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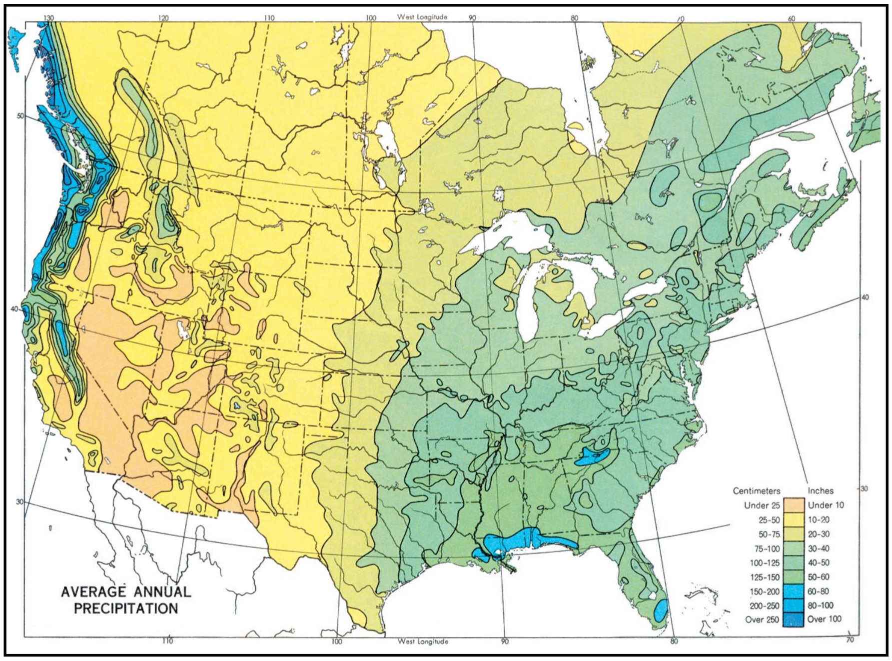
Cotton Water Use

Water is the very essence of all life on earth and comprises about 90% of most living organisms. Stress caused by lack of adequate water to keep plant cells hydrated is the single greatest factor limiting productivity of all crop species. Cotton production is certainly no exception. This newsletter offers some basic principles of crop water use to help you minimize the risk of having plant water stress adversely affect your crop's productivity.

Because cotton may actually be more sensitive to water stress than many other crops, water management is a critical component of most cotton production systems. Although rainfall across the US Cotton Belt ranges from 60 inches per year in the humid Southeast to less than 10 inches in the arid Southwest (Figure 1), supplemental irrigation is practiced across the entire Cotton Belt.



USDA

Figure 1. Precipitation in the United States.

How Cotton Plants Use Water

Cotton, like all land plants, must maintain enough water in its cells and tissues to be able to grow and develop. Without adequate water, cells cannot expand and contribute to plant growth. An expanding balloon is a lot like a growing cell. Increasing air pressure created by the person blowing up a balloon causes it to expand. Similarly, increasing water pressure or turgor causes plant cells to enlarge and grow.

In order to maintain turgor (keep their cells adequately hydrated), plants develop a closely coupled balance between the liquid water supply stored in the soil and the evaporative demand of the atmosphere surrounding the shoot. The difference in concentration of water in the soil and that in the air creates a driving force that pulls water from the soil, into the roots, up

INSIDE:

The Cotton Physiology Education Program (CPEP), now in its 11th 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.

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through the plant and into its stomates (leaf pores open to the atmosphere) where it evaporates.

The rate of evaporation of water is dependent upon the energy load (from the sun, in this case) and the vapor pressure deficit of the atmosphere (a measure of how much water the air can hold at a particular temperature). Short wave solar radiation and long wave thermal radiation are the sources of energy used to convert liquid water to water vapor. The vapor pressure deficit is an expression of the water vapor content or pressure of the air relative to its water holding capacity. The vapor pressure deficit is the driving force that moves water vapor from the evaporating surface into the air.

Evaporative Demand

In 1948, Penman developed the mathematical relationships defining the evaporation process from a free water surface. His original equation has been modified and is now used to define evaporation rates from crop systems. The modified Penman equation has the form:

$$ETo = c[W \bullet Rn + (1 + w) \bullet f(\mu) \bullet (e_a - e_d)]$$

where:
- ETo = reference crop evaporation (mm/day)
- C = adjustment factor to compensate for difference between day and night weather conditions
- W = temperature-related weighting factor
- Rn = net radiation in equivalent evaporation (mm/day)
- $f(\mu)$ = wind-related function
- $(e_a - e_d)$ difference between the saturation vapor pressure at mean daily temperature and the actual vapor pressure of the air (both in mbar)

Only four measured weather parameters are needed to calculate the daily evaporative demand (ETo). They include air temperature, humidity, incoming solar radiation, and wind speed.

