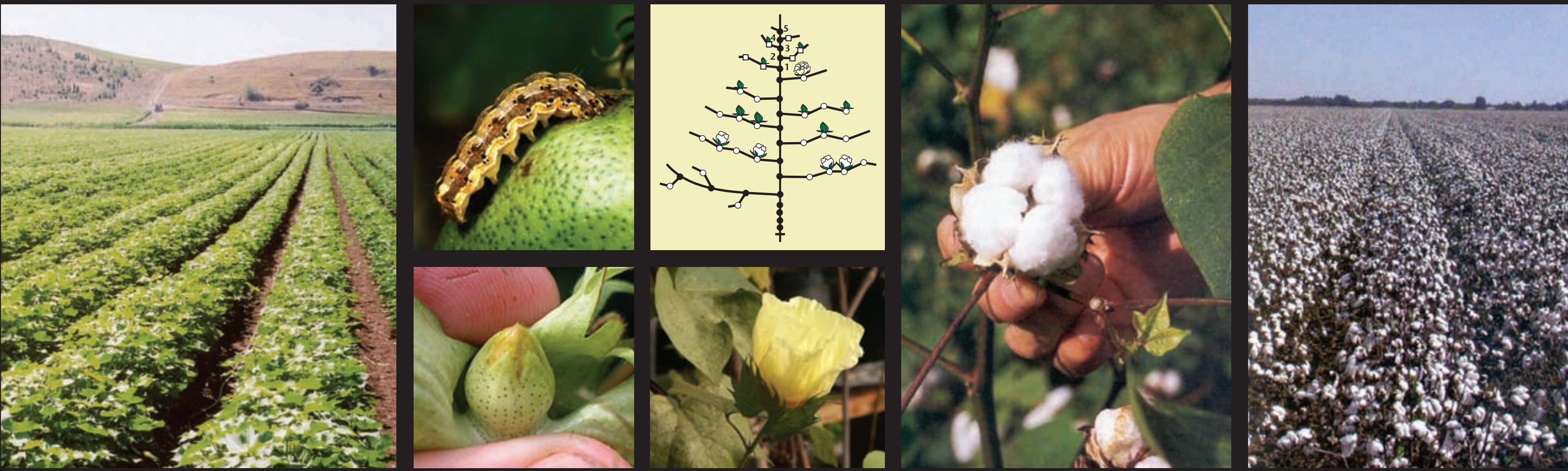
COTMAN™

Crop Management System

Compiled and Edited by

Derrick M. Oosterhuis and Fred M. Bourland



A Development of
University of Arkansas Division of Agriculture
and Cotton Incorporated

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DIVISION OF AGRICULTURE

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The strategic component development and validation was accomplished through the combined efforts of researchers, graduate students, extension personnel, consultants, representatives from industry, and producers across the U.S. Cotton Belt. A number of people also contributed to the development of the software program, which supports the COTMAN Crop Management System. It would be difficult, if not impossible, to mention all the people who have contributed to the development and establishment of the COTMAN crop management program. However, without their help and input the program would not have been successfully developed.

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Table of Contents

Chapter 1:

Overview of the COTMAN Crop Management System

Derrick M. Oosterhuis, Fred M. Bourland, N. Philip Tugwell, Mark J. Cochran, and Diana M. Danforth

The COTMAN™ Expert System was developed by the University of Arkansas System Division of Agriculture (Agricultural Economics and Agribusiness, Entomology, and Crop, Soil, and Environmental Science departments). The program was first tested in 1994 and has subsequently been evaluated in Arkansas, Alabama, Georgia, Louisiana, Missouri, Mississippi, Tennessee, Texas, and Virginia. Testing has been conducted by consultants, growers, state experiment stations, and cooperative extension services. Cotton Incorporated, University of Arkansas Center for Alternative Pest Control, and the Altheimer Foundation supplied primary funding for development of the program.

COTMAN is a crop monitoring system that utilizes selected plant indicators to follow plant development and fruit load from initiation of squaring through effective flowering. Information on plant growth patterns, current and historical weather data, and farm and field parameters are integrated into COTMAN to enhance cotton crop management.

Utility of COTMAN

COTMAN provides continuous in-season crop monitoring to assist in achieving earliness and to provide timely feedback on plant development and early detection of plant stress. The *Target Development Curve* (TDC, Fig. 1) serves as a benchmark for determining whether the crop is developing at an acceptable rate (*i.e.*, on or off target) and whether the crop is progressing toward maturity in an early, efficient manner (timing of physiological cutout).

End-of-season management decisions regarding timing of insecticide termination and defoliation based on cutout date are facilitated by COTMAN. End-of-season management is based on the maturity of the last effective boll population, since these bolls are the youngest cohort and susceptible to insects and premature defoliation. Flowering date of the last effective boll population is identified by a *nodes above white flower* (NAWF) value of 5 (physiological cutout) or by last date from which, historically, 850 heat units (HU) can be expected (seasonal cutout).

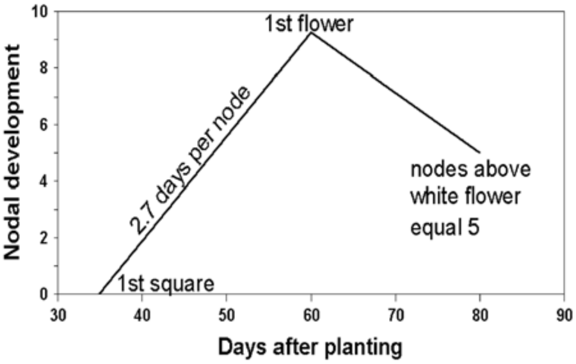

Fig. 1. The Target Development Curve used in COTMAN.

COTMAN can also be used to compare physiological progress and cutout dates for different fields. Fields can then be grouped by their relative maturity, which can aid in development of defoliation and harvest plans. Surveys indicate that users spend less than $2 per acre per season to collect data and produce weekly reports using COTMAN software (Robertson et al., 1997). Compared to its potential benefits, COTMAN data are relatively inexpensive to collect.

COTMAN consists of two expert systems, SQUAREMAN (primarily used to monitor pre-flowering plant development) and BOLLMAN (used to monitor post-flowering plant development).

SQUAREMAN Component

The SQUAREMAN component of COTMAN primarily is used to monitor the crop from first square to first flower. Two critical early-season management issues are addressed by SQUAREMAN. First, printouts of square retention indicate whether square retention is acceptable. Management inputs may be required if square retention is very high (to meet fruit demands) or very low (to ameliorate cause of square loss). Secondly, SQUAREMAN provides an indication of whether or not plants are developing at an acceptable rate. Both the ascent (slope) and position (left or right) of the crop development curve relative to the TDC provide information relative to the growing conditions and health of the plants.

SquareMap data (Fig. 2) are used by SQUAREMAN. Once per season, users of SQUAREMAN must input farm and field identifiers along with the planting date of each field. Prior to or coincident with first collection of SquareMap data, stand density and average first-fruiting node number are determined. SquareMap data are collected once or twice per week and include measurement of average plant height and mapping of 10 plants at each of 4 to 8 sites per field. Starting at the top of a plant, first positions on fruiting branches are mapped for the presence or absence (shed) of squares. Estimated time to map four sites in a field is 17 to 23 minutes.

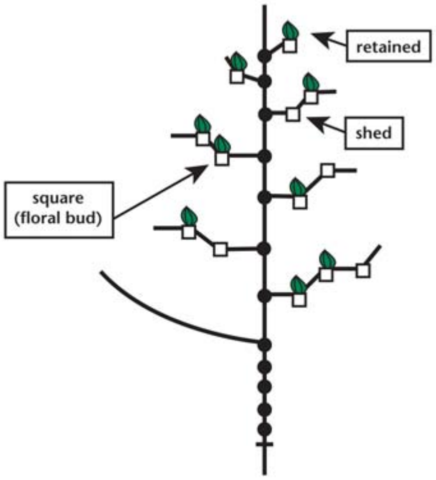

Fig. 2. Collection of SquareMap data.

SQUAREMAN outputs include reports on both field and farm levels. The field-level reports include: 1) square retention rates and analysis of change in retention, 2) measurements of plant vigor (plant height, height-to-node ratio charts, and analysis of height-to-node ratio change), 3) population estimates of number of plants per acre and number of first position squares per acre, and 4) crop status compared to the TDC. The farm-level reports provide summary tables of square sheds, plant vigor, and nodal development for each field within the farm.

BOLLMAN Component

The BOLLMAN component of COTMAN monitors the crop from first flower until cutout using NAWF (Fig. 3) and calculates HU from cutout. The primary use of BOLLMAN is as an aid in making end-of-season management decisions.

BOLLMAN inputs include farm and field identifiers (same as SQUAREMAN) plus identity of the historical weather location and weather risk level that the user wishes to employ. BOLLMAN uses NAWF counts made on 10 plants at 4 to 8 sites per field, collected once or twice per week. NAWF is determined by counting the number of main-stem nodes above the uppermost white flower in the first fruiting position. The estimated time to monitor NAWF for 4 sites in a field is 16 to 23 minutes. BOLLMAN also requires daily input of local minimum and maximum temperatures from cutout to defoliation.

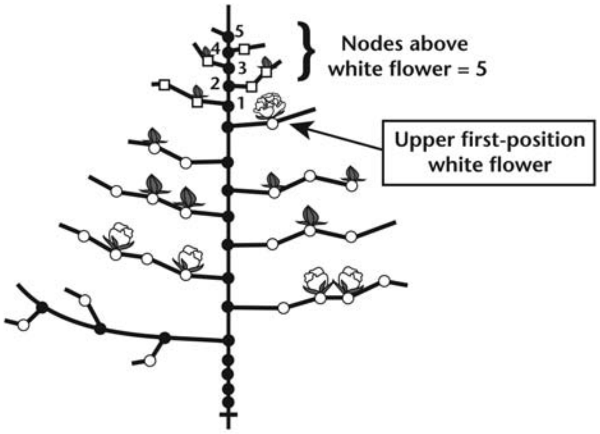

Fig. 3. Cotton plant at NAWF = 5.

Like SQUAREMAN outputs, BOLLMAN outputs are available on field and farm-levels. Prior to cutout, the BOLLMAN field reports provide crop status compared to the TDC, average NAWF, and cutout status. After cutout, the report chronicles heat unit accumulations from cutout and projects (or lists) insecticide termination and defoliation dates. The farm-level BOLLMAN report includes tables showing average NAWF, cutout, and heat unit accumulations for each field with fields listed in order of maturity.

Physiological and Season Cutout

Identification of cutout is critical to BOLLMAN, and defined as the flowering date of the last effective boll population relative to the latest possible cutout date. The last effective boll population is defined as the latest developing flowers that are likely to develop into bolls with adequate size and fiber properties. At NAWF=5, boll retention drops, and number of flowers required for a pound of seed cotton increase (Fig. 4).

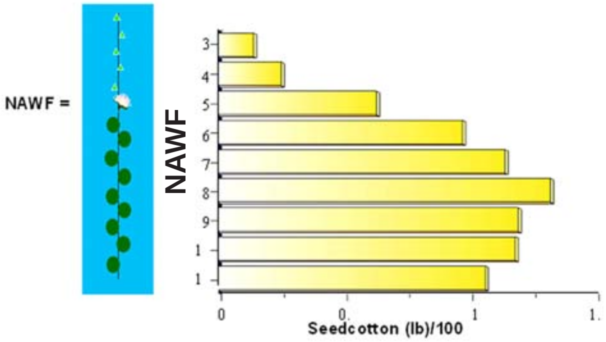

Fig. 4. The increase in number of flowers per pound of cotton and decrease in boll retention at NAWF=5.

The latest possible cutout date is the latest date likely to allow sufficient heat unit accumulation for boll maturation before end of season. It is based on historical weather patterns in a specific geographic region and on the level of risk a producer is willing to accept. The latest possible cutout date is delayed as a user moves from north to south and as the user is willing to accept greater risks (Table 1).

Physiological cutout occurs if a field achieves NAWF=5 prior to the latest possible cutout date. The last effective boll population is then determined by crop maturity rather than weather restraints. Flowering date of the last effective boll population is the date that crop development reaches NAWF=5, and end-of-season management is determined by maturation of the crop.

Fig. 5. Latest possible cutout dates for selected sites (from north Arkansas to south Louisiana) and two risk levels.

Location	15% Risk	50% Risk
Keiser, AR	August 2	August 11
Marianna, AR	August 8	August 14
Stoneville, MS	August 15	August 21
Winnsboro, LA	August 17	August 23
Hattiesburg, MS	August 20	August 26
Baton Rouge, LA	August 21	August 26

Seasonal cutout (late-maturing) occurs if a field does not achieve NAWF=5 prior to the latest possible cutout date. The last effective boll population is then determined by the latest possible cutout date, regardless of when or if NAWF=5 occurs. Flowering date of the last effective boll population is the date of the latest possible cutout, given producer weather risk preference, and end-of-season management is determined by weather restrictions.

