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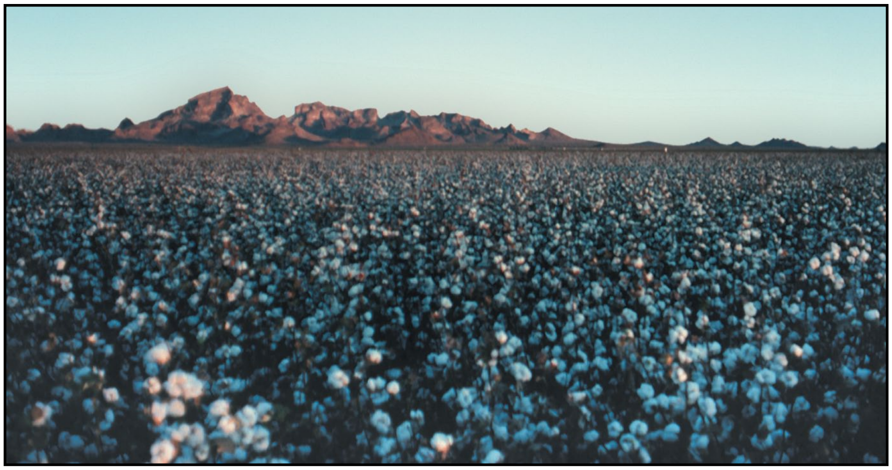
Factors Affecting Water Use

Being able to apply enough water to cotton exactly when it is needed is not always an option, but when it is, crop progress and subsequent yields benefit (Figure 1). If you have the luxury of being able to irrigate, many factors influence when and how much to apply. In this newsletter Dan Krieg shares insights as to how soils and delivery systems affect the amount of water you need to produce healthy plants.



J.C. Silvertooth

Figure 1. Timeliness of irrigation can enhance yield.

Soil Types Affect Water Availability

The soil system is the storage site for liquid water accessible to the plant via the root system. Two physical features (texture and depth) of the soil system determine the total water supply available to the plant. Soil texture, or the relative distribution of sand, silt, and clay particles, is the major determinant of water-holding capacity of the soil.

Water molecules adhere to the soil surface. Therefore, the more surface area per unit volume of soil, the greater the water holding capacity. Sand particles have the largest diameters, the least surface area per unit weight, and retain the least water. Clay particles have the smallest diameter and the greatest amount of surface area per unit weight. In addition, clay particles carry an electrical charge (negative) and establish multiple layers of water around each particle due to the polarity of water. Agricultural soils are mixtures of sand, silt, and clay and have textural classifications ranging from clays to sands. The associated water holding capacities at field capacity and permanent wilting point are listed in **Table 1.**

Table 1. Texture affects a soil's water holding capacity as indicated here by the inches of water held per foot of soil depth (D.R. Krieg).

Textural class	Clay loam	Loam	Sandy loam	Loamy sand
Field capacity	4.8	4.2	3.6	2.4
Permanent wilting point	2.4	2.1	1.8	1.2
Plant available water	2.4	2.1	1.8	1.2
Initiation of stress	1.3	1.1	0.9	0.8

INSIDE:

The Cotton Physiology Education Program (CPEP), now in its 12th year, is funded by a grant to the Cotton Foundation by BASF, makers of Pix®Plus plant regulator. CPEP's mission is to discover and communicate more profitable methods of producing cotton.

AUTHORS:
Anne F. Wrona, National Cotton Council; Dan R. Krieg, Texas Tech University

Just what is field capacity? When the pore space (space between particles) of a soil system is filled with water, it is called saturated. Gravity drains water out of a saturated soil, usually for a few days, until a certain point at which it stops draining. That point is the field capacity. The water in a soil at field capacity is held in the soil by capillary action.

If no additional water is applied, a soil at field capacity continues to dry out. Water becomes unavailable to most plants before the capillaries are completely empty. At that point, the permanent wilting point, the plants wilt. No water is available for them to maintain enough turgor to keep their cells full. The cells deflate like limp balloons. Because plants have no skeleton like animals, they fall over and shrivel up. The permanent wilting point is different for different species of plants.

Soil depth is defined as the effective rooting depth and is highly variable across regions as well as in individual fields. Rooting depth can be restricted by both physical and chemical problems in the subsoil layers. The total water supply available to the growing crop is determined by the textural status of each soil zone in the effective rooting depth.

