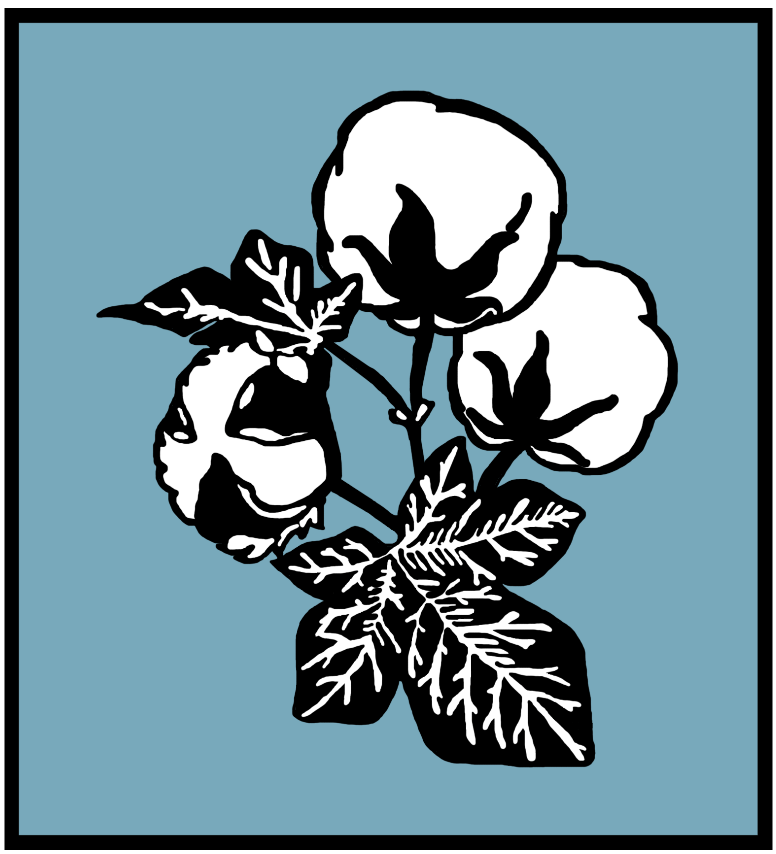
Cooperative Extension Service
The University of Georgia College of Agricultural and Environmental Sciences

Cotton Growth and Development



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Cotton Growth and Development

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Introduction

Domestic cotton has a unique origin and history among cultivated crops. The wild ancestors of modern cotton species were perennial vines that inhabited several distinct geographic areas, including Africa, Arabia, Australia and Mesoamerica. During the past several centuries, people native to these regions developed four distinct species of cultivated cotton, including upland cotton (*Gossypium hirsutum* L.), the primary species grown in the United States. Despite the selective breeding efforts of humans, many of the wild characteristics of cotton have not been removed, making cotton management difficult and unique.

Wild cotton is a tropical perennial plant with an indeterminate fruiting habit, meaning that it continues to produce new foliage even after it begins to create seed. Despite its inherent perennial growth habit, however, cotton is managed as an annual crop plant, and growers try to produce as much lint and seed as possible. Continued vegetative growth after flowering diverts the plant's energy away from lint and seed production, so the perennial nature of even modern cultivars opposes our current production system.

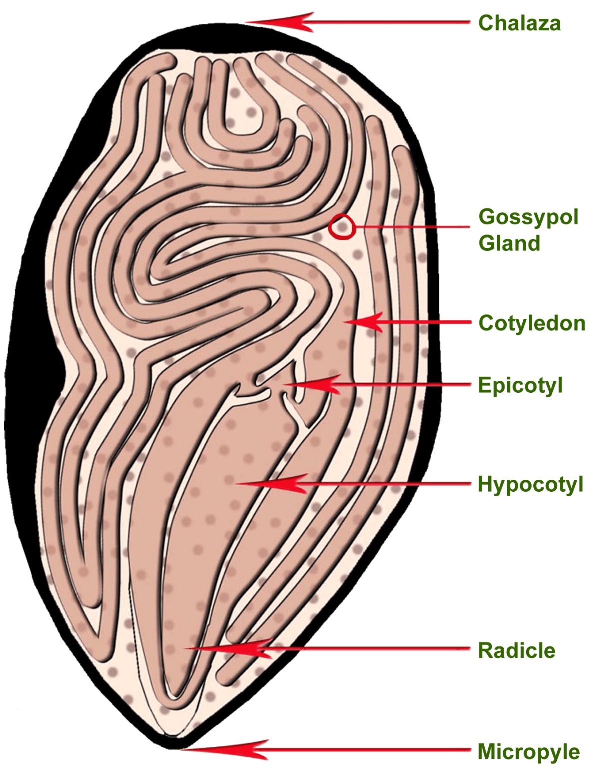

Figure 1. A small, dormant seedling rests inside a mature seed. When the seedling emerges, the radicle will be the primary root, the hypocotyl will be the stem under the cotyledons, and the epicotyl will be the stem above the cotyledons from which shoot growth occurs.

The cotton plant also produces fruit on two different types of branches, each unique in growth habit, further complicating crop management. In addition, cotton growth is very sensitive to temperature and soil conditions. As in other crops, producers use chemicals in cotton to control weeds and insects, but cotton is unique in that crop growth must also be regulated and eventually terminated by chemical means. Understanding the growth and development of the cotton plant helps producers grow a high-yielding, high quality crop.

The following discussion is intended to provide applicable information on the growth and development of the cotton plant. The *Georgia Cotton Production Guide* (updated annually) is an excellent data source for the agronomic inputs required for producing cotton. The production guide and other useful cotton links can be found on the University of Georgia Cotton Web Page at **http://www.griffin.peachnet.edu/caes/cotton.**

Inside the Seed

A mature cotton seed contains all of the organs necessary to produce a small seedling. The seed is pointed on one end (the *micropyle*) and rounded on the other (the *chalaza*). The tip of the primary root, or *radicle,* faces the micropyle, and the precursors of the stem and cotyledons are plainly visible within the seed (Figure 1).

The chalaza is the primary site of water and oxygen absorption during germination. The tip of the primary root, or radicle, is the first part of the plant to emerge through the micropyle. The cotyledons that will nourish the new seedling are folded inside the seed, with the hypocotyl below them ready to elongate and push the seedling through the soil. The *gossypol glands* visible throughout the inside of the seed are also visible in the tissues of the growing plant.