Basis for End-of-Season Management Decisions

Starting at the cutout date (physiological or seasonal), local daily HU (DD60s) are calculated and accumulated. Termination of insecticides for most insect pests is advised at 350 HU after cutout. At 350 HU, bolls resist penetration by weevils and small worms, and the attractiveness of the host declines. Optimum heat unit accumulation from cutout for termination of irrigation appears to vary from 350 to 550 HU. Defoliation is advised at 850 HU from cutout.

Promote Earliness with COTMAN

Advances in worm and boll weevil control have lessened the benefits of earliness in cotton production. However, timely maturity of cotton still provides insect control benefits by avoiding potential expensive late-season battles with insect pests, reducing late-season insect control costs, and reducing selection pressure for insect resistance. In addition, timely maturity in many cotton production areas reduces the risks of poor weather conditions for defoliation and harvest. Cool fall temperatures increase the time and cost of defoliation. As harvest is delayed, lint yields and quality are reduced and daily harvest capacity is reduced by shortening day length and by adverse field conditions. Consequently, profits are often reduced as earliness is lost.

Chapter 2:

Initial Development of the COTMAN Program

Fred M. Bourland, N. Philip Tugwell, Derrick M. Oosterhuis, and Mark J. Cochran

The COTMAN™ program was principally formulated in the early 1990s during frequent trips from Fayetteville to the Delta and during weekly noon meetings at the University of Arkansas Student Union. However, the founding principles of COTMAN are based on concepts of cotton plant growth and development and insect control, which began forming in the early 1900s. During that time, scientists recognized the need to establish early maturity in cotton to avoid the ravishing effects of the boll weevil, a newly introduced pest (Redding, 1905). Predictable and sequential development of cotton fruiting was soon realized, and concepts of crop maturity in cotton began to emerge. As reviewed and extended by McClelland and Neely (1931), the order and development of the cotton plant fruiting were established by research in the early 1900s. Tharp (1960) and numerous other subsequent studies validated this basic order and development of the plant.

The development of insecticides to control the boll weevil relaxed the emphasis on early maturity. However, chemical control of the boll weevil soon caused outbreaks of bollworm and other insect pests. As insecticides were developed to control resistant bollworms, emphasis on earliness was again relaxed. Insects then developed resistance to new insecticides and renewed emphasis on earliness ensued until new insecticides were developed. This cycle has continued and now we primarily rely upon transgenic *Bt* cotton for bollworm/budworm control. With the development of transgenic *Bt* cotton and the progress of the boll weevil eradication program, emphasis on early maturity in cotton has again been relaxed.

COTMAN was conceived prior to the release of transgenic *Bt* cotton and before expansion of the boll weevil eradication program. At that time, the bollworm/budworm complex and boll weevils were extremely difficult and expensive to control. The initial focus of COTMAN was the development of the *nodes above white flower* (NAWF) measurement and its use in determining when to terminate insecticide applications. Work on use of NAWF to time defoliation soon followed. Variation in NAWF patterns (curves) during effective flowering was then observed. This observation led to understanding the importance of having substantial NAWF at first flower, which is dependent upon nodal development prior to first flower. Methods to monitor the development of main-stem nodes and retention of squares prior to flowering were then developed. COTMAN was subsequently separated into two parts: 1) BOLLMAN (boll management), which uses NAWF for managing boll development, and 2) SQUAREMAN (square management), which uses nodal mapping to monitor pre-flowering nodal development, square retention, and vigor of the plant.

NAWF as a Measurement of Maturity

Waddle (1974) was perhaps the first to use the progression of first-position white flowers to the plant apex as a measure of maturity. He used a one-time (late August) count of uppermost white flower as a pre-harvest indicator of maturity among varieties. The "uppermost white flower" was measured by counting the number of main-stem nodes from the plant apex to the highest first-position white flower. Since uppermost white flower counts include the node number of the white flower, it is equal to NAWF plus one node. Using sequential NAWF counts, maturity of varieties was later characterized by the number of days from planting until NAWF=5 or physiological cutout (Bourland et al., 1991a, 1992a; Danforth et al., 1993). It was soon recognized that "days to NAWF=5" could be used to determine relative maturity of various types of treatments or different fields (Bagwell et al., 1992, 1994; Benson et al., 1995; Bourland et al., 1991b; Guthrie et al., 1993; Kirby, 1991).

Last Effective Flower Population

Waddle (1982) noted that new boll production ceased when a first-position white flower occurred within 7.6 cm (3 inches) of plant apex. In reality, apical nodal development either slowed or ceased, while squares in the upper part of the plant continued to develop into white flowers (Oosterhuis et al., 1989, 1992). Bernhardt et al. (1985) began using node count (above the uppermost white flower) rather than distance to plant apex to define the last effective population of flowers. Bourland et al. (1992) and Kirby and Goodall (1990) independently confirmed that NAWF=5 best defines this population of flowers in most environments and growing conditions. Oosterhuis et al. (1992) also showed that physiological changes in the plant accompanied the occurrence of NAWF=5, hence NAWF=5 became known as physiological cutout.

Development of BOLLMAN Applications

Once the flowering date of the last effective flowering population was defined, the logical next step was to determine when those flowers were mature enough to cease insect control and mature enough for defoliation. Obviously, bolls derived from the last effective flowers represent the youngest bolls that need to be protected. Zhang et al. (1993) developed methods to evaluate long-term weather to establish targets for harvest completion, and thereby to sequence latest possible cutout dates.

Bernhardt et al. (1985, 1986a and b) were the first to explore the use of the concept to determine when insecticides, primarily for heliothine species and boll weevil, could be safely terminated. Using caged insect studies, Bagwell and Tugwell (1992) subsequently defined periods of boll susceptibility to insect damage in terms of heat units (HU) from flower.

Later, Oosterhuis and Kim (2004) demonstrated that anatomical and biochemical changes occurring in the boll wall at about 350 HU after NAWF=5 coincided with the increased resistance to insect feeding. Entomologists in other states, notably Aubrey Harris at Mississippi State University, Roger Leonard at Louisiana State University, and John Benedict and Jim Leser at Texas A&M University, initiated experiments to confirm whether the insect termination concepts could be applied in various cotton-growing regions and with different insect pests.

Timing of defoliation based on defining and monitoring development of the last effective population of flowering was the obvious next use of the NAWF measurement (Bourland et al., 1994; Wells, 1991; Zhang et al., 1994). Dale Wells, a graduate student working with N.P. Tugwell, initiated crop defoliation using uppermost white flower in 1987 (Wells, 1991). Benson et al. (2000) summarized much of the early work on timing defoliation based on heat unit accumulated past cutout. In addition to assisting with end-of-season decisions, research soon indicated that sequential measurements of NAWF revealed variation in growth patterns (Benson et al., 1995; Bourland et al., 1997). These patterns reflect the combined effects on crop maturity associated with plant structure at first flower and the subsequent effects of stress due to environment, plant health, nutrition, and fruit retention (Bourland et al., 1998).

Target Development Curve

The establishment and importance of NAWF patterns led to the development of a full-season *Target Development Curve* (TDC). The TDC is based on four assumptions: 1) 35 days from planting to first square, 2) 25 days from first square to first flower, 3) a vertical fruiting interval of 2.7, and 4) 20 days from first flower to NAWF=5. The first three are from Tharp (1960), who summarized long-developed principles of cotton plant growth. Interestingly, the second assumption can be traced back to work in the 1800s (Hammond, 1896). With the goal of monitoring rather than modeling plant development, the TDC is sequenced by number of days rather than heat unit accumulation. Throughout the growing season, plant development can be compared to the TDC to determine if timely development is occurring and how the plants are progressing to maturity. The TDC is thus merely a standard and does not reflect optimal plant development in every situation.

SQUAREMAN Component of COTMAN

The TDC indicated that monitoring the plant prior to first flower was needed. About the same time, Hake et al. (1991a,b) were developing methods for early-season mapping and were emphasizing the importance of early-season growth. Slaymaker et al. (1995) wrote the first documentation for the SQUAREMAP procedures, which were developed to input data into SQUAREMAN. An early version of the SQUAREMAP procedure was called "TOPMAP," because it mapped the presence or absence of first-position squares starting at the top of plants and moving down (Bourland et al., 1995). Danforth et al. (1995) related SQUAREMAP data to earliness, showing that early-season growth and square retention affected late-season plant development. Meticulous work employing tarnished plant bugs on field-grown plants further demonstrated the relationship of retention of first-position squares with maturity (Holman et al., 1995). SQUAREMAN uses SQUAREMAP data to calculate and report nodal development, square retention, and vigor indices variables (Bourland et al., 1998). The vigor indices reported by SQUAREMAN are similar to those previously developed (Kerby and Goodell, 1990; Hake et al., 1990).

Persons Involved with Initial Development of COTMAN

A team of four professors at the University of Arkansas was primarily responsible for the development of COTMAN. Much of the original inspiration that led to COTMAN can be attributed to entomologist Phil Tugwell, who combined knowledge of the insects, the cotton plants, and their interactions. Agronomist/cotton breeder Fred Bourland used his insights on cotton plant structural growth and maturity to help develop plant measurements and characterize maturity differences in varieties. Plant physiologist Derrick Oosterhuis led research that showed that the COTMAN plant measurements had a physiological basis. Agricultural economist Mark Cochran established the economic costs and benefits of using COTMAN and provided leadership in developing the computer program. Under Dr. Cochran's guidance, Diana Danforth was responsible for maintenance of the computer program and coordinated much of the distribution, training, and communications associated with COTMAN. Later, entomologist Tina Gray Teague continued and extended much of Dr. Tugwell's research and led in the development of training materials.

J.P. Zhang (a Ph.D. student working with Tugwell and Cochran) was primarily responsible for the evaluation of long-term weather and initial COTMAN programming. He coined the term "COTMAN," which is short for "cotton management." Prior to the name "COTMAN," the program was referred to as managing by nodal development or simply reading the plant (Bourland et al., 1992a,b). In addition, numerous other graduate students, assistants, extension personnel, and consultants contributed to the development of COTMAN. The COTMAN program was first field tested on the David Wildy Farm (Mississippi County, Ark.) and the John Curry, Jr., Farm (Ashley County, Ark.) and was soon extended to additional farm evaluations (Klein et al., 1994). COTMAN versions 2.x, 3.x, and 4.x were distributed in 1995, 1996, and 1997, respectively. COTMAN version 5.0 was publicly released in 1998. Throughout the development of COTMAN, Cotton Incorporated has provided funding and support for the program. Dr. Pat O'Leary, Senior Director—Cotton Incorporated, has administered much of the funding and provided counsel and great assistance to the development, distribution, and training associated with COTMAN.

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Chapter 3:

Measures of Cotton Growth and Development

Derrick M. Oosterhuis and Thomas A. Kerby

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 always 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 decent of 0.2125 nodes per day (Fig. 1).

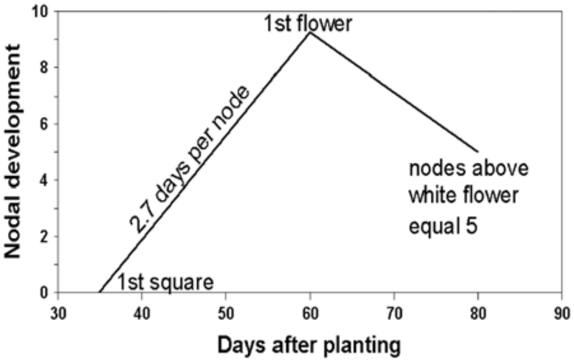

Fig. 1. Standard target development curve used in COTMAN showing the increase in the number of nodes above the first square with time in days after planting.

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

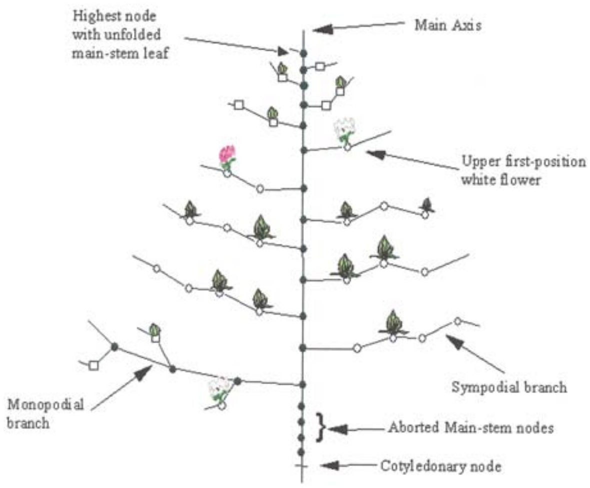

Fig. 2. Cotton plant showing a white flower five internodes from the terminal (NAWF=5).

