W 809-C

The Basics of Cotton Irrigation in Tennessee

Brian Leib, Associate Professor, Irrigation Systems and Management
Tim Grant, Extension Assistant, Soil and Water Resources
Department of Biosystems Engineering and Soil Science

Tyson Raper, Assistant Professor, Cotton and Small Grains
Department of Plant Sciences

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Quick Facts

1. The four essential factors for making effective irrigation decisions in cotton are growth stage, water-use rate, soil type and rainfall pattern.
2. In most years, cotton grown in deep silt loam soils has yielded best when irrigation was delayed until after first bloom.
3. In a majority of years, cotton in sandy soils yielded best when irrigation was initiated at square.
4. For a majority of years in silt loam soil and for a couple of years in sandy soil, yield reduction has been observed when high rates of irrigation were applied during square.
5. Since variable rainfall can create soil conditions too wet or too dry for optimal cotton yield, a managed depletion irrigation (MDI) approach is recommended. MDI prescribes a significant withdrawal of soil water before initiating irrigation to create storage capacity for capturing rainfall that alleviates crop stress from water logging and inhibits excess vegetative growth while maintaining a buffer of easily available soil water to prevent drought stress.
6. Once the MDI level is reached, water should be applied at a rate equal to crop-water use from rainfall and supplemental irrigation (the highest rates will be around 1.6 inches per week).

7. Center pivot application amounts should be set as high as possible without creating significant run-off: 0.3 to 0.5 inches per revolution on sloping fields and 0.5 to 0.8 inches per revolution on flatter river bottoms.
8. Cotton irrigation should be terminated at cracked boll if there is sufficient soil water and/or rainfall to finish filling viable bolls. In sandier soils, cotton yield can benefit from added irrigation just prior to cracked boll.
9. MDI can be implemented by a water balance method that keeps track of both the water added to the soil by rainfall and irrigation as well the amount used and removed by the crop.

10. MDI also can be implemented by soil sensor methods that are a direct measurement of soil water status at specific locations and depths.

Cotton irrigation recommendations for Tennessee are based on more than 10 years of AgResearch and Education Center trials and farm demonstration sites. A more detailed understanding of these recommendations is provided in the remainder of the publication.

Water Use, Soil Type, Rainfall and Irrigation Approach [1]

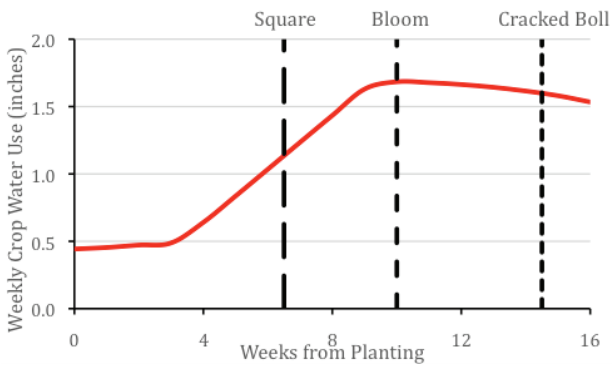


Figure 1: Historic average weekly crop-water use of cotton shown as a solid red line. Crop-water use of any given time period can vary from this line by up to 15 percent, as the weather conditions vary from normal.

Cotton **water use** varies by growth stage and weather conditions. The rate of water use is an important factor for deciding when and how much to irrigate. As shown in Figure 1, water use is less than 0.5 inches per week after establishment and increases to just above 1.0 inch per week by square. From square to bloom, water use increases rapidly from 1.0 to 1.7 inches per week. Thereafter, water use averages about 1.6 inches per week until after cracked boll. Note that these are historic averages, and a sunny, hot week could require up to 15 percent more water while a cloudy, cool week could require up to 15 percent less water. [2]

Soil type is also an important consideration when making irrigation decisions. A soil profile that is

deep silt loam could contain 4 inches of readily available water in a cotton root zone when it is at field capacity (highest amount of water a soil can contain if it drains freely). However, a soil profile that is sandy throughout may only contain around 1.5 inches of readily available water when it is at field capacity. If a deep silt loam and a sandy soil are refilled to field capacity by a large rain event in early bloom, how long would it be before we would need to irrigate each soil? Since water use is averaging over 1.6 inches per week at this point, we can expect the sandy soil to need water in less than a week. On the other hand, the deep silt loam soil can provide enough readily available water to supply that crop for almost three weeks before the crop starts losing yield potential. The differing abilities of soils to hold water can have implications on irrigation management across fields and even within the same field. [3]