Germination and Seedling Development

Germination begins as the seed absorbs water and oxygen through its chalaza after planting. The water swells the dormant tissues, and cell growth and division begin to take place. The radicle emerges through the micropyle, turns downward, and grows deeper into the soil, providing a taproot that will supply water and nutrients throughout the life of the plant (Figure 2a and b). The hypocotyl elongates from the radicle and forms an arch or crook that begins to push up through the soil, a brief period often referred to as the "crook stage" (Figure 2c).

Seedling emergence normally takes place 4 to 14 days after planting. At the soil surface, the hypocotyl straightens and pulls the folded cotyledons out of the soil (Figure 2d), a process known as *epigeal germination.* After the cotyledons are pulled through the soil surface, they unfold and expose the epicotyl and the apical meristem, or growing point, which will be the source of subsequent growth (Figure 2e-f). At this point, germination and seedling emergence are complete and the plant begins its active vegetative growth.

The Cotyledons and First True Leaves

The cotyledons (Figure 3) serve a dual role in germination. Before they unfold, they supply stored food to the germinating seedling. After the cotyledons unfold, they produce chlorophyll, become green, and produce energy through photosynthesis. The apical meristem emerges at the base of the cotyledons, and all further vegetative and reproductive growth of the plant occurs through the meristems.

A week or so after seedling establishment, the first true leaf appears above the cotyledons (Figure 4). The first leaf shifts the plant's primary energy source from storage to photosynthesis and signals the move from emergence to vegetative growth.

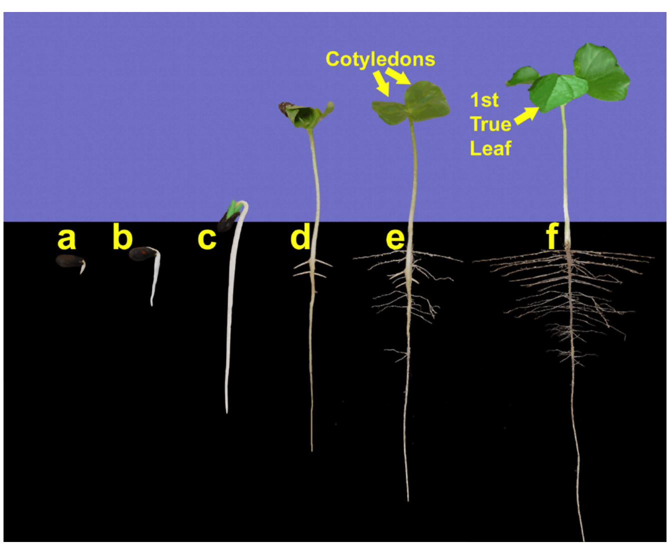

Figure 2. Germination and early seedling development. Root growth dominates the early growth of the plant.

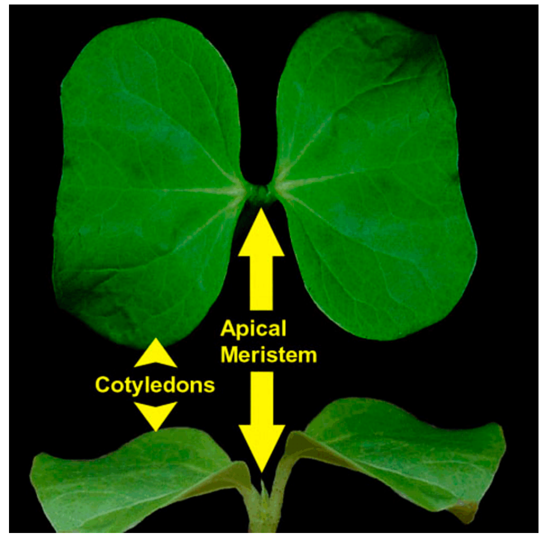

Figure 3. The cotyledons are storage organs that are formed in the seed and emerge from the soil as leaf-like structures oriented opposite each other on the seedling stem. The cotyledons provide nutrients for the seedling. The apical meristem emerges through the cotyledons and will be the source of new growth as the plant matures.

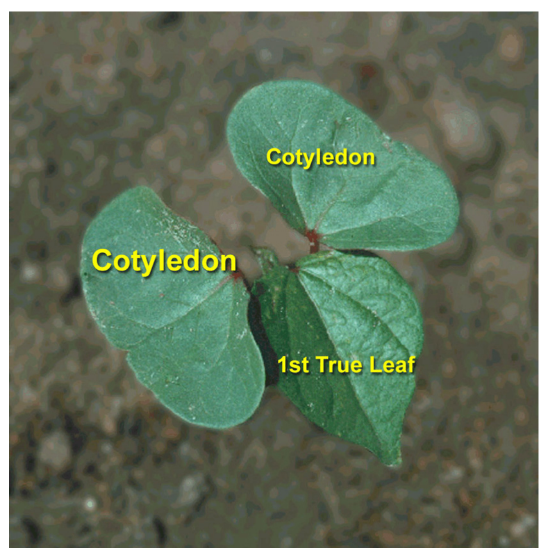

Figure 4. The first true leaf emerges about 7 days after seedling establishment. From this point on, the meristems will produce all vegetative and reproductive structures on the plant.

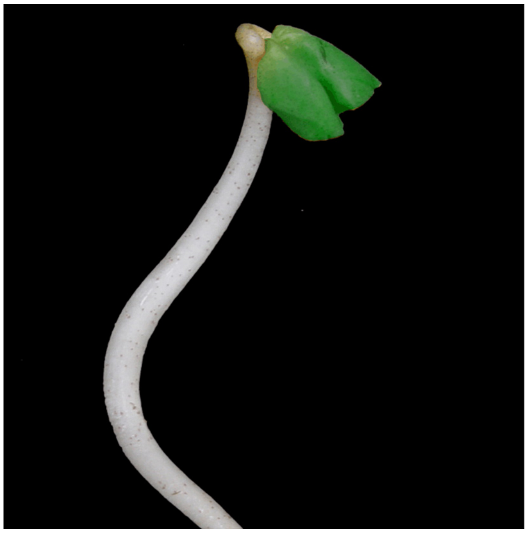

Figure 5. Thick shank in a cotton seedling. Soil crusting, compaction or other mechanical factors can cause thick shank.

Soil Effects on Germination and Early Root Growth

Root growth dominates the growth of the cotton plant during germination and seedling establishment. In fact, the taproot may be as deep as 10 inches by the time the cotyledons emerge. This is a critical time for the development of the root system. Cold soils, seedling disease, low soil pH, water stress, hard pans and herbicide injury all inhibit root growth and development, but careful crop management can minimize most of these stresses. The roots absorb water and nutrients that are vital to the development of the plant, and any hindrance of root development in these early stages of cotton growth may cause a disappointing production season.

