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Cotton Plant Development and Plant Mapping

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The growth and development of a cotton plant is unique among the commonly grown row crops in the United States. Understanding cotton's growth and development pattern is very important for timely management in the short-season environment commonly experienced in Missouri. Cotton is a semi-tropical, perennial plant that has been bred and cultivated for production as an annual plant under a wide range of temperate environments. With a good understanding of how a cotton plant grows and develops, growers will be better prepared to predict how cotton will grow and to make good management decisions.

Vegetative growth pattern

A cotton plant begins its growth with its two cotyledons (the seed leaves that form nodes opposite each other at the base of the main stem) providing the only energy (stored and from photosynthesis) for the plant to use until it grows its first true leaves to improve its photosynthetic "factory." The carbohydrate (sugar) production from photosynthesis is the primary energy source for growth of vegetative and reproductive organs.

Development of a healthy root system for acquiring soil nutrients is often overlooked but is equally important in supplying the plant with the necessary components for growth. Temperature determines the developmental rate of the plant, i.e. how quickly the plant adds new plant parts. Plant growth depends on a combination of:

- Radiation used by healthy leaf area for carbohydrate production
- Temperatures for rapid plant development
- A healthy root system to take in the nutrients required by the basic plant structure and to feed the growing plant.

Main stem and branches

As a cotton plant begins to grow, it develops a series of nodes up the main stem. At each of the early nodes (prior to fruiting), one main-stem leaf is found. The stem will extend to the next node, with the growth between the two nodes referred to as the internode. If a vegetative branch or fruiting branch grows, it will form at the node. The vegetative branches typically form prior to the fruiting branches on one of the first four to seven nodes.

Vegetative branches have a similar morphology to the main stem and will produce their own fruiting branches. Many of the first four or five nodes will not bear any branch structure. Beginning with the fifth or sixth node, the plant begins to form fruiting branches, which bear the developing cotton fruit (square, bloom, boll). A typical cotton plant grown in Missouri will continue to add nodes and fruiting branches for a total of 18 to 22 nodes, with 12 to 16 fruiting branches. Most of the yield is set on eight to 10 fruiting branches. Under "normal" growing conditions, a new mainstem node will form on the plant every three days in Missouri. A cotton plant can set its boll load in as little as three weeks and still have good to excellent yield potential.

Leaves

To provide the carbohydrate energy supply for adding nodes and branches and for growing bolls, leaves function as the energy conversion factory. Photosynthesis converts light energy to chemical energy that is stored as sugars in the plant. All plant metabolic reactions are dependent on this energy source. An efficient plant will develop a canopy quickly to capture nearly all of the solar radiation available. Plants that have established a full canopy by the bloom period will be able to keep more bolls and fill them more effectively.

As a cotton plant adds new nodes, it is also adding new leaves to the photosynthetic factory. The leaf area on a cotton plant is very small prior to first square. When the plant begins to square, two leaves are added at each node (one mainstem leaf and one on the fruiting branch), which results in a large increase in leaf area. Since leaves reach their maximum photosynthetic production between 16 and 21 days of age, a cotton plant is able to enlarge its photosynthetic production by adding new leaves throughout the bloom period.

Roots

During early vegetative growth, development of a strong root system is the plant's top priority. The taproot penetrates through the soil rapidly and may reach a depth of 10 inches by the time the cotyledons unfold. Roots may grow at a rate of 0.5 to 2.0 inches per day during the early vegetative stage, permitting early roots to be twice as long as the plant height.

When plants begin to set bolls with a large demand for carbohydrates, root growth slows abruptly. Root length actually begins to decline as older roots die during the boll-fill period. Root activity drops as roots grow older, leading to a less effective root system for uptake of water and nutrients during boll-fill when the plant's demand for carbohydrates and mineral nutrients is at a peak. For cotton in Missouri, this limited root growth does help to slow down growth of the plant late in the season and should be used as a means to help manage crop maturity without decreasing yields.

Reproductive growth pattern

Fruiting branches

Fruiting branches typically form above the fifth or sixth node on a cotton plant and bear the developing fruit. The developing branch terminates in a square, but a second square and leaf develop adjacent to the first leaf and extend a new internode of the branch away from the first fruiting position. The fruiting branch grows by repeating this process to produce several squares, leaves and internodes in a zigzag pattern, as illustrated in Figure 1.

