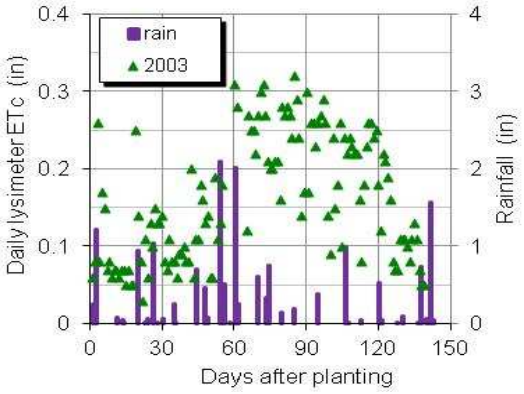

Figure 2. Water use in 2003, Stoneville, MS

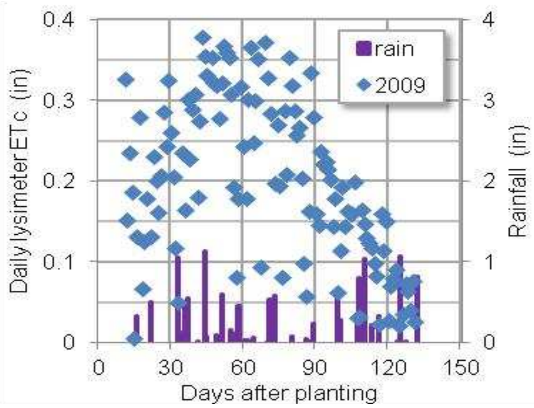

Figure 3. Water use in 2009, Blackwell, SC

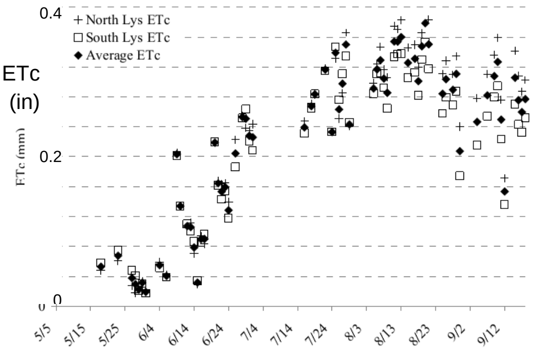

Figure 4. Water use in 2007, St. Joseph, LA

Water use at different growth stages

Crop water use changes throughout the season in response to changes in crop development. Daily ETc measurements and an average crop water use curve are shown in

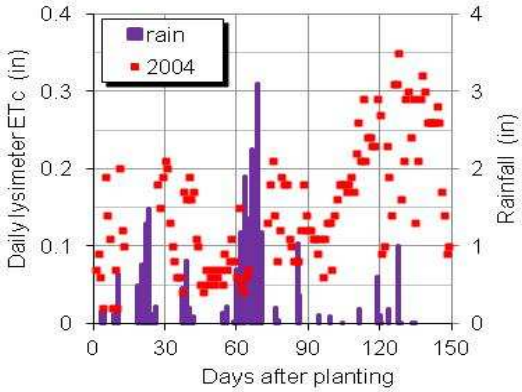

Figure 5. Water use in 2004, Stoneville, MS

Figure 6, along with essential crop growth stages. Daily water use is expressed as a function of days past planting, and increases steadily from planting to first open boll, after which it begins to decline. This suggests the need to maintain well-watered field conditions through first open boll. After about 60% boll opening, water use tends to decline.

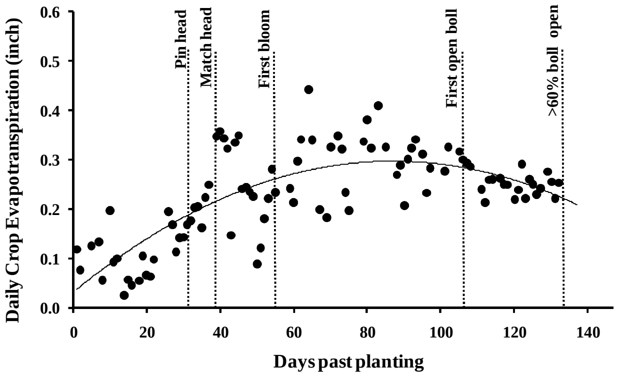

Figure 6. Crop water use at different growth stages at St. Joseph, LA.