Cotton emerges the quickest from warm, moist soil. Low temperatures (below 60 degrees F) or less than adequate soil moisture may hinder germination by slowing metabolic processes (see the discussion on heat units). Physical impedance, such as crusting, does not slow germination, but it can prevent the hypocotyl from emerging. This often causes thickening of the hypocotyl and a condition referred to as "big shank" or "thick-legged" cotton, resulting in reduced seedling vigor (Figure 5). Generally, the longer it takes for emergence to occur, the greater the risk of plant death and yield loss. A rule of thumb for planting cotton in most regions of the U.S. Cotton Belt is that the soil temperature at 4 inches deep should be at least 65 degrees F for 3 consecutive days, with warm temperatures in the forecast.

Root Development

As the cotton plant grows, the radicle that originally emerged from the seed becomes a taproot, from which lateral roots begin to form and grow. Lateral roots and the taproot collectively make up the basal root system. Other "higher order" roots then develop from this basal root system. These higher order roots have a functional life of about 3 weeks. They form when environmental conditions are good, and then die when nutrients and water are depleted in the area in which they developed.

As the plant matures, the roots continue to spread and probe deeper in the soil profile for water and nutrients. Therefore, the distribution of roots tends to match the most fertile soil zones. Figure 6a shows an example of the root distribution of an unstressed cotton community. Most of the roots in this case can be found between 1 and 3 feet deep in the soil, but large quantities of roots can still be found more than 4 feet deep in the soil. The

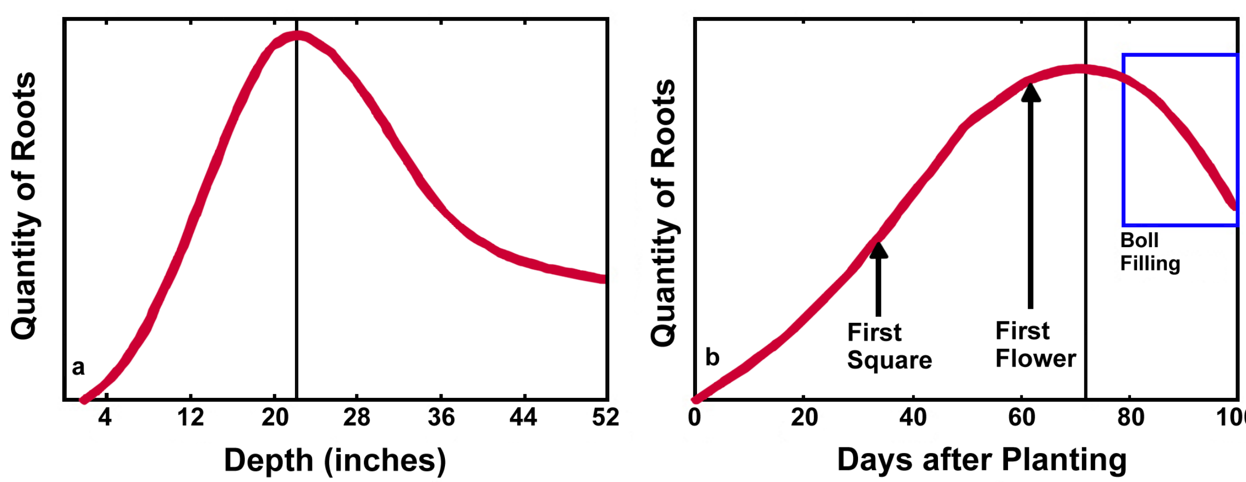

Figure 6. (a) Comparison of root quantity with soil depth for a mature cotton plant. New roots are constantly produced in areas of the soil profile that have water and nutrients. (b) Comparison of root quantity with cotton growth stage. Roots begin to decline after flowering as the cotton plant shifts its energy from root to boll development.

amount of roots generally peaks during the cotton flowering phase then declines as the plant partitions more carbohydrates to the developing bolls (Figure 6b).

The Meristems

The cotton plant has meristems, or growing points, at the top of the main stem and on its fruiting branches. These meristems allow the plant to simultaneously grow upward and outward. Figure 7a is a micrograph of the apical meristem and first two fruiting branches, which are too small to be seen without magnification.

Thrips feed on these young meristems, and plant injury occurs when the thrips insert their mouth parts into the cells to feed. The cells near the insertion point die, but the cells around them continue to expand and divide, resulting in crinkling and distortion of expanding leaves. Thrip damage slows plant growth, and thrip-damaged leaves have a puckered appearance and may have holes in them because of this damage (Figure 7b).

Vegetative Growth

Cotton has an indeterminate growth habit and can grow very tall under conditions of unrestrained growth. Growth regulators, such as mepiquat chloride, are generally applied to cotton to slow internode elongation, especially for well-fertilized irrigated cotton. Otherwise, vigorous cotton varieties with plenty of water and nutrients can develop very tall, heavy vegetative growth (Figure 8, page 7). This type of rank 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 9, page 7). Main 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 3 days, although nodes develop more quickly early in the growing season than later in the season.

The stem-like structure that connects the leaf with the stem is called a petiole. 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. Fruit produced closer to the main stem will receive more carbohydrates from the main stem leaf than fruit produced at more distal positions.

