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## Cotton's Microclimate

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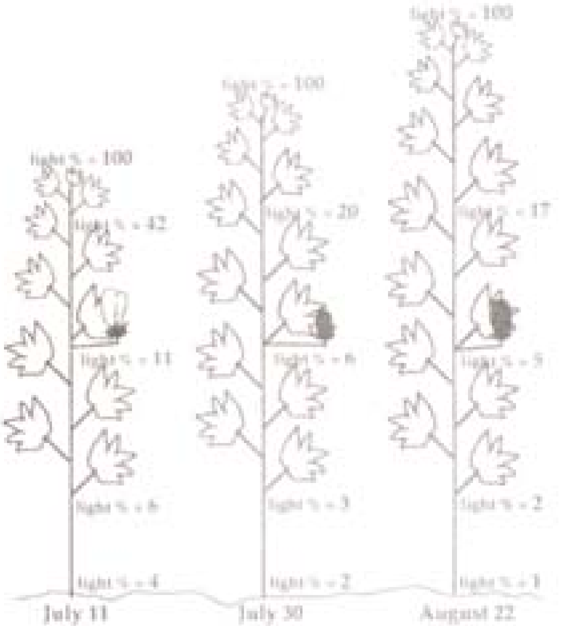
Many experts believe the continued upward expansion of U.S. cotton yields will require a greater allocation of cotton's vegetative mass to reproductive mass. In other words, less leaf and stem and more fruit. But this will require greater efficiency from each leaf. Ten to 20 years ago when yield expectations were less and plant size larger, we could tolerate an inefficient cotton machine. There was plenty of horsepower for putting on a 1 to 1-½ bale crop, even when the leaves were stressed for water or nitrogen. But as yields push upward with varieties that produce less vegetation and more fruit, cotton farmers need to increase the total efficiency of a smaller and smaller leaf area. The efficiency of cotton leaves, and thus yield, is limited by 3 components of cotton's microclimate — light, temperature and gas transfer.

### Light Efficiency

One of the major limitations to pushing cotton yields upward is light efficiency. Compared to other broadleaf plants, the cotton is relatively efficient with light; never-the-less, cotton fields often develop a growth pattern that limits light efficiency. Many of the production practices that we currently employ, and others being researched, are aimed at trying to increase cotton's efficiency with light.

One example of cotton's light inefficiency is demonstrated by the poor light penetration into the cotton canopy or the layers of leaves. Top leaves receive more light than they can use efficiently, shading lower leaves that are light-starved. Light-starved leaves prematurely age and lose their ability to produce carbohydrates. The following figure shows the amount of light that penetrated into various depths of the canopy. In this tall Acala cotton, over half of the useful sunlight was depleted by the <u>top 3 nodes</u> of the plant. Less than 11% of the light reached down to the bloom height on July 11. Keep in mind, that light which reaches the white bloom's, subtending leaf, the leaf adjacent to the fruit, is particularly efficient. If the white bloom's subtending leaf is shaded, retention of that fruit is severely threatened. If we return to that same fruit 20 days later, after it has grown from a white bloom to a boll beginning fiber thickening, we find that only 6% of the light is reaching the boll. This minute amount of light reaches the leaves near the boll during its greatest need for light energy. Although bolls can pull nutrients from leaves at the top of the plant, this diverts nutrients from new leaf growth and causes the plant to cutout.



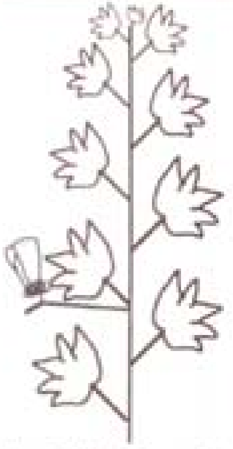

(Kerby and Hoffman, unpublished)

If cotton leaves were arranged like tiles on a floor, one layer of leaves would be sufficient to intercept all of the sunlight. This amount of leaves is referred to as a Leaf Area Index (LAI) of 1, measured as area of leaves per area of ground. Since leaves are unevenly shaped and distributed, an LAI of 3 is usually required before most of the sunlight is fully absorbed by the plant. In the above figure, on July 11, the LAI just exceeded 3 with all but 4% of the sunlight intercepted.