Another very important feature affecting soil water is structure. Soil structure is a measure of the type and degree of aggregation among soil particles defining the texture. Soil aggregate formations result from the content of organic matter and clay, as well as the type of clay in the soil. Soil aggregates affect the ratio of macropores to micropores. This ratio affects infiltration and drainage of water and movement of gases in the soil system.

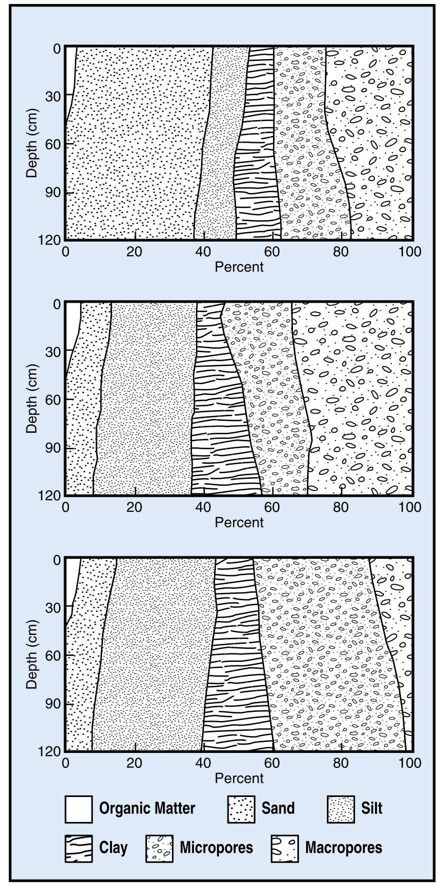
Water drains by gravity from macropores, but it is held by capillary action in micropores. Air and water generally move freely through macropores. Micropores fill with water and do not allow much air movement into or out of the soil. Although there is not a fine line of demarcation, macropores are usually greater than, and micropores less than, about 0.06 mm (0.0024 inches) in diameter.

The volume distribution of organic matter, sand, silt, clay and both macro and micropores determines characteristics of a soil. The volume distributions of three different soils are shown in Figure 2. The sandy loam has close to 40% sand and around 10% silt. Micropores and macropores are about evenly distributed (roughly 20% each).

In the silt loams, these proportions are switched. They both have about ¼ as much sand as silt. However, the silt loam with good structure has at least three times as many macropores as micropores. The silt loam with poor structure has primarily (almost 40%) micropores with less than 5% macropores.

The soil water available to the growing crop represents only a fraction of the total water holding capacity of the soil system. Plant available soil water is that volume held between field capacity and the permanent wilting point. These two cardinal points are based on the free energy status of water in the soil system and represent -0.3 bars of tension for the field capacity value and –15 bars tension for the permanent wilting point.

The volumetric water supply between field capacity and the permanent wilting point does not differ as much among textural classes as do the absolute volumes at each point. For example, a clay soil at field capacity has 40% volumetric water, but a sandy loam has only 22%. At the permanent wilting point (-15 bars), the clay would still have more than 20% volumetric water and the sandy loam would have less than 5%.



N.C. Brady (1984)

Figure 2. Distribution of textures in different soil types.

The volume of water that can be extracted from any given soil without having the plant experience stress is that volume between field capacity and approximately –2 bars of tension. This value represents about 60% of the volume between field capacity and permanent wilting. This is the volume that must be replenished to allow the cotton crop to grow and produce closer to its genetic potential to achieve maximum productivity. This is the volume that irrigation management seeks to replace for maximum efficiency.

Delivery Systems, Water Supplies, Salinity, and Drainage

Application of irrigation water has come a long way in the past 50 years. A need for efficiency, as a result of increasing acreage and decreasing water supplies, has necessitated changes in application systems. Applying water on one end of a field and letting it slowly migrate to the other end (flood irrigation) was the first application method widely used and continues to be the method of choice in much of the U.S. It works best when fields are level, have predominantly clay loam soil textures, and abundant supplies of relatively inexpensive water exist (Figure 3).

Modifications have been made in the flood system to both reduce the volume of water required per application and to increase the efficiency of the application system. The earliest irrigation water sources (wells, canals, etc.) discharged into an open earthen ditch as the conveyance system to and across the irrigated area. Siphon tubes were used to apply the water to the field from the ditch. Depending on soil texture, slope, and length of run, application volumes ranged from 3-8 acre inches per application. Uniformity of application was less than 60%.

Concrete lined ditches and underground concrete pipe soon replaced the open conveyance ditches. Both evaporation and deep percolation losses were reduced and resulted in considerable savings of irrigation water. Often 20-25% of the total water supply was lost from seepage in the open soil conveyance ditches.