Adjusting to **rainfall** in combination with crop-growth stage and soil type is the key to good irrigation management in cotton. Yet, this can be complex since rain is extremely variable in a humid region

like Tennessee. To illustrate the impact of highly variable rainfall patterns, consider this question that is faced by Tennessee irrigators: What is coming next — a four-week drought, a 4-inch rain, or something in between? If we knew a four-week drought was coming, we would irrigate frequently to keep soil moisture close to field capacity to avoid stress and ensure high yield. If we knew a 4-inch rain was coming, we would let the soil dry out in order to utilize that rainfall and avoid overly wet conditions that could harm yield. Since we do not know what weather is on the horizon with a high degree of accuracy, we need to allow soil moisture to deplete to a reasonable level that will facilitate the capture and use of rainfall yet not lose yield potential.

Since center pivots are usually designed to "keep-up" with crop-water use during peak demand periods with no rain, and cannot "catch-up" and return the profile to field capacity once significant depletion has occurred, these systems are best managed by maintaining a desired level of soil water depletion. A guiding principle of our **irrigation approach** is to allow a significant but safe soil water depletion to develop according to soil type and crop-growth stage, and then use center pivot irrigation to maintain a "managed depletion" of soil water that facilitates rainfall capture while preserving some readily available water to prevent crop stress. We are calling this approach managed depletion irrigation or MDI.

Initiating Irrigation

Tennessee-based research has consistently shown that cotton grown on differing soil types ought to begin receiving irrigation at different growth stages. In most years, cotton grown in deep silt loam soils has yielded best when irrigation was delayed until after first bloom. The exception to this was in

2012 when an extended dry period occurred in June requiring irrigation during square. Even in the severe drought of 2007, cotton yield in silt loam soils was optimized by waiting to irrigate until two weeks after first bloom and then supplying a high rate of irrigation. However, in four out of 11 years, cotton has not needed irrigation to maximize yield in silt loam soils because rainfall was sufficient (4)

In contrast, soils with much higher sand content and lower water-holding capacity required irrigation in every year tested; however, determining when irrigation should begin has varied year-to-year. Soils with higher sand content are found primarily in the major river bottoms, especially in the Mississippi River Delta. While some wet years have allowed cotton on sandy soils to do well without early irrigation, in a majority of years, cotton in sandy soils yielded best when irrigation was initiated at square. [4]

The simplest solution may be to "start irrigation at square," thereby taking care of both sandy and silt loam soils in case of early dry periods. However, yield reduction has been observed when high rates of irrigation were applied during square for a majority of years in silt loam soil and for a couple of years in sandy soil. Saturation and poor drainage are known to cause yield loss in most crops but did not appear to be the cause for this yield loss in cotton because the sites tested were well drained with soil water depletions managed below field capacity. This yield loss is thought to be related to promoting vegetative instead of reproductive growth through early irrigation in a crop that would be a perennial if not terminated at harvest. [4]

Irrigation with "managed depletion" of soil water can be beneficial to cotton yield while reducing irrigation inputs. On average, a yield increase of 900 lbs/ac of lint in sandy soil, 500 lbs/ac in silt over sand, and 200lb/ac in deep silt loam was obtained with 7.0, 4.0 and 2.0 inches of irrigation for each soil, respectively. The irrigated yield in all soil types was fairly equal approaching 1,500 lbs/ac of lint. Remember that these are average amounts of water applied and individual years will require more or less irrigation based on rainfall. [4]

We have discussed the impact of soil textural differences on irrigation initiation, but much of our cotton is grown on rolling loess hills where the texture is consistently silt loam. In this case, we expect topography to be the primary driver of irrigation decisions with side slopes requiring earlier irrigation than hilltops and low-lying areas due to soil erosion limiting the rooting depth on the side slopes. However, from 2013 to 2017 in several fields across West Tennessee, this pattern did not appear, and in fact the opposite has most often been true with higher soil moisture measured on the sloping ground due to the fragipan impeding drainage of water in wetter years. Yield maps tell us that in a dry year, sloping grounds can certainly become water-limited, and in those years the sloping ground could benefit from either earlier irrigation or more irrigation. In wet years, however, there does not appear to be much merit to irrigating sloping grounds differently than level ground on the loess hills of Tennessee. [5]

Irrigation Amounts

Another important part of irrigation decisions is how much water to apply and rates of 1.5, 1.0 and 0.5 inches per week were tested as a combination of rain plus irrigation. In silt loam soils, the best yields occurred at various supplemental irrigation rates depending on the year. In wetter than average years when there was more soil water in the profile at bloom or more rain after first bloom, lower irrigation rates optimized yield including no irrigation at all. In drier than average years, the silt loam soils required 1.5 inches per week as a combination of rainfall and irrigation. In contrast, sandy soils, once irrigation was initiated, always required a water input of 1.5 inches per week, between rainfall and irrigation. Because sandy soils cannot provide nearly as much available soil water carryover, it is necessary to supply water to match crop-water demand. Once soil moisture is at the desired "managed depletion" level, you should strive to provide water input equal to crop-water use through rainfall and supplemental irrigation in order to maintain soil moisture near the "managed depletion" target level.