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 temperature 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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Chapter 4:

Effects of Insect-Plant Interactions on Crop Development

B. Roger Leonard, Tina Gray Teague, Randy G. Luttrell, and S. Aubrey Harris

Cotton Insect and Mite Pest Occurrence

Cotton is a long-season crop, which is attacked by a diverse group of insect and mite pests throughout plant development and maturity. Numerous insect and mite pests are capable of reducing cotton yields across the United States (Leigh et al., 1996). The most common pest problems in the southern region are cutworms, *Agrotis* spp.; thrips, Thysanoptera; cotton aphid, *Aphis gossypii* Glover; tarnished plant bugs, *Lygus lineolari*s (Palisot de Beauvois); cotton fleahoppers, *Pseudatomoscelis seriatus* (Reuter); stink bugs, Pentatomidae; boll weevil, *Anthonomus grandis grandis* Boheman; spider mites, Acari; bollworm, *Helicoverpa zea* (Boddie); tobacco budworm, *Heliothis virescens* (F.); fall armyworm, *Spodoptera frugiperda* (J. E. Smith); beet armyworm *Spodoptera exigua* (Hübner); and soybean looper, *Pseudoplusia includens* (Walker).

In 2005, cotton producers across the United States spent $816.4 million to control these pests on over 14 million planted acres (Williams, 2006). The range of insect and mite pests change as the cotton crop develops during the season (Fig. 1). In addition, pest density and their potential to injure the harvestable crop usually increase during the season. The number of pests and the relatively high crop value per acre cause insect pest management to be a significant annual variable production cost for cotton. During some years of intense insect and mite pest pressure, annual insect control costs can exceed $100/acre.

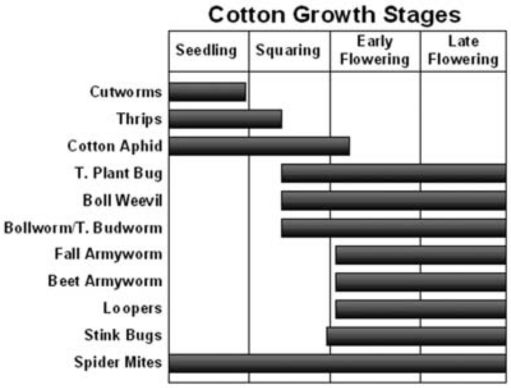

Fig. 1. Major cotton insect pests attacking selected stages of cotton across the Mid-South cotton region.

During the seedling stage, thrips and cotton aphids are usually the most common insect pests. As cotton plants initiate squaring (flower bud formation), a complex of boll weevil, tarnished plant bug, cotton fleahopper, spider mite, and caterpillar pests is capable of reducing yields. During the flowering stage, square-feeding insects can persist as problems, but additional caterpillar pests such as armyworms, stink bugs, loopers, and clouded plant bugs can become important yield-limiting pests. The evolving status and sporadic occurrence of multiple pests during the crop production season add to the difficulty of scouting and making the correct decision on pesticide application timing.

Cotton Plant Development and Plant Response to Pest Injury

The indeterminate growth pattern of cotton plants also complicates cotton pest management practices. Cotton plants generally produce more fruiting structures than can be retained during the entire growing season. Excess fruiting structures are abscised from the plant in response to several factors including environmental stresses (weather), biotic injury (pests), or competition among fruiting sites (Guinn, 1982; Mauney, 1986). The abscission of reproductive structures, regardless of the reasons, is a natural process that a plant utilizes to maintain optimal numbers of fruiting forms. The concurrent development of vegetative growth (leaves and stems) and reproductive forms (squares, flowers, and bolls) can allow up to 50% of the total fruit load to be abscised during the season and still produce optimal yields (Bourland et al., 1990; Kennedy et al., 1991). This is an important consideration because insect and mite pests can be allowed to injure the crop at low levels without producing measurable yield losses. As the production season progresses, fruiting forms reach a peak value, and plants lose the ability to fully compensate for their loss during the remainder of the season (Gore et al., 2000).

During the pre-flowering phase of cotton development, losing up to 20% of first-position cotton squares usually will not decrease yields if environmental conditions are favorable for plant development during the production season (Holman, 1996). The cotton plant naturally sheds relatively high numbers of the fruiting forms after anthesis. The rate of boll abscission directly affects final cotton yield and the actual timing of boll loss has an equally important influence on final yield. Considerable (>50%) injury to flowers and bolls during the initial weeks of flowering may not influence yields, but low levels (<15%) can contribute to significant yield losses during peak flowering (Gore et al., 2000). The cost of losing fruiting forms during the pre-flowering and flowering interval is usually a delay in crop maturity if the crop is allowed to produce optimal yields.

Boll and Yield Susceptibility to Insect Pests

The indeterminate growth pattern of cotton also allows bolls to develop on the plant over an interval of several weeks. Natural boll abscission peaks at five to six days after anthesis and decreases to 0% on bolls retained at 12 to 15 days after anthesis. Direct insect injury to young bolls usually results in abscission. For older bolls (12 to 15 d-old), insect injury can reduce yield in one or more locules, but the boll may not abscise from the plant. Considerable research has examined the interactions between boll age [heat units (HU) beyond anthesis] and yield loss from insect injury. Numerous cotton insect pests injure cotton during the production season, and it is unlikely that one threshold for boll susceptibility could be used for all pests. Initial studies during the previous decade found heat unit accumulation to be a consistent method of aging the susceptibility of bolls to pests (Bagwell and Tugwell, 1992).

Bolls appear to be relatively safe from direct feeding injury by boll weevil, bollworm, beet armyworm, tarnished plant bug, brown stink bug, southern green stink bug, and western tarnished plant bug, *Lygus hesperus* Knight, at 299 to 559 HU after anthesis (Fig. 2). For foliage-feeding insects, yield losses were not observed until defoliation occurred on plants that had accumulated 550 HU after setting the last effective boll. However, in similar studies, late-instar fall armyworm larvae successfully penetrated >60% of non-*Bt* cotton bolls that had accumulated 852 HU, but <10% of transgenic *Bt* bolls that had accumulated 864 HU. In addition, studies are currently underway to evaluate the interactions between boll age, insect-induced boll injury, and fiber quality.

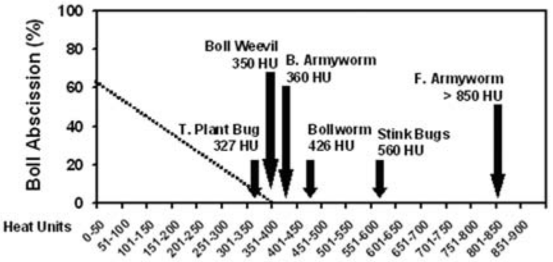

Fig. 2. The effects of boll maturity on insect pest-induced boll abscission.

Cotton Plant Development and Pest Management Decisions

Pest management decisions must rely on information about the pest as well as crop health and development patterns. Plant monitoring techniques were originally developed to document the effects of environmental stresses on plant growth (Hake et al., 1990; Bourland et al., 1992) but now are used as decision aids in the application of production inputs including pest management treatments (Cochran et al., 1994; Bourland et al., 1998).

The most widely accepted plant monitoring tool is the COTMAN™ program, which can provide information on plant development during the entire season. COTMAN data give a reference and seasonal perspective of crop fruiting patterns that can be coupled with insect and mite infestation counts to make a well-informed decision. Extension recommendations for most of the Mid-South cotton production states rely upon square retention levels as well as insect numbers to determine the needs for pesticide applications. The sub-program routine SQUAREMAN of COTMAN is an effective tool for collecting and processing data on square retention.

Late-Season Pest Management

The decision of when to terminate late-season insect pest management strategies has been a persistent problem for the cotton industry. Returns through increased yields and improved fiber quality must exceed the cost of these control strategies to justify late-season insecticide treatments. Another COTMAN component, BOLLMAN, has been used to estimate the critical time to terminate insect-pest management strategies at the end of the growing season. This program uses *cutout* [main stem *nodes above white flower* (NAWF) ≤5], as the endpoint for the last effective boll population set on the plant (Oosterhuis, 1990; Bourland et al., 1992). Many bolls produced by the plant after cutout do not have enough time remaining in the season to produce mature cotton fibers (Bernhardt et al., 1986). As a general rule, after cutout has occurred and the crop has accumulated 350 to 550 HU, harvestable bolls are considered safe from attack by most fruit-feeding insect pests (Oosterhuis and Kim, 2004). If the definition of cutout is reduced to NAWF≤4 for some regions, then the heat unit accumulation rules remain the same. Physiological cutout is a key factor that must be defined accurately for each situation to eliminate late-season treatments used to protect cotton bolls that normally abscise or will not produce mature fiber.

Unfortunately, there are situations in which the crop develops in such a manner that the NAWF never progresses to within 5 main stem nodes of the plant terminal. Under these conditions, an alternative to using a physiological basis for cutout is to estimate the latest possible cutout date using a calendar day. This endpoint of crop development uses long-term weather data for a specific location and represents the last day in which a white flower has a 50% chance of receiving enough HU to mature into a boll of sufficient size and quality.

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Chapter 5:

COTMAN Sampling and Data Collection

Tina Gray Teague and Diana M. Danforth

COTMAN™ plant monitoring data represent a "snapshot" of the crop's status in a particular field on a specific day. Field data are collected by COTMAN mappers whose responsibility includes selecting appropriate sampling sites and collecting crop growth and maturity and fruit retention information. These crop data are analyzed using the COTMAN software and summarized into reports from which growers make important decisions. Good site selection and mapping techniques are essential for providing accurate information for crop managers to make good decisions.

The SQUAREMAN component of COTMAN is run pre-flower, and the BOLLMAN component is run post-flower (Fig 1). SQUAREMAN reports provide information on pace of crop development and retention of squares and if continued after flowering, boll retention. BOLLMAN reports provide information for end-of-season decision making, including the date of crop cutout. It is not necessary to run SQUAREMAN in order to run BOLLMAN.

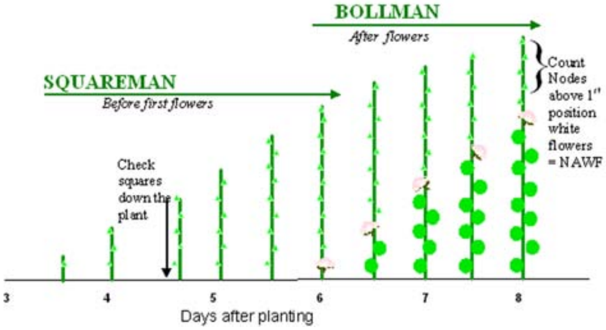


Fig. 1. COTMAN is divided into two components: *SQUAREMAN*, which is used to monitor preflower plant development and square retention; and *BOLLMAN*, which is used starting at first flower to help with end-of-season decisions including defining date of physiological cutout, and scheduling insect control and irrigation termination and defoliation timing. Bollman utilizes NAWF data.

Data can be collected on paper forms (*See* Appendices, page 99) or on PDAs.

The sampling protocol outlined in this chapter addresses the following questions: Where should sample sites be located in the field? and What, When, and How to sample?

Where Should Sample Sites be Located in the Field?

Field size for COTMAN sampling generally should not exceed 80 acres, and it is recommended that at least 4 sites per field be sampled weekly. If a large field cannot be broken into two or more fields, it is recommended that mappers sample more sites. Up to 64 sample sites can be used per field in the COTMAN software program.

COTMAN mappers should confer with the grower on site selection at the beginning of the season. Field history along with management priorities may affect the areas of the field where the grower wants to make management decisions.

Samples should be taken at sites where plants represent the predominant growing conditions in each field. Sites should be avoided where plants vary greatly because of differences in soil type, drainage patterns (e.g., high or low spots in the field), stand density, or random physical injury (e.g., hail damage or mechanical injury from farm equipment). Samples should be taken in the same general areas in the field and in the same order each week. Mappers should avoid sampling the same plants each week. Sample sites should be located no less than 100 ft from the edge of the field and separated by at least 150 ft.

Mappers also should avoid:

- Weed infested areas,
- Areas with irregular irrigation patterns such as "dryland" corners of center-pivot irrigated fields or low spots prone to flooding, and
- Replanted areas (these sections of the field will not be apparent later in the season) or areas receiving "spot" treatments.

If there are large portions of the field (25% or more) with obvious plant growth or vigor differences, then the sampling plan should be modified. If the grower feels that a large enough portion of the field is represented by these special situations, *and* the grower wants to manage these areas separately, then the field should be divided and treated as two or more separate fields. An example would be a center-pivot irrigated field where plants located in the corners of the field are water stressed and stunted compared to the irrigated portion of the crop. A sampling plan also might be modified if areas of the field are bordered by crops or landscape features that are known habitats for arthropod pests (e.g., a corn field or wooded areas). Mappers should include at least one sample site adjacent to such areas, even if the field is not divided.