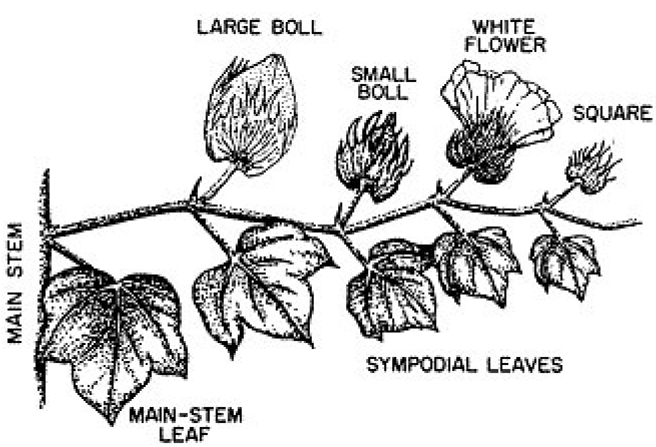

Figure 1
Cotton fruiting forms.

Fruiting structures

Squares are the flower bud that first appears on the plant when reproductive growth begins. The flower bud is enclosed by three bracts. Squares grow for about three weeks before a bloom appears. During this time numerous events are occurring within the flower bud structure. Two weeks before the square is visible on the plant, the floral stimulus is initiated, and just prior to the pin-head square, the number of ovules (potential seeds) is established. The male and female parts of the flower undergo their development within the square and the fiber cells begin to differentiate just prior to bloom. The actual number of seeds within a boll is dependent on effective fertilization of the bloom.

Blooms open at the culmination of the square period. The cells of the flower petals expand rapidly during the 24 hours preceding bloom, and the flower opens during the early to midmorning hours. During this time the male and female flower parts expand rapidly. The flower opens when the cotton reproductive system has reached maturity. The embryo sac is fully developed and ready for fertilization by the pollen from a mature antherat bloom. If the ovules are not fertilized properly, the plant sheds the young boll. The flower petals turn pink on the second day and later dry up and drop off the young boll.

Boll development begins with fertilization of ovules and alters the status and growth of the plant. Rather than sending most of its resources to vegetative growth, the plant must now support continued vegetative growth as well as growing bolls. The growth of a boll can be divided into three phases: enlargement, filling and maturation. The enlargement phase determines the final volume of the boll and seeds, while the fibers are elongating during the first 20 days after bloom. The filling period is the next 20 days after bloom, when much of the dry matter is added to the boll through secondary wall formation of the fiber; oil and proteins are added to the seed during this time as well. The maturation period allows both the fiber and the seed to mature physiologically and dry down prior to boll opening.

Nutrient demand

The demand for carbohydrates and nutrients increases with the growth of the cotton plant. The plant's ability to supply carbohydrates and nutrients becomes limited during boll growth because the plant shifts its priorities from building the suppliers (leaves and roots) to feeding the consumers (seed and lint). When the source or supply becomes limited, the highest priority structures are supplied first. This principle is evidenced in the cutout of a cotton plant. The high priority structures are bolls, and the growth of new mainstem nodes become secondary. Addition of new mainstem nodes slow down and then stop, and the squares that had been formed up the main stem bloom successively to the terminal.

As the cotton plant matures and bolls open, the demand for nutrients and carbohydrates is reduced. With warm temperatures, moist soil and excess nitrogen, the plant may revert to a second cycle of vegetative growth, adding mainstem nodes to the terminal along with new squares. In Missouri's short-season environment, good management would supply only enough inputs to meet the demands of the crop through boll fill, discouraging second growth. By manipulating the source/sink relationships of a plant, a high-yielding, early maturing crop can be achieved in Missouri.

Fruit shed

When a cotton plant can no longer supply the needs of both vegetative and reproductive growth, it adjusts its growth pattern. Vegetative growth gradually slows and then stops.

However, some short-term deficiencies are relieved by reducing the number of fruit on the plant. Fruit structures with the lowest priority and least investment are aborted: squares and small bolls. This reduces the immediate demand for carbohydrates and nutrients. Squares require very little carbohydrate from the plant, but they represent future demand when they become bolls. Bolls are a much higher priority than squares, because the plant already has a large investment in medium to large bolls and is biologically programmed to survive by producing the seed sound in the boll.

The fruit shed phenomenon, particularly a physiological fruit shed and not fruit loss due to insect feeding, is typically found after bloom and after cloudy days. Reduced radiation on cloudy days reduces the carbohydrate supply of the plant and results in squares shed from the plant. If shedding squares does not reduce the nutritional shortfall, then small bolls are shed. Cotton plants never shed blooms and rarely shed bolls more than seven days old.

