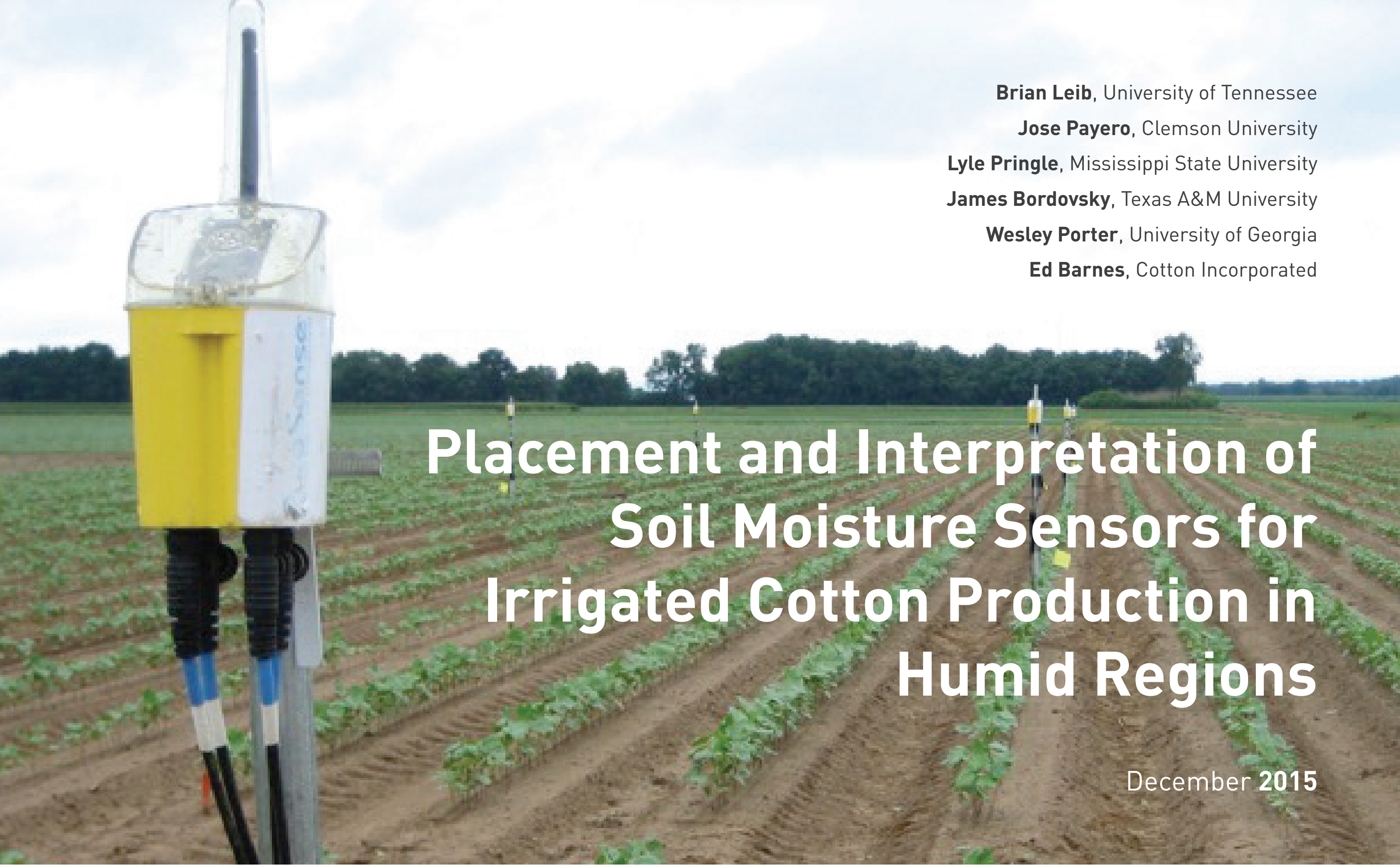

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Placement and Interpretation of Soil Moisture Sensors for Irrigated Cotton Production in Humid Regions