The uneven distribution of cotton leaves actually is beneficial because a cotton leaf in the top of the canopy cannot efficiently utilize direct sunlight. On a bright sunny day, that leaf in the top of the canopy receives 50% more light than it can efficiently use. Additional light energy is often wasted, evaporating water and depriving lower leaves of necessary light for photosynthesis. The uneven overlap and shape of top leaves spreads the light over a larger number of leaves, allowing lower leaves to remain partially sunlit and thus active.

The limited useful life of a leaf is another example of cotton's light inefficiency. By the time a leaf is 40 days old (from a small unfurling leaf) it starts a fast downhill slide in productivity. This slide in productivity starts earlier and is steeper when water stressed. If we could design a full season cotton plant that made good use of these young leaves, it would continue to produce new healthy leaves at the top of the plant to maintain an active LAI of at least 3. Top leaves would be small and angled to transmit and reflect light into the lower canopy. The white bloom might be 6 to 7 nodes from the terminal (Nodes Above the White Bloom).

**An Efficient Cotton Plant**




### Improving Light Penetration

Light penetration into the canopy can be improved with several methods:

- Reduced crowding down the row will increase light penetration into the canopy. This partially explains why narrow row cotton, when planted to the same population, has increased boll set at the first position on the fruiting branch. The more even plant distribution allows more even light penetration.
- Skip row planting allows more light to reach into the lower canopy, with a resulting increase in fruit retention. Johnie Jenkins, in Mississippi, has demonstrated a 15% increase in boll retention with skip rows compared to solid planted cotton.
- Cotton plants shaped more like columns with shorter branches, increase light penetration. Tom Kerby has coined the word "columnar" or stovepipe for short-branched cottons which have increased light penetration into the lower canopy. These types of plants are especially suited to narrow rows where the plant can be 10 inches thinner and still shade out the weeds.

### Small Leaves Can Be More Efficient

Smaller leaves let more light penetrate into the canopy. This is one of the benefits of PIX in the Mid-South, where humidity promotes large leaves; but also cottons such as Pima and okra-leaf varieties have improved light penetration due to the open shape of the leaf. Okra-leaf cotton can utilize sunlight with less leaf weight and area. This increases the photosynthetic energy produced for each unit of energy expended on leaf growth. In addition, okra-leaf cotton allows more light to reach mid-canopy leaves and increase their functional duration. Pima, with its okra-shaped leaf, has roughly double the light penetration into the canopy compared to Uplands. The result is greatly increased square retention, boll retention and vegetative branch formation.

Okra-leaf cottons are not planted in the U.S. partially because their small leaf area does not provide sufficient sunlight interception early in the season or where leaf size is reduced by stress. However, recent work has shown a strong promise for okra-leaf cottons in narrow rows, where light interception is enhanced by the more uniform plant and leaf distribution. Leaves more uniformly distributed in narrow rows, intercept 15% more light than conventional-row cotton at the same LAI (Heitholt 1990).

Nitrogen deficiency influences LAI by decreasing the expansion of leaves and cutting their final size. Although N deficient plants have smaller leaves and fewer leaves, in the humid Mid-South they can have efficient canopies in terms of light utilization. The small leaves allow more light to penetrate to the lower canopy increasing photosynthesis per area of leaves (LAI) (Wullschleger and Oosterhuis 1990). However, N deficiency is not a recommended practice for increasing light efficiency because it often reduces yield by at least 25%. N deficiency dramatically limits the number of squares, blooms and bolls produced. Additionally, in area's where LAI is limited by drought, cold or short statured varieties, any further reduction in leaf size may reduce yield.

### North/South vs East/West Rows

Row orientation in solid planted cotton, whether N/S or E/W, affects light penetration prior to canopy closure. N/S rows increase light interception and reduce surface evaporation when the sun is low on the horizon. When cotton is planted in skip rows, the orientation can affect light penetration season long. The N/S orientation is preferred for skip rows in the irrigated west. On the other hand, we would expect that E/W rows would be less humid due to the increased light warming of the soil. In the Mid-South, where humidity is more damaging, E/W rows have a slight yield advantage when surface drainage allows (Spurgeon and Hursh 1969).

