UT Extension
W287

Cotton Growth and Development

Christopher L. Main, Associate Professor
Extension Cotton and Small Grains Specialist, Plant Sciences

Cotton has many unique qualities as a commercial crop. Understanding the history, growth habit and development of cotton allows for more efficient and profitable production system. Cotton is a perennial plant adapted to tropical and subtropical areas of the world. It has an indeterminant growth habit in which both vegetative and reproductive growth occur at the same time. The indeterminent habit allows cotton to endure environmental stresses and continue to produce fibers. There are two main commercial species of cotton grown in the United States: Gossypium hirsutum L., or upland cotton, and Gossypium barbadense L., or pima cotton.

Heat Units or DD_{60}'s

Cotton growth milestones are often given in terms of days after planting or between growth stages, but the development rate of cotton is strongly influenced by temperature. A cotton crop grows more slowly on cool days than on warm days, so temperature measurements during the cropping season help estimate when a crop reaches a specific developmental stage. Heat units, or DD_{60}'s, are an estimation of this accumulated temperature effect during a day, based on the average of the maximum and minimum daily temperatures in degrees Fahrenheit ($°F_{max}$ and $°F_{min}$, respectively). The number 60 is subtracted from this average, because 60 degrees F is generally accepted as the lowest temperature at which cotton growth occurs. The formula for calculating heat units per day is as follows:

$$DD60 = \frac{(°F_{Max} + °F_{Min})}{2} - 60$$

Calculating the accumulated heat units of a crop over time can then be used to estimate the growth of the cotton during the season. Table 1 demonstrates how to calculate accumulated heat units over a five-day period. Table 2 provides basic benchmarks in heat unit accumulation for different developmental stages of cotton growth.

Table 1. Calculation of daily and accumulated heat units based on daily high and low temperatures.

Day	Daily High Tempera-ture ($°F_{max}$)	Daily Low Tempera-ture ($°F_{min}$)	Average Daily Temperature ($°F_{max}+°F_{min}$)/2	Daily Heat Units ($°F_{max}+°F_{min}$)/2 – 60	Accumu-lated Heat Units
1	89	60	74.5	14.5	14.5
2	91	59	75	15	29.5
3	90	64	77	17	46.5
4	85	68	76.5	16.5	63
5	82	70	76	16	79

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Table 2. Typical heat units required for various cotton growth stages.

Growth stage	Heat units
Planting to seedling establishment	50-60
Nodes up the main stem	45-65
Emergence to first square	425-475
Square to white flower	300-350
Planting to first flower	775-850
White flower to open boll	850
Planting to harvest	2300

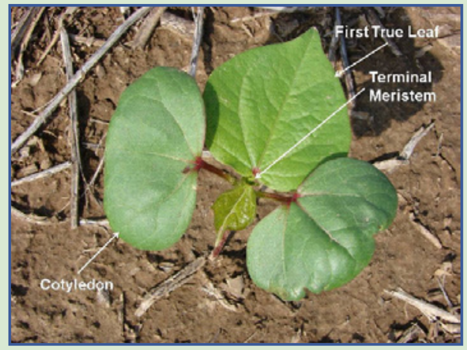

Figure 2. *Seedling cotton.*

Germination and Emergence

Cotton seeds contain all the essential ingredients for germination except one, water. Cotton seed begin to germinate when seed weight increases by 50 percent, due to water entering the seed. As the seed swells, the seed coat splits, allowing the radical to emerge. This process takes about three days if adequate soil moisture is present. Tissues between the elongating radical and the cotyledon leaves (seed leaves) swell rapidly. As the hypocotyl extends to the soil surface, the seedling is said to be in the 'crook' stage (Figure 2). The term 'crook' comes from the appearance of the curvature of the hypocotyl as it pulls the cotyledons from beneath the soil surface. At this stage, cotton is extremely susceptible to soil crusting, preventing the cotyledons from emerging.

