

Chapter 3:

Measures of Cotton Growth and Development

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A clear understanding of cotton growth and development in commercial production is essential in the continuing efforts of farmers to produce seed and lint more efficiently and profitably. This is particularly important with rising energy costs, increasing technology fees, low commodity prices, and global competition. The following provides a description of some key points in the growth and development of the cotton plant that are important in crop monitoring for efficient and timely production management.

Overall Pattern of Growth and Key Steps

The growth and development of the cotton plant follows a distinctive and unique pattern that has been well defined (Tharp, 1960; Oosterhuis, 1990; Kerby et al., 2008). The cotton plant is reputed to have the most complex structure of any major field crop because of its indeterminate growth pattern and sympodial flowering habit (Mauney, 1986). However, this growth pattern can be broken down into some logical phases and the development of the crop followed.

Plant development proceeds through a number of phases, which for practical reasons may be divided into five main growth stages: germination and emergence, seedling establishment, leaf area and canopy development, flowering and boll development, and maturation (Oosterhuis, 1990). Others have broken development into the vegetative stage of planting to the appearance of squares in the terminal of the plant, and the reproductive stage after square appearance including squaring, flowering, and boll development. However, the transition between these successive stages is subtle and not al-

ways clearly distinguishable. Furthermore, each stage may have different physiological processes operating with different requirements. If growers are aware of these stage-dependent differences in cotton growth requirements, then many problems in crop management can be avoided resulting in increased yields and profits.

Current thinking is that the flowering stage, when boll (retention and/or shedding) development is occurring, is the most critical stage since the resources that the plant requires increase exponentially and the plant is therefore much more susceptible to environmental stress and poor management (Kerby et al., 2007). The development of the boll load needs to be clearly understood and the fruit development nurtured through timely management inputs.

Target Development Curve

All measures of crop development require some standard against which progress of current crop can be compared. In the COTMAN™ crop monitoring program, the *Target Development Curve* (TDC) provides this standard or benchmark curve for comparing current crop fruiting development progress, and also for measuring the efficiency of management strategies that promote earliness in the crop (See Chapter 1 in this publication). The TDC represents the hypothetical development curve of a normal, non-stressed cotton crop. It begins with first square at 35 days after planting and displays a progression in nodes above first square at a rate of 2.7 days per node. At 60 days, which approximates the time from planting to first flower, the curve reaches an apogee at 9.25 squaring nodes. The TDC then begins its descent of 0.2125 nodes per day (Fig. 1).

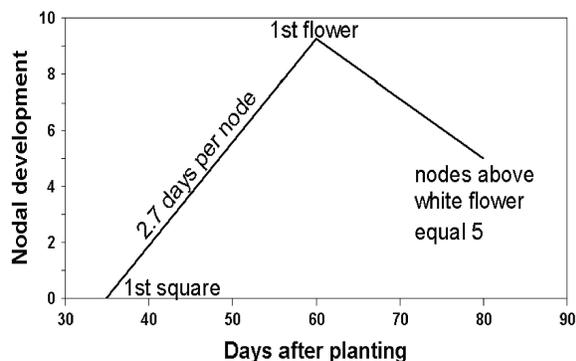


Fig. 1. Standard target development curve used in COTMAN showing the increase in the number of nodes above the first square with time in days after planting.

Fruiting Pattern

The cotton plant has a distinctive and predictive flowering pattern (Oosterhuis, 1990). The first flowers to open are low on the plant usually on main-stem nodes 5 to 7 and on the first position along a fruiting branch. About 3 days elapse between the opening of a flower on a given fruiting branch and the opening of a flower at the same relative fruiting position on the next higher fruiting branch. On the other hand, the time interval for the development of two successive flowers on the same branch is about 6 days. The order is thus upward and spirally outwards. These flowering intervals are not constant and vary with environment, fruit retention, and perhaps genotype; however, they do provide a useful guide for assessing plant development. Flowers will continue to be produced until defoliation or frost, if the plant has not gone into cutout and is still actively growing. Variations in this pattern occur when a second crop is allowed to develop following cutout, which can occur in longer-season environments. However, this second cycle of boll development should not be permitted because of insect control restrictions. The illusion of upper canopy bolls developing late in the season contributing significantly to yield is unfortunate. Bourland et al. (1992) showed that bolls developing above (later) than the NAWF=5 main-stem nodal position were dramatically smaller in size, had lower lint quality, and tended to abscise easier. Therefore, investing time and resources into the protection and nurturing of these upper canopy bolls is unwarranted.