A fruiting 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

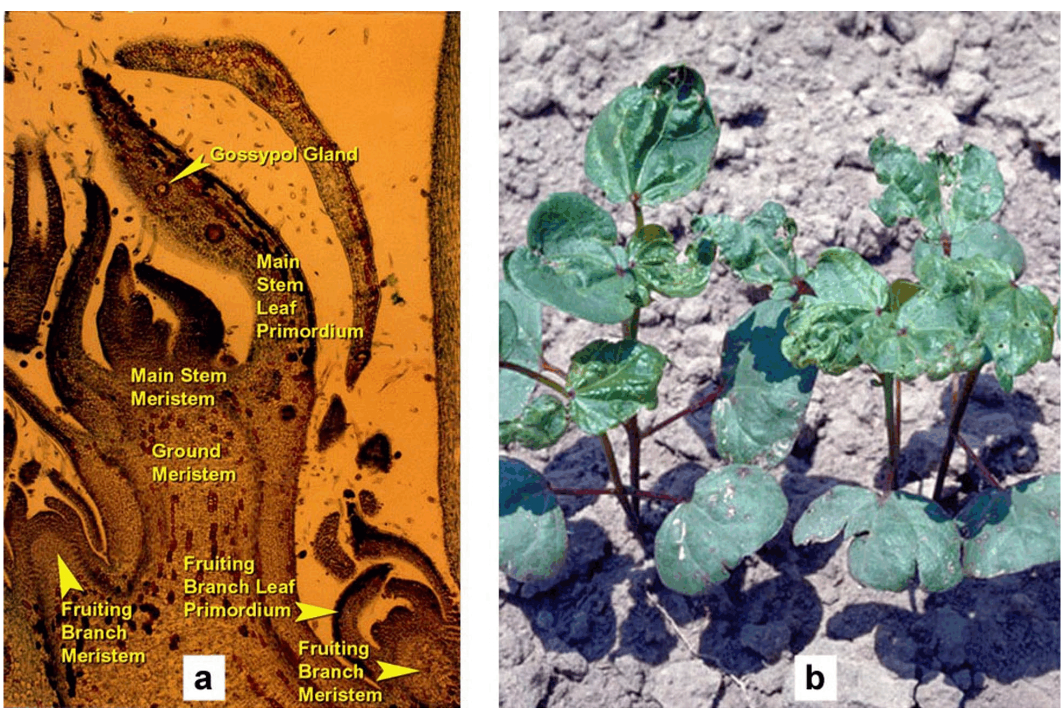

Figure 7. (a) Light micrograph of a cotton plant apical meristem magnified 40x. The two fruiting branches in this micrograph are too small to be seen with the naked eye. (b) The cells where thrips feed on the meristems die, and the resulting leaves appear crinkled and have holes in them.

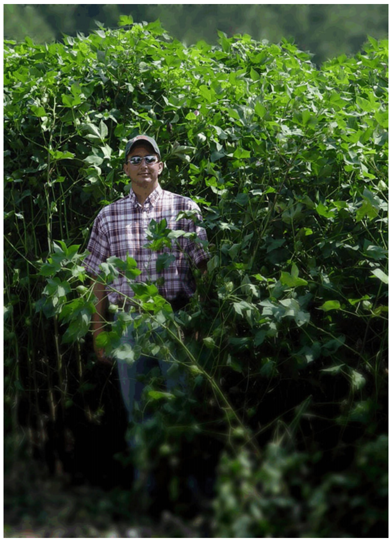

Figure 8. Cotton can grow very tall if its growth is not held in check by environmental factors or management practices.

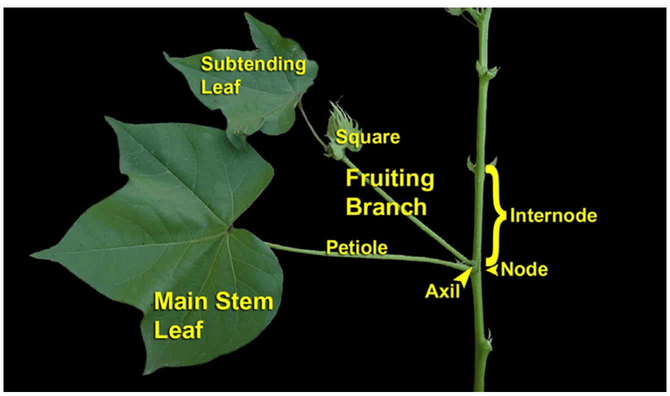

Figure 9. Growth of a fruiting branch from the main stem. The branch forms in the axil above a main stem leaf. The leaves and stems on nodes above and below the one illustrated have been removed.

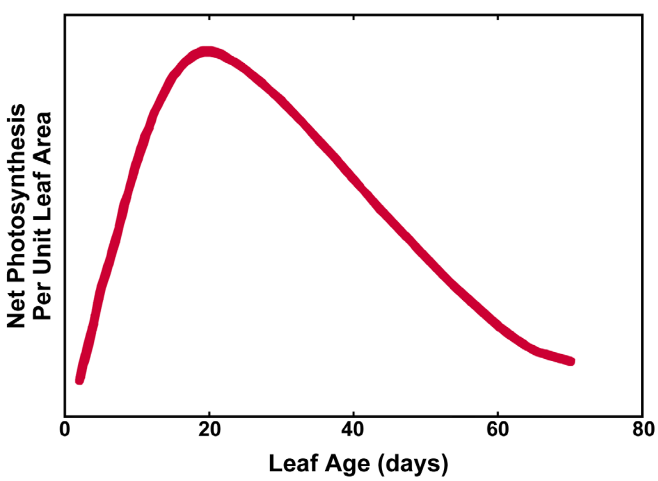

Figure 10. Photosynthetic capacity of a cotton leaf relative to leaf age. Leaves reach peak photosynthetic capability about 20 days after they unfold, after which their efficiency decreases over time.

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.

Leaf and Canopy Development

Plant growth and development are both functions of sunlight interception and temperature. 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 of new leaves steadily declines. Therefore, fruit development occurs with a leaf population that is steadily aging.

Leaf photosynthesis does not remain constant as the leaf grows and develops (Figure 10). A cotton leaf reaches its maximum photosynthetic capacity at about 20 days of age, after which it declines. Collectively, as the reproductive growth of the cotton plant is increasing, it is doing so with the support of a leaf canopy that is aging. 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 Source to Sink Relationship

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 carbohydrate source to sink relationships (Figure 11, page 8). Carbohydrates are transported from supply areas, called sources, to areas of growth or storage, called sinks. The leaves are the primary source of carbohydrate production during the early vegetative growth of cotton. Carbohydrates are produced through photosynthesis in the leaves and channeled through the phloem to the roots, which act as the main carbohydrate sinks during this phase. The source-to-sink phenomenon also applies to the transport of inorganic nutrients and water. The roots are the source for all inorganic nutrients and water, which are transported through the xylem to sinks throughout the plant. Thus, the root and shoot systems are very interdependent, and damage to either system slows growth and decreases yield.

As bolls begin to develop, they become much

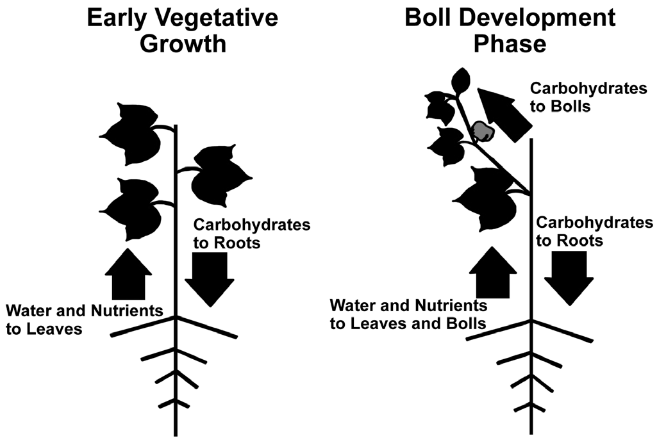

Figure 11. Source to sink relationships at two stages of cotton growth. During early vegetative growth, most of the carbohydrates produced by the leaves are sent to the root system. Later in the season, however, most of the carbohydrates are sent to the developing bolls, and the root system and shoot growth rate decline.

stronger carbohydrate sinks than roots and shoots. At this stage, root and shoot growth slow, and boll development dominates plant growth, and the widely established roots continue to supply large quantities of water and nutrients to the shoot.