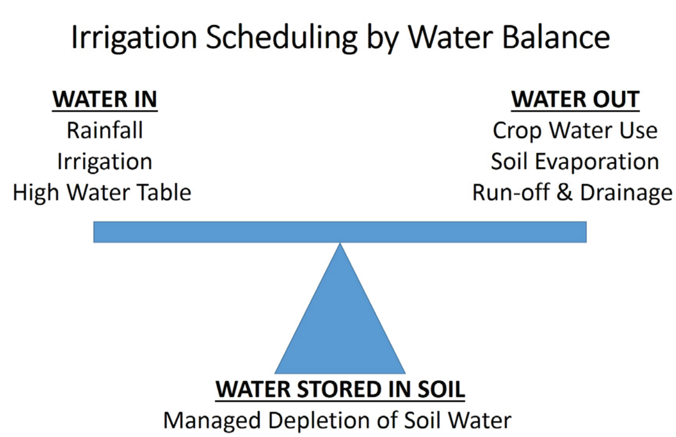
There are also some practical considerations concerning the amount of water applied per irrigation. Most center pivots are designed to be capable of applying 0.3 inches over 24 hours, meaning you potentially could apply just over 2 inches in a week. In flat river bottom ground, where many of our sandy soils are found, it is appropriate to apply higher amounts like 0.5 to 0.8 inches per revolution where runoff is not a substantial concern. However, on sloping fields or fields where infiltration is an issue, limiting irrigation to 0.3 to 0.5 inches per revolution will lead to a more effective irrigation application. We recommend setting pivot application amounts as high as possible without creating significant runoff [6]

Terminating Irrigation

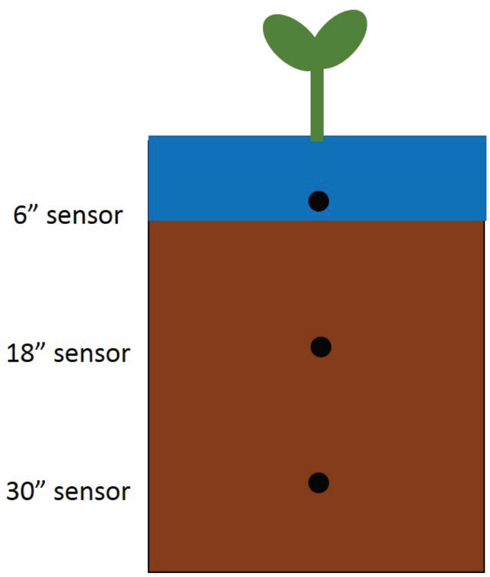
In an effort to limit water applied to open bolls which can degrade cotton quality, typically irrigation is stopped once the crop reaches cracked boll. While water is still needed to finish maturing the crop, soils with good water-holding capacity will usually have sufficient available water to supply the remaining crop-water needs. An exception to this rule occurred in 2007 when irrigating a week past cracked boll helped obtain nearly four-bale yields in deep silt loam soil. In low water-holding capacity soils, there is more potential benefit to irrigating past the first cracked boll. In two years of cotton irrigation termination studies, sandy soils yielded higher with irrigation either continuing past cracked boll or with a heavy application of irrigation leading up to cracked boll. Because these results have not been as consistent as desired, it is recommended that irrigation in sandy soil also be ended at cracked boll to avoid unnecessary water on open bolls. When possible, though, a high rate of water application leading up to cracked boll on sandy soils could increase yield, especially when dry conditions are likely. [4]