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OBJECTIVE

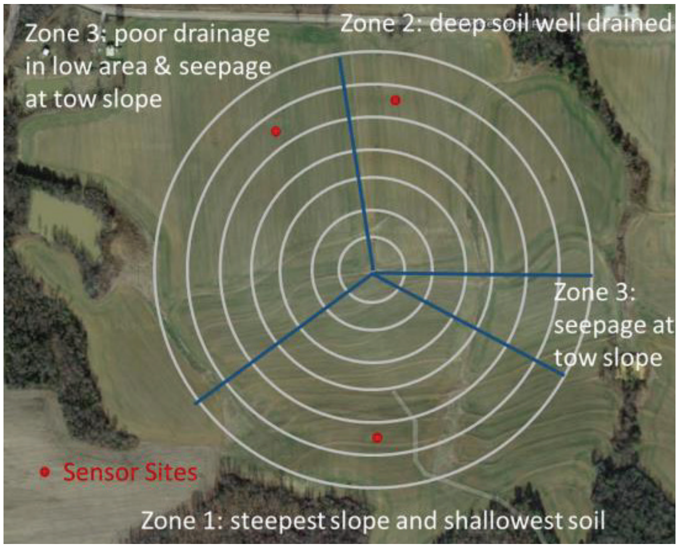
Recent survey data from Cotton Incorporated found that cotton producers who were using sensors for irrigation management were achieving both higher water use efficiencies (cotton produced per unit of water) and higher yields than those who were not. This is an example of increasing the precision of an irrigation management system, which will have both economic and environmental benefits. The goal of this factsheet is to assist producers and consultants with proper placement and interpretation of soil water sensors in order to improve cotton irrigation management (resulting in increased yield while minimizing water use). For information on choosing the type of soil moisture sensing system for your situation, please consult section 6 of "Cotton Irrigation for Humid Regions" (link at end of this document). Installation techniques should be obtained from the manufacturer of the sensor system that is chosen.

SITE SELECTION IN A FIELD

Selecting where to place sensors within a field is fairly straight forward if the entire field has uniform soil, elevation, and drainage. The location should have easy access (close to a field road), but placed far enough into the field to avoid an edge effect and multiple planting passes. In addition, the sensors should be located in cotton rows that avoid damage from field operations, such as spraying and side dressing.

Also, site selection is affected by the type of irrigation system used. Figure 1 shows how sensors may be placed in zones of a center pivot field. In fields with center pivots, you should avoid areas of poor application uniformity, like near the pivot point, near the end-gun, and near the wheel tracks. You may consider placing the sensors toward the outer spans where there is greater potential for run-off and less water is likely to infiltrate the soil due to the high irrigation application rates in this region. In furrow irrigation, there is generally more water applied to the head of the field (where water enters) than the bottom (where water exits) due to the time required for water to advance across the field.

Figure 1: Sensor Site Selection



Initially, sensors should be placed in the head and bottom quarters of the field to determine the adequacy of irrigation across the field. In placing sensors at the head and bottom of a furrow irrigated field, be sure to avoid wet areas caused by leaky pipes, water seepage from head ditches, and low lying areas where water backs up in the row due to slow draining tail water ditches. Once irrigation practices have been adjusted to provide better infiltration uniformity down the furrow, a single sensor location can be located ½ to ⅔ of the way down the row for irrigation scheduling in graded fields. Even though subsurface drip irrigated fields should be designed with high uniformity across drip lines, it is important to avoid low areas that the drip lines drain to when the system is turned off and areas near connections that can potentially leak.

Site selection is more complex when soil type and drainage patterns vary significantly across a field. A simple approach has been to identify and place sensors in the soil with the lowest water holding capacity (WHC). The rationale being that if this portion of the field is kept well watered, then the rest of the field will also be well watered. This approach works well when: the water resource is non-limiting and inexpensive, all the soils within a field are well drained, and the crop responds well in all growth stages to a high level of readily available water. Evidence suggests irrigated cotton yield is improved by managing stress early in its development (also referred to as controlled stress, regulated deficit irrigation, and primed acclimation). Irrigating according to the lowest WHC soil (if it is a small portion of your field), would optimize yield in that portion, but lose yield potential in the majority of the field. A better approach is to place sensors in the predominant soil type in order to get optimum yield for a majority of the field. However, lower WHC soils provide a greater increase in yield from irrigation than higher WHC soils which have a lower rate of yield loss from over irrigation. In a situation where the low WHC soil makes up 30–40% of the field, it may be best to irrigate based on the lower WHC soil, even though it is not the predominate soil type, because the yield gained will exceed the yield lost.