An example of the daily evaporative demand (ETo) for the period from May 1-October 31 for the past three years for the southern High Plains of Texas is depicted in Figure 2.

Many states within the Cotton Belt are developing weather station networks on a county basis. The Cooperative Extension Service is assuming the responsibility of delivering the weather data to the producers. The daily evaporative demand (ETo) is an essential component of this information, especially for irrigation management.

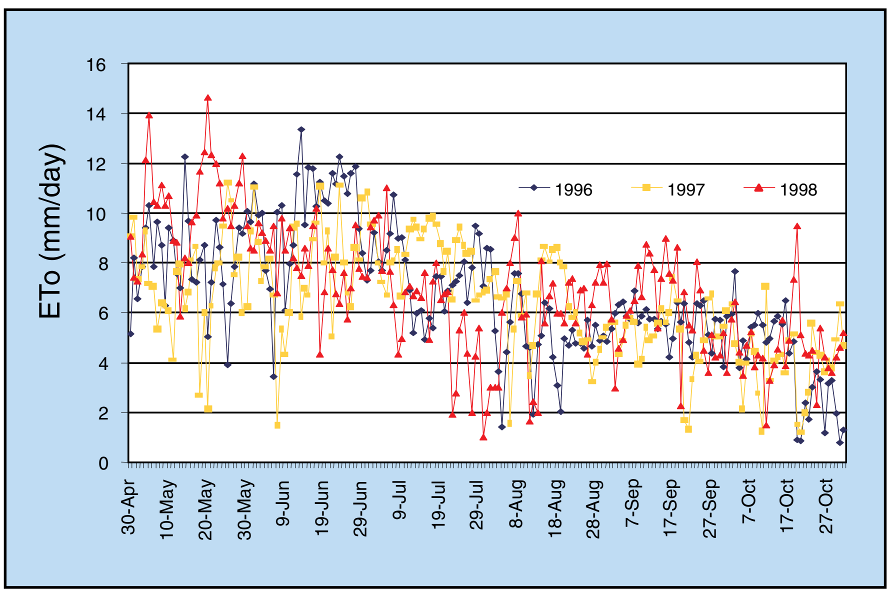

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Figure 2. Evaporative demand varies from May through October on the Texas High Plains.

Rate of Water Use

The actual rate of water use from the cropping system is some fraction of the daily evaporative demand (ETo). There are two components to water loss from the crop system. One is the soil evaporation loss and the second is the crop transpiration loss.

Total water loss due to evaporation from the bare soil surface has both rate and duration components. When the soil surface is wet (immediately following a rain or an irrigation), the rate of water loss from evaporation is equal to the daily evaporative demand (ETo). As the soil surface dries, the duration

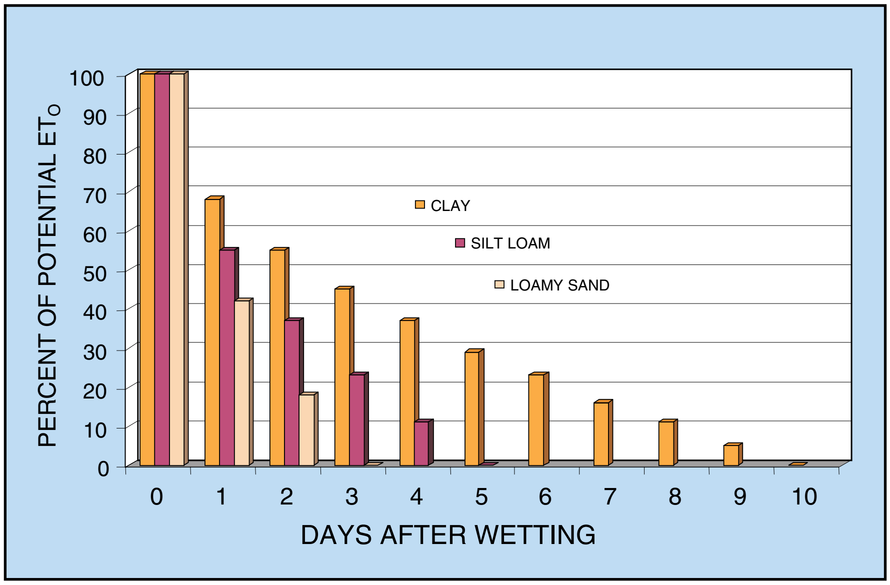

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Figure 3. Rates of evaporation from soil differ with the amount of clay in the soil.

