COTTON PHYSIOLOGY TODAY

Vol. 13, No. 2 SUBSCRIBE Newsletter of the Cotton Physiology Education Program – NATIONAL COTTON COUNCIL UNSUBSCRIBE May, 2007

Growth and Development – First 60 Days

Bill Robertson, Craig Bednarz, and Charlie Burmester

Each cotton season presents it own unique challenges. Crop management decisions are largely based on current conditions and past experiences. Growers are advised, however, not to make knee jerk management decisions based on what worked or didn't work last season. With this in mind, a good understanding of the early growth and development of a cotton crop can provide an objective gauge to evaluate this crop's progress, regardless of the season's challenges.

Compared to most plants, cotton's early season growth is very slow. However, this perceived rate of early season growth of a cotton plant can be deceiving. While above-ground plant growth is slow, plants are actively developing their root systems. Sluggish above-ground growth is a result of low levels of light being intercepted by a small plant and is often compounded by cool air and soil temperatures that are normally encountered during early spring.

Fortunately, cotton growth and development is very predictable. The amount of time required by the plant to pass through each stage of plant growth is consistent. This consistency is a result of plant genetics and the environment. Temperature is one easily measured environmental factor. The heat accumulated in a day can be measured in heat units (HUs) or day degrees (DDs). The minimum or base temperature for cotton growth is 60°F. Daily HUs or DD60s can be defined as:

$$\frac{\text{Daytime high °F} + \text{Nighttime low °F}}{2} - 60 = \text{DD60}$$

Plant physiologists have determined the range of heat units required for each stage of growth. The approximate rate of node or main stem leaf development can be determined by tracking the daily high and low temperatures. Up to bloom under non-stressed conditions, expect a new node with every 50 DD60 accumulations. At this rate of node production, a plant should have 9 to 11 fruiting nodes at first flower.

Growth Stage	Days	Heat Units – DD60s
Planting to Emergence	4 to 9	50 to 60
Emergence to First Square	27 to 38	425 to 475
Square to Flower	20 to 25	300 to 350
Planting to First Flower	60 to 70	775 to 850

Modified from Oosterhuis, 1992

A question that is common this time of season deals with irrigation of pre-squaring cotton. In the past, producers would rarely consider irrigating pre-flowering cotton. In more recent time, the value of early irrigation initiation to avoid or minimize deficit moisture stress at the onset of squaring and beyond has been realized. An initial response to stress by a cotton plant can be observed by a slowdown in the production of mainstem nodes or leaves. It is not unusual to see node production slow from a predicted three day development time based on DD60s to six days as a result of dry conditions. In areas of the Cotton Belt where the length of the growing season is limited, the loss of development days reduces the ability to preserve high yield potential. Careful evaluation of seasonal irrigation capacity, yield expectation, and length of the growing season is necessary to make the best decision concerning irrigation initiation of pre-squaring cotton.

Furrow irrigation prior to layby also presents a challenge for most producers. An early layby will stretch the limits of the herbicides, while layby after irrigation can result in damage to irrigation equipment. Producers who understand that irrigation initiation is critical at this time opt to harvest more cotton and tolerate a few more weeds.

By the time a square reaches a pinhead in size, the number of locks and ovules, or seed, have been determined and the pollen grains are starting to divide. First pinhead square is the point at which avoiding deficit moisture stress should be a top priority, even in areas with an extended growing season. A square will develop into a flower in 20 to 25 days. If node production has slowed to five days per node, only five squaring nodes would be present above the flower at first flower. It is difficult, costly, and will require some luck to achieve high yields in this situation.

Nodes above white flower (NAWF) may be viewed as a measure of the plants "horsepower." A realistic goal at first flower is 8 to 10 NAWF. Many people agree that it is important for more determinate or early varieties to have a good level of horsepower at first flower. Late maturing varieties that possess good levels of late-season growth will not require the same level of horsepower at first flower that a short stature, very early maturing variety would need to preserve high yield potentials. Contact the Extension Service for more information regarding local recommendations.