Fruit shed is of particular concern in Missouri when it occurs early in the fruiting cycle and potentially delays the maturity of the crop. Measuring fruit shed and managing to avoid problems with fruit shed are important strategies and one of the primary purposes of plant mapping.

Heat unit requirements

Cotton develops at a pace determined by the temperatures that the plant encounters. If temperatures are between 65 and 85 degrees Fahrenheit, a cotton plant develops at a very predictable rate. In other words, above a base temperature of 60 degrees Fahrenheit, a cotton plant grows. Below that threshold, little or no development occurs. The calculation of heat units is very straightforward for the conditions encountered in the middle-south region of the Cotton Belt. The calculation is made by averaging the maximum and minimum temperatures for a day and subtracting the base temperature to find the heat units. It is illustrated as follows:

$$\text{Heat units} = \frac{\text{max. temp.} + \text{min. temp.}}{2} - 60$$

You can find heat units listed in some weekly farm magazines or in the monthly Missouri Cotton News, distributed by MU Extension at the Delta Center. A study of heat units can be helpful in managing your cotton crop's development throughout the season. Table 1 provides an outline of the heat unit requirements for a cotton crop to help you assess your crop's rate of development.

Table 1
The average number of heat units required for various growth stages of cotton in Missouri

Developmental stage	Heat units (DD-60s)	Average date[1]
Planting	0	May 1
Seedling emergence	55	May 12
Add nodes to the main stem	45 to 65 per node	3 days per node
First square	500	June 17
First bloom	850	July 6
Cutout (assuming 20 mainstem nodes and 10 to 12 effective fruiting branches)	1,300 to 1,450	July 28 to Aug. 6
First open boll	1700	Aug. 20
Harvest	2,150 to 2,300	Sept. 21+

[1]Based on average heat unit accumulation for Portageville, Mo.

Since the Missouri Bootheel region accumulates 2,250 heat units on average from May 1 to Oct. 1, it becomes evident that close management and monitoring of the crop are necessary to mature and harvest the crop in a timely manner. Plant mapping is a new and effective technique that growers can use to ensure that they keep their crop on schedule.

Plant mapping

By quantifying several growth parameters of the cotton plant, growers and consultants can identify potential problems or opportunities for managing their cotton. This management approach requires the time and effort to collect and interpret these simple plant maps. Early approaches to plant mapping were a very intensive effort that required every fruiting site on the plant to be recorded as either a square, bloom, boll or aborted position. This was very similar to the plant maps used by cotton researchers. Further studies have shown that a few easily collected numbers can quickly provide much information for managing cotton.

Measurements

Sampling a cotton field usually calls for going to four areas of a field and measuring five plants in each area. Three sampling periods are important: prebloom, bloom and postbloom. The measurements taken before bloom are important in measuring the early growth pattern and avoiding early problems that slow development of mainstem nodes and leaf area. During the bloom period, the primary concerns are retention of fruit on the plant and how quickly the plant is moving to "cutout." After cutout and while bolls are opening, correct timing of harvest aids can be determined by some simple plant mapping techniques.

Node of first fruiting branch
To assess the shift from vegetative growth to the beginning of fruit development, count the number of nodes to the first fruiting branch. During early squaring, this is the first node that has a square. Count the nodes by finding the cotyledons. Begin counting the first node above the cotyledons that was formed by a true leaf (cotyledons = 0).

The first fruiting branch will typically form on the fifth or sixth node on cotton in Missouri. Forming lower than the fifth node is unusual and may lead to the cotton plant cutting out too quickly, since it may not have enough leaf area to support the fruit forming on the plant. If the first fruiting branch is delayed to the seventh or eighth node, then the beginning of the fruiting cycle is delayed, which may require a shorter fruiting period if the late fruit on the plant is unable to mature in a short season. Avoiding insect damage or other stresses are good management strategies to help the cotton plant begin fruiting on an optimal node.