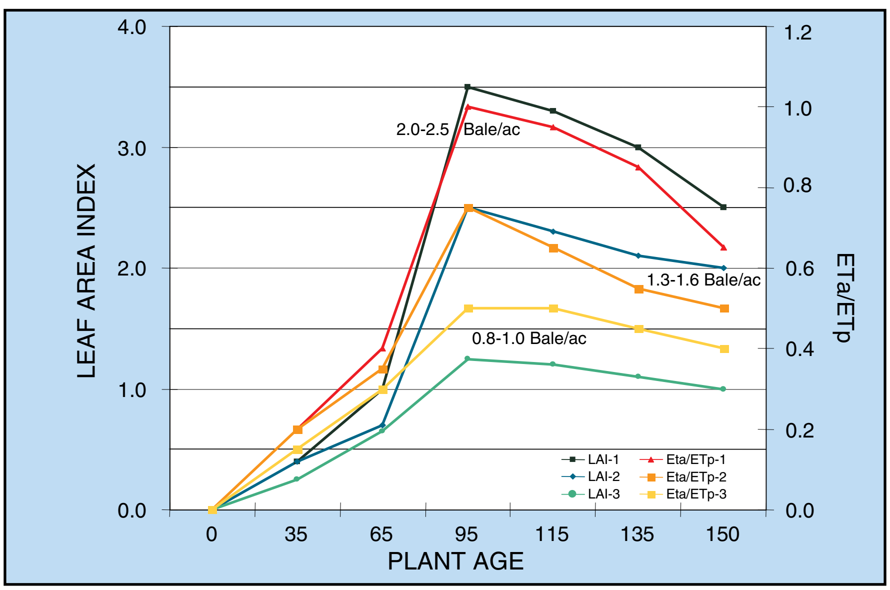

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Figure 4. Cotton growth and water use.

of loss of water is dependent upon soil texture as it affects hydraulic conductivity. Evaporation losses from three soil textures differing in clay content are depicted in Figure 3.

When clean tillage and wide row spacings are used, as is typical in a lot of cotton production systems, the frequency of wetting and percent of bare soil surface have major effects on how much of the total water resource is lost to evaporation from the soil.

Leaf Area Affects Transpiration

Crop water use, transpiration, is largely a function of leaf area index (a measure of the degree of ground cover). The relationship between crop water use (ETa) and daily evaporative demand (ETo) has been developed for cotton and verified by a number of different groups (Figure 4).

This ratio of crop water use to daily evaporative demand (ETa/ETo) is called the crop coefficient. The development of leaf area by a cotton crop is relatively slow compared with grass crops such as corn or sorghum, or even broadleaf crops such as soybeans. The maximum leaf area index developed is dependent upon variety and growing conditions. Genetics strongly influence maximum blade size and number of main stem nodes. Growing conditions greatly affect attainment of those genetic potentials. Relative maximum leaf area indices (LAI's) for both genetic and growing conditions are listed in Table 1.

Table 1. Relative maximum leaf area index* (LAI) for cotton as determined by genetics and environment as measured 90 to 100 days after emergence (DAE).

Genetics	LAI (90-100 DAE)
Stripper Types	
Determinate	3.0-3.5
Mod-determinate	3.5-4.0
Picker Types	
Delta	4.0-5.0
Acala	5.0-6.0
Pima	5.0-6.0
Growing conditions	
Well watered	
High Plains	3.0-3.5
Coastal Bend	4.0-4.5
Delta	4.0-5.0
California	5.0-6.0
Southeast	4.0-5.0
Moderate water stress (periodic)	
High Plains	2.0-2.5
Coastal Bend	3.0-3.5
Delta	3.5-4.0
California	4.0-5.0
Southeast	3.5-4.0

*LAI or leaf area index is a measure of leaf area relative to total ground surface area. For example, a cotton crop with an LAI of 5.0 has five times more leaf area in its canopy than ground surface below the plants.

Seasonal water use (demand) is the product of daily evaporative demand (ETo) and leaf area development and duration. Typical seasonal daily evaporative demand (ETo), the water use pattern of cotton, and rainfall for the Texas Southern High Plains are depicted in Figure 5.