An alternative approach would be to place sensors in the major soil types and/or drainage patterns, limiting the number to three or four areas. With sensor information from the entire field, a better decision can be made on when to irrigate the entire field. Having sensors in the predominant soil/water zones will also promote the appropriate adoption of Variable Rate Irrigation (VRI), which provides the ability to irrigate each zone closer to its optimum yield potential. We often think of VRI as being limited to center pivots with "section control" allowing for hundreds of zones. Multiple zones can be accomplished with all irrigation types with varying degrees of zone delineation. Low cost VRI can be accomplished by: speed control in center pivots, zone valves or drip line valves in subsurface drip, and gate valves in furrows.

Thus far we have mostly discussed placing sensors on the basis of WHC, which is strongly correlated to soil texture; sands having low WHC with silts/clays having higher WHC. Another important factor is drainage, which is strongly related to terrain. Hill tops tend to have deep, well-drained soils, while bottom soils tend to also be deep, but not necessarily well drained. In the middle, the side slopes can be eroded with shallow soils and have less ability to infiltrate water due to ease of water movement down slope. Yield maps from fields with this kind of terrain can reveal much about water management. In dry years, the bottom soils perform well without irrigation, but irrigation can still increase yields while the hilltops and side slopes require a high level of irrigation to obtain high yields. In wet years, the hilltops perform well without irrigation with some irrigation helping yield, while the bottoms may have reduced yields from waterlogging, in which case irrigation can be detrimental. Therefore, terrain and drainage patterns should be considered *in addition to* soil texture and water holding capacity when determining where to place sensors.

PLACEMENT IN A SOIL PROFILE

During the growing season, the soil profile does not dry or rewet uniformly, so more than one sensor is needed to evaluate the water status of the entire profile. Initially, you are more likely to see the sensors near the surface dry out before deeper ones. Even when roots have fully developed, cotton will first use the more easily available water at the top of the root zone where the rooting density is highest. As the growing season progresses and rainfall occurs, or irrigation is applied at rates lower than cotton water use, you may see a reverse relationship with the upper sensors rewetting while the deeper sensors become drier. If your goal is to develop a managed level of stress to increase cotton yield, these kinds of wetting and drying patterns are to be expected. A word of caution: if the stress is too severe for a given soil type, yield reducing stress can occur. Furthermore, any irrigation system failure during a time of managed stress could delay irrigation and also result in yield loss.