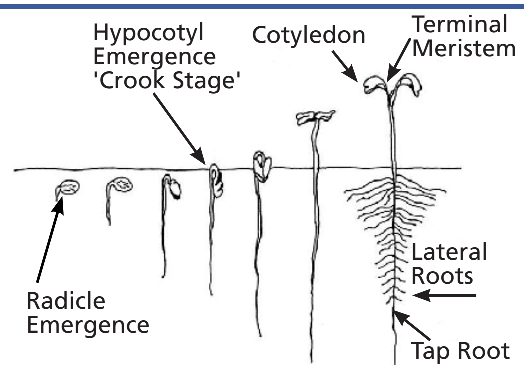

Figure 1. *Cotton seedling establishment.*

Seed germination and successful emergence is favored by adequate soil oxygen, moisture and warm soil temperatures (above 65 degrees F). Problems with germination are typically related to excessively dry or wet soil conditions, soil crusting, salinity, herbicide residue, cool temperatures and poor seed quality. In Tennessee we typically have marginal soil temperatures when planting begins, since we have a short growing season. Also, the high percentage of no-till production acres in Tennessee present problems with maintaining adequate seed-to-soil contact across various soil types, moisture conditions, soil residue and compaction zones.

Cotton Planting Forecast

To aid in making planting decisions, a cotton planting forecast can be calculated. A planting forecast will consider the predicted temperatures, DD_{60} accumulation, rainfall and potential for drying winds. Forecasts are subject to the same inaccuracies associated with weather prediction. This information should be used along with good judgment for making a planting decision (Table 3).

Table 3. Probability of cotton stand establishment based on DD_{60} accumulation.

Predicted DD_{60} accumulation 5 days after planting	Outlook for stand establishment
<10	Very poor
11-15	Poor
16-25	Marginal
25-50	Good
>50	Very good

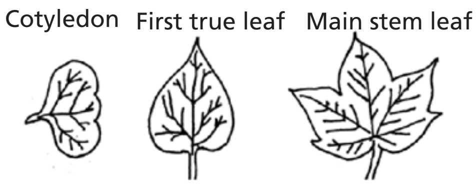

Figure 3. *Cotton leaf shapes.*

Once the cotyledons unfold, photosynthesis promotes development of new plant tissues from the apical meristems located between the cotyledons. The next structure to develop is the first true-leaf, which is ovate in shape (Figure 4). It typically develops 7 to14 days after the seedling becomes established. The emergence of the first true leaf shifts the plant's energy supply to gain carbohydrates from photosynthesis instead of the stored carbohydrates in the cotyledons. The first several true leaves to develop are important for proper plant development and need protecting from insect damage, as the carbohydrates created are responsible for the development of a deep, healthy root system. Cold soil, insect injury, seedling disease, nematodes, low soil pH, water stress, hard pans and herbicide residues can inhibit root development. Root development continues during the early season. Peak root mass is achieved during early flowering and then declines into the late season. Carbohydrates are redirected to metabolic sinks associated with boll formation instead of root and vegetative growth at this time.

Vegetative Growth

Cotton has an indeterminate growth habit and can grow very tall under favorable environmental conditions. Growth regulators, such as mepiquat chloride, are generally applied to cotton to slow internode elongation, especially for well-fertilized, irrigated cotton. Increased vegetative growth promotes boll rot and fruit abscission and makes a cotton crop difficult to harvest.

The first vegetative structures that appear on the main stem are main stem leaves (Figure 3 and 4). Main

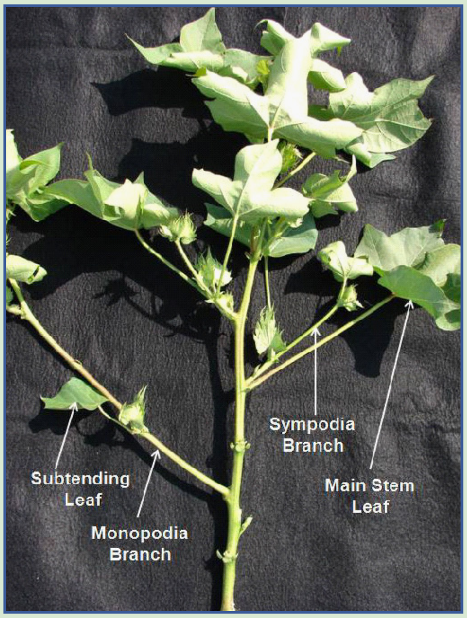

Figure 4. *Stem arrangement.*

stem leaves and branches form at points of attachment on the main stem called nodes. As a general rule, a new node is produced from the apical meristem an average of every three days, although nodes develop more quickly earlier rather than later in the season. Leaves that arise directly from the main stem are referred to as *main stem leaves,* while leaves that arise from the fruiting branch are referred to as *subtending leaves*. The fruit produced by a branch will primarily receive carbohydrates produced by the leaf subtending that fruit. However, the main stem leaf also supplies carbohydrate for fruit development