Additional Information

Most states have production information online. The Cooperative Extension Service provides unbiased, research based recommendations. However, it is sometimes helpful to visit neighboring state sites. Search "Extension Cotton Information" for a quick reference to many University sites. Great online publications are available and can be found by searching "Cotton Growth and Development." For more in-depth or detailed information visit the Journal of Cotton Science http://www.cotton.org/journal/. Research papers are categorized into nine disciplines. Specific topics may be searched across all disciplines. Other journals including Agronomy Journal, Crop Science, Journal of Environmental Quality, and Soil Science Society of America Journal may be searched by topic of interest http://www.scijournals.org/search.dtl.

Bill Robertson, National Cotton Council, Memphis, TN;
Craig Bednarz, Texas Tech University and Texas Agricultural Experiment Station, Lubbock, TX;
Charlie Burmester, Auburn University, Belle Mina, AL

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Updated by Bill Robertson, Craig Bednarz, and Charlie Burmester

The period from planting to early square can be frustrating. The cotton appears unresponsive to best management efforts at this time. Even applying the full complement of recommended practices, including seed bed preparation and crop protection materials, may achieve only mediocre success. Unfortunately, once established, the crop may display only marginal improvements for several more weeks to come. Meanwhile, the cotton plants struggle and a whole host of pests thrive.

Until cotton outgrows this stage, all manner of preventative and remedial actions are considered. Producers may resort to applying materials that have not been adequately evaluated. If the application coincides with the arrival of favorable environmental conditions, the crop responds. Squares become visible, the growth rate accelerates and the past fades, at least until next year. Did the treatment make the difference, or was it the weather, or a combination of the two? In order to effectively manage cotton prior to squaring, it is important to understand the cause of the growth delay and what, if any, long term affects may linger to hobble future prospects.

One fundamental cause of the slow early season growth rate can be traced back to the young plant's limited leaf area. Solar radiation is the ultimate energy source that drives cotton growth and development. Sunlight that reaches the ground is photosynthetically lost to the plant. Additionally, only a narrow band of this radiation, referred to as photosynthetically active radiation, is harvested by the plant to produce sugars. Leaf area index (LAI) is one convenient measure used to describe the ability of a plant to intercept radiant energy. The LAI is defined as the total area of leaves in a crop divided by the land area. For example, a LAI = 2 means that one acre of land (43,560 ft^2) is covered by 43,560 X 2 = 87,120 square feet of leaves.

A cotton crop is able to intercept all direct sunlight or incident solar radiation when LAI reaches about 3. At peak bloom the LAI may exceed 5. In contrast, young cotton LAI ranges from less than 0.01 at emergence to perhaps as much as 1 at pinhead square. This means that a very small proportion of the total available radiation is used by the plant to make the raw materials needed for leaf initiation and expansion. Before canopy closure, the ability of the canopy to intercept light is of the utmost importance in determining photosynthesis and hence crop growth. Greater early LAI attainment translates into greater early growth. Once canopy closure is reached, light interception is maximal. With each additional healthy leaf, LAI and the rate of growth increases. It is a question of time and numbers.

Sub-Optimal Temperatures

The initial period of slow growth resulting from limited LAI can be shortened or extended by weather encountered during the early season. Most production regions within the U.S. must resort to planting cotton in sub-optimal temperatures in an effort to capture additional yield by extending the growing season or to mature the crop in advance of heavy insect pressure and/or unfavorable weather. Cotton, a tropical and subtropical native, grows most rapidly at around 90°F. The growth rate is proportionately less at lower temperatures. Heat unit accumulations are a convenient way of expressing this temperature dependence. DD60 heat units are defined as:

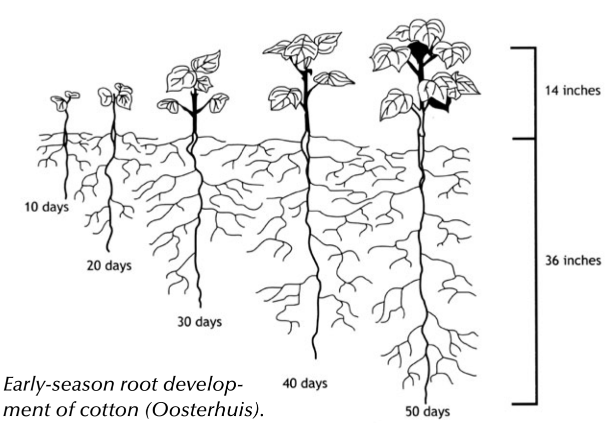
$$\frac{\text{Daytime high °F + Nighttime low °F}}{2} - 60 = \text{DD60}$$