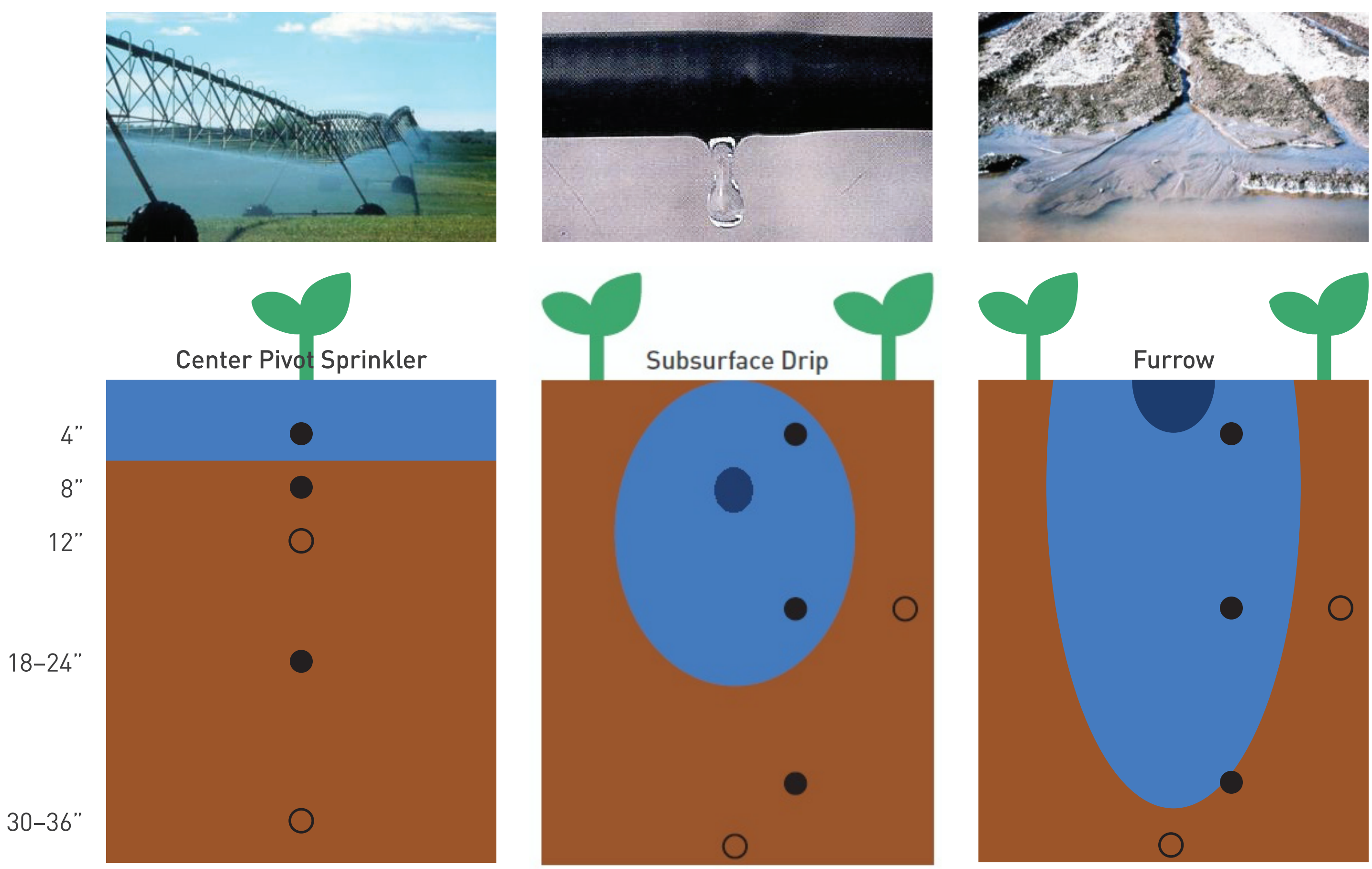
Sprinkler irrigation applies water similar to rainfall, in a vertical direction. However, furrow and subsurface drip have two dimensional wetting patterns with vertical and lateral water movement dependent on soil texture and soil layering. Generally, more water moves laterally in a fine textured soil and along the textural interfaces of soil layers. Since subsurface drip and furrow systems generally apply water to the middle of every other cotton row, there are locations in the soil profile that may never receive irrigation water, such as the non-irrigated row middle or the plant row itself. Placing sensors in these areas would show unrealistically low soil water content. At the other extreme, if sensors are placed too close to the drip tube or furrow, they would show unrealistically high soil water content. On low infiltrate rate soils, it may be necessary to irrigate every furrow, and in this case, sensors located in the plant row would be acceptable.

Two sensor depths per location are the minimum required to get a helpful picture of water in soil profile. Three sensors would be better and is our standard recommendation. More than five sensors per location would be unnecessary. Figure 2 shows sensor placement in the soil profile for sprinkler, drip and furrow irrigation with respect to the plant row. Center pivot sprinklers are most often operated at fast speeds and light application amounts in order to prevent run-off. These light applications do not penetrate very far into the soil profile, requiring sensors to be placed at shallow depths. A deep sensor is still important for understanding water storage remaining in the profile. Subsurface drip and furrow irrigation systems have deeper water penetration patterns, which justifies placing sensors deeper in the profile. A shallow sensor is still important because of rainfall events that do not penetrate deep into the soil profile. Most importantly, drip and furrow sensors need to be placed between the point of water application and the row of cotton to avoid an overly wet or overly dry representation of the soil profile. Extra sensors can be placed in the crop row to better understand soil water content outside of the irrigation zone and to see how far water is soaking laterally. In trying to move water laterally, it can be important to place a sensor deep under the point of application to help minimize water lost to deep percolation.