Cutout

Understanding cotton growth and development is essential for the producer to be able to respond to crop requirements and the environment. *Crop monitoring* provides a means of following crop development and providing signals of plant stress and pending production problems. An important consideration when using crop monitoring to guide production management decisions is accurate determination of *cutout* (i.e., the end of the effective fruiting period). However, much confusion surrounds this important phenological stage and its implication and use in crop management.

Cutout is an empirical term used to signify the cessation or extended lapse in terminal growth because of the development of the boll load sink and the resulting demand for available nutrient and photosynthate resources for boll development (Oosterhuis et al., 1996). For crop monitoring, cutout signals the end of the *effective fruiting period* or the *last effective flower population* that will yield bolls of acceptable weight and quality. Therefore, cutout identifies the last effective boll population that needs to be protected. The critical late-season decisions of when to terminate insecticides, when to defoliate, when to terminate irrigation, and determination of harvest schedules for individual fields are based on the accurate detection of cutout.

Cutout has traditionally been associated with flowers in the upper plant canopy. Using COTMAN, cutout is more precisely identified by white flowers in the first fruiting position at the fifth node from the plant apex, i.e. NAWF=5 (Fig. 2). However, some questions have arisen about the universal nature of using NAWF=5 as a signal of physiological cutout (See Kerby et al., 2008, Chapter 13 in this publication). Recent research has shown that NAWF=5 is a good representative indication of physiological cutout for most cultivars and geographical regions except under conditions of stress (drought and nitrogen deficiency and excessive use of mepiquat chloride), when NAWF=4 may be a more appropriate indication of cutout. However, plants responding to these extreme stress conditions will move from NAWF=5 to NAWF=4 in a very short time (1 to 2 days), and thus, even in high-stress situations, NAWF=5 remains a good signal of cutout.

In BOLLMAN (the post-flowering component of COTMAN), cutout designates the end of the

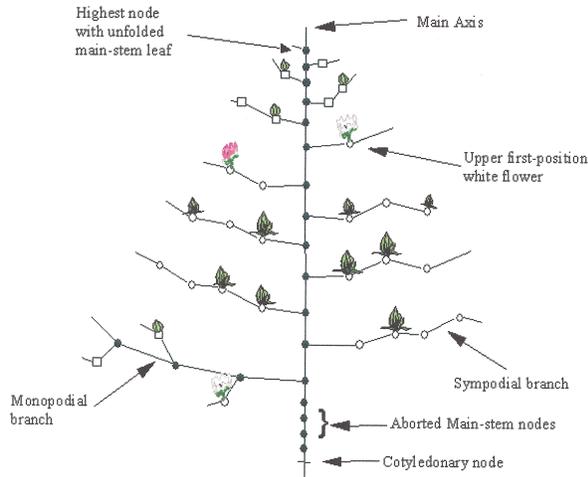


Fig. 2. Cotton plant showing a white flower five internodes from the terminal (NAWF=5).

effective fruiting period, which may be related to the physiology of the plant (physiological cutout), to the end-of-season growing conditions (seasonal cutout), or to excessive stress (premature cutout).

Physiological Cutout

Crop development stage characterized by an average NAWF=5 is referred to as Physiological Cutout. Without end-of-season restraints, physiological cutout signals the flowering date of the *last effective boll population*, i.e., NAWF=5 occurs before the last possible cutout date.