The seasonal crop water use represents about 50% of the potential daily evaporative demand (ETo) across the same time frame. However, crop water use exceeds seasonal precipitation by 10-12 inches and causes excessive water stress to limit yield potential under rainfed conditions. Supplemental irrigation is practiced on about 1.6-1.7 million acres of cotton on the Texas High Plains. Yields of this irrigated cotton approach two bales/acre annually.

Supplemental irrigation is also widely practiced in the Southeast where it has helped stabitize cotton yields under a wide range of seasonal rainfall levels. In the arid semiarid West, irrigation often must supply nearly all crop water requirements.

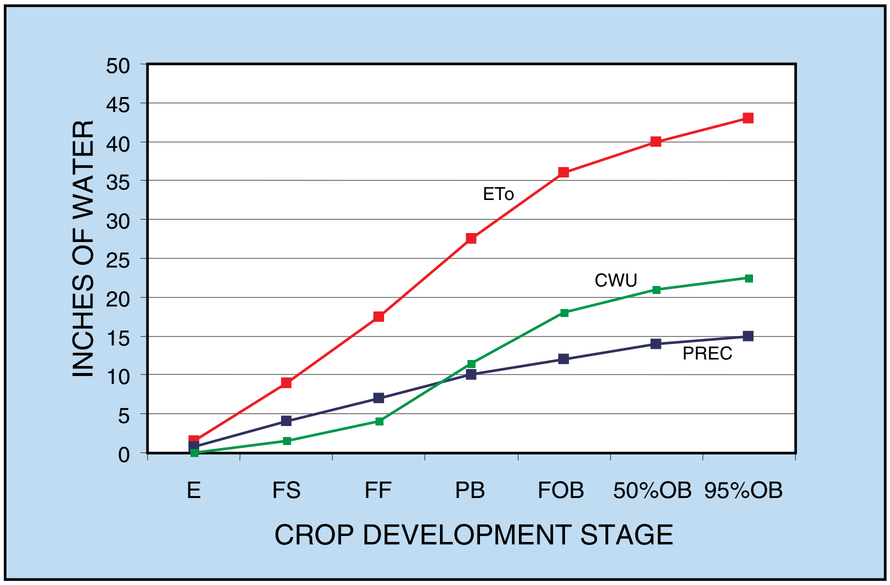

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Figure 5. Daily evaporative demand (ETo), rainfall (PREC), and water use of cotton (CWU) at different developmental stages. E, emergence; FS, first square; FF, first flower; PB, peak bloom; FOB, first open boll; 50% OB, 50% open boll; 95%OB, 95% open boll.

Sensitivity to Stress and Stage of Development

Cotton has an indeterminate growth habit and can suspend growth and development under adverse conditions. Even so, there are periods in the life of the plant that are more sensitive to water stress than others. Growing conditions during these periods of sensitivity determine yield.

Every production environment has length limits, whether they be weather-related or insect-related. Therefore, earliness is critical to production of an acceptable, economical yield. Analyses of the relationship between water supply during select developmental periods and lint yield and its respective components are shown in Table 2. Notice that the period from initiation of squaring to first flower has the highest correlation with lint yield per acre. This period is strongly correlated with boll number and boll size.

The concept of nodes above white flower (NAWF)[1] is an excellent indicator of yield potential at first flower. If a cotton plant has 8-10 NAWF at first flower, it already has established 15-18 floral buds per plant and has tremendous yield potential. It is a robust plant.

However, if the plant starts to flower with only 5-6 NAWF, it has suffered major water stress resulting in only first position fruiting sites. Its yield will be severely limited, no matter what the subsequent conditions.

Boll size (lint/boll) also was strongly correlated with water supply from square initiation to first flower. Boll size has a strong genetic component, but lint per boll is highly correlated with seed per boll. A healthy cotton plant at first flower (8-10 NAWF) produces 30-32 seed per boll; whereas, a stressed plant has more variation from boll-to-boll and averages only 24-26 seed per boll, or less.

Table 2. Supplying water to cotton at specific stages of development affects its subsequent yield as well as the components of that yield. The higher the number in the table, the more closely correlated the factors are.