COTTON IRRIGATION THRESHOLDS

Most soil moisture sensors measure Volumetric Water Content (VWC — % water per bulk soil) and important soil information like Available Water Holding Capacity (AWHC). Soil saturation, field capacity and permanent wilting point are also published in VWC units. VWC can also be directly related to the amount of water cotton is removing from the soil profile and to rainfall or irrigation that is added to the soil profile. One difficulty with VWC sensors is that irrigation trigger points can be extremely different by soil type. For instance, a silt loam should be irrigated before it reaches 20% VWC, but this level of water would be field capacity or higher in a sandy soil and not require irrigation. If a VWC sensor is not calibrated for your soil type, you cannot utilize published values of field capacity and wilting point to determine irrigation thresholds. A VWC sensor that is not calibrated could result in values reading 25% when the actual water content is 30%. We recommend field calibration methods that do not require any specialized equipment or soil sampling, but do require observing how your sensors react under certain field conditions.

Figure 2. Locating Sensor Systems by Irrigtaion Type



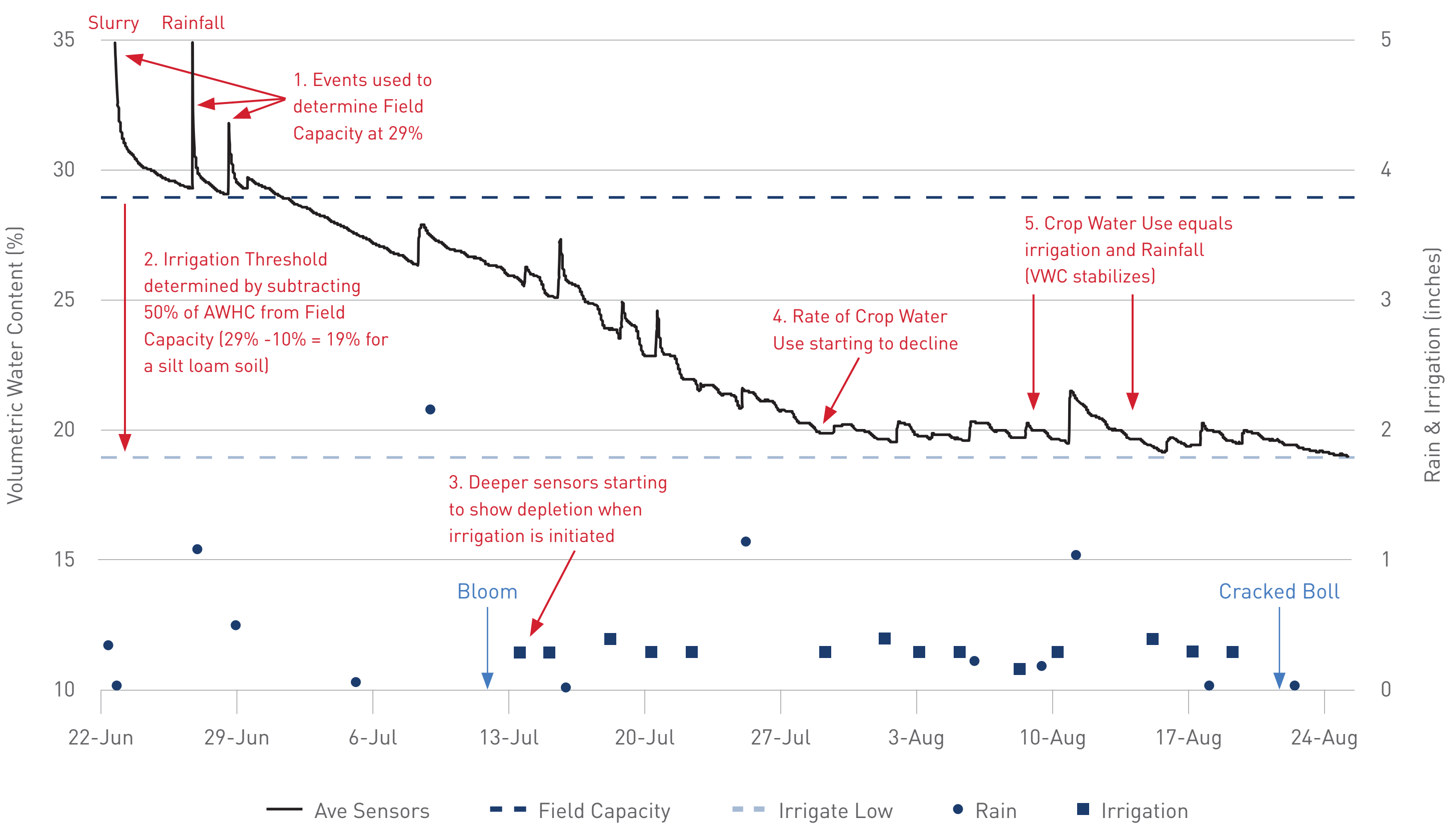
The first step is to determine field capacity from sensor readings. It is recommended to do this soon after sensor installation, when plants are small and when wet soil from slurried installation or rainfall allows identification of when rapid drainage stops as the soil comes to field capacity. The next step is to establish the irrigation threshold, below which yield loss can be expected for a particular sensor and soil type. This step is more difficult, but useful estimates can be obtained by:

1) Subtracting a management allowable depletion from field capacity (30 to 50% of available water holding capacity),
2) Noting when water is being depleted from deeper sensors in the soil profile, and/or
3) Observing when the rate of drying slows down between irrigation or rain events.

An excess slowdown in the rate of drying could indicate that significant stress is reducing crop water use and cause you to increase the irrigation threshold. Figure 3 is an example showing how VWC field calibration methods were applied to a cotton irrigation schedule.

Figure 3. Example of Setting Irrigation Thresholds in a Managed Stress Cotton Field

This plot of silt loam over sand (starting at around 30 inches) was deficit irrigated by delaying irrigation until bloom and never applying more than 1-inch of water per week. It was the highest yielding plot in this soil type increasing yield to 1291 lbs of lint per acre as compared to rainfed yield of 786 lbs of lint per acre. About 4.0 inches of irrigation were applied.



Soil Matric Potential (SMP) is another way soil water status can be measured and the unit of measurement is usually kilopascals (kPa) or centibars (cBar). SMP is the opposite or negative value of soil tension, measuring the energy required for cotton to pull water from the soil (a greater negative value means the soil is drier). An important advantage of SMP sensors is that irrigation thresholds are more similar between soil types, creating less concern of misinterpreting sensor readings. Irrigation thresholds and soil status indicators have been published for SMP sensors in different soil types, as summarized in Table 1. Figure 4 provides an example of using SMP based irrigation thresholds in cotton irrigation scheduling. It should be noted that SMP sensors do not respond in a linear fashion to the amount of water in the soil. This means, that in the wet range, a small change in SMP can mean a large change in soil water and, in the dry range, a small change in soil water can result in a large change in SMP. This may make you wonder why these sensors don't change in value very much during some high water use days when the soil is wet, but the good thing is they will change rapidly when the soil is dry and are better at getting your attention when it is time to irrigate. Once they are dry and significant rewetting occurs, SMP sensors might lag in their response time because water needs to first displace the air in the sensor in order to rewet the sensor.

Some perspective is needed concerning irrigation thresholds. Center pivots and subsurface drip systems are usually operated at high frequencies applying small amounts of water at one time. When you reach a threshold and irrigate, you should not expect the soil water to go up to field capacity because these systems are usually applying water about as fast as it is being used by the crop. You are more likely to see a stabilization of soil moisture around the threshold value without big increases and decreases in the moisture level. For pivots and drip you could choose an irrigation threshold that depletes water without risk of overfilling the profile. These drier levels were chosen to allow cotton roots to use water deeper in the profile, reduce unwanted vegetative growth, and leave soil storage space to capture sizeable rainfall events that occur in humid regions. Furrow irrigation, on the other hand, usually applies more water at one time, and you should expect to see soil water move significantly toward field capacity after irrigation, if the sensors are not too far away from the furrow to be influenced by the water infiltration pattern.