Development of Fruiting and Vegetative Branches

The branches on a cotton plant can be classified as either vegetative branches *(monopodia)* or fruiting branches *(sympodia).* Vegetative branches, like the main stem, are referred to as monopodia (meaning "single foot") since they have only one meristem. Because vegetative branches have only one meristem, they grow straight and erect, much like the main stem (Figure 12). Vegetative branches can also produce fruiting branches.

The branches from which fruiting buds arise are called fruiting branches, or sympodia (meaning "multiple feet"), 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 (Figure 13). 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 "zig-zag" growth habit is a consequence of the stop-and-go growth of the fruiting branch.

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 over-fertilization 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.

The cotyledons are oriented opposite each other on the stem, but the true leaves and branches of the cotton plant occur in a 3/8th alternate phyllotaxy, meaning the distance from one leaf to the next is 3/8th of a complete turn around the stem (Figure 14a). Branches on the main stem also show this 3/8th alternate arrangement, since they grow adjacent to the leaves. Nodes are numbered in the same order the leaves are numbered

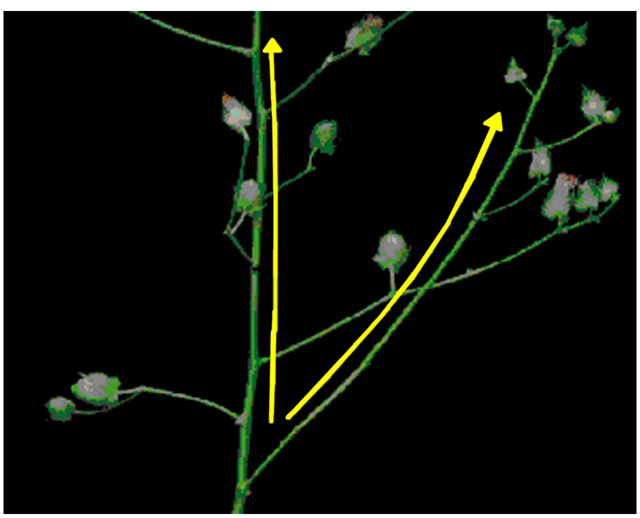

Figure 12. A cotton plant with leaves removed shows the straight growth habit of the main stem and the vegetative branch.

Figure 13. A fruiting branch with leaves removed shows its zig-zag growth habit.

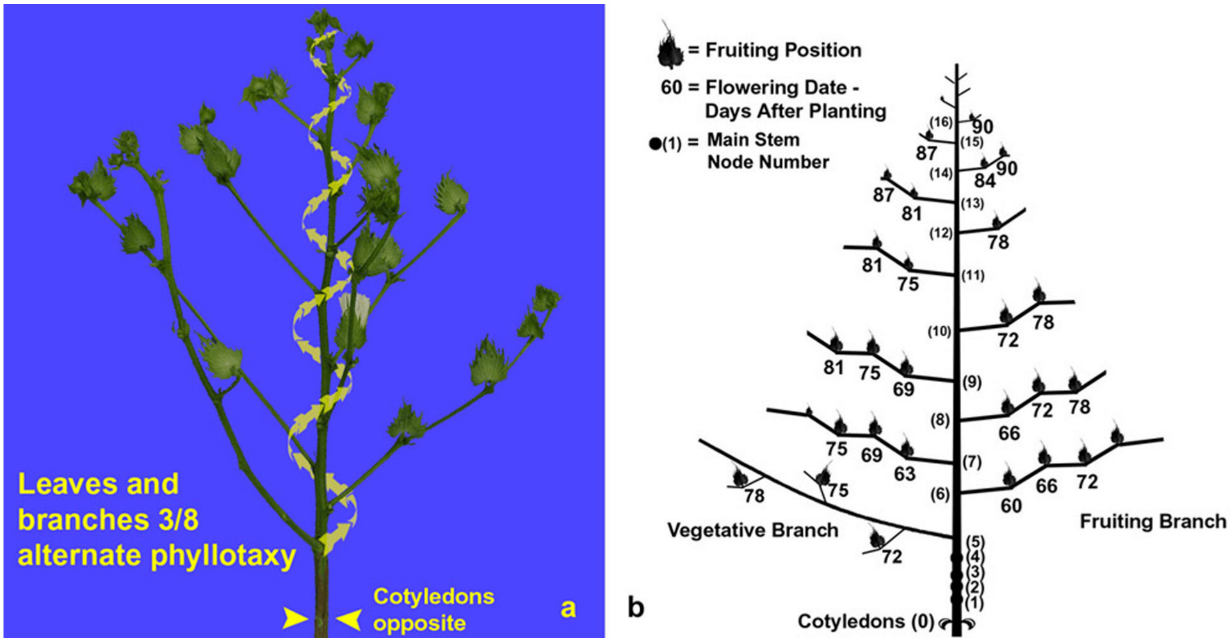

Figure 14. (a) A defoliated cotton plant shows the ⅜ alternate phyllotaxy of branches. Each branch is ⅜ of a turn around the stem from the branch below it. The branches form from the axils of main stem leaves. (b) A diagram of the general timing of flower emergence from buds on the fruiting branches by fruiting position.

where the cotyledonary node is considered node 0 (Figure 14b).

New fruiting branches are generally believed to develop approximately every 3 days, although recent studies show that this developmental rate varies. Squares are produced at new positions on a fruiting branch approximately every 6 days. The age of fruiting structures on a cotton plant can be mapped according to this time sequence (Figure 14b).

Formation of the Cotton Bud From Square to Bloom

During the 21-day period from square to bloom, there are several recognized developmental stages of the cotton flower bud. A "pinhead" square is the first stage at which the square can be identified. The next stage of square growth is "match-head" or "one-third grown" square. Just prior to the time the flower opens, a candle shape can be seen (Figure 15d, page 10). This period of square development prior to bloom is called "squaring."