### Cotton's Leaves Track the Sun

Look at a cotton field early in the day or late in the evening and you will see that cotton leaves are heliotropic, they track the sun. This allows leaves to better use the early morning or late afternoon sun, but when the sun is intense and overhead, heliotropism blocks the light from reaching deeper into the canopy. Other crops, like corn and wheat, have top leaves that stand vertical and permit more light to pass through to the horizontal leaves below.

## Temperature Efficiency

The temperature of a cotton plant is a major factor in determining how well the parts of that plant function. When they are cool, they not only function slowly but ultimately attain less size. Likewise, temperatures that are too hot result in inefficient and wasteful metabolic processes and ultimately thermal death of the tissue (cooked like fried okra).

The temperature of a plant part is a result of all the ways that energy can enter and leave that part, not just the air temperature:

- **Sunlight** on the plant is the major source of energy during the day and thus increased temperature. Cotton absorbs 80 to 85% of the sunlight it intercepts.

- **Long wave radiation** is non-visible light that radiates onto and out of the plant. All terrestrial objects emit long-wave radiation. During the night, long-wave radiation by plants into a clear, dry-air sky is a major source of energy loss or cooling. During the day, the warm sky and clouds radiate long-wave light back to the plant. Cotton plants do not cool well at night when the night sky is humid or overcast.
- **Evaporative cooling** of green plant parts occurs during the day when stomates are open and water can evaporate. If the air is saturated (near 100% relative humidity) evaporative cooling is limited and day time plant temperatures can exceed air temperature.
- **Air movement** against the plant parts transfers heat to and from the plant depending on which is warmer — the air or the plant. The degree of air mixing from within the canopy to the air above is determined by the wind protection and speed. At night, the plant is at air temperature unless it is a very clear night with no wind movement, then the plant can be 1 to 2 degrees cooler than the air.

### Sunlight and Plant Warming

When sunlight is absorbed by an object, the light energy is converted to heat energy. Cotton plants are good absorbers of light and heat up readily when the sun comes out. But due to the plant's high surface area, much of the sun's heat is rapidly transferred to the air in contact with the plant. A thin layer of still air, approximately 1/16 inches thick, is warmed by contact with the plant. As the wind speed increases this boundary layer of still air thins. Leaf hairs thicken this zone of still air next to the leaf, providing the same benefit as a flannel shirt. Warm air trapped next to the leaf can rapidly mix with the surrounding cooler air and be lost, if the wind speed is high.

Early and late in the season, warmth is the major limiting factor for growth. The hours of daylight and the angle of the sun are less; and when the sun is lower on the horizon, the heat energy is spread over a larger surface area. In addition to the limited sunlight during the early spring, much of the available warmth is dissipated in warming the cold air and soil. Although loss of warmth into the soil is of strong benefit in enhanced root growth, loss of warmth into the air is of no benefit. Fortunately, methods exist to limit the loss of warm air, especially in the spring. Restrictions to air flow, such as wind breaks, create pockets of still air near plant. This warm air acts like a thermal blanket trapping the sun's warmth.

### Evaporative Cooling

We often think of plants as cold-blooded organisms that are totally unlike mammals which regulate their body temperature for maximum activity and efficiency. Despite this misconception, plants do regulate their temperature. We can take their temperature, just as with mammals, to determine their health. The energy of the long-wave radiation (discussed above) indicates plant temperature. Infrared thermometers measure the energy given off by a plant and use this number to calculate plant temperature. When a plant has a fever usually the problem is lack of water, but it also can detect disease or insect damage.

Few plants have the ability to dramatically warm themselves, except skunk cabbage and snow flowers. Both use an inefficient metabolic pathway which generates excess heat to volatilize odors or melt through snow. However, all land plants have the ability to cool themselves via evaporative cooling. When the air is dry, this cooling can maintain plant temperature between 74°F and 90°F. Above or below these temperatures, biochemical reactions inside the cell either break down or proceed slowly. During the day small pores in the surface of green plant parts open, allowing carbon dioxide to enter and water vapor to exit. During the night the plant does not need carbon dioxide and stomates close, with the deleterious side effect of shutting down evaporative cooling. Evaporation from wet soil will cool the air around the plant at night.