What, When and How to Sample

WHAT TO SAMPLE	WHEN TO SAMPLE	HOW TO SAMPLE
Stand Density	Once per season after the plant stand is well established.	Randomly select a starting point where the plant stand appears to be typical for the field. From the starting point count the number of plants in 3-foot row sections in a straight line across 24 consecutive rows. Move at least 150 feet to another site where the plant stand appears typical for the field and repeat the sampling procedure. A "T" stick may be used to facilitate data collection (Fig.2).
First Fruiting Node (FFN)	Once per season at the time of the first SQUAREMAN data collection	Squares should be visible on at least 40% of plants before FFN is determined. Select a starting point at 4 sites in each field where the plants represent those that the farmer will use to make management decisions. Sample 5 consecutive squaring plants in the row by counting the number of nodes upward from the cotyledonary nodes (Fig. 3) to the first fruiting branch. Cotyledonary nodes are counted as zero (Fig 3 and 4). Turn to the adjacent row at the site and sample 5 more plants in the same manner. Go to the next site.
Squaring Nodes and Square Retention (SquareMap)	Once or twice per week from the time squares first become visible until flowers appear.	Repeat the following procedure in 4 to 8 different sites in each field: 1. Measure the average plant height (in inches) from soil to terminal. 2. From five consecutive plants in one row: * Start at the first fully-expanded true leaf in the terminal (Fig 5). * Check for the presence or absence of first position squares. * Record a "1" if a square is present and enter a "0" if the square has shed. 3. Repeat steps 1 and 2 on the adjacent row. The procedure is shown in Fig. 6.

Nodes Above White Flower (NAWF)	Once or twice per week starting when flowers appear. Sample until NAWF is less than 5 or until latest possible cutout date has been reached. Note: When the crop is just starting to flower, mappers may have to look down the several feet of row to find plants with flowers. As the crop matures, take extra care to sample only first position flowers. Do not count nodes above flowers at the second position, at extra-axillary nodes or on monopodial branches (Fig 7).	From ten plants at each of four to eight sites per field: NAWF: Count the number of nodes above the uppermost first position whie flower (Fig. 8). * When counting, stop at the uppermost unfurled leaf in the terminal. (Do not count a leaf that has not yet unfurled.) * Sample plants from two or more rows at each site. * Skip plants with a terminal aborted above the flower
Weather	Daily, beginning at cutout and continuing until defoliation.	Obtain high and low temperatures (°F) from a reliable local source

Fig. 2. Measure the stand density by counting the number of plants in 3 ft of row from 24 consecutive rows. To facilitate counting plants, construct a "T" shaped sampling stick using a 3-ft PVC pipe attached to a 4-ft piece of 1-inch diameter PVC pipe.

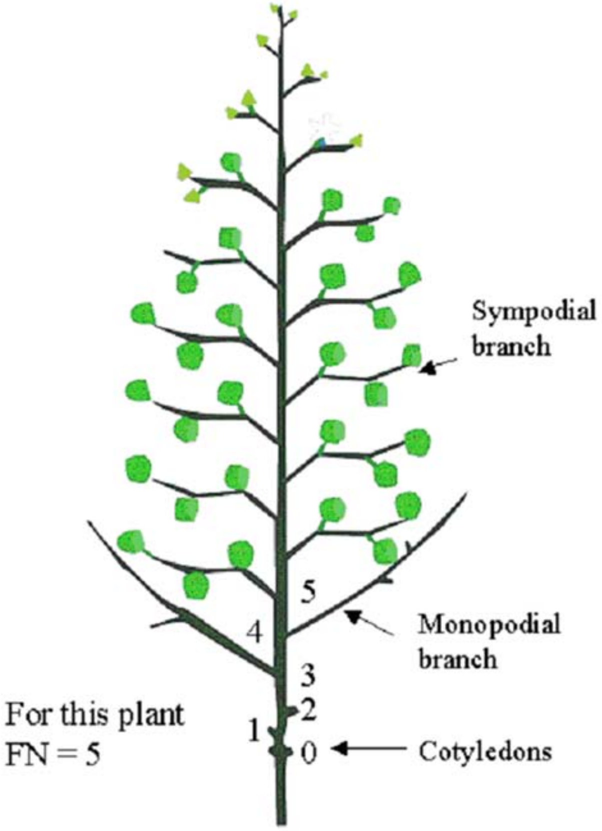
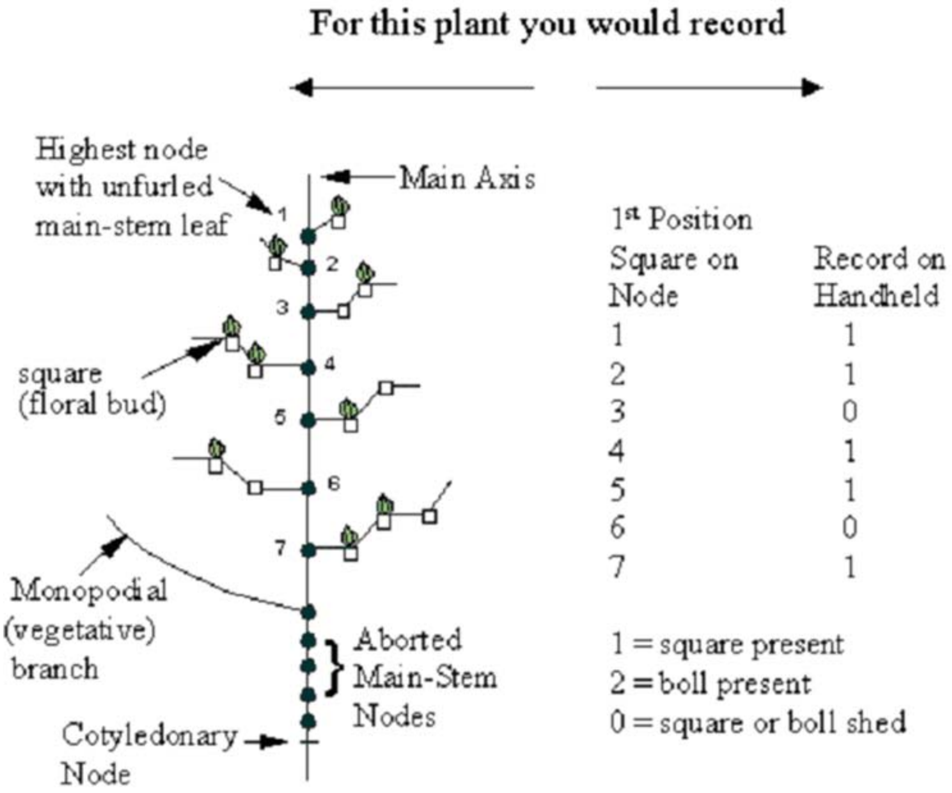


Fig. 3. Count from the cotyledons (node "0") up to the first main-stem sympodial branch to determine the first fruiting node (FFN). Calculate mean FFN from samples of 10 plants selected at 4 to 8 sites per field.

Fig. 4. Description of cotyledons, main-stem sympodia, monopodia, and first fruiting node.

Fig. 5. When using SquareMap, mappers should start counting squaring nodes down from the first unfurled leaf (above). A "one" is recorded for each main-stem squaring node if the square is present and a "zero" is recorded for each squaring node if the square is missing (below).



1st Position Square on Node	Record on Handheld
1	1
2	1
3	0
4	1
5	1
6	0
7	1

1 = square present
2 = boll present
0 = square or boll shed

Fig. 6. The SquareMap Procedure - mapper tips.

Fig. 7. The BOLLMAN sampling protocol calls for counting the number of nodes above a first position white flower on the main stem. Mappers should use caution and not count NAWF at the second position, extra axillary flowers, or flowering occurring on monopodial branches.

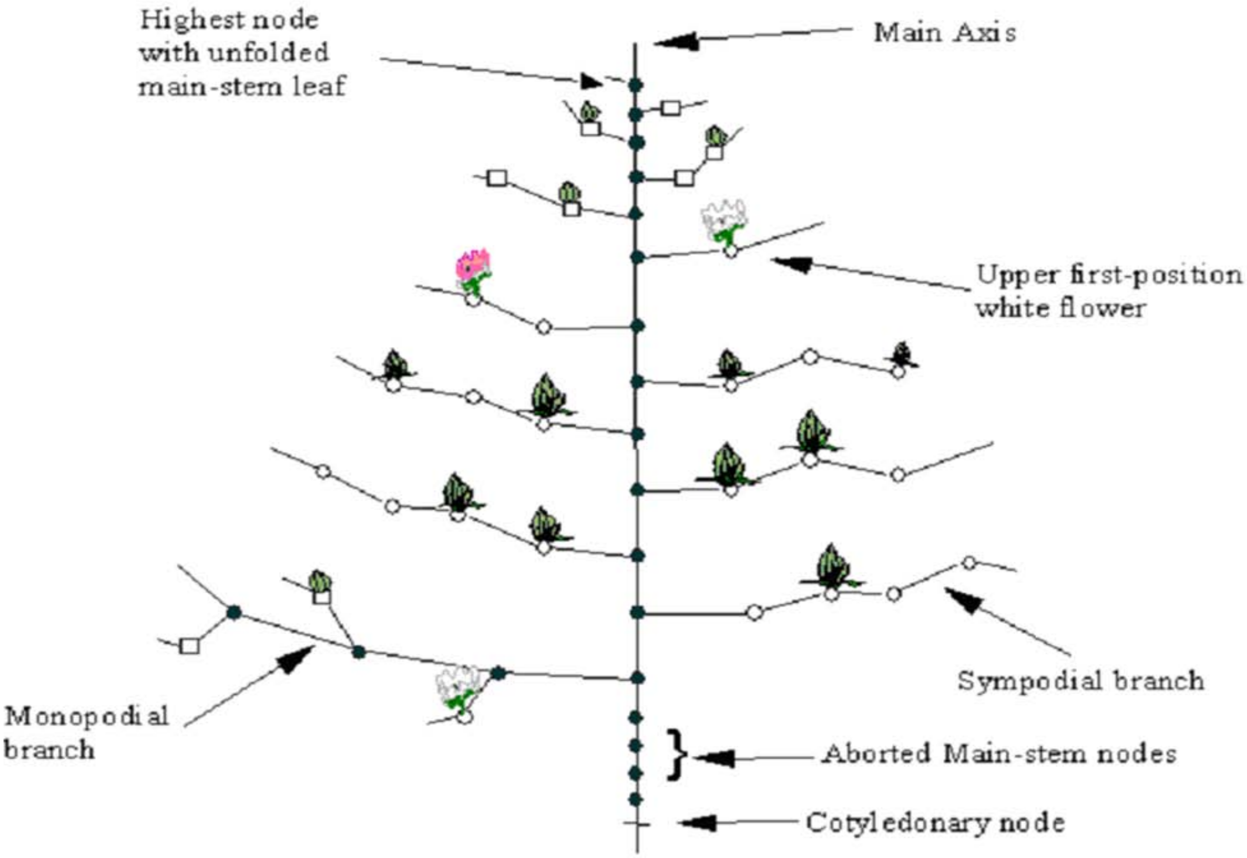


Fig. 8. NAWF: Count the number of nodes above the uppermost first-position white flower.

Chapter 6:

SQUAREMAN Decision Aids

James F. Leser, Diana M. Danforth, and Fred M. Bourland

SQUAREMAN decision aids use number of squaring nodes, square retention, and *height-to-node ratios* (HNR) to assist growers with decisions involving irrigation initiation, early-season insect control, in-season fertility, and plant growth regulation. The aids apply to the plant growth and development period prior to the appearance of the first flower. They are diagnostic in nature and designed to identify when fields are under stress or otherwise deviating from optimal growth and development. Suggestions for the course of action growers should follow to remedy potential problems detected through SQUAREMAN are listed where appropriate. Follow-up field verification of a potential problem detected through SQUAREMAN is always recommended. The purpose of this chapter is to enumerate these aids and summarize the triggers associated with them.

Basis for Triggering Decision Aids

SQUAREMAN utilizes SquareMap data to primarily address two crop management questions: 1) Is plant development progressing at the acceptable pace? and 2) Is square retention acceptable?

To address these questions, 45 decision aids (listed under Application of Decision Aids section) have been incorporated into SQUAREMAN, and each is triggered by different combinations of crop development measurements (initiation of node development, rate of node development, plant vigor) and square shed levels (Bourland et al., 1998).

The pace of crop development is determined by sequential measurements of first-position *squaring nodes*. Prior to flowering, the number of squaring nodes corresponds to the number of sympodia (fruiting branches) that develop from the main stem. In SQUAREMAN, first-position squaring nodes are plotted against days from planting and compared to the shape and ascent of the *Target Development Curve* (TDC) to the apogee (*See* Chapter 3).

There are three decision aid bases. *Base I Decision Aids* are triggered by *position* and *slope* of the actual growth curve relative to TDC.