Premature Cutout

Premature cutout is a form of physiological cutout associated with excessive stress, e.g., drought, nitrogen deficiency, diseases or nematodes, which causes NAWF=5 to occur so early that adequate plant structure is not achieved. Benson and his colleagues in 1999 characterized fields that attained NAWF=5 in less than 70 days as premature cutout (unpublished).

Seasonal Cutout

Seasonal cutout occurs when the flowering date of the last effective flower date is determined by end-of-season weather restraints rather than crop maturity. In COTMAN the latest possible cutout date is primarily based on the probability determined by long-term weather patterns of obtaining sufficient

heat units (HU) needed to mature the bolls from current flowers.

Accurate prediction and detection of the end of the effective fruiting period (i.e., cutout) is an important prerequisite for guiding late-season production management decisions. Pinpointing cutout and determining the type of cutout (i.e., physiological or seasonal cutout) provides: 1) valuable information about the state of the crop in relation to the timely progression of maturity, 2) the last effective boll population (i.e., that will have adequate size and quality) that needs to be protected, 3) a benchmark date from which to base end-of-season decisions, and 4) data for sequencing of fields for harvesting.

Final Plant Map Data Supports COTMAN NAWF Cutout Concepts

With transgenic technology and boll weevil eradication, questions have been raised if this affects the use of NAWF=5 and the timing of cutout. Delta and Pine Land (D&PL) has historically collected plant monitoring data to support cultivar evaluation and positioning. NAWF was not directly measured in 477 DP&L field tests representing 42 cultivars (11 conventional, 12 Roundup Ready, and 19 Bollgard and Roundup Ready), but data were collected near the time of defoliation to establish maturity differences and the number of nodes not significantly contributing to yield. Any regrowth (and nodes associated with regrowth) was ignored in the final maps. The node of the uppermost harvestable first-position boll was established. The data showed that the number of nodes above the last first-position harvestable boll corresponded very closely to NAWF at the time of cutout. The introduction of transgenes has not affected the number of uppermost nodes for timing of cutout. Eleven conventional cultivars averaged 4.6 across all environments compared to 4.65 for the 12 Roundup Ready cultivars and 4.67 for the 19 cultivars containing both Bollgard and Roundup Ready.

Plant Height and Vigor Indices

The cotton plant grows indeterminately, which means that it will continue to grow vegetatively (become taller) as the plant flowers and develops fruit. Plants grow by adding main-stem nodes at the terminal and become taller in proportion to the distance between the nodes (i.e., internode length).

Since main-stem nodes are added at a relatively constant rate, plant height is directly related to internode length. Internodes gradually increase in length, but only the top five internodes significantly expand at any time. Final internode length reflects the growing conditions (water, nutrition, and environment) that occurred while the internode was elongating.

Plant height should steadily increase until shortly after first flower. The rate of height development should then slow down as competition for resources by the fruit load increases. Except where secondary growth occurs, final plant height is essentially achieved at physiological cutout (i.e., NAWF=5). Few main-stem nodes are subsequently added to plants after physiological cutout and internodes between any subsequently added nodes are typically very short. Internode lengths should be relatively uniform up the main stem until the developing fruit load causes them to become shorter.

Relationships of plant height and number of main-stem nodes are commonly referred to as *plant vigor* and related measurements are called *vigor indices*. Vigor indices provided by SQUAREMAN include plant height and *height-to-node ratio* (HNR).

Plant Height Chart

The critical time to directly monitor plant height is before flowering. Thereafter, height should be naturally controlled if fruit set and boll development are adequate. The development of plant height over time is charted by SQUAREMAN. The user should observe these charts and note any major deviations from a steady increase in height. Prior to flowering, slowing of height development signals plant stress that may be associated with insufficient water, cool temperatures, aphids, etc. Accelerated height development is typically associated with low light intensity, excess nitrogen, or excessive square loss. If deviation in the pattern of plant height is observed, check the HNR and/or the length of the top five internodes (ALT5) to confirm problems with plant vigor.