	Lint Yield m^{-2}	Boll m^{-2}	Boll $plant^{-1}$	Lint $boll^{-1}$	Lint $plant^{-1}$
Total Water Suppl y	0.34	0.35	0.37	0.12	0.36
WS P - SI	-0.32	-0.18	-0.08	-0.24	-0.22
WS SI - FF	0.73	0.58	0.54	0.65	0.68
WS FF- PB	0.32	0.55	0.23	0.04	0.13
WS PB- Maturity	-0.43	-0.45	-0.23	-0.56	-0.27

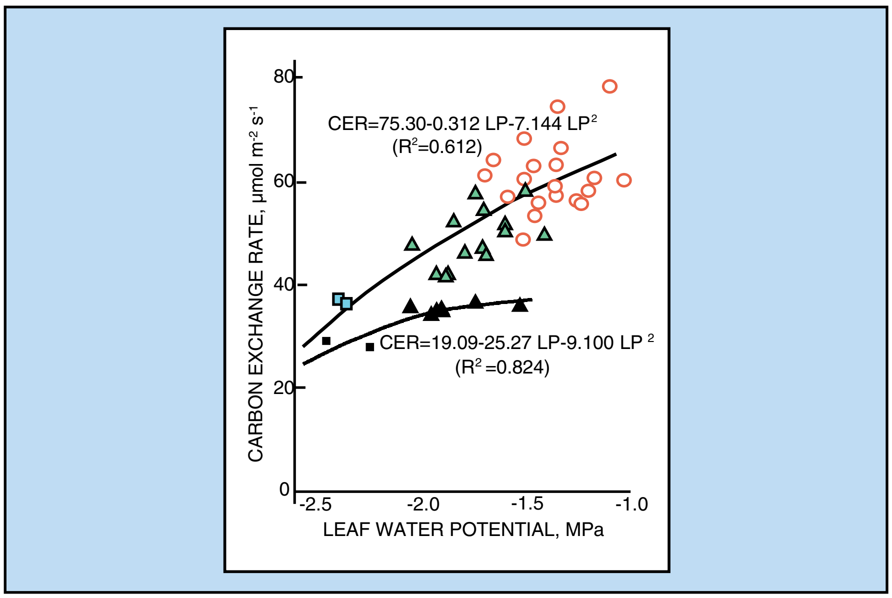
WS - Water Supply P- Planting SI - Square Initiation FF - First Flower
PB - Peak Bloom

[1]NAWF (nodes above white flower) is obtained by counting the number of main-stem nodes above the white flower in first position on the lowest fruiting branch with a white flower.

Fruit retention is also much affected by water supply. Young fruit (less than 12 days of age) are very sensitive to water stress and are subject to abortion. The cause of young fruit abortion has been debated for more than 50 years as to nutritional versus hormonal causes.

In support of nutritional causes of fruit shed, we know that the photosynthetic activity of cotton leaves is reduced by water stress (Figure 6); therefore, the carbon supply for embryo growth is reduced. Nitrogen reduction and assimilation also are reduced by water stress. The 6-10 day-old-fruit has a strong demand for reduced nitrogen at this time.

As for hormonal imbalances causing fruit shed, the developing embryo in the seed also is very dependent on an adequate supply of growth-promoting hormones being translocated into the young fruit from leaves and roots. The young embryo has a rather high concentration of inherent abscisic acid. Stress causes an imbalance in the growth promoters versus the growth inhibitors. This imbalance of hormones results in either retention or abortion depending on the individual embryo within a fruit and also the relative differences among individual fruit on a single plant. Fruit age and relative sink strength are primary considerations in allocation of reduced carbon and nitrogen, and probably, transported hormones.



D. Baker

Figure 6. Degree of cotton leaf hydration (shown here as leaf water potential) affects rate of photosynthesis.

Lower Yields from Water Stress

Net results of water stress include reduced growth and significantly reduced yield. If the stress occurs prior to flowering, yield loss is from a reduction in the number of fruiting sites produced. However, if water stress occurs during the period of fruit development (first four weeks of flowering), yield decreases because young fruits are shed. Irrigation water management becomes extremely critical to minimize the risk of excessive water stress during either of these critical time frames.

It is very interesting to note that the water supply following first open boll (about 1800 heat units) is negatively correlated to yield. On the Texas High Plains this yield loss was related to rejuvenation of vegetative growth, especially root growth and carbohydrate storage in the basal stem and upper taproot zones of the plant. The plant moved its photosynthate into vegetative rather than reproductive growth. The immature fruit in the top third of the plant suffered the consequences. These fruit were smaller (less lint per boll) due to immature fiber (low micronaire) than fruit that developed when the water supply was restricted and photosynthate was channeled into developing fruit (reproductive growth). Even though we treat cotton as an annual plant, because it truly is a woody perennial, storage of food reserves (in the taproot and lower stem) for regrowth the next spring is programmed in its genes.

Conclusions

Here we have shown how water moves into cotton from the soil through the roots and what environmental factors influence its availablity. We also began the discusion of how water deficits can affect yields. In the next issue of *Cotton Physiology Today* we will discuss how timely irrigation can boost cotton yields.

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