Base II Decision Aids contain decision aids that address changes in square shed rates. In addition to the position and slope of the curve, a third factor used to trigger the decision aids is square retention. SQUAREMAN expresses square retention as the percentage of first-position squares that are shed. The decision aids are then triggered by either a high (>15%) or low (<15%) level of square shed, which is especially useful in anticipating approaching square-retention management decisions and evaluation of any remedial action taken to correct earlier square-retention problems.

Base III Decision Aids use changes in HNR for evaluating *plant vigor* (*See* Chapter 3 for other vigor indices).

Plant Compensation and Square Shed Limits

The cotton plant has the potential for tolerance and/or compensation for early fruit loss (producing many more squares than it can possibly mature into harvestable bolls), depending upon the subsequent management and environmental growing conditions. Previous studies have shown that some levels of early-season square loss under certain conditions rarely affected yields (Kletter and Wallach, 1982; Terry, 1992; Montez and Goodell, 1994; Holman, 1996) and sometimes increased yields (Pedigo et al., 1986; Sadras, 1995; Doederlein et al., 2002) because of the plant's compensation ability. However, early square loss can cause maturity delays even if yield is unaffected (Leser et al., 2004). For every 1% increase in square loss, the crop is delayed by 0.1818 days. These delays can expose growers to a higher risk of adverse weather during harvest and require a higher level of and cost for managing late-season insect infestations (Eaton, 1931; Munro, 1971; Bagwell and Tugwell, 1992; Cochran et al., 1994; Sadras, 1995).

The ability of a crop to compensate for early-season square loss can be affected by several factors including cultivar, planting date, plant density, fertility inputs, yield potential, available heat units, insect infestations, disease, and water stress. Leser et al. (2004) found that where water and heat units were not limiting factors, plants could compensate for most if not all pre-flower square loss (even from second-position fruiting sites). There is a 0.97% yield loss for every 1% square shed rate increase above the compensation capacity of the crop. As yet, research has not been able to provide the information needed to define an individual field's compensation capacity. In irrigated systems, water stress is probably the most relevant factor influencing compensation capacity that is under the control of the grower. Teague et al. (2005) found that delaying irrigation can lead to pre-flower water deficits and a subsequent decrease in the crop's compensation capacity for injury from early-season insect pests.

Since SQUAREMAN monitors only first-position fruit, the ability to monitor the recovery from early-season square loss may be compromised because most compensation takes place in second and third sympodial branch positions rather than by adding nodes through increases in plant height (Leser et al., 2004). By producing more squares than can be matured as harvestable bolls, most fruit-load adjustments in the cotton plant take place through small-boll shed late in the season. Much of the compensation for early-season square loss is through an increase in boll retention rather than an increase in later square retention.

Square loss levels used for early-season insect control decisions vary considerably between states in the Cotton Belt. Texas uses a range of 10 to 25% depending upon location in the state and week of squaring during the pre-flower period (Baugh et al., 2005) while much of the Mid-South has long used 20 to 25% (Johnson and Jones, 1996; Turnipseed et al., 1995). Holman (1996) estimated that square loss lower than 19% at first flower did not affect yields while Johnson and Jones (1996) used 25%, Gutierrez et al. (1981) used 30%, and Leser et al. (2004) used 40% as compensation limits. The 15% square shed limit is the default value used by SQUAREMAN. There is currently no option available to the user to enter a different square shed limit value.

Generalized Interpretations of Base I Decision Aid Trigger Options

Position relative to target (3 options) (*See* Chapter 9 for graphic examples)

Left of target: Early plant development, such as associated with fast emergence and/or rapid development of plant structure, often accompanied by a low first-fruiting node.

Near target: Development at a pace for optimal combination of earliness and yield.

Right of target: Delayed plant development such as associated with high plant density or cool temperatures accompanied with a high first-fruiting node, *or* slow development of plant structure such as associated with low seedling vigor.

Slopes of growth curve prior to apogee (4 options) (*See* Chapter 9 for graphic examples)

Slope flatter than target: Stressed plant growth where intensity of stress is indicated by flatness of curve and fewer number of squaring nodes. Stress related to flattening of the slope between sampling dates after following the TDC slope is often associated with lack of needed moisture to continue optimal growth pace. Late initiation of irrigation is often the cause.

Slope similar to target: Development at optimal pace.

Slope steeper than target: Plant development progressing at a rapid pace, likely evidenced by excess vegetative growth (often associated with fruit shed). When the slope steepens between two sampling dates after being flatter than the TDC, plant stress is most likely relieved, e.g., rain/irrigation if water had been deficient.

Slope not determined: The situation when only one sample date is available.

Square shed (2 options)

High: User should determine the cause of square shed and be aware that significant loss of squares may stimulate excessive vegetative growth. Square shed can be either physiological or insect induced (e.g., thrips, cotton fleahoppers, plant bugs).

Low: User should be prepared to meet high demands for water and nutrients by the developing fruit load.

Application of SQUAREMAN Base I-III Decision Aids

Base I Decision Aid set. The first check is to see if the field is already flowering. If so, then the user should switch from SQUAREMAN to BOLLMAN. If no flowers are present, then there are 24 aids covering combinations of thee observed growth curve positions by four slopes (relative to the TDC prior to the apogee) by two square shed options. Table 1 provides a summary of these Base 1 Decision Aids.

The *Base II Decision Aid* set contains ten more decision aids (*See* Table 2). If the field is already flowering, the user should switch to BOLLMAN. If the field has only one data point, the user must wait until a second sample is taken before square shed rate change can be evaluated.

The *Base III Decision Aid* set contains three decision aids pertaining to evaluating changes to the height-to-node ratio (*See* Table 3). Again, if the field is already flowering, the user should switch to BOLLMAN. At least two sample dates are required for the program to calculate height-to-node ratio change.

Summary

SQUAREMAN decision aids provide a means to evaluate crop development and can often signal potential problems. Users should also consider other information in making management decisions during the pre-flower period (e.g., weather, cultivars, insect infestations, soil factors, moisture situation, field experiences) as well as other SQUAREMAN outputs (e.g., measures of first-fruiting node, estimates of plants per acre, first-position fruit per acre, square shed by position). Integration of this information should help the user to determine the appropriate action to take to maintain optimal pace of crop development and fruit retention.

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Table 1. Base I Decision Aids: Evaluating most recent growth curve and square shed.

Nodal development relative to TDC^z	Slope relative to TDC (nodal) development pace)^y	First position square shed rate (High, ≥15%; Low, <15%)	Considerations
Above	Steep	High	Square shed has exceeded 15% and nodal development is faster than normal. Determine the cause of square shed. Monitor plant growth. Excessive vegetative growth has occurred, or is likely.
Above	Steep	Low	Although fruit retention is good, nodal development is faster than normal. This is an unusual (often transient) condition. Continue to monitor plant growth for signs of excessive vegetative growth.
Above	Flat	High	Nodal development is slower than normal which indicates possible plant stress from increased fruit load or certain pest, cultural, or environmental conditions. Square shed has exceeded 15%; determine the cause of square shed.
Above	Flat	Low	Nodal development is slower than normal which indicates possible plant stress from increased fruit load or certain pest, cultural, or environmental conditions. Check for water stress and monitor crop fertility needs. Early infestations, thrips, nematodes, or sublethal seedling disease may be involved. Deficient or excessive water, cool temperatures, cloudy conditions, or herbicide injury may be causes.
Above	Target	High	Square shed has exceeded 15%; determine the cause of square shed. Monitor plant growth; conditions for possible excessive vegetative growth exists.
Above	Target	Low	Fruit retention and nodal development are good. Fruit load may cause increased demands for water and nutrients.
Above	1-Sample	High	Field started squaring earlier than normal. Early squaring may be due to fast emergence or develement of first squares at a relatively low (e.g., <6) main-stem node. Square shed has exceeded 15%; determine cause of shed. Monitor plant growth; conditions for possible excessive vegetative growth exist.
Above	1-Sample	Low	Field started squaring earlier than normal. Early squaring may be due to fast emergence or development of first squares at a relatively low (e.g. <6) main-stem node. Fruit retention and nodal development are good. Fruit load may cause increased demands for water and nutrients.
Below	Steep	High	Square shed has exceeded 15% and nodal development is faster than normal. Determine the cause of square shed. Monitor plant growth; excessive vegetative growth has occurred or is likely.
Below	Steep	Low	Although fruit retention is good, nodal development is faster than normal. This is an unusual (often transient) condition.
Below	Flat	High	Nodal development is slower than normal which indicates possible plant stress from increased fruit load or certain pest, cultural, or environmental conditions.
Below	Flat	Low	Nodal development is slower than normal which indicates possible plant stress from increased fruit load or certain pest, cultural, or environmental conditions.
Below	Target	High	Square shed has exceeded 15% -- determine the cause of square shed. Monitor plant growth; conditions for possible excessive vegetative growth exist.
Below	Target	Low	Fruit retention and nodal development are good. Fruit load may cause increased demands for water and nutrients.
Below	1-Sample	High	Square shed has exceeded 15%; determine the cause of square shed. Monitor plant growth; conditions for possible excessive vegetative growth exist.

continued

Table 1. Continued.

Nodal development relative to TDC[z]	Slope relative to TDC (nodal) development pace)[y]	1st Position square shed rate	Considerations
		(High, ≥15%; Low, <15%)	
Below	1-Sample	Low	Field started squaring later than normal. Late squaring may be due to slow emergence or development of first squares at a high (e.g. > 7) main-stem node. Fruit retention and nodal development are good. Fruit load may cause increased demands for water and nutrients.
Target	Steep	High	Square shed has exceeded 15% and nodal development is faster than normal. Determine the cause of square shed. Monitor plant growth; excessive vegetative growth has occurred or is likely.
Target	Steep	Low	Although fruit retention is good, nodal development is faster than normal. This is an unusual (often transient) condition.
Target load	Flat	High	Nodal development is slower than normal, which indicates possible plant stress from increased fruit or certain pest, cultural, or environmental conditions. Square shed has exceeded 15%; determine the cause of square shed.
Target	Flat	Low	Nodal development is slower than normal which indicates possible plant stress from increased fruit load or certain pest, cultural, or environmental conditions.
Target	Target	High	Square shed has exceeded 15%; determine the cause of square shed. Monitor plant growth; conditions for possible excessive vegetative growth exist.
Target	Target	Low	Fruit retention and nodal development are good. Fruit load may cause increased demands for water and nutrients.
Target	1-Sample	High	Square shed has exceeded 15%; determine the cause of square shed. Monitor plant growth; conditions for possible excessive vegetative growth exists.
Target	1-Sample	Low	Fruit retention and nodal development are good. Fruit load may cause increased demands for water and nutrients.

[z] Nodal development relative to TDC is evaluated by comparing observed number of nodes to target number of nodes at days after planting (DAP) for the latest SquareMap sampling date in a field.

To calculate *Target nodes above first square* (NAFS) for the date, start at 0 on 35 DAP and add 0.37 per day.

To calculate *Actual* NAFS for the date, subtract 1 from the # sympodial branches.

Calculate *Ratio* = *Target/Actual*.

If sampling date ≤35 then Development = "Above."

Otherwise: If *Ratio* ≥ 1.15 then Development = "Above."
If *Ratio* < 1.15 and *Ratio* >0.86 then Development = "Target."
If *Ratio* ≤ 0.86 then Development = "Below."

[y] Slope relative to TDC slope (Pace of nodal development) is evaluated by computing the daily change in nodes between the latest two SquareMap sampling dates and comparing to the daily change expected from the TDC, which is 0.37 nodes/day.

Actual *Rate* of change/day = $(\text{Nodes}_t - \text{Nodes}_{t-1})/(\text{DAP}_t - \text{DAP}_{t-1})$

If only one SquareMap sampling date then Pace = "1-Sample."

Otherwise: If *Rate* ≥ 0.49 then Pace = "Steep."
If *Rate* < 0.49 and Pace > 0.25 then Pace = "Target."
If *Rate* ≤ 0.25 then Pace = "Flat."

Table 2. Base II Decision Aids: Evaluating square shed rate change between consecutive sampling dates

Shed rate change	Current shed rate	Previous shed rate	Considerations
No change			The square shed rate has not significantly changed since the previous data collection date.
	< 15%	< 15%	The shed rate has remained below 15% on both sampling dates.
	< 15%	≥ 15%	The shed rate was at or above 15% on the previous sampling date and is now below 15%.
	≥ 15%	< 15%	The shed rate was below 15% on the previous sampling date and is now at or above 15%.
	≥ 15%	≥ 15%	The shed rate has remained above 15% on the latest two sampling dates. Determine whether square shed is insect or physiologically induced.
Significant decrease			The square shed rate has significantly decreased since the previous data collection date. This may indicate recovery from a previous problem.
	< 15%	< 15%	The shed rate remained below 15% on both sampling dates.
	< 15%	≥ 15%	The shed rate was at or above 15% and is now below 15%.
	≥ 15%	≥ 15%	The shed rate has remained at or above 15% on both sampling dates. Determine whether square shed is insect or physiologically induced.
Significant increase			The square shed rate has significantly increased since the previous data collection date. This may or may not indicate a problem.
	< 15%	< 15%	The shed rate has remained below 15% on both sampling dates.
	≥ 15%	< 15%	The shed rate was below 15% and is now at or above 15%. Determine whether square shed is insect or physiologically induced.
	≥ 15%	≥ 15%	The shed rate was above 15% and has further increased. Determine why square shed continues to increase. Determine whether square shed is insect or physiologically induced.