Height-to-Node Ratio (HNR)

The HNR is calculated by dividing plant height (distance in inches from the soil to the upper main-stem node with an unfurled leaf) by the total number of main-stem nodes and is equal to the average internode length. HNR is very sensitive to tempera-

ture early in the year. Before 10 main-stem nodes are produced, HNR generally is more indicative of early-season temperatures than any management decisions. Work in California has shown that prior to seven main-stem nodes, a low HNR will not limit yield potential because the main-stem leaves that support bolls have not yet developed. After 7 main-stem nodes, changes in HNR become very important and determine the stature and fruit/boll carrying capacity of the plant (e.g., 70% of yield comes from branches on main-stem nodes 7 to 16).

In Arkansas, a desired final plant height for irrigated cotton is considered to be 45 to 50 inches on a 38-inch row width and 35 to 40 inches on a 30-inch row. Non-irrigated cotton is typically proportionately shorter than irrigated cotton. Normally, we expect a total of about 23 nodes in well-watered cotton. Therefore, average HNR should be about 2 inches (i.e., 45 divided by 23). Low HNR indicates slow height development associated with stressed conditions, while high HNR indicates excess vegetative growth. Interpretation of HNR is limited because it reflects the average of plant development from the start of the season rather than being a measure of the most recent growth.

Mepiquat Chloride Application

A major use of vigor indices is to assist with timing of mepiquat chloride (MC) applications. Early work in California established a target vigor curve for plant height plotted against main-stem node number. If height-by-node observations were above the target curve, MC was recommended. The growth pattern associated with this target curve was generally found to be too vigorous for cotton in Arkansas and did not seem applicable to the highly variable soils and environment of the Mid-South. Also, this system does not allow for subtle changes in crop vigor over a short period of time.

Researchers in Australia and California used HNR to time MC use. They found that a HNR>2.16 was needed for the period immediately prior to flowering to get an economic response to MC. Research in Arizona has shown that the optimum HNR changes with stages of growth (Silvertooth et al., 1996). Optimum HNR varied from 0.75 inches at eight main-stem nodes to 1.5 inches at 28 nodes and then declined. With the desired height and nodes for

cotton in Arkansas, MC is probably needed when HNR>2 inches (Bonner, 1993).

A system developed in south Texas further refined the measure of vigor by directly measuring the average length of the top five main-stem nodes, ALT5 (Landivar et al., 1996). They used a stick with marks at around 7 inches (average internode length, ALT5=1.4 inches) and around 9 inches (ALT5=1.8 inches). If ALT5 is less than 1.4 inches, MC is not needed; if ALT5 exceeds 1.4 inches, MC may be needed; if ALT5 exceeds 1.8 inches, MC is definitely needed. ALT5 has not been incorporated into COTMAN but appears to be a sound approach since it directly measures the most recently expanded internodes. However, the stick may need to be calibrated for different growing regions and growth stages. Research in Arkansas indicated that MC is needed when total length of the top 5 main-stem nodes exceeds 6 inches (ALT5=1.2 inches).

Elongation Rate

Both elongation rate and days/node were early attempts to quantify vigor. They are still included in SQUAREMAN because some users have gained confidence in them. Elongation rate, a measure developed in California, is calculated by dividing the change in plant height by the change in main-stem nodes between two consecutive sampling dates. Thus, elongation rate indirectly measures the growth of the plant since the previous sampling date and should be more reflective of recent growth than HNR. Days/node are calculated as the change in number of main-stem nodes divided by the number of days between sampling dates. The days/node index has no research base and intuitively has little relation to vigor since it includes neither height nor internode length data. Use of data from two sampling dates is a major problem with both of these indices. Effects of sampling errors can be large, and erratic values may occur. Some users have reduced sampling errors by marking their sampling sites and returning to adjacent plants for subsequent measurements. Values of elongation rate should reflect average internode lengths of the most recently developed nodes. However, since sampling date interval is variable, target values cannot be determined. We cannot, and do not, make any recommendations from either elongation rate or days/node data.

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