The rate of node or leaf formation can be estimated by tracking the daily highs and lows. Up to bloom under non-stressed conditions, a new node is produced with each 50 DD60 accumulation. Over 20 DD60s accumulate per day when the highs and lows reach 90°F/70°F, temperatures routinely met and surpassed in many production areas from June through August. In contrast, fewer DD60s (5 to 10/day) accumulate when temperatures are cooler. Prolonged cold weather following a cold front may slow node development to a node every 10 to 14 days.

The first two months of the season can have a dramatic impact on crop maturity and final yield. This influence is most apparent along the northern tier of the Belt where low temperature limits on yield are most pronounced. This is illustrated in the following example: if 200 DD60s (~7/day) are normally accumulated in May on May 1 planted cotton, at the end of the month the plants would have about three true leaves (or 50 DD60s until emergence plus 3 X 50 = 200 DD6Os). If instead 300 DD60s accumulate (~10/day), the plant has an additional 2 true leaves and can be expected to reach early bloom about 5 to 7 days earlier.

Early Season Root Growth

Initially, root growth is more rapid than above-ground growth. The young tap root (radical) may extend 6″ or more into the soil



Early-season root development of cotton (Oosterhuis).

Bill Robertson, National Cotton Council, Memphis, TN;
Craig Bednarz, Texas Tech University and Texas Agricultural Experiment Station, Lubbock, TX;
Charlie Burmester, Auburn University, Belle Mina, AL;
Ken Lege', Delta and Pine Land Company, Piedmont, AL;
Tom Kerby, Delta and Pine Land Company, West Jordan, UT

by the time the first true leaf is visible. Soon thereafter, the roots begin developing an extensive system of lateral branches. The early predominance of root growth could certainly have some adaptive value by allowing the young root system to explore a large soil volume for water and nutrients.

This adaptation may be an outgrowth of cotton's genetic heritage. Upland cotton and most of its relatives are native to arid regions or areas that have pronounced wet and dry cycles. This places a high biological priority on securing an adequate water supply before the onset of drought. Research data supports this view. Although root and shoot elongation is greatest at about 90°F, when soil moisture was reduced, top growth declined by 90 percent while root growth was reduced by less than 30 percent.

Temperature and Oxygen Effects on Roots

Beyond early bloom, once boll loading begins, the root systems' exploration of new soil drops dramatically. Additionally, older roots die and are not replaced as rapidly, which serves to decrease the total root absorption potential. In other words, the best opportunity to develop a large and healthy root system is limited to the early season.

There are several environmental factors that can hinder root growth. Reduced soil moisture was already mentioned. Low temperatures, whose impact on above-ground growth was previously mentioned, also can hamper root growth. As temperatures decline, root growth is reduced and fewer lateral roots are formed. As a consequence of this reduced growth, water and nutrient uptake also declines. If soil oxygen is limited, the root tips cannot produce the cellular products required to support the root expansion.

The atmosphere contains about 20 percent oxygen and less than 0.1 percent carbon dioxide. The relative proportions differ in the soil air where the oxygen levels decline and carbon dioxide may increase to 5 percent. Cotton roots can absorb oxygen directly from the soil air. When the soil moisture is at or below field capacity, oxygen can occupy soil pore spaces. But if the soil is waterlogged, soil pores are filled with water which prevents the diffusion of atmosphere oxygen and limits the concentration available to the root. To illustrate the importance of oxygen to the roots, consider this: waterlogged soils may contain less than 2 percent oxygen and the tap root may die after a short exposure to zero oxygen levels.