Once the cotton begins to bloom, it is said to be "flowering." A cotton plant typically blooms or flowers for about 6 weeks. Thus, until the cotton begins to produce fruit, the stage of development is discussed in terms of leaves or nodes. Once fruiting begins, the stage of cotton development is discussed in terms of square development and the number of nodes. Once blooms are present, the stage of cotton development is discussed in terms of weeks of bloom.

The Cotton Flower

As discussed previously, the cotton square is actually a flower bud. 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 (Figure 16, page 10). The first square is typically visible on node 5 to 7 about 35 days after planting. *Anthesis*, or a flower bloom, occurs approximately 21 days after the first square appears.

When a pollen grain reaches the stigma, it germinates into a pollen tube. The pollen tube grows through the style, the micropyle, and into the ovule chamber, where fertilization takes place. Anything that reduces egg or pollen viability or tube growth in a flower adversely affects the final yield for that boll.

Stages of Flowering

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 (Figure 17, page 11). On the day a flower opens it is white in color. Pollination of that flower usually occurs within a few hours after the white flower opens.

On the second day the flower will have a pink-like color, and a red color on the third day. Approximately 5

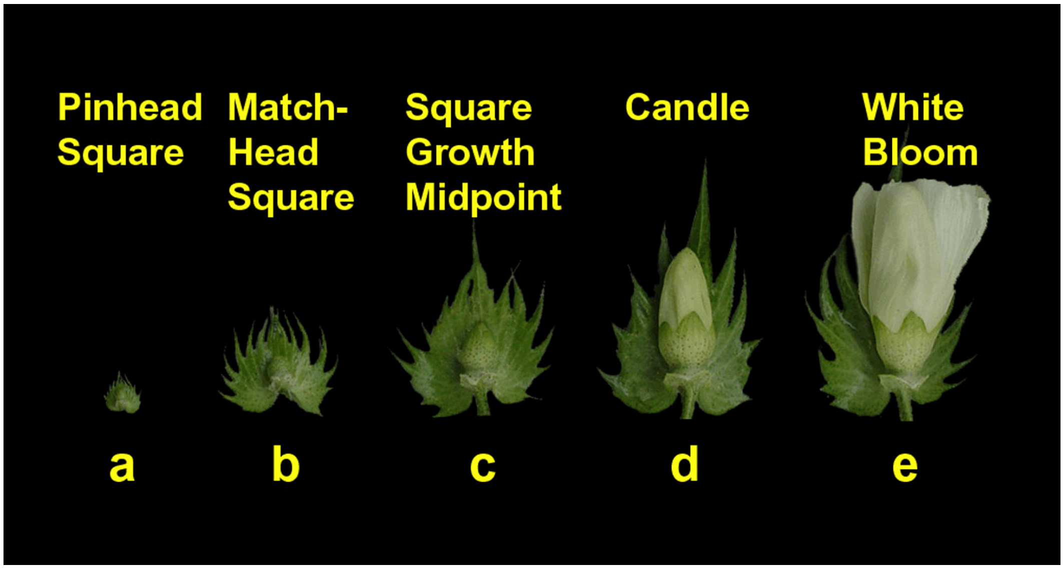

Figure 15. Development of the bud from a match head square (a) to a flower (e) involves both a size increase and petal development. Two bracts have been removed from each square, candle and bloom to show this development.

to 7 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* (Figure 17d, page 11).

Nodes Above White Flower And Cutout

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 approximately 9 to 10 NAWF (Figure 18, page 11). As the season progresses, the number of NAWF decreases. This reduction in NAWF can be related to the source to sink relationship of carbohydrate supply. 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 and less available for the production of new vegetative growth. As flowering progresses up the plant, less top growth is produced, allowing the NAWF to 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.

Defoliation and Harvest Timing

Defoliants, or harvest aids, are used to defoliate cotton, enhance boll opening, and control regrowth prior to harvest. Defoliants effectively terminate the cotton crop and prepare it for machine harvest at the end of the growing season. These chemicals also give the producer some control over harvest timing and increase harvest efficiency.

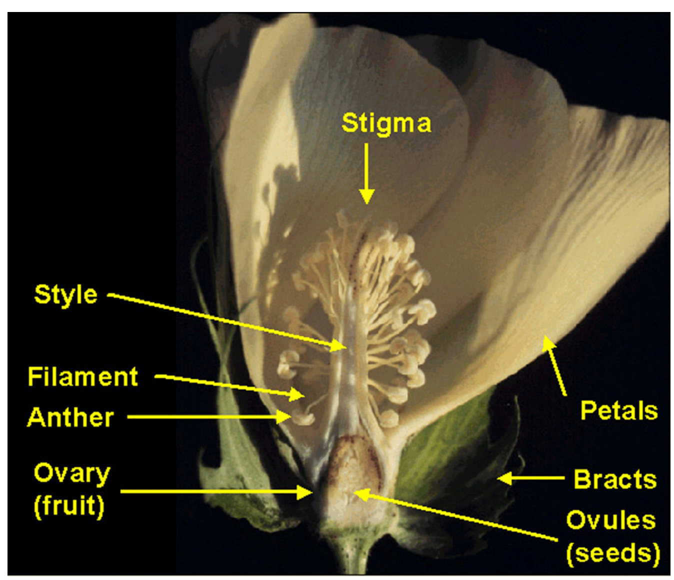

Figure 16. Parts of a mature cotton flower. The cotton flower contains both male and female parts.