J.C. Silvertooth

Figure 3. Furrow irrigation in which water is run from one end of field to other in furrows next to beds.

Next gated pipe replaced the siphon tubes for the delivery mechanism (Figure 4). Soon, surge valves were developed to apply the water in alternate cycles to each side of a set. They greatly enhanced the application efficiency. Leveled fields and alternate row irrigation enhanced the distribution uniformity. As a result of these improvements, a well-designed flood irrigation system now can deliver and apply irrigation water with approximately 80% efficiency (water available for use by the crop/total water available).

D.R. Krieg

Figure 4. Gated pipe being used to irrigate cotton.

Sprinkler systems were soon developed to allow irrigation of land not suited to flood irrigation (moderately rolling terrain and soils with sandier textures). The first sprinklers were solid set and required 40-50 psi pressure. These systems were inefficient and labor intensive. Mobile sprinklers soon replaced the solid-set systems. They reduced the labor requirements, but still required high pressure. The most common of the mobile sprinklers was, and continues to be, the center pivot.

In the mid-1980's, the application system was changed from a high pressure-overhead nozzle system to a low pressure-drop nozzle system (Figure 5). The nozzles were designed for broadcast application and were located 36-48 inches above the soil surface. Application rates on the small coverage area greatly exceeded the infiltration rates of even some of the coarsest soil textures. Runoff was a serious problem resulting in considerable waste of the water resource and highly variable crop yields, depending on the slope changes across the field.

The **L**ow **P**ressure **P**recision **A**pplication (LEPA system was designed as a modification of the low pressure-sprinkler system (Figure 6). Bill Lyle and Leon New, agricultural engineers with the Texas Agricultural Experiment Station and Extension Service at Lubbock, were primarily responsible for its design and development. LEPA is a farming system developed around a center pivot that applies water directly to the ground via a hose attached to the nozzle (rather than broadcasting the water). In order to make this application system most efficient, it requires circular rows, so the hoses stay in the same space relative to the plants' row. Because of the extremely large application volumes per unit soil area, LEPA requires furrow disking to hold the water in place for maximum application uniformity.

D.R. Krieg

Figure 5. Center pivot sprinkler types. High pressure overhead nozzle (left) and low-pressure drop nozzle sprinkler (right).

If one compares the application efficiency of the sprinklers, one finds that the high pressure-overhead systems range from 65-85%, depending on the weather conditions during application (Figure 6). The low pressure-broadcast spray system (LESA) greatly reduces evaporation of the water droplet, resulting in both less distance of travel and more uniform droplet size due to less pressure. Both of these systems cover the entire soil surface with water and have equal losses due to bare soil evaporation. The LEPA system wets less than 50% of the soil surface area per application, and therefore, reduces bare soil evaporation losses by nearly 50%. Free water is never exposed to the air until it hits the ground surface, and therefore, the evaporation losses from both the plant canopy and the bare soil are either eliminated or greatly reduced. The major detriment of the LEPA system is the extremely high application rate per unit surface area which greatly exceeds the infiltration rates of even the coarse soil textures. To minimize runoff and hold the water in place, furrow disks are necessary especially if the land has any slope.