Table 3. Base III Decision Aids: Evaluating height-to-node ratio (HNR) change between consecutive sampling dates.

Change in HNR	Considerations
No change	No significant change in HNR has occurred since the previous data collection date.
Significant decrease	The HNR has significantly decreased since the previous data collection date. Plant stress is indicated. Check for aphid infestations, water stress or other factors that may inhibit plant development.
Significant increase	The HNR has significantly increased since the previous data collection date. Excessive growth is indicated. Check square retention and plant vigor and determine whether vegetative growth should be controlled.

Chapter 7:

Stepwise Progression Through BOLLMAN with Instructions for Non-Computer Users

Fred M. Bourland, Derrick M. Oosterhuis, N. Phillip Tugwell, and Mark J. Cochran

A non-computerized version of BOLLMAN can serve as an excellent teaching tool and can be used by individuals who would like to try the system on a small scale. The user should then be able to gain confidence in the system and an appreciation of the power of the computer-based version. However, this simplified “paper” version should not be considered as a substitute for the computer-based system. Due to voluminous data manipulations, it is not practical to attempt the SQUAREMAN portion of COTMAN™ without a computer. Similarly, as BOLLMAN is conducted on an increasing number of fields, the need for a computer to handle the data greatly increases.

The logic of BOLLMAN is to identify cutout date, i.e., the flowering date of the last population of bolls that is expected to make a profitable contribution to yield, then adjust end-of-season management on the maturation of these bolls. Cutout either coincides with crop maturation (physiological cutout) or is dictated by end-of-season weather (seasonal cutout). BOLLMAN assists with timing of insecticide termination and application of defoliants, as well as with sequencing of fields by their relative maturity.

BOLLMAN requires four steps:

- Sequentially monitor *nodes above white flower* (NAWF) to determine date of physiological cutout.
- Estimate latest possible cutout date from historical local weather data to determine date of seasonal cutout.
- Establish last effective flowering date to determine true cutout date.
- Calculate and accumulate heat units (HU) after true cutout date for each field.

Step 1. NAWF

Initiate NAWF Measurement

Each field should be monitored for the appearance of first flowers. Start collecting NAWF data at first flower and collect once or twice per week until NAWF is less than 5 or until the latest possible cutout date occurs.

NAWF counts should be initiated at first flower because early NAWF counts can be important crop growth indicators (Robertson et al., 1996). Sequential monitoring of NAWF once or twice a week gives information on the progressive maturity of the crop. Timely initiation of NAWF counts also allows the user to distinguish between true cutout (first incidence of NAWF=5) and second growth (or late-flowering plants). Fruit associated with second growth is often costly to protect and contributes little or nothing to yield. Therefore, monitoring NAWF of second growth nullifies the value of BOLLMAN.

NAWF Measurement

Users should make copies of the blank NAWF data collection sheet (Appendix D, page 104). Select at least four sample sites within a field or management unit. For fields larger than approximately 40 acres, add a sample site for each additional 10 acres. It is essential to choose a representative site within each sample site. Find a plant having a first-position white flower, and count the number of main-stem nodes above the branch bearing a first-position white flower. The uppermost node counted is the highest one having an unfurled leaf, i.e., edges not touching (Fig. 1). Find a second plant having a first-position white flower, and count NAWF. Repeat this procedure for 10 plants in each sample site. Do not sample all 10 plants from the same row. Go to the next sample site and repeat the procedure. Deter-

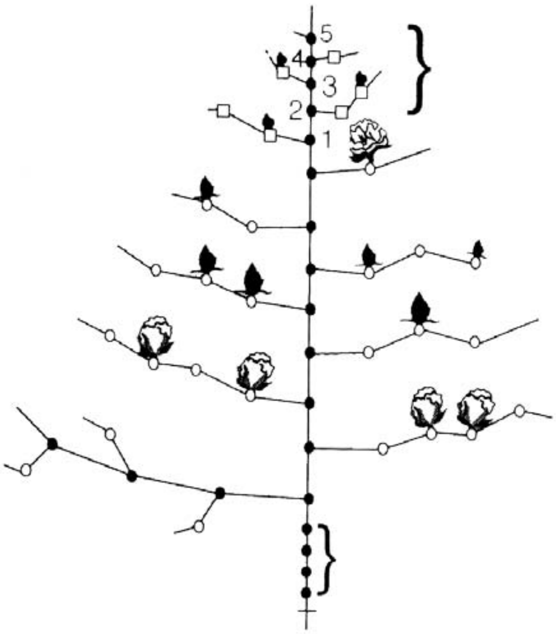

Fig. 1. Plant diagram illustration of NAWF.

mine the mean NAWF for each site (round to nearest 0.1). *Average the site* means to determine a field mean NAWF value (round to nearest 0.1). For each field, NAWF should be determined once or twice per week from first flower until cutout (*See* Physiological Cutout on page 47).

NAWF Variation

Considerable plant-to-plant variation in NAWF within a field is normal. The amount of variation in these values within and across sites can be meaningful. Variation within a site reflects plant-to-plant variation in growth and development. Major contributors to such variation are as follows:

- Differences in stand density,
- Sporadic insect injury, causing loss of fruit or vigor,
- Random physical injury, e.g., hail damage,
- Incidence of non-lethal plant disease, and
- Spot-replanting within an area.

Variation between sites is often related to differences in soil types or water status (excess or deficiency). If sites vary greatly, be sure that the sites properly represent the field. In some cases, you may want to substitute a sample site that better represents the area of the field upon which you wish to base your decisions. Generally, as variation increases, sample sizes and number of samples should be increased to reduce sampling errors.

Chart NAWF

Prior to initiating NAWF counts, make a NAWF chart (Appendix D, page 104) for each field and fill in information relative to field name, planting date, soil type, and cotton variety. The NAWF chart plots “days after planting” (DAP) on the horizontal axis against the NAWF value on the vertical axis. Calendar dates associated with the various DAPs should be determined and entered below each 10-day increment. For example, with a May 1 planting; 50, 60, 70, 80, 90, 100 and 110 DAP would be June 20, 30, July 10, 20, 30, August 9, and 19, respectively. Designating the calendar dates associated with DAPs will greatly facilitate subsequent plotting of data and other information on the chart.

As data are collected, plot the average NAWF against DAP for each sampling date. The chart can also be used to maintain other field management records. For example, it would be useful to indicate inputs such as fertilizer, irrigation (and rainfall), and insecticide applications. Those inputs occurring after 50 DAP can be indicated on the chart by their respective dates of application. Earlier inputs and observations regarding other factors that might influence the plants (damage from disease, hail, herbicide, etc.) may be noted in the margins. At the end of the season, the user may wish to include information regarding yield and quality. Such charts can be maintained as a permanent record and provide valuable insight on both the productivity of the field and the influence of various management inputs on plant growth, yield, and quality.

Observed values generated by sequential, average NAWF can be compared to the right side of the *Target Development Curve* (TDC, Fig. 2). The TDC assumes first flower at 60 DAP, vertical squaring interval of 2.7 days, 25 days from first square to first flower, and NAWF=5 at 80 DAP. Based on these assumptions, NAWF on the TDC at 60 DAP is 9.25, i.e., 25 days from square to flower divided by 2.7-day interval between new main-stem node formation.

The curve generated in the observed NAWF values may be near, below, or above the TDC. Visual observation of the charted line against the TDC provides immediate information on the potential

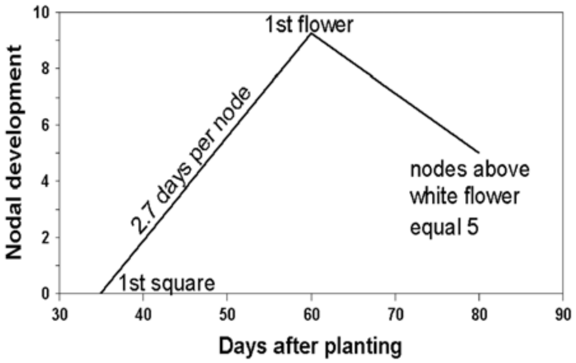

Fig. 2. Target Development Curve.

yield and maturation of the crop. Fields having NAWF that are plotted near the TDC are developing at a pace that should provide the best combination of high yield and early maturation. Stressed growing conditions (e.g., lack of water), are indicated by NAWF values below the TDC (i.e., slope does not parallel and is more steep than TDC). Such conditions can often incite shedding of fruit. If the stressed conditions are alleviated, the plants may initiate second growth and have delayed maturity. Otherwise, plants in these stressed fields reach cutout earlier than desired. Typically, cotton plants are unable to fully recover from severe stress that occurs after flowering. A major reason for using SQUAREMAN in the computer-based COTMAN is to help detect stress early enough that remedial action may be effective.

A NAWF curve above the TDC can be caused by slow early-season growth, which delays plant development and maturity (such a situation could be detected by SQUAREMAN). Of much greater concern is a situation in which NAWF values are not declining over sampling dates. Relatively flat NAWF slopes indicate that plants are not progressing toward maturity in a timely fashion. A high (relative to TDC) and flat-sloped NAWF curve is usually because of lack of fruit development (poor retention/small bolls) in relation to vegetative growth of the plants. Such fields will likely have low yields and delayed maturity. In contrast, relatively flat slopes that have low (relative to TDC) NAWF indicate that vegetative growth is barely sufficient to maintain additional reproductive development. Increased stress on these plants will likely cause premature cutout and low yields. However, if such fields can maintain this precarious vegetative to reproductive balance and experience good late-season conditions, acceptable yields are possible. In these cases, yields will tend to increase as maturity is delayed, with corresponding increases in production costs and risks.

Physiological Cutout

Monitoring of NAWF should be stopped when a field has reached cutout, i.e. the flowering date of the last effective boll population (Oosterhuis et al., 1996a). Based on crop development, an average NAWF=5 typically indicates physiological cutout, so monitoring of NAWF should cease when average NAWF<5. Fields that have experienced prolonged stress (particularly water stress) usually have plants that are relatively short with a low NAWF (5 to 6) at first flower. Under such stressed conditions, the relative value of flowers at NAWF=4 increases, but the time between NAWF=5 and NAWF=4 is usually very short. Users may wish to use NAWF=4 as the indicator of cutout in these severe cases.

Do not attempt to identify cutout with one observation of NAWF late in the season. Doing so may result in a false, late indication of cutout if true cutout has previously occurred. In these cases, either plants with second growth (flush of vegetative growth after cutout) or atypically late-maturing plants (where best plants have already ceased flowering) make it impossible to detect true cutout.

The date of physiological cutout in a field can be determined from the NAWF chart by interpolating between sample dates to determine the approximate date that physiological cutout (NAWF=5) is attained.

Step 2. Latest Possible Cutout Date

Determination

If crop maturity is delayed (particularly in northern regions of the Cotton Belt), the crop may not have sufficient HU to mature the late bolls even if they resulted from flowering prior to NAWF=5. Research has indicated that 850 HU (DD60s) are needed for flowers to develop into mature bolls. If physiological cutout occurs after the latest date from which accumulation of 850 HU is likely, cutout is defined by weather rather than plant development. Weather constraints rather than plant development then dictate cutout, and flowers occurring very late in the season are not likely to have adequate time to develop into bolls. The latest possible cutout date is then determined as a function of probable weather estimated from long-term weather patterns.

For estimating the latest possible cutout date based on HU, long-term weather data have been evaluated for several weather stations. Using these data, the latest dates from which 850 HU were attained in 50 and 85% of historical years have been determined. To determine the latest possible cutout date for a field, choose the long-term weather station from Table 1 that is nearest to your farm. Choice of the percentage of years of weather data (risk factor) upon which you wish to base your decisions provides the latest possible cutout date. Indicate the latest possible cutout date on the NAWF chart (Appendix D, page 104) with an asterisk (*) on the NAWF=5 line.

Determination by factors other than heat units

In some regions, weather restrictions other than lack of HU (e.g., high probability of late-season rainfall) may effectively limit the time for crop development and harvest. In these cases, users should establish the latest possible cutout date upon probabilities associated with the factor that limits the length of the effective growing season. These probabilities may be determined by additional analysis of long-term weather data or may be based on practical experience.