Leaf and Canopy Development

As a cotton plant develops, new leaves appear and expand, increasing sunlight interception. Initially the carbohydrates produced by the leaves are used to produce roots and more leaves. This production of new leaves causes the leaf area of the cotton plant to increase rapidly. Once reproductive structures begin to develop, carbohydrate supplies are slowly shifted to the developing fruit. As the fruit load on the plant increases and ages, the carbohydrate demand increases, and the development rate of new leaves declines. Premature aging of the cotton leaf canopy due to water stress, low fertility and other stresses further reduces the photosynthetic capacity of the crop.

The branches from which fruiting buds arise are called fruiting branches, or sympodia, because each fruiting branch contains multiple meristems. Fruiting branches have a "zig-zag" growth habit, as opposed to the straight growth habit of the vegetative branches. The initial growth of a fruiting branch is terminated once a fruiting bud forms. The fruiting branch, however, initiates a new growing point, called an *axillary meristem.* The axillary meristem is located at the base of a leaf that subtends the newly formed fruiting bud.

The first fruiting branch will generally arise at main-stem node 5 or 6. A cotton plant will mainly produce fruiting branches, but several common environmental factors such as low population density, insect and disease pressure, and overfertilization can cause vegetative branches to form. Vegetative branches are produced after fruiting branches, and develop at nodes directly below the node at which the first fruiting branch was developed. For instance, if the first fruiting branch is initiated at main-stem node 5, a vegetative branch may develop at main-stem node 4.

New fruiting branches generally develop approximately every three days, although recent studies show that this developmental rate varies. Squares are produced at new positions on a fruiting branch approximately every six days. The age of fruiting structures on a cotton plant can be mapped according to this time sequence.

Photosynthate Partitioning

Most of the cotton plant's carbohydrate energy is directed to root growth prior to the time reproductive growth begins. This is a function of source-to-sink relationships. Carbohydrates are transported from supply areas (leaves), called sources, to areas of growth or storage (roots, shoots, bolls), called sinks. As bolls develop, they become carbohydrate sinks. Root and shoot growth slow, boll development dominates plant growth and roots continue to supply water and nutrients to the shoot.

The branches on a cotton plant can be classified as either vegetative branches *(monopodia)* or fruiting branches *(sympodia).* Because vegetative branches have only one meristem, they grow straight and erect, much like the main stem (Figure 4). Vegetative branches can also produce fruiting branches. A flower bud, called a square, begins to form at the initiation of the fruiting branch. The first square produced on a fruiting branch is referred to as a first-position square. As this square develops, the portion of the fruiting branch between the main stem and the square also elongates. This portion of the fruiting branch is also called the *internode,* similar to the portion of the main stem between main-stem nodes. An axillary meristem also develops adjacent to this square. The axillary meristem produces a second position square and subtending leaf. As many as four squares may be produced in this fashion on a fruiting branch.

Squaring through Boll Development

The cotton flower bud has several recognized developmental stages. A *pinhead* square is the first stage at which the square can be identified. The next stage of square growth is *match-head* square. Just prior to the time the flower opens, a candle shape can be seen (Figure 5). This period of square development prior to bloom can be called *squaring, pre-bloom or pre-flower.*

Figure 5. *Pinhead square, matchhead square, candle and white.*

The first visible structures of the square are the leaf-like bracts, or *epicalyx.* Three bracts surround the flower bud in a pyramid-like shape. The cotton plant produces perfect flowers, meaning the flower contains both male and female organs. The first square is typically visible on node 5 to node 7 about 35 days after planting. *Anthesis*, or flowering, occurs approximately 21 to 28 days after the first square appears. A cotton plant typically blooms or flowers for about four to six weeks, depending on environmental conditions. Thus, until the cotton begins to produce fruit, the stage of development is discussed in terms of leaves or nodes. Once flower buds are present, the stage of cotton development is discussed in terms of square development and the number of nodes. Once blooms and bolls are present, the stage of cotton development is discussed in terms of weeks of bloom.