Pests and Environmental Stress

Damage due to pests and other stresses is magnified by environmental stress. One example is observed when thrips feed on cotton during cool weather. The primary feeding site is the young terminal, which during warm (80°/60°) temperatures produces a new node in about five days. If DD60s decline to ≤5/day, the same leaf primordia are subject to thrips injury for at least twice the length of time. Weed pressure may also be greater during a cool spring. Weeds adapted to more temperate climatic zones are less impacted by the cooler temperatures and therefore are more competitive. Cotton damage from diseases is also more prevalent following any stresses that delay growth such as low temperatures and saturated soils. As a final example, plant protection products normally considered benign can cause phytotoxicity if growth is delayed or the plant is stressed. This damage may become pronounced if cool, wet conditions are replaced by hot, sunny weather. A field can be lost when a combination of these individually sub-lethal stresses overwhelm the young, compromised plants.

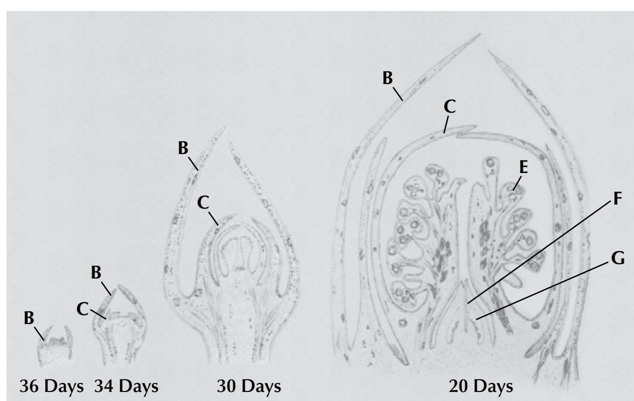
Days Before Flower	Size of Bud	Comments
40	Microscopic	Square initiation can occur as early as 2nd true leaf expansion. Hot weather induces four-bract squares, cool weather delays square initiation.
32	Microscopic	Lock numbers determined. Carbohydrate stress decreases number from 5 to 4.
23	2 mm PHS	Ovule number determined. Carbohydrate stress decreases potential seed number.
22	2 mm PHS	Pollen cells divide.
19	3 mm MHS	Pollen viability reduced by high nighttime temperatures.
5	13 mm	Squares start expanding rapidly
3	17 mm	Fibers begin to form
0	Flower Opens	Pollen sheds and fibers start to elongate. Extremes of humidity or water disrupts pollen function
+1	Flower	Fertilized ovules are now referred to as seeds.

Modified from Stewart, 1986 25.4 mm = 1 inch

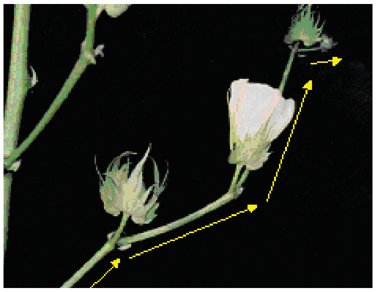
Early Season Developmental Priorities

The time from emergence to pinhead square is the least complicated growth stage in cotton's development. Squares that have initiated in the plant's terminal are minute, with minimal demands for nutrients or water. In time, they become dominant sinks for carbohydrates, mineral nutrients and water. But for now, their influence on vegetative growth and development is minor. Above is a typical timeline for the development of the first square on the plant. Other squares develop at a slightly faster speed due to warmer temperatures later in the year.

A fruiting or sympodial branch is fundamentally different from a vegetative or monopodial branch. A fruiting branch is independent of control by the terminal meristem. The fruiting branch meristem, instead of maintaining itself, produces an internode that terminates in a flower. The parts of the flower are



*The development of a flower bud or square. Numbers refer to estimated days prior to anthesis or white flower (Quintanilha et.al., 1962). **B**-bracts; **C**-petals; **E**-anthers; **F**-ovary (carpel); **G**-ovules. Drawings adapted from those of Baranov and Maltzev (1937).*



A cotton fruiting branch.
(Photo Craig Bednarz)

produced in a set order; first the subtending leaf, then the bracts, sepals, petals, anthers and finally the carpels (immature locks). The last formation of a fruiting branch meristem is the carpels. Further growth of the fruiting branch requires another meristem to grow, which is located at the base of the square (just outside the bracts), giving rise to the characteristic zigzag shape of the fruiting branch. Because the cells divide in the center of the meristem and turn (differentiate) into specific plant parts near the meristems edge, the oldest parts are outside of the younger parts in the flower.