Irrigation Management Tools

Variation in soils and unpredictable rainfall make real-time irrigation decisions for cotton challenging. Soil moisture sensors, a water balance or both methods together can be utilized to manage cotton



irrigation. The **water balance method** keeps track of both the water added to the soil by rainfall and irrigation as well the amount used and removed by the crop. Table 1 presents MDI (Managed Depletion Irrigation) target values depending on soil type and growth stage for a water balance. Also shown is the Maximum Allowable Depletion (MAD) of 65 percent, beyond which point yield loss is likely. These values are percentages of plant available water that has been removed from the soil profile such that field capacity is 0 percent depletion and permanent wilting is 100 percent. Maintaining soil moisture around the MDI value creates storage space in the soil to capture rainfall while keeping a buffer of easily available soil water to prevent yield loss. Water balance tools like the **MOIST** (**M**anagement of **Irrigation** **S**ystems in **T**ennessee) **spreadsheet** can help you maintain soil-water in a reasonable depletion range, thus increasing the potential of obtaining optimum yield with minimum irrigation. [7]



A water balance approach can be very inexpensive (only requiring a rain gauge) while soil moisture sensors require the purchase and installation of sensor equipment. **Soil moisture sensors** are a direct measurement of soil water status at a specific location. Matric potential sensors (Watermark from Irrometer and MPS-6/TEROS-21 from Meter Group) measure how difficult it will be for a plant to extract moisture from the soil while volumetric sensors (many types and manufacturers) measure the percentage of water in bulk soil. More detailed articles are available to describe the differences between sensor types and how to best use each sensor type (8).

UT’s recommendations are built around matric potential sensors because their readings are more transferable across soils than volumetric sensors, which require very different trigger points based on soil type compounded by the fact that not all types of volumetric sensors are calibrated the same. Soil moisture sensors should be installed at more than one depth because the soil profile does not dry or rewet uniformly. This means there will be multiple values to consider when making irrigation decisions. A shallow sensor or sensors are needed to detect rainfall and irrigation events while deeper sensors reveal whether water is being used throughout the entire root zone. While cotton needs adequate soil moisture somewhere in the root zone, it does not necessarily need easily available water throughout the soil profile. Soil at some sensor depths should be allowed to dry significantly in an MDI approach as long as water is easily available to the crop at other points in the root zone. Table 2 presents the MDI target values for matric potential sensors. The MPS-6/Terros-21 values have been incorporated into the **MOIST+ APP**. [9]

Water Balance		
Maximum Allowable Depletion of 65%		
MDI Target (% Depletion)		
	Sand	**Silt Loam**
Squaring to 2 wks past First Bloom	45	55
2 weeks past First Bloom to Open Boll	30	45

Table 1: Maximum allowable depletion and managed depletion irrigation (MDI) Levels (as a percent of plant available water depleted for cotton when using the water balance method). The MDI Target Value is not the only soil water depletion target level that can result in optimum yield. It is recommended as a means to balance the effect of unpredictable rainfall patterns by leaving enough water in the soil to prevent drying below the maximum allowable depletion (MAD) and over wetting the soil from excess rainfall; both conditions can lead to yield loss.

Watermark (kpa or cbar) (photo 10)
Easily Available Soil Water Range

	Sand	Silt Loam
Squaring to 2 weeks past First Bloom	8 to 60	8 to 120
2 weeks past First Bloom to Open Boll	8 to 45	8 to 80

MPS-6/TEROS-21 (kpa or cbar) (photo 10)
Easily Available Soil Water Range

	Sand	Silt Loam
Squaring to 2 weeks past First Bloom	11 to 80	11 to 200
2 weeks past First Bloom to Open Boll	11 to 45	11 to 100

Table 2: Guideline matric potential values for Watermark and MPS-2 sensors in cotton to maintain a managed depletion irrigation (MDI) strategy by growth stage and soil type.

1. Saturated conditions occur at values less than the range minimums.
2. Easily available water is not required or recommended in the entire soil profile. Only one sensor needs to be within the recommended range.
3. Yield loss may occur if all parts of the crop root zone are greater than the range maximums.

Extension provides several resources to assist producers in implementing cotton irrigation scheduling (see links below). Additionally, several crop consultants in Tennessee are offering irrigation management as part of their services. [10]

Supplemental Publications

1. Irrigation Water Management – A Simple Analogy.
2. How Much Water Is Your Crop Using?
3. How Soils Hold Water, a Home Experiment.
4. Summary of Cotton Irrigation Studies in Tennessee.
5. Determining Irrigation Management Zones for Center Pivots.
6. What Is Your Center Pivots Application Rate?
7. Using a Water Balance to Make Irrigation Decisions: MOIST spreadsheet.
8. Using Soil Moisture Sensors for Irrigation Management in Tennessee.
9. Automating and Combining Water Balance and Sensor Based Irrigation Scheduling: MOIST+ APP.
10. List of Irrigation Consultants in Tennessee.

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