### Wind

Wind is another major component of cotton's microclimate that we tend to worry about only when seed beds are drying or spray schedules interrupted. Extensive research into the effect of wind on cotton has been conducted in that part of Texas that seems to generate a lot of hot and cold air, the High Plains. Wind increases the mixing of air near the plant with the air above the plant. Air flow causes turbulence and eddy currents that mix the surface air with the air several yards higher.

In the Texas High Plains where the air is often cool and dry in the early season, mixing with the sun-warmed air near the soil and plant is undesirable. Wind shelters that retard wind movement increase the daytime air temperature near the plant. At night, temperatures are the same whether sheltered or open due to the radiation cooling as warmth is lost to the cold sky. Wind sheltering increases both day and night humidity in the High Plains.

Due to the warmer temperatures and higher humidities, wind sheltering in the High Plains causes (1) earlier fruiting and improved boll retention, (2) larger plants which use more water but have higher water use efficiencies and (3) a 35% increase in yield. Wind sheltering for seedling cotton can be obtained by planting into a wheat cover crop. The residue from the stubble retards the wind speed near the plants. Even a rough soil surface will slow the wind and protect seedling cotton from the wind and blowing sand. The height of the wind obstruction, whether it is a row of trees or just large clods, will determine the thickness of air and the distance downwind that is affected.

Decreasing wind mixing with shelters may be detrimental in other regions, such as Arizona, where excess heat is generated. Wind mixing allows plants to cool themselves during the heat of the afternoon, by conducting the hot air away from the plant.

## Gas Transfer Efficiency

The third factor in cotton's microclimate that limits yield, is gas transfer of carbon dioxide ($CO_2$) and water vapor. $CO_2$ is converted by photosynthesis into the backbone of all plant parts and although it constitutes over 90% of the plant's weight, $CO_2$ is less than 1% of the atmosphere (350 ppm). $CO_2$ limits yield in crop plants, especially cotton. The ability of cotton to set bolls over a long time period makes it highly responsive to increases in $CO_2$. Of all the commercial crops, cotton would benefit the most by an increase in $CO_2$ near the plant. The concept of augmenting $CO_2$ in the plant canopy is being explored by Jack Mauney and others. Although at current prices it is not economically feasible, there may be a time in the future where during short periods of the growing season it becomes commercially viable to augment $CO_2$. Since plants consume $CO_2$, its concentration in the plant canopy is lower than in the open air several feet above, when the air is calm. The $CO_2$ in the plant canopy must be refreshed from air above, by wind movements and diffusion. Researchers are looking at ways to increase this transfer of $CO_2$ into the plant canopy using different planting patterns that promote eddy transfer and wind turbulence.

### Water Vapor

Water vapor is another gas that limits cotton production. Unlike $CO_2$, it is the excess not lack of water vapor that decreases yield by providing an environment favorable for boll rot. Producers in the rainbelt and irrigated west are familiar with the yield-robbing boll rots that can occur in humid canopies and their control methods. Improving air movement transfers moist air from the lower canopy to the drier air above. PIX treated cotton is shorter with smaller leaves and allows better air movement for boll rot suppression (Chamber 1991). Skip-row cotton not only increases air movement into the sides of the plant but also allows the sun to warm the dry soil between the rows. That, in turn, lowers the relative humidity of the air in contact with the soil. For example, if air at 100%RH is heated from 75°F to 90°F, the relative humidity drops to 63%.

### The Cotton Field is a Box

We each tend to think of cotton fields differently; a big green photocell, a factory, a painfully honest old friend when we have made a poor management decision. To understand many of our cultural practices and optimize them, it helps to think of the cotton field as a stack of thin green boxes — full of leaves. Within each box, bolls can be produced and matured only if all of the necessary ingredients can get into that box: sunlight, gas and warmth. Since these ingredients have to travel through the boxes above and below, some boxes have excess ingredients and others too little. To maximize the efficiency of this stack of boxes requires that the ingredients be spread around so that more of the boxes can be productive. When we manage the plant for maximum yield, we're improving the distribution of these ingredients so that more bolls can be supported with fewer boxes of leaves.



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