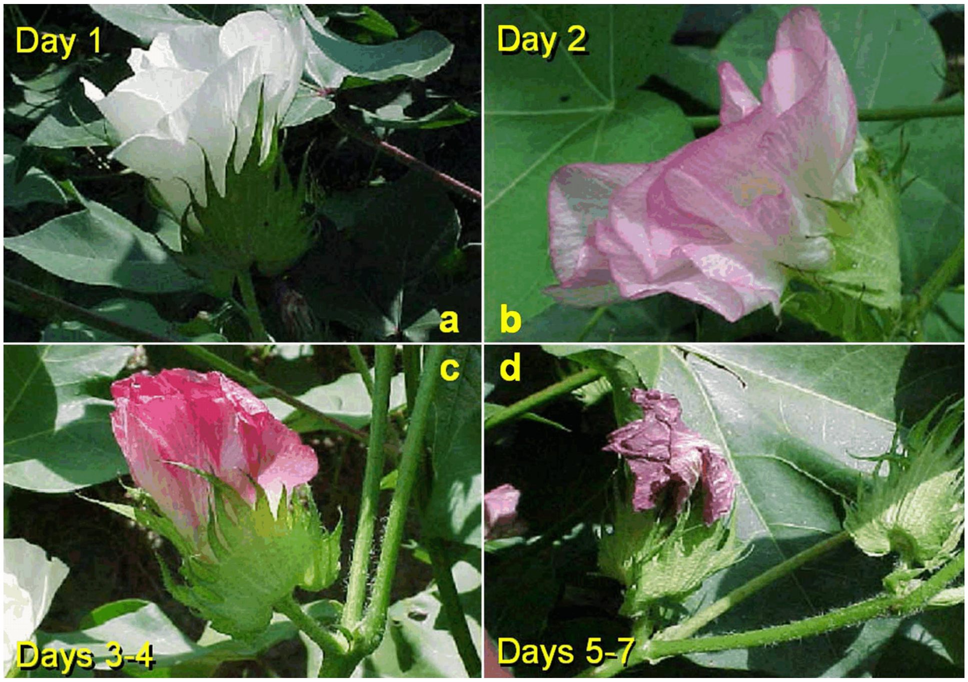

Figure 17. Development of a cotton bloom. A white flower emerges on day 1 (a), then gradually darkens and takes on a red color during days 2, 3 and 4 after emergence (b and c). The bloom eventually dries up and either falls off or becomes a bloom tag (d).

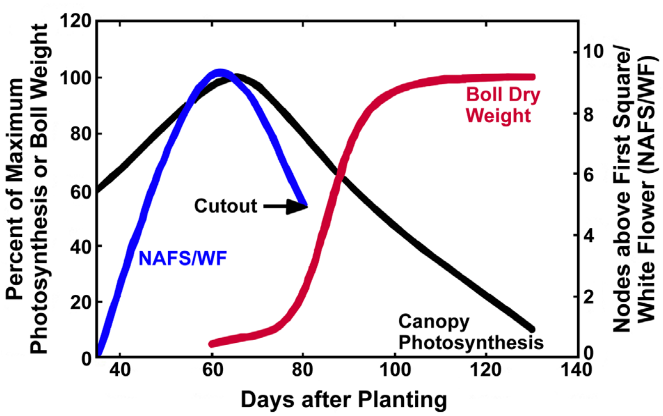

Figure 18. Comparison of canopy photosynthesis with boll development. Cutout occurs as photosynthesis declines and more energy is partitioned to forming bolls.

Defoliant performance is affected by temperature, plant condition, spray coverage and product rate. Temperature is the primary force in determining harvest-aid rate. Under optimal conditions, a cotton crop might be harvestable in as little as 7 days after defoliation, but cool temperatures will prolong the defoliation process.

Cotton harvest aids can be classified into two modes of action, herbicidal and hormonal. Herbicidal harvest aids injure the leaf, stimulating the production of ethylene. Hormonal harvest-aids increase the ethylene concentration in the leaves without causing any injury. A list of the active ingredients in most defoliants is found in Table 1.

Table 1. Active ingredients of chemicals used for defoliation and harvest preparation of cotton.

Class of Defoliant	Active Ingredient	Comments
Hormonal	Thidiazuron	Enhances ethylene production and inhibits auxin transport.
	Dimethipin	Causes rapid water loss through the stomata of the leaves, which leads to ethylene production as leaves become water-stressed.
	Ethephon	Increases ethylene production; used primarily for boll opening.
Herbicidal	Tribufos	Injures leaf cells to trigger ethylene production.
	Carfentrazone	Inhibits a step in chlorophyll synthesis, causing destruction of cellular membranes and ethylene production.
	Pyraflufen Ethyl	Inhibits a step in chlorophyll synthesis, causing destruction of cellular membranes and ethylene production.
	Paraquat	Non-selective desiccant.
	Chlorates	Non-selective desiccant.
	Glyphosate	Used for regrowth control and weed management.

A detailed discussion of defoliation and harvest timing can be found in the University of Georgia exten-

Figure 19. Square shedding is a common occurrence in cotton.

sion publication *Cotton Defoliation, Harvest-Aids, and Crop Maturity,* by Philip Jost and Steve M. Brown, and yearly updated specific harvest-aid suggestions can be found on the University of Georgia Cotton Web Page at **http://www.griffin.peachnet.edu/caes/cotton**

Fruit Shedding

A phenomenon often seen in a cotton field is square shedding (Figure 19). The shedding of squares may be the result of several factors, including water stress, shading (from prolonged cloudy weather), nutrient deficiencies (especially N), high temperatures, high plant populations, high percent fruit set and insect damage. In addition, the reproductive cells formed during square development are very sensitive to environmental conditions. High temperatures and humidity, and nutrient deficiencies (especially boron) can inhibit gamete production and result in flower sterility and ultimately square loss. Sterility may also decrease seeds per boll and locks per boll. One cause of pollen sterilization and subsequent yield loss is misapplication of glyphosate in Roundup Ready® cotton.

Flowers and young bolls may also be shed from the plant due to the same factors that lead to square shedding (Figure 20). Generally, though, the sensitivity of squares, flowers and bolls to shedding can be related to their age. Young fruiting forms are more likely to be shed than are more developed squares and bolls.

Boll Development

After pollination occurs the boll begins to develop. 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 3 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. Also during this time, the fiber is basically a thin walled tubular structure, similar to a straw. Each fiber develops from a single epidermal cell on the seed coat. During the boll enlargement and fiber elongation phase, the development of the 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.

The filling phase of boll development begins during the fourth week after flowering (Figure 21, page 13). At this time, fiber elongation ceases and secondary wall formation of the fiber begins. This process is also known as *fiber filling*, or *deposition*. Cellulose is deposited inside the elongated fiber every 24 hours, filling the void space of the elongated fiber. The deposition of cellulose into the fiber cell is also sensitive to environmental conditions. Water, temperature and nutrients (especially potassium) are the primary environmental factors that influence this stage of boll development. The filling phase of boll development continues into the sixth week after pollination.

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

Figure 20. Examples of square and boll shedding. Shedding can be related to several environmental factors such as population density, water, nitrogen, insect pressure and disease. Newly formed bolls and young squares tend to be the most susceptible to shedding.