Weekly and seasonal water needs

As crop water use changes, the amount of water that must be available for crop use changes. Rainfall is often sufficient early in the season, but may not supply enough water later, and supplemental irrigation may be needed. During initial stages of the crop, daily ETc is low, usually less than 0.1 in/day, and weekly water requirements may be less than 0.5 in/week. As the crop develops, ETc increases and water requirements may increase to 1.0 - 1.5 in/week. During midseason, plant growth and fruiting increase water use, and requirements can exceed 2.0 in/week (see Figure 7). Monitoring rainfall amounts and being aware of changing crop water needs can help producers better time irrigations and prevent water stress.

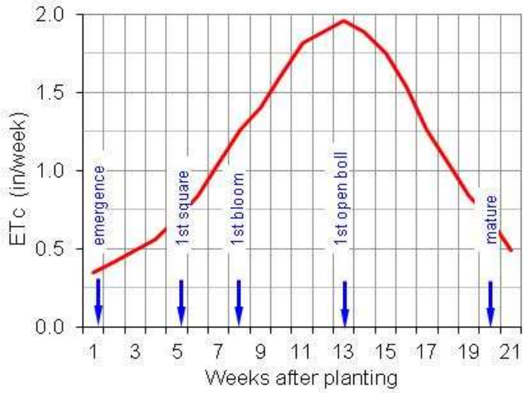

Figure 7. Weekly water requirements.

In the southeastern region, seasonal ETo normally totals 25 - 30 in, and cotton ETc totals 20 - 25 in. While annual rainfall totals may be 40 - 50 in, rainfall occurring during the growing season is often less than crop water requirements, and supplemental irrigation is needed. This is illustrated in Figure 8 for the 2012 season at Stoneville, MS. Seasonal ETc

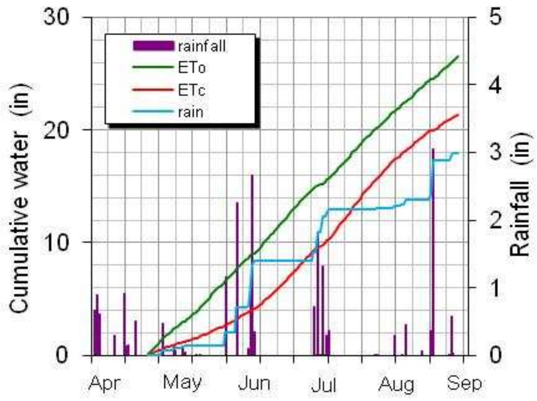

Figure 8. Total water in 2012 at Stoneville, MS.

totaled 22 in, while less than 18 in of rainfall occurred. Rainfall was sufficient through June, but several weeks of hot and dry weather began to deplete soil-water reserves. Heavy rainfall in July was followed by clear skies and high temperatures, which stimulated crop growth and increased ETc rates. Minimal rainfall occurred then until early September, and supplemental irrigation was needed.

Water balance and irrigation scheduling

To maintain an accounting of available water resources, a water balance model can be developed. The water balance, like a checkbook, keeps track of incoming and outgoing amounts, and tracks total available resources (or total depletions). For crop production and irrigation, the main components of the water balance are shown in Figure 9.

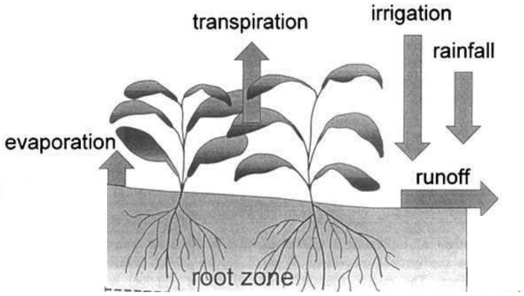

Figure 9. Water balance showing main incoming and outgoing components.

For scheduling irrigations, a simple water balance model is used to monitor the daily soil-water deficit (SWD). The soil-water deficit is determined by keeping track of the daily movement of water into and out of the soil profile, and is defined as

$$SWD_i = SWD_{i-1} + I + Pe - ETc$$

where SWD_i = today's soil-water deficit
SWD_{i-1} = yesterday's deficit
I = irrigation water applied
Pe = effective precipitation
ETc = crop evapotranspiration.