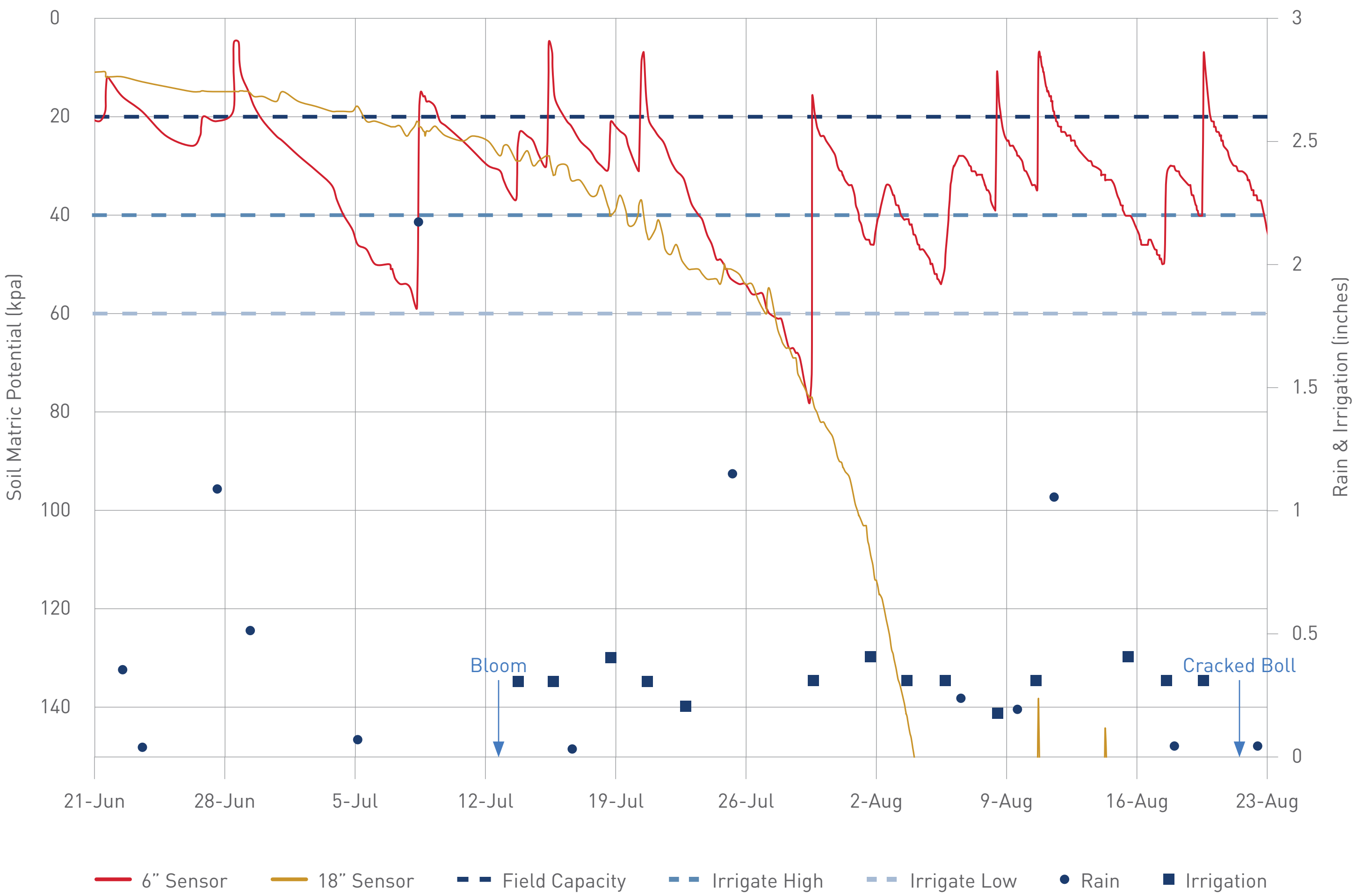
Table 1. Irrigation Thresholds for Matric Water Potential (negative Soil Tension) Sensors