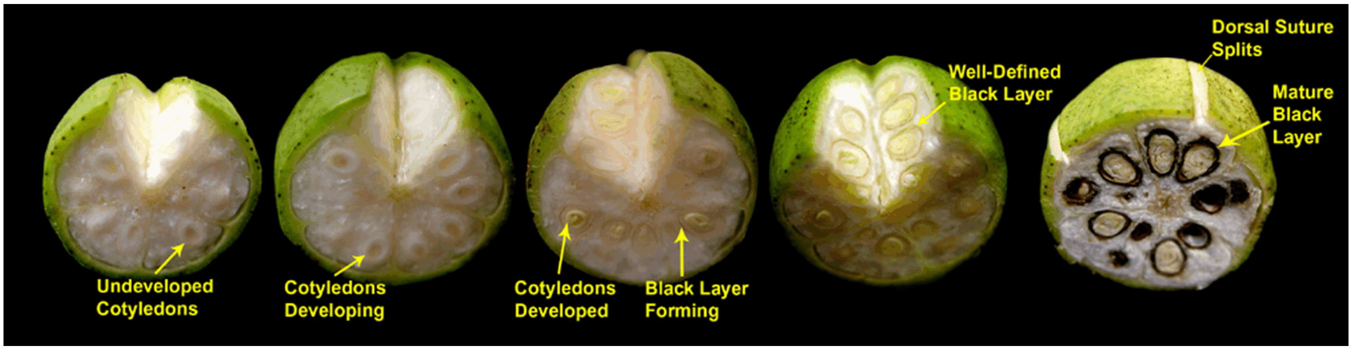

Figure 21. Development of the cotton boll. Undeveloped cotyledons have a jelly-like consistency. As the cotyledons develop, they become firm and leaf-like, and a black layer that will become the seed coat begins to form around the seed. As the black layer matures and the outside of the boll dries, the dorsal suture splits, allowing the cotton boll to open.

the cells adjacent to the dorsal suture 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 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 (Figure 22).

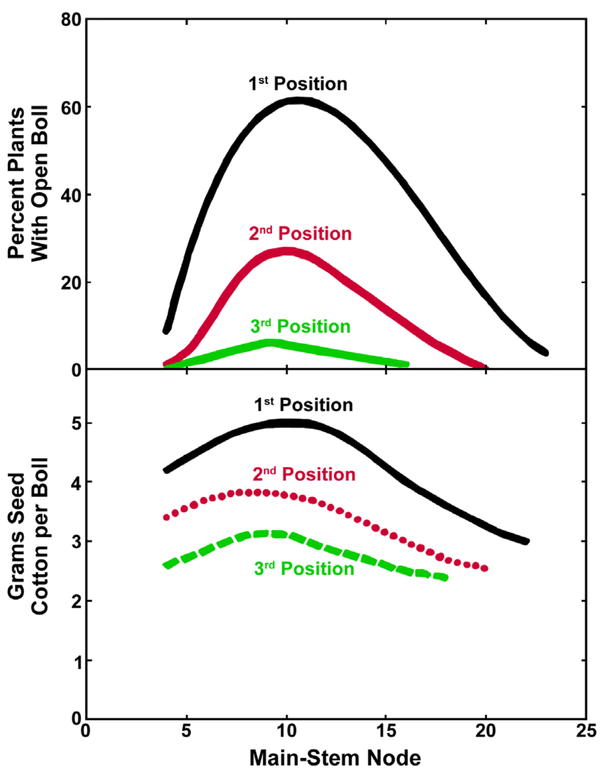

Figure 22. Comparison of cotton yield by fruiting position and main-stem node. First position bolls are heavier and more abundant than bolls at the other positions, making them the primary source of yield.

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 ($^oF_{max}$ and $^oF_{min}$, 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:

$$DD_{60} = \frac{(^oF_{max} - {^oF_{min}})}{2} - 60$$

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 2 demonstrates how to calculate accumulated heat units over a 5-day period.

Scientists at the University of Georgia Tifton Campus have measured daily temperature data since 1928, and the average heat unit accumulation pattern for a cotton crop planted on May 1 at this location is illustrated in Figure 23.

Table 2. Calculation of daily and accumulated heat units based on daily high and low temperatures.

Day	Daily High Temperature ($°F_{max}$)	Daily Low Temperature ($°F_{min}$)	Average Daily Temperature ($(°F_{max}+°F_{min})/2$)	Daily Heat Units (°Fmax+°Fmin)/2 – 60	Accumulated Heat Units
1	81	61	71	11	11
2	83	63	73	13	24
3	82	62	72	12	36
4	85	66	75.5	15.5	51.5
5	80	62	71	11	62.5

Table 3 shows typical heat unit accumulations at which a cotton crop reaches various growth milestones, as well as the average number of days after planting that these heat units are accumulated in South Georgia. These numbers will vary according to location, year and cotton variety.

Table 3. Accumulated heat units required for a normal cotton crop to reach a specific growth stage. These values will differ by variety. The third column shows the average number of days after planting at which these heat units are accumulated, based on historical data from Tifton, Ga.

Growth Stage	Heat Units	Days
Emergence	50	5
First Square	550	38
First Flower	950	59
Open Boll	2150	116
Harvest	2600	140

Summary

Cotton is a unique crop plant, and its innate growth pattern makes it challenging to grow. However, the plant develops in a somewhat predictable pattern. Initially, leaf area and vegetative structures are developed that will then support future reproductive growth. If this initial vegetative growth is compromised, subsequent reproductive growth also suffers. Unlike many other crops, the cotton plant continues vegetative growth after flowering begins. The development of fruiting structures ultimately reduces vegetative growth as the plant matures. The environment regulates every developmental process of the cotton plant, both vegetative and reproductive. Heat unit accumulation dictates development as much as time.

Due to increasing production costs and decreasing or stagnate commodity prices, cotton producers must be able to critically evaluate every input. An understanding of the development of the cotton plant is crucial for making management decisions and maintaining profitable production.

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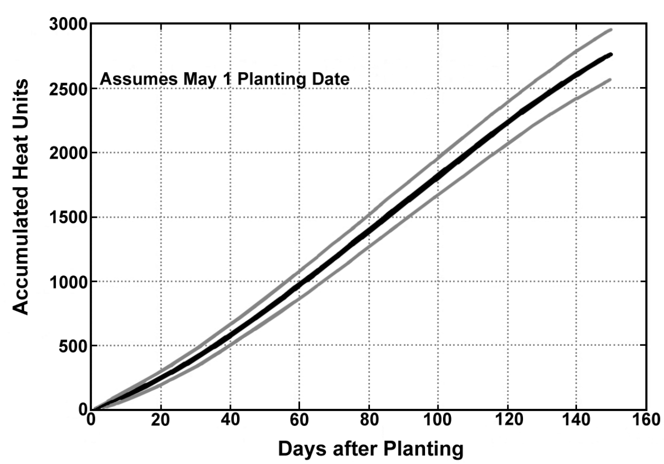

Figure 23. Accumulated heat units during the growing season based on historical data at Tifton, Ga., from 1928 to 2003, assuming a May 1 planting date. The heavy bar represents the average accumulated heat units, and the light bars are ± 1 standard deviation.

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