Flowering is important to cotton production because pollinated flowers form cotton bolls. The bloom process takes several days, and bloom age can be estimated by the bloom characteristics. On the day a flower opens it is white. Pollination of that flower usually occurs within a few hours after the white flower opens. On the second day, the flower will become pink, then turn red on the third day. Approximately five to seven days after a flower appears it usually dries and falls from the plant, exposing the developing boll. Occasionally a flower will stay attached to the developing boll for a longer period of time. This is referred to as a *bloom tag.*

The development of the cotton plant, in terms of leaf number, node number and fruiting stage, is discussed in previous sections. During the flowering period, the stage of cotton development can also be discussed in terms of *Nodes Above White Flower* (NAWF). This is a measurement documenting the number of nodes separating the uppermost first position bloom and the terminal of the plant.

When the cotton plant first begins to bloom, there will be typically nine to 10 NAWF. As the season progresses, the number of NAWF decreases. NAWF generally decreases more quickly after bloom in early maturing varieties than in mid- or full-season varieties. As the flowers develop into bolls, they become stronger sinks for carbohydrates and their combined demand for carbohydrates increases. Eventually, the carbohydrate supply produced by the leaves will be used primarily by developing bolls, leaving less available for the production of new vegetative growth. As flowering progresses up the plant, less top growth is produced, and the number of NAWF will decrease.

As the flowering approaches the top of the plant, the plant eventually puts all of its energy into boll development and ceases flower development. This event is termed *cutout.* Cutout generally occurs at 4 or 5 NAWF. Cutout occurs when carbohydrate supply equals demand and vegetative growth ceases. At cutout, no more harvestable fruit is set.

Fruit Shedding

A phenomenon often seen in a cotton field is square shedding. The shedding of squares may be the result of several factors, including water stress, shading (rank growth or prolonged cloudy weather), nutrient deficiencies (especially N), high temperatures, high plant populations, high percent fruit set and insect damage.

Flowers and young bolls also may be shed from the plant due to the same factors that lead to square shedding. Generally, though, the sensitivity of squares, flowers and bolls to shedding can be related to their age. Small squares and bolls are more likely to be shed than are more developed squares and bolls.

A boll begins to develop after pollination occurs. Under optimum conditions, it requires approximately 50 days for a boll to "open" after pollination occurs. Boll development can be characterized by three phases: enlargement, filling and maturation. The enlargement phase of boll development lasts approximately three weeks. During this time, the fibers produced on the seed are elongating and the maximum volume of the boll and seeds contained therein are attained.

The filling phase of boll development begins during the fourth week after flowering. Fiber elongation ceases and secondary wall formation of the fiber begins. Cellulose is deposited inside the elongated fiber, filling the void space. During the boll enlargement and fiber elongation phase, the development of fiber is very sensitive to adverse environmental conditions. Low water availability, extremes in temperature and nutrient deficiencies (especially potassium) can reduce the final fiber length, strength and micronaire. However, bolls at this stage will rarely shed.

The boll maturation phase begins as the boll reaches its full size and maximum weight. During this phase, fiber and seed maturation take place and boll *dehiscence* occurs. The capsule walls of the boll dry, causing the cells to shrink unevenly. This shrinking causes the suture between the carpel walls to split, and the boll opens.

Yield Distribution

The contribution of a single fruiting structure to the overall yield of the cotton plant depends largely upon its position on the plant. First-position bolls are typically heavier and produced in higher quantities than bolls at any other position. In cotton populations of three plants per foot of row, first-position bolls contribute from 66 to 75 percent of the total yield of the plant, and second-position bolls contribute 18 to 21 percent.

Yield distribution research is an intensive, detailed process that involves counting and weighing bolls from each fruiting position on many plants. First-position bolls tend to fill out more and be heavier than bolls from other positions, so the majority of boll weight on plants generally comes from the first-position fruit between nodes 7 and 20. However, second-position bolls or bolls from upper nodes will get larger (compensate) if extensive shedding of first-position fruit occurs. This may increase the time to crop maturity and delay harvest.

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