	Soil Type/Texture				
	Loamy Sand	**Sandy Loam**	**Loam**	**Silt Loam**	**Clay Loam**
Saturation (kPa or cbar)	0 to -5	0 to -5	0 to -7.5	0 to -10	0 to -10
Field Capacity (kPa or cbar)	-10	-15	-20	-20	-25
Irrigation Threshold (kPa or cbar)	-25 to -30	-30 to -40	-35 to -50	-40 to -60	-60 to -80

Sensor interpretation should be weighted toward the active root zone. Initially roots will be active around the top sensors as the cotton grows. As cotton continues to grow, root activity will progress deeper and deeper into the profile, unless limited by compaction, acidic pH, moisture or other limitations to root growth. Cotton roots are expected to reach the deepest sensors (30 to 36") around bloom to mid-bloom. Once the roots have reached the deeper levels, upper sensors should be given a higher priority, because roots are generally more concentrated at this location and this is where water is being replenished by irrigation and rainfall. Notice that some of the sensor arrangements in Figure 2 place more sensors in the top foot and weight the readings toward the upper soil region. Be careful if you weight or average SMP sensors, because one dry sensor can have a large number that will make the entire profile look dry.

Figure 4. Example of Irrigation Thresholds for Soil Matric Potential Sensors in a Managed Stress Cotton Field

This plot of silt loam over sand (starting at around 30 inches) was deficit irrigated by delaying irrigation until bloom and never applying more than 1-inch per week. It was the highest yielding plot in this soil type, increasing yield to 1291 lbs of lint per acre, as compared to rainfed yield of 786 lbs of lint per acre. About 4.0 inches of irrigation were applied.



OTHER CONSIDERATIONS

Growth stage is very important for cotton irrigation management, but it is difficult to provide a one-size-fits-all recommendation due to variations in soil and weather. In a humid region, usually the first growth stage at which to consider irrigation would be at first-square, when it can be very important to provide supplemental irrigation to develop a crop canopy that can support a high yielding boll load. Irrigation at this early stage is needed in low WHC soils when rainfall is normal or below normal. Irrigating a high WHC soil at first-square can lead to loss of yield potential; but if there is little or no rainfall during this period, these soils can also benefit from irrigation. By bloom, most low WHC soils will need some irrigation, even in above average rainfall periods, while high WHC soils may still not need irrigation. There is less evidence that unnecessary irrigation will reduce yield during bloom in high WHC soils. A couple of weeks post-bloom, high WHC soils will benefit from irrigation in most years. Boll filling is the most critical growth stage for cotton irrigation in all soil types. First cracked boll is often considered a time to terminate cotton irrigation under sprinklers; but if soil water is depleted and a dry period occurs, some yield potential can be lost at this stage. Thus, furrow and drip irrigation could aid in retaining this yield potential without risk of reducing fiber quality.

Some final considerations are: how to respond to weather forecasts and the time required to complete an irrigation cycle. The irrigation thresholds of this publication are not considered an unalterable single number, and a window or range of values is expected for each soil type. So if a high probability of rain is in the forecast, you may consider delaying irrigation toward the lower soil water content of that range. On the other hand, if there is no foreseeable rain in the forecast, you may want to trigger irrigation at the higher soil water range so as not to get behind in an extended drought period. You should also note where your sensors are located in regard to your irrigation cycle. If it will take several days to get water to the sensor location, you will want to trigger irrigation at a wetter threshold level.

This publication is intended to provide guidelines for placement of, and data interpretation from, soil moisture sensors for cotton irrigation scheduling in humid regions. It is not possible nor practical to include all situations that may be encountered in irrigated cotton production. When implementing these guidelines, you are encouraged to consult local experts and practitioners to ensure the best possible outcome.

ADDITIONAL INFORMATION

For more information on cotton irrigation management, see:

(1) Cotton Irrigation Management For Humid Regions: https://cottoncultivated.cottoninc.com/wp-content/uploads/2015/02/Cotton-Irrigation-Management-for-Humid-Regions.pdf