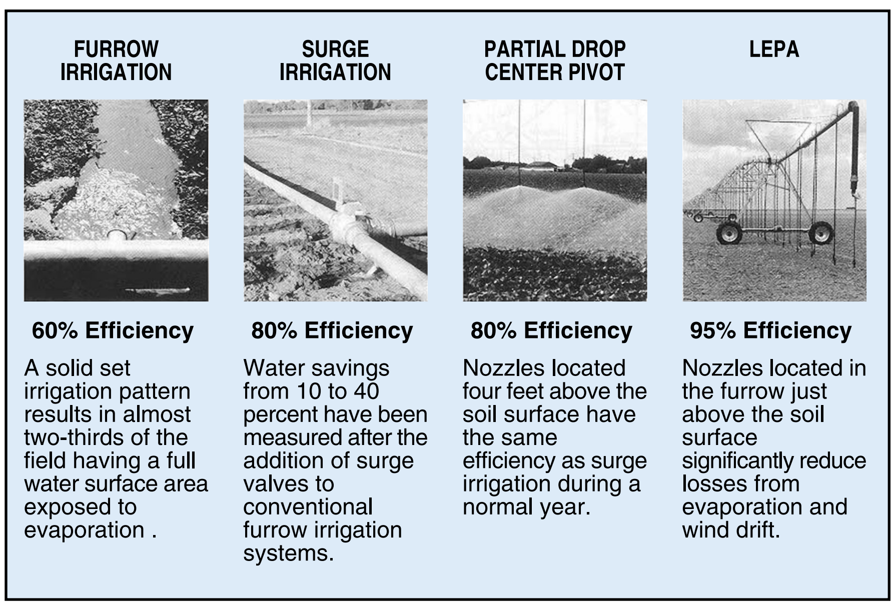
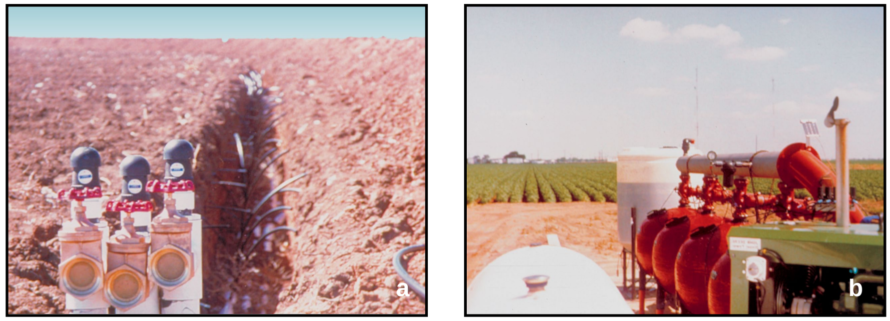


Figure 6. Efficiencies of different types of irrigation systems.

When irrigation water supplies are less than crop water use requirements, LEPA outyields LESA by 10-15% with the same water output. When water supplies are adequate to meet the crop water demand, the difference between the two application systems is less pronounced.

The subsurface drip irrigation system represents the ultimate in water application efficiency since no irrigation water ever reaches the soil surface when the system is properly managed (Figure 7). The two disadvantages of the buried drip are high capital costs and the inability to move water vertically and get the seed zone wet in soils that have an appreciable sand content (sandy loams to loamy sands).

The volume of water required for irrigation is dependent upon the ratio between rainfall and crop water use rate (Figure 8). The greater the differential, the more water required. We commonly refer to irrigation water supply in gallons per minute per acre (GPMA, Table 2). One (1) GPMA is equivalent to 0.055 acre inches of water. If crop water use at peak demand averages 0.33 acre inches per day, one would need 6 GPMA to satisfy that requirement. If rainfall averages 0.15 inches/day during the same period of time, then the irrigation water requirement would be 0.18 acre inches per day or 3.3 GPMA. The relationship between GPMA and acre inches per day is listed in Table 2.



D.R. Krieg

Figure 7. Laying subsurface drip (a) and the pump that maintains the flow of water through the system (b).

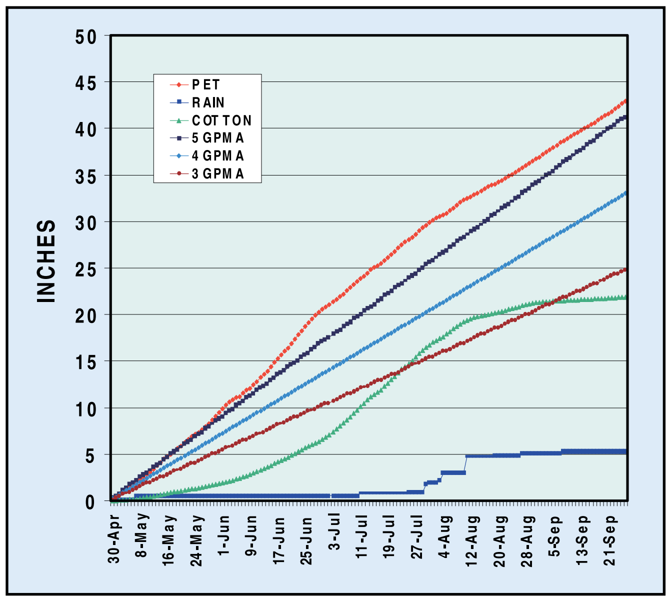


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Figure 8. Relationship between rainfall received and amount of water needed for irrigation.

Table 2. Relationship between irrigation water supply and Etp replacement. GPMA is gallons per minute per acre.