Abnormal Squares and Bolls

Although many of the abnormal squares and bolls are caused by physical damage from insects, some are caused by adverse weather disturbing the meristem's normal function. The High Plains of Texas, where adverse weather is experienced just about every year, has a preponderance of odd and misshapen bolls; other regions can also experience extremes of weather that disrupt the meristems. Two most common abnormal square types are four-bract squares and supernumery carpels.

After the fruiting branch meristem forms the subtending leaf, it starts to form the bracts. High spring temperatures (average day/night temperature above 80°F) can cause this meristem to attempt to produce another leaf after the subtending leaf, but before the bracts are formed. This extra leaf forms a fourth "bract", and is located just outside the normal three bracts. The lowest fruiting branches appear most susceptible to four-bract squares, because high temperatures later in the season do not have the same effect. Four-bract squares are more susceptible to shed and thrips injury. The fourth bract provides an opening for thrips to enter the young square.

Within 10 days after a square starts to form, the meristem completes its production of floral parts, ending with the carpels or locks in the center of the square. If the meristem growth doesn't terminate with the carpels, a boll abnormality called "supernumery carpel" results. This is a small, skinny boll at the center of the first boll. It forms when the meristem keeps on making new parts, in this case another set of carpels, after the first carpels are formed. Alabama Cotton Specialist Charles Burmester, has reported that supernumery carpels were common in the bottom bolls of early-planted fields in which extreme cold weather occurred very late in the seedling stage. The extreme cold weather was thought to have been responsible for disrupting the meristem's normal development. Meristems are hardy parts of the plant and function despite severe temperature, nutrient or drought stress, up to a limit. Pima cotton appears more susceptible to bottom boll abnormalities, especially when fields are planted early and experience cold weather after emergence.

Locks per Boll

When the meristem is producing carpels, the number of locks is determined. Whether an upland boll produces a four- or five-lock boll, is influenced by the health of the plant. If ample supply of carbohydrates is available (usually just before and after early bloom), the microscopic squares will produce more five-lock bolls. Plant health is usually reduced early in the square period (from cool temperatures) and from mid to late bloom (heavy boll load), and thus squares initiated at this time result in a higher proportion of four-lock bolls.

Abnormal square containing only bracts. (Photo Ken Lege')

Abnormal square with four bracts and extruded stigma.
(Photo Tom Kerby)

Abnormal square with four bracts. (Photo Tom Kerby)

Supernumerary carpel boll. (Photo Tom Kerby)

Terminal of a cotton plant with typical sized squares at first flower. (Photo Bill Robertson)

Terminal of a deficit moisture stressed plant exhibiting large squares in the terminal at first flower. (Photo Bill Robertson)

Pollen and Ovule Formation

One of the fortuitous developments in evolution was genetic recombination. The recombining of parental genes to make a novel genetic offspring allowed evolution to proceed at an explosive pace and species to adapt to changing conditions. Genetic recombination starts with the production of pollen cells in the anthers, approximately 22 days prior to bloom. A pollen cell has half the genetic material of the mother plant, but when combined via fertilization with an ovule (which also has half the genes), the result is a normal seed with a full set of genetic material. Shortly after pollen formation, approximately 17 to 19 days before bloom, pollen is vulnerable to high nighttime temperatures. Pollen sterility is a problem when nighttime temperatures remain above 80°F, which results in anthers that fail to shed pollen and retain a smooth appearance the day of bloom.

Another event that occurs approximately 22 days prior to bloom is the formation of ovules. When plants experience stress (cold or hot temperatures), the number of ovules per lock in pinhead squares is reduced. Although by 22 days prior to bloom the upper limit of seeds per boll has already been set (locks per boll X ovules per lock), up to half of the ovules fail to develop into a seed and terminate development as a mote.

Square Growth

When the square is 5 days away from bloom, it starts an explosive growth in size, as the petals expand, readying themselves for bloom. Large squares are now firmly attached to the plant and drawing some nutrients from nearby leaves. Young squares, on the other hand, are almost entirely fed by their own bracts, which are better adapted than leaves to low light, cool weather or N deficiency. Large squares are also less likely to shed.

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