The SWD is updated daily, and when the deficit reaches a predetermined allowable limit, an irrigation is signaled.

Runoff is difficult to measure or estimate, and can be accounted for in Pe, the effective precipitation term. Pe is an estimate of the amount of rainfall which effectively enters into the soil and does not run off.

Crop evapotranspiration, ETc, is estimated based on reference ETo. ETo quantifies the evaporative demand of the atmosphere. A crop-specific crop coefficient, Kc, is then applied to account for differences between the crop and the reference (grass). ETc is estimated as ETc = Kc * ETo. A cotton Kc function developed at Stoneville, MS is shown in Figure 10, and is similar to those developed from lysimeter measurements at Blackwell, SC and S. Joseph, LA.

Figure 10. Cotton crop coefficient for Stoneville, MS.

To illustrate the use of weather data and water-balance modeling, a water balance model was developed in an Excel spreadsheet using the SWD method. The model was run for a cotton field at Stoneville, MS during the 2012 growing season. The resulting daily soil-water deficit, along with daily rainfall and irrigation events, is shown in Figure 11. While almost 18 in of rainfall was received, it occurred in three main events, resulting in significant runoff. The first irrigation appears to have been well-timed, but

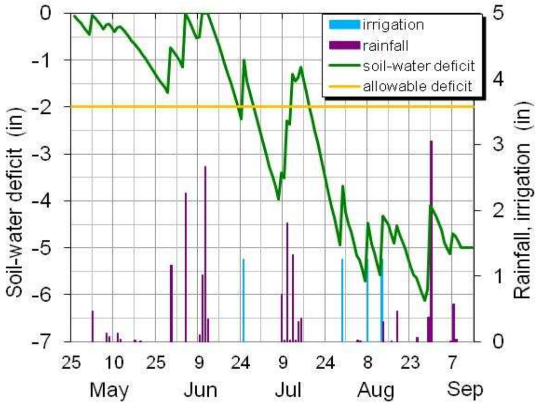

Figure 11. Soil-water deficit estimated for 2012 using a spreadsheet water balance model.

did not completely replenish the deficit. Three later irrigations also did not appear to be sufficient.

A variety of water-balance irrigation scheduling models are available for use by producers. Internet-based scheduling tools have been developed in Mississippi and Tennessee. The Arkansas Irrigation Scheduler is a stand-alone program developed for irrigators in the Mississippi Delta region. The computer program runs under the Windows operating system, can be downloaded and used free of charge, and is simple to use and requires minimal input data.

The original version of the program required only daily values of maximum air temperature and effective precipitation. The program calculated reference ETo using an empirical function based on air temperature. The program was later updated to allow the user to directly enter daily values of reference ETo.

To use the program for irrigation scheduling, daily values of air temperature (or ETo) and effective precipitation are input to the program. ETc is calculated using built-in crop-coefficient functions, the soil-water deficit is updated, and the current soil-water deficit and a projection of the deficit for the next few days are output. The user then decides whether to irrigate based on an allowable deficit level that he chooses, with guidance from the program based on soil type, crop, and irrigation system.

Since summer rainfall in the Mid-South often occurs from "pop-up" storms, rainfall can vary significantly over the region, over small distances, and even across the same field. Local rainfall measurements are, therefore, critical, and an estimate of the effective amount is required for accurate accounting.

The Arkansas Irrigation Scheduler was run for the 2012 growing season at Stoneville, MS, using air temperature as input. The daily soil-water deficits are shown in Figure 12, and were similar to those obtained from the spreadsheet model shown in Figure 11.

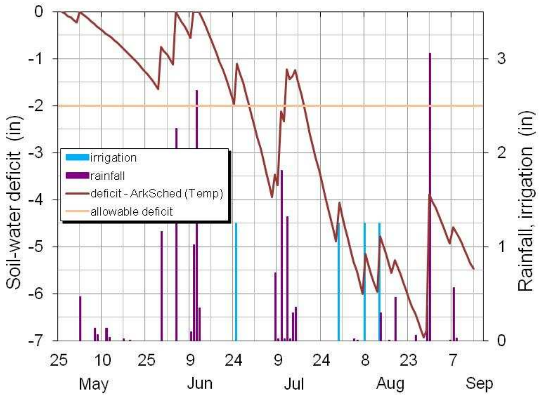

Figure 12. Soil-water deficit estimated for 2012 using Arkansas Irrigation Scheduler (air temperature input).