Irrigation, GPMA	1	2	3	4	5	6
Irrigation, in/ac/d	0.052	0.104	0.155	0.207	0.259	0.311
Et replacement, %	0.17	0.34	0.52	0.69	0.86	1.04

Irrigation frequency, especially with center pivots and drip systems, is another water management tool that can greatly affect productivity per unit water applied. ***Contrary to popular belief, cotton does prefer frequent, low volume applications of water compared to large, less frequent volumes.***

Research conducted on clay loams and loamy sands on the southern High Plains of Texas reveals that at supplies greater than 3 GPMA, frequencies of less than 3-4 days are ideal **(Figure 9).** With irrigation supplies less than 3 GPMA, frequencies of greater than five days, but less than seven days are ideal. Our opinion is to never apply less than 0.5 inch per application using the LEPA mode or less than 1.0 inch using the broadcast mode. Evaporation loss per application is constant; therefore, the less water applied, the greater the percent loss to evaporation of the water applied.

Subsurface drip has no limits on frequency and loss due to evaporation. The major concern with subsurface drip is the volume of soil wetted and maintained in a fairly wet state. If total water supplies are less than potential crop water use, this issue becomes extremely critical. Small root volumes expose the crop to greater risk of severe damage if the water source is lost for a brief time period.

Irrigation water management must be closely coupled with nutrient management. Maximum yield and water use efficiency only can be achieved if the nutrient demands are met as the water supply changes with irrigation. Application of nitrogen through the water is common with irrigation systems that apply the water directly to the soil (furrow, LEPA, and SSDI). Low quantities of N can be applied through broadcast systems if the evaporative demand and the energy load are not excessive. Leaf margin damage can occur from foliar applications of UAN (32-0-0) under adverse weather conditions. Results from many years of N-water interaction experiments have indicated that on the Texas High Plains a ratio of 5 pounds N per inch of total water supply during the growing season maximizes productivity and water use efficiency (Figure 10).

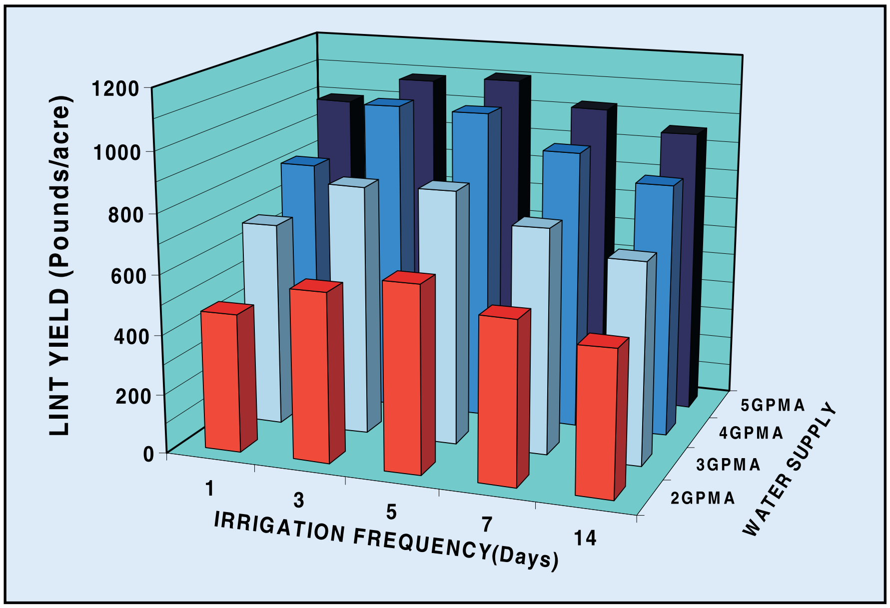

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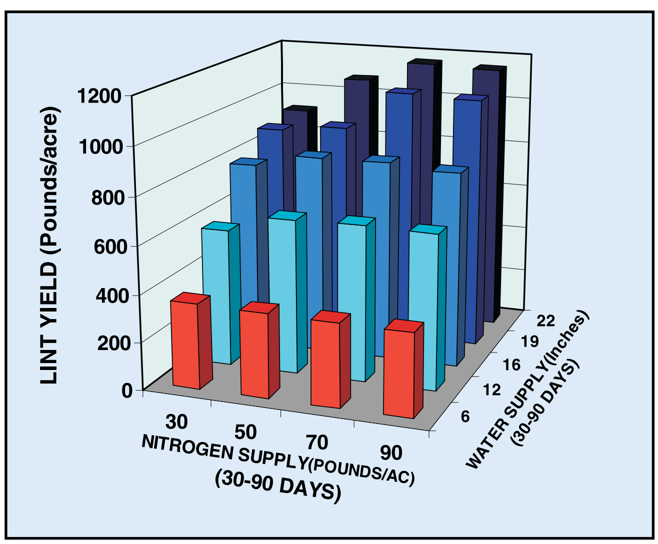
Figure 9. Frequency of irrigation for cotton on clay loams and loamy sands of the southern High Plains of Texas.