Height-to-node ratio
To assess the vigor of the cotton crop, measure both the height and node number of several cotton plants and calculate the ratio of height to nodes by dividing (plant height divided by the number of mainstem nodes). This ratio indicates the amount of stress that a cotton plant has encountered, because the development of nodes is not influenced by stress (before boll set) while plant height is greatly influenced by various stresses. In other words, the number of nodes is the age of the crop, and the height is an indicator of stress encountered. The target value for this ratio will vary according to variety and time of the season, but the following values can serve as general guidelines (in warm, moist conditions):

- Seedling cotton
  0.5 to 0.75 inches per node
- Early squaring
  0.75 to 1.2 inches per node
- Large square to first bloom
  1.2 to 1.7 inches per node
- Early bloom
  1.7 to 2.0 inches per node

Several management strategies exist when the height-to-node ratios are outside of these ranges. If the crop is too short for its age, then you need to look at what stresses may have been encountered by the crop. Is the crop under water stress? Is irrigation available to relieve the stress? Has the plant encountered thrips damage? Look for the source of the stress and what possible response could relieve that stress. If the crop is too tall (height to node ratio above the guidelines), then use of a growth regulator such as mepiquat chloride or PIX® may be needed. Slow the height growth of the plant only if there are no stresses evident for the crop. Plant height is closely related to canopy size and photosynthetic capacity of the plant. Using these guidelines of height-to-node ratio should lead to canopy closure by mid-bloom, to optimize available sunlight.

Fruit retention

Throughout the reproductive growth phase, the cotton plant is constantly adding squares to the plant and then aborting squares or young bolls to balance out the demand of the growing boll load. By counting the number of fruiting branches above the uppermost first position white flower (with squares) and the number of squares at the first position sites, the percent square retention can be calculated. Similarly, by counting the number of nodes below the uppermost first position white flower and number of bolls at the first position sites, the percent boll retention can be calculated.

Percent retention for squares prior to bloom should remain very high, since squares only need small quantities of carbohydrate for their survival. Physiological square shed doesn't occur until the demand for carbohydrate is peaked by growing bolls. Square shed prior to first bloom may be caused by insect feeding, particularly by plant bugs or boll weevils. If square loss before bloom is noticed, a look at insect pressure is needed.

Early square shed can also delay maturity, which may require a closer watch on the maturity of the crop as it approaches cutout. Boll retention should begin near the level of square retention and show a gradual decline throughout the bloom period as the plant reaches its capacity for supplying bolls with carbohydrates.

Young bolls are sensitive to physiological shed when carbohydrate supplies are limited due to cloudy weather, high temperatures, water stress, leaf damage or a heavy boll load. During this stage, management options should help the plant keep the supply of carbohydrate large, to permit the boll load to grow and supply all the carbohydrate need for boll growth. Avoid problems that can reduce carbohydrate supply by timely irrigation, good fertility and avoiding stresses that would reduce the canopy size.

Nodes above white flower (NAWF)

A very accurate and sensitive measure of the cutout of cotton is the number of nodes from the uppermost first position white flower to the terminal node of the main stem. As the fruiting cycle of cotton reaches its peak, the plant cannot meet the demands for both unlimited vegetative and reproductive growth, so the plant slows and eventually stops adding mainstem nodes. The squares that were formed with each node eventually form blooms that are progressively closer to the terminal. The NAWF usually starts near the eighth or ninth node in Missouri and then moves to the fourth or fifth node for cutout as the bloom moves up the main stem.

To take advantage of the fruiting period, the NAWF of 5 should be reached by Aug. 10 to 12 in Missouri to permit sufficient time for that boll to mature. By monitoring NAWF from bloom to cutout, management inputs can be fine-tuned to optimize production. If the NAWF is dropping too rapidly and may reach cutout too early (before Aug. 5 to 10), then irrigation management should be considered, if available. Nitrogen deficiency can also lead to a premature cutout, which should be confirmed through a petiole test before foliar applications of nitrogen are made. If the NAWF is not dropping fast enough to reach cutout by Aug. 10, then additional PIX® or mepiquat chloride may be required to slow the growth of the terminal and promote an earlier cutout.

Nodes above cracked boll (NACB)

As the crop approaches maturity and time for harvest aid application, the opening of bolls up the cotton plant mimics the pattern of white flowers blooming up the plant prior to cutout. The NACB is determined by counting the number of nodes from the uppermost cracked open boll to the uppermost harvestable boll. When NACB reaches nodes four to six, then harvest aids (Prep® + defoliant) can be applied with risk of only small levels of yield loss (0 to 2 percent). Counting the number of unopened and opened first position bolls and calculating percent open bolls is recommended. More than 50 to 60 percent of bolls should be open before applying harvest aids to avoid yield and fiber quality losses.

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The measurements approach described in this publication is very similar to those used by the Cotton Physiology Education Program (CPEP) of the National Cotton Council. General explanation and background material is available from several CPEP publications on plant mapping.

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Related MU Extension publications

- G4258, Plant Growth Regulators for Cotton
  http://extension.missouri.edu/publications/DisplayPub.aspx?P=G4258
- IPM1025, Cotton Pests: Scouting and Management
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