Sensor-based irrigation scheduling

Another approach to determining when an irrigation is needed is to use soil-moisture sensors installed in the soil profile. Rather than relying on theoretical models and estimates, sensors provide a direct indication of soil-water reserves in the field. A variety of sensors and monitoring systems are available, and range from simple to sophisticated, inexpensive to very costly, manual or automated, etc. Advances in communications capabilities (wireless, radio, cellphone) are allowing field data to be available more easily, providing more information to help producers make irrigation decisions.

Soil-moisture sensors were installed at three depths (6, 12, and 24 in below the soil surface) in a cotton field at Stoneville, MS in 2012, and collected measurements at hourly intervals throughout the season. Water-potential measurements from an irrigated plot are shown in Figure 13 and from a non-irrigated plot in Figure 14.

Water potentials near 0 indicate saturated conditions, and increase downwards as the soil dries. If using the sensors for scheduling irrigations, the -60 kPa line would indicate the need to irrigate. Similar to the water-balance models in Figures 11 and 12, the sensors indicate that more irrigation water may have been needed in the latter part of the season.

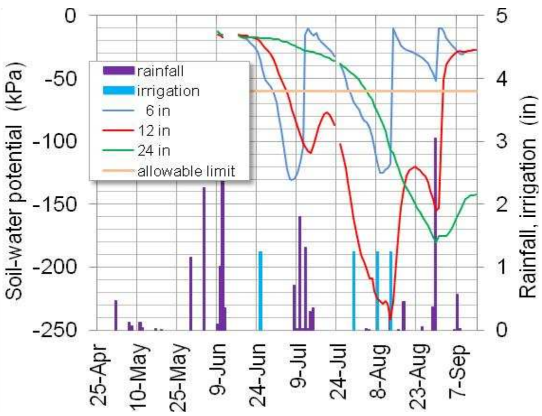

Figure 13. Soil-moisture sensor measurements from an irrigated plot in 2012 at Stoneville, MS.

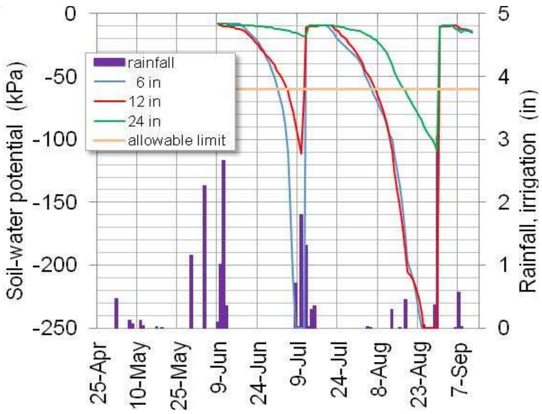

Figure 14. Soil-moisture sensor measurements from a non-irrigated plot in 2012 at Stoneville, MS.

Retrospective use of sensor data

While soil-water sensor measurements are usually used for real-time scheduling, the information could also be used in a retrospective, post-harvest analysis of the growing season. Automated monitoring stations can be installed in the field and allowed to operate throughout the season. The producer carries out his normal production and irrigation activities while the sensors collect soil-water data passively. At the end of the season, the soil-water data are examined, in conjunction with other production information, to gain insight into how above-ground activities affect below-ground water resources, and vice-versa.

A post-season analysis of the soil-moisture data shown in Figure 13 could be useful in evaluating conditions encountered during the season. The heavy rain in July, while totaling 3.5 in, had little effect on the sensors, suggesting that little rainfall was effective in replenishing soil-water resources. Irrigation application depths might need to be increased next year, or irrigations started earlier in July to avoid moisture stress.

Further information

Cotton irrigation is a challenge in the humid southeast. Proper water management is key for achieving good yields and using water efficiently. Information and tools are available to help producers better understand crop water use and manage irrigation and water resources. More information is available on the preceding discussion in Section 4: Cotton water requirements, and Section 7: Irrigation scheduling tools, in Cotton Incorporated's "Cotton Irrigation Management for Humid Regions" publication, available online (http://www.cottoninc.com/fiber/AgriculturalDisciplines/Engineering/Irrigation-Management).