D.R. Krieg

Figure 10. Relationship between amount of nitrogen supplied per inch of water applied and water use efficiency for cotton on Texas High Plains.

Application of nitrogen through the irrigation water ensures an adequate N supply in the root zone throughout the period of high demand (fruiting period). Phosphorus and sulfur also are being applied with the N providing a balanced nutrient supply **(Figure 11).**

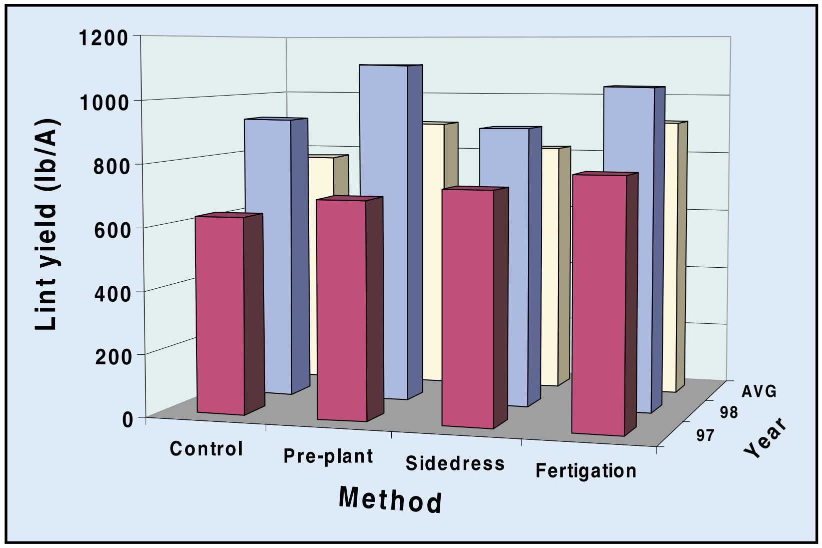


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Figure 11. Relationship between amount of nitrogen supplied per inch of water applied and water use efficiency for cotton on Texas High Plains.

Irrigation Scheduling

The two major questions concerning irrigation are “when?” and “how much?” Numerous methods for scheduling irrigation exist (Figure 12) and will be discussed in depth in an upcoming issue of *Cotton Physiology Today***.** Some are based on actual measurement of the soil water content or the plant water status. Others are empirical and based on calculated crop water use derived from weather data and estimated crop coefficients.

Each method has inherent advantages and disadvantages that make it less than ideal as an irrigation scheduling technique. Soil monitoring systems include tensiometers, gypsum blocks, neutron probes and time domain reflectometry which, when properly calibrated, define the soil water status from either a water content or water potential standpoint. The question, “how much?,” can be addressed rather easily.

In order to use soil measurements as a scheduling tool, one must know the plant water status as affected by soil water status and evaporative demand. Plant monitoring techniques include measurements of tissue water content (relative water content) or tissue water potential that primarily tell you when the plant is beginning to experience a shortage of water supply. These monitoring techniques are time consuming, dependent on weather conditions as well as soil water conditions, and tell you nothing about quantity of water required to fill the profile.

Estimating daily crop water use and replacing the amount used at some periodic interval is gaining momentum as an irrigation scheduling technique across the Cotton Belt. The potential evaporation rate is calculated from measured weather parameters which are common across a fairly large area (500-1000 square miles) and multiplied by a crop coefficient which is unique to each field. Knowledge of the water holding capacity of the soil and the application capacity of the irrigation system are essential to make this approach to irrigation scheduling work properly.

D.R. Krieg

Figure 12. Various methods exist for determining when to irrigate.

Summary and Conclusions

Maintaining an adequate soil water supply in the root zone to meet the daily water requirements of the growing cotton crop is the single greatest limitation to attainment of maximum genetic yield potential. Timely application of an appropriate volume of irrigation water is essential to minimize the risk of plant water stress reducing yield potential. Knowledge of the relationship between the soil water supply and the plant interacting with the atmospheric demand is essential to minimize the risk of excessive plant water stress reducing yield potential. Knowledge of the limitations of the irrigation system and the soil system are essential in applying the appropriate quantity of water required to just fill the soil profile in a timely manner and maximize water use efficiency.

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