Choosing a Risk Factor

Obviously, the latest possible cutout date based on HU occurs later at more southern weather stations. Also, the date can be delayed by assuming higher risks, i.e., basing your decision on a lower percentage of years. Some situations in which it may be advisable to accept higher risks include:

- locations in the more northern regions of the Cotton Belt, since full maturity of the crop (850 HU past physiological cutout) may be difficult to attain,
- locations considerably south of the long-term weather station from which you are obtaining data,
- situations where plant maturity differs widely across the field, and
- fields that have low late-season insect infestations.

Step 3. Last Effective Flowering Date

Depending on which occurs first (i.e., earliest), the last effective flowering date (true cutout) within a field is either the date of physiological cutout (i.e., when NAWF=5) or the date of seasonal cutout (i.e., latest possible cutout date). If the NAWF slope intersects the NAWF=5 line prior to the latest possible cutout date, then the last effective flowering date is the date of physiological cutout. Otherwise, the seasonal cutout date becomes the last effective flowering date.

The last effective flowering date signals the initiation of heat unit accumulation to monitor the development of the last effective population of bolls in a field. Since all other bolls are older and more mature, end-of-season management can be based on the development of bolls arising from the last effective flowering date.

Step 4. Heat Units

Calculation

Heat units are, to a certain extent, a measure of physiological time and they measure the pace of growth and development of a plant. In cotton, HU are typically measured by DD60s (degree day 60s), which indicate the amount of heat accumulation (daily average temperature over a threshold of 60°F). Calculation and recording of DD60s must be started on the day of the last effective flowering date and continued daily until critical HU associated with various management decisions have been accumulated for each field. Daily high and low temperatures should be obtained from either a maximum/minimum thermometer located in the shade within a relatively close proximity of the field (one thermometer may service several or all your fields) or from a nearby weather station (extension office, television report, etc.). To calculate DD60s for a day, average the high and low temperatures [(high + low) / 2] then subtract 60. If the daily DD60 is a negative value, enter it as zero.

Heat Unit Chart

A simple heat unit chart can be developed (Appendix G, page 107). The chart should have 4 standard columns plus a column for each field that is being monitored. The first column is for "Date." The first date should coincide with the day that the earliest

Table 1. Latest possible cutout dates for weather stations in several cotton-production areas.[z]

Location	Years analyzed	Harvest completion date[y]	Latest possible cutout date[x] 50% years	Latest possible cutout date[x] 85% years
Alabama				
Andalusia	1959-2007	11/30	08/24	08/17
Huntsville	1959-2007	11/30	08/15	08/06
Lafayette	1968-2007	11/30	08/16	08/07
Mobile	1948-2007	11/30	09/03	08/27
Arkansas				
Bentonville	1944-2007	10/31	08/02	07/26
Jonesboro	1940-2007	10/31	08/13	08/06
Keiser	1960-2007	10/31	08/11	08/02
Little Rock	1948-2007	10/31	0817	08/12
Marianna	1948-2007	10/31	08/14	08/08
Newport	1940-2007	10/31	08/13	08/07
Pine Bluff	1940-2007	10/31	08/19	08/13
Rohwer	1960-2007	11/14	08/19	08/10
Stuttgart	1948-2007	10/31	08/15	08/08
Arizona				
Phoenix	1948-2007	11/18	09/15	09/10
Yuma	1955-2007	11/18	09/13	09/09
California				
Bakersfield	1949-2007	11/18	08/27	08/22
Fresno	1950-2007	11/29	08/19	08/12
Hanford	1948-2007	11/29	08/13	08/07
Los Banos	1949-2007	11/29	08/14	08/09
Sacramento	1949-2007	11/18	08/07	07/30
Florida				
Milton	1949-2007	11/30	08/31	08/27
Plant City	1950-2007	12/30	09/28	09/22
Tallahassee	1954-2007	11/30	09/04	08/29
Georgia				
Albany	1949-2007	11/30	08/30	08/24
Macon	1949-2007	11/30	08/24	08/18
Tifton	1948-2007	11/30	08/28	08/23
Kansas				
Ulysses	1949-2007	10/31	08/01	07/25
Wellington	1949-2007	10/31	08/28	08/23
Louisiana				
Alexandria	1957-2007	10/31	08/25	08/20
Baton Rouge	1948-2007	10/31	08/26	08/21
Lake Providence	1948-2007	10/31	08/22	08/17
Monroe	1948-2007	10/31	08/22	08/16
Shreveport	1948-2007	10/31	08/24	08/19
Winnsboro	1948-2007	10/31	08/23	08/17
Missouri				
Portageville	1952-2007	110/31	08/08	07/31
Mississippi				
Hattiesburg	1960-2007	11/14	08/26	08/20
Meridian	1960-2007	11/14	08/23	08/16
Natchez	1960-2007	10/31	08/23	08/17
Port Gibson	1965-2007	10/31	08/18	08/13
State University	1948-2007	11/14	08/19	08/13
Stoneville	1960-2007	11/14	08/21	08/15
Tupelo	1948-2007	10/31	08/16	08/08

continued

Table 1. Continued.

Location	Years analyzed	Harvest completion date[y]	Latest possible cutout date[x]	
			50% years	85% years
North Carolina				
Fayetteville	1952-2007	11/14	08/13	08/20
Greensboro	1948-2007	10/31	08/01	07/26
Greenville	1949-2007	11/14	08/13	08/07
Jackson	1952-2007	11/14	08/08	07/31
Raleigh	1948-2007	11/14	08/07	07/31
New Mexico				
Artesia	1948-2007	11/18	08/10	07/30
Portales	1949-2007	11/18	08/02	07/27
Tucumcari	1948-2007	11/18	08/06	07/30
Oklahoma				
Altus	1948-2007	10/31	08/20	08/13
Ardmore	1948-2007	11/14	08/26	08/20
Newkirk	1948-2007	10/31	08/14	08/05
South Carolina				
Columbia	1948-2007	10/31	08/10	08/03
Orangeburg	1960-2007	11/30	08/23	0/14
Tennessee				
Covington	1948-2007	10/31	08/10	08/03
Dyersburg	1949-2007	10/31	08/11	08/04
Jackson	1948-2007	10/31	08/09	08/02
Memphis	1948-2007	10/31	08/18	08/12
Texas				
Abilene	1960-2007	11/14	08/24	08/19
Bay City	1960-2007	10/31	08/31	08/28
Childress	1960-2007	10/31	08/17	08/10
College Station	1960-2007	11/14	09/03	08/30
Corpus Christi	1960-2007	09/29	08/12	08/11
Dumas	1964-2007	11/14	08/03	07/26
El Paso	1948-2007	12/30	08/21	08/15
Harlingen	1960-2007	11/30	09/21	09/16
Hereford	1960-2007	10/31	07/28	07/23
Lamesa	1954-2007	10/31	08/13	08/07
Lubbock	1960-2007	10/31	08/09	08/03
San Angelo	1960-2007	11/14	08/24	08/20
San Antonio	160-2007	11/14	09/05	08/31
Virginia				
Farmville	1960-2007	10/31	07/28	07/22
Suffolk	1960-2007	10/31	08/07	07/31

[z] Data for new locations are being added periodically. Contact the Texas A&M University for the most recent updates (361) 265-9203).

[y] Target dates for completion of harvest at the Arkansas and Stoneville, Miss., locations were based on day length and probability of dry weather. Dates for all other locations were estimated by cotton extension specialists or researchers in the respectively states.

[x] The latest date from which 850 HU were accumulated in 50 and 85% of years. Calculations assumed 14 days from defoliation of latests fields to harvest completion

maturing field reaches last effective flowering date. The second and third columns are for the high and low temperatures associated with that date. The fourth column is the calculated DD60s for that date.

Beginning in the fifth column, enter "Field Name" at the top of the column on the day that last effective flowering date is attained for the field. Place an asterisk (*) in the field column on the date it reaches cutout. DD60 accumulation commences on the day after the last effective flowering date. As fields are added, they will be arranged from earliest (fifth column) to latest (extreme right column) maturity. Add the daily DD60 to the accumulative DD60 values in each field column. Users may wish to use a simple spreadsheet to facilitate these calculations.

Critical Heat Units for Insecticide Termination

Since the last effective boll population represents the youngest bolls that should be protected, insecticide termination can be sequenced with the development of these bolls (Oosterhuis et al., 1996b). For example, research has indicated that developing bolls resist damage by tarnished plant bugs, bollworms, and boll weevils at about 350 DD60s after white flower (*See* Chapter 4). Therefore, when a field has accumulated 350 DD60s past the last effective flowering date (determined in the heat unit chart), control of these insects can be terminated. In cases in which there is considerable variation (*See* NAWF Variation on page 46), consider extending control to 450 DD60s. After attaining 350 DD60s past the last effective flowering date, fields should still be monitored for the presence of defoliating pests, such as loopers and armyworms. These insects should not be allowed to prematurely defoliate the crop until it is safe to be chemically defoliated.

Critical Heat Units for Defoliation

Defoliation can also be timed by the maturity of the last effective boll population. To achieve near maximum yield and revenue, 850 DD60s should be accumulated after the last effective flowering date prior to defoliation. Some have suggested that 650 to 750 DD60s may be appropriate for defoliation when plants set fruit in a short period so that 60 to 70% of crop is open. Other situations in which early defoliation might be advisable include:

- fields located in northern extreme of Cotton Belt in which full maturity may not occur,
- fields in which picker capacity is limited and harvest should be initiated earlier in some fields, and
- fields for which adverse weather forecasts indicate a need for early harvest.

Heat Unit Chart Example (Table 2)

Average high and low temperatures from historical weather data for July 29 through Oct. 31 at Marianna, Ark., are charted and daily DD60s are calculated in this example chart. This provides an indication of the maximum/minimum temperatures and daily HU that can be expected in the central Delta region of Arkansas. Obviously, actual temperatures within a specific year will fluctuate much more than these average temperatures.

In the example, seven hypothetical fields that used the same weather station are listed in the order they attained cutout. Field A1 and B2 reached physiological cutout long before the latest possible cutout date and are easily able to accumulate 850 HU after cutout. Both fields C3 and D4 reached physiological cutout on Aug. 8, the latest possible cutout date based on 85% of years at Marianna. Note multiple fields having identical cutout dates will accumulate HU at the same rate, provided the fields are using the same weather station. Field E5 reached physiological cutout on Aug. 14, the latest possible cutout date based on 50% of years. For all fields reaching cutout after the latest possible cutout date (Aug. 8 or Aug. 14, e.g., Field F6), heat accumulation for end-of-season management would begin at the latest possible cutout date.

This example illustrates the importance of attaining timely cutout. Since heat unit accumulation was relatively constant throughout August, variation among fields for days to cutout was similar to the variation in number of days required to accumulate 350 HU after cutout. However, as physiological cutout was delayed, the time required to attain maturity (NAWF=5 + 850 HU) was greatly prolonged. The 8-day delay in cutout between Fields B2 and C3 caused only a 13-day difference in time to 850 HU, whereas the 6-day delay between C3 an E5 resulted in a 25-day delay to 850 HU. Field G7 further illustrates the ineffectiveness of accumulating late-season HU. Attaining cutout only one day later than Field E5, Field G7 never reached 850 HU.

Final Remarks

Hopefully, this “by hand” version of BOLLMAN will be helpful to producers or consultants in making some critical end-of-season management decisions. As experience with this paper version of BOLLMAN is gained, we encourage users to obtain information on the whole COTMAN system. The full value of plant monitoring can be achieved only when the entire growth pattern with COTMAN components SQUAREMAN and BOLLMAN is evaluated.

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Fig. 4. Heat Unit Chart Example.

	Temperature[1]		Daily	Accum. DD$_{60}$'s by fields, listed sequentially as cutout is reached					
Date	High	Low	DD60's[2]	A1	B2	C3/D4	E5	F6	G7
7/28	92	71	21.5	21.5					
7/29	92	71	21.5	43.0					
7/30	92	71	21.5	64.5					
7/31	92	71	21.5	86.0					
8/1	92	71	21.5	107.5	21.5				
8/2	92	70	21.0	128.5	42.5				
8/3	92	70	21.0	149.5	63.5				
8/4	92	70	21.0	170.5	84.5				
8/5	92	70	21.0	191.5	105.5				
8/6	92	70	21.0	212.5	126.5				
8/7	92	70	21.0	233.5	147.5				
8/8	91	69	20.0	253.5	167.5	20.0			
8/9	91	69	20.0	273.5	187.5	40.0			
8/10	91	69	20.0	293.5	207.5	60.0			
8/11	91	69	20.0	313.5	227.5	80.0			
8/12	91	69	20.0	333.5	247.5	100.0			
8/13	91	69	20.0	353.5	267.5	120.0			
8/14	91	69	20.0	373.5	287.5	140.0	20.0		
8/15	91	68	19.5	393.0	307.0	159.5	39.5	19.5	
8/16	91	68	19.5	412.5	326.5	179.0	59.0	39.0	
8/17	91	68	19.5	432.0	346.0	198.5	78.5	58.5	
8/18	91	68	19.5	451.5	365.5	218.0	98.0	78.0	98.0
8/19	91	68	19.5	471.0	385.0	237.5	117.5	97.5	117.5
8/20	91	68	19.5	490.5	404.5	257.0	137.0	117.0	137.0
8/21	91	68	19.5	510.0	424.0	276.5	156.5	136.5	156.5
8/22	91	68	19.5	529.5	443.5	296.0	176.0	156.0	176.0
8/23	91	68	19.5	549.0	463.0	315.5	195.5	175.5	195.5
8/24	91	68	19.5	568.5	482.5	335.0	215.0	195.0	215.0
8/25	91	68	19.5	588.0	502.0	354.5	234.5	214.5	234.5
8/26	91	68	19.5	607.5	521.5	374.0	254.0	234.0	254.0
8/27	91	68	19.5	627.0	541.0	393.5	273.5	253.5	273.5
8/28	91	68	19.5	646.5	560.5	413.0	293.0	273.0	293.0
8/29	90	68	19.0	665.5	579.5	432.0	312.0	292.0	312.0
8/30	90	67	18.5	684.0	598.0	450.5	330.5	310.5	330.5
8/31	90	67	18.5	702.5	616.5	469.0	349.0	329.0	349.0
9/1	90	67	18.5	721.0	635.0	487.5	367.5	347.5	367.5
9/2	89	66	17.5	738.5	652.5	505.0	385.0	365.0	385.0
9/3	89	66	17.5	756.0	670.0	522.5	402.5	382.5	402.5
9/4	89	65	17.0	773.0	687.0	539.5	419.5	399.5	419.5
9/5	89	65	17.0	790.0	704.0	556.5	436.5	416.5	436.5
9/6	89	64	16.5	806.5	720.5	573.0	453.0	433.0	453.0
9/7	88	64	16.0	822.5	736.5	589.0	469.0	449.0	469.0
9/8	88	64	16.0	838.5	752.5	605.0	485.0	465.0	485.0
9/9	87	64	15.5	854.0	768.0	620.5	500.5	480.5	500.5
9/10	87	63	15.0		783.0	635.5	515.5	495.5	515.5
9/11	86	63	14.5		797.5	650.0	530.0	510.0	530.0
9/12	86	63	14.5		812.0	664.5	544.5	524.5	544.5
9/13	86	63	14.5		826.5	679.0	559.0	539.0	559.0
9/14	86	62	14.0		840.5	693.0	573.0	553.0	573.0
9/15	86	62	14.0		854.5	707.0	587.0	567.0	587.0

Table 2. Continued.

9/16	85	62	13.5			720.5	600.5	580.5	600.5
9/17	85	62	13.5			734.0	614.0	594.0	614.0
9/18	85	62	13.5			747.5	627.5	607.5	627.5
9/19	85	62	13.5			761.0	641.0	621.0	641.0
9/20	85	61	13.0			774.0	654.0	634.0	654.0
9/21	85	61	13.0			787.0	667.0	647.0	667.0
9/22	84	59	11.5			798.5	678.5	658.5	678.5
9/23	83	59	11.0			809.5	689.5	669.5	689.5
9/24	82	57	9.5			819.0	699.0	679.0	699.0
9/25	82	57	9.5			828.5	708.5	688.5	708.5
9/26	82	57	9.5			838.0	718.0	698.0	718.0
9/27	81	57	9.0			847.0	727.0	707.0	727.0
9/28	81	56	8.5			855.5	735.5	715.5	735.5
9/29	81	55	8.0				743.5	723.5	743.5
9/30	81	55	8.0				751.5	731.5	751.5
10/1	81	55	8.0				759.5	739.5	759.5
10/2	81	55	8.0				767.5	747.5	767.5
10/3	81	55	8.0				775.5	755.5	775.5
10/4	80	55	7.5				783.0	763.0	783.0
10/5	80	54	7.0				790.0	770.0	790.0
10/6	79	53	6.0				796.0	776.0	796.0
10/7	78	52	5.0				801.0	781.0	801.0
10/8	78	52	5.0				806.0	786.0	806.0
10/9	78	52	5.0				811.0	791.0	811.0
10/10	78	52	5.0				816.0	796.0	816.0
10/11	78	52	5.0				821.0	801.0	821.0
10/12	78	52	5.0				826.0	806.0	826.0
10/13	78	51	4.5				830.5	810.5	830.5
10/14	77	51	4.0				834.5	814.5	834.5
10/15	77	50	3.5				838.0	818.0	838.0
10/16	77	51	4.0				842.0	822.0	842.0
10/17	76	50	3.0				845.0	825.0	845.0
10/18	75	48	1.5				846.5	826.5	846.5
10/19	75	48	0.0				846.5	826.5	846.5
10/20	74	47	0.0				846.5	826.5	846.5
10/21	74	48	1.0				847.5	827.5	847.5
10/22	74	49	1.5				849.0	829.0	849.0
10/23	74	48	1.0				850.0	830.0	850.0
10/24	73	47	0.0					830.0	
10/25	72	46	0.0					830.0	
10/26	72	46	0.0					830.0	
10/27	72	46	0.0					830.0	
10/28	72	46	0.0					830.0	
10/29	71	46	0.0					830.0	
10/30	71	46	0.0					830.0	
10/31	71	46	0.0	(target harvest completion date)				830.0	

[1] Based on historical high:low temperatures at Marianna, AR

[2] DD_{60} = [(High + Low) - 60

Chapter 8:

Reading COTMAN Analysis Reports

Diana M. Danforth

The COTMAN™ analysis routine allows the user to produce SQUAREMAN and BOLLMAN reports. Prior to generating reports, the user can select from all available farms and years. Users can choose from pre-defined report formats and/or define custom report formats by selecting from all of the available report options. When reports are generated, a Web browser displays an index of thumbnail graphs with hyperlinks that allows the user to navigate to individual field-level reports or to farm-level summary reports.

SQUAREMAN analysis uses SquareMap, first fruiting node, and stand count data to analyze plant growth and fruiting form retention. The analysis is conducted during the squaring period before first flower. Reports can display graphs of plant development, information about plant structure and plant vigor, square shed rates, per-acre populations of plants, and retained fruiting forms. Descriptions of SQUAREMAN report items available in field detail reports and farm-level summary tables are presented in Tables 1 and 2.

BOLLMAN analysis uses *nodes above white flower* (NAWF) and local weather data to analyze plant maturity and calculate heat unit accumulation. The analysis is conducted from first flower until defoliation. Descriptions of BOLLMAN report items available in field detail reports and farm-level summary tables are presented in Tables 3 and 4.

Viewing Reports

Graph Thumbnail Report

When reports are generated, a Web browser window opens to display thumbnail-sized nodal development graphs of all fields that were selected for analysis. The graphical index allows a quick review of growth patterns across all fields to help identify particular fields that warrant additional attention (Fig. 1). Each graph is labeled below with the field name. The graph thumbnail is a hyperlink to the detailed field report. The farm summary tables can be viewed by clicking on the labeled hyperlink at the top of the graphs.

Farm-Level Summary Report

This report displays the farm-level summary table(s) selected for the analysis. The header displays key data about the farm. Each table displays information about each field selected from the farm. By default, fields are listed in alphabetical order in the table. However, that order can be changed by defining a custom report where fields are sorted on the values of another item in the table. For example, fields can be listed in order of maturity by sorting on the date that NAWF=5. The farm summary tables can be used to quickly compare fields on characteristics of interest. The field name is a hyperlink to the detailed report for that field (Fig. 2).

Field Detail Report

Each field detail report is presented in a separate Web page and controls are provided to browse through those reports or return to the graph thumbnail screen.

Defining Custom Reports

The user can define and save custom report formats for the Field Detail Reports of each analysis type. Only one Field Detail Report can be selected for each analysis. Custom Farm Summary Tables can also be defined and saved. Each table is restricted to the number of items that can be printed using standard paper (8 1/2” x 11”) in portrait mode. The number of items per table varies depending on the column width required to print each included item. Multiple tables can be selected for each analysis.

Table 1. SQUAREMAN Field Detail Report Items.

GROUP	ITEM	DESCRIPTION
Graphs	Height/Node Graph	A plot of plant height and height-to-node ratio (HNR) for each SquareMap sampling date. The horizontal axis shows days after planting. The left vertical axis shows plant height in inches while the right vertical axis shows the HNR in inches. The HNR is the average internode length between main-stem branches, both sympodial and monopodial.
	NAFS/NAWF Graph	Graph of field nodal development compared to Target Development Curve (TDC): The vertical axis displays nodes above first qquare pre-flower (calculated from SQUAREMAN data) and nodes above white flower (NAWF) after first flower. The horizontal axis shows Days After Planting. The TDC serves as a standard for comparing plant development. It assumes first square at 35 days after planting with the addition of one new main-stem node every 2.7 days until first flower at 60 days after planting. At first flower the TDC shows 9.25 NAWF. After first flower the production of new main-stem nodes slows and the number of NAWF declines. The TDC expects NAWF to equal 5 (physiological cutout) at 80 days after planting.
Plant Structure	Days Per Node	The average number of days for each main-stem branch added between the latest two consecutive SquareMap sampling dates. This measure is calculated for the latest two consecutive SquareMap sampling dates by dividing the change in number of main-stem branches by the number of days between sampling dates. For reference, the TDC uses 2.7 days per node before first flower. For this measure, the effects of sampling errors can be large and erratic values may occur. This statistic is included because some users have gained confidence in it, but there are no COTMAN recommendations associated with this measure.
	Elongation Rate	The average increase in height for each main-stem sympodial branch added between each consecutive pair of SquareMap sampling dates. This measure is calculated for the latest two consecutive SquareMap sampling dates by dividing the change in plant height by the change in number of main-stem branches between sampling dates. For this measure, the effects of sampling errors can be large and erratic values may occur. This statistic is included because some users have gained confidence in it, but there are no COTMAN recommendations associated with this measure.
	First Fruiting Node	Average node number of first sympodial/fruiting branch. The first fruiting node number is entered using the Add/Modify a Field routine. The data is collected only once per season so this statistic does not change across time.
	Fruiting Nodes/ Plant	Three items are included with this choice: 1. Fruiting Nodes - Average number of sympodial branches (main-stem fruiting branches) per plant on each sampling date for the field. 2. Squaring Nodes - Average number of main-stem sympodial branches that have not yet set a first-position flower on each sampling date. 3. Post-flower Nodes - Average number of main-stem sympodial branches that have already set a first-position flower on each sampling date.
	Height/Node Ratio (HNR)	HNR on each sampling date for the field. This is the average internode length in inches between main-stem branches, both sympodial and monopodial. If a statistically significant difference is detected between consecutive sampling dates, “+” or “-” will be displayed to the right of the ratio on the later date. A “+” indicates a significant increase, and a “-” indicates a significant decrease compared to the previous sampling date.
	Plant Height	Field average plant height (inches) on each sampling date.
	Retained Fruit/ Plant	Average number of first-position fruiting forms retained per plant on each sampling date for the field.
	Total Nodes/ Plant	Average number of main-stem sympodial plus monopodial branches on each sampling date for the field.

continued

Table 1. Continued.

GROUP	ITEM	DESCRIPTION
Populations	Bolls/Acre	Number of retained first-position bolls per acre on each sampling date. This item will only have a value if SquareMap data is collected after first flower. Stand count data for the field is required in order to calculate this statistic.
	Fruit/Acre	Number of retained first-position fruiting forms (squares plus bolls) per acre on each sampling date. Stand count data for the field is required in order to calculate this statistic.
	Plant/Acre	Number of plants per acre. Stand count data for the field is required in order to calculate this statistic. This statistic will not change across the season, because stand count data is only collected once per season.
	Squares/Acre	Number of retained first-position squares per acre on each sampling date. Stand count data for the field is required in order to calculate this statistic.
Shed Rate	% Boll Shed	Percent of first-position bolls that were shed at each sampling date.
	% Other Square Shed	Percent of first-position squares below the top three that were shed at each sampling date.
	% Small Square Shed	Percent of the top three first-position squares that were shed at each sampling date.
	% Square Shed	Percent of first-position squares that were shed at each sampling date. If a statistically significant difference is detected between consecutive sampling dates, "+" or "-" will be displayed to the right of the rate on the later date. A "+" indicates a significant increase, and a "-" indicates a significant decrease compared to the previous sampling date.
	% Total Shed	Percent of first-position fruiting forms (squares plus bolls) that were shed at each sampling date.
	Node specific % Shed	Node-specific percent of first-position fruiting forms that were shed at each sampling date. Node 1 is the upper-most sympodial/fruiting branch, Node 2 is the second highest branch, etc. Note that the higher node numbers represent branches lower on the plants. Rates calculated for the lower branches may be based on fewer plants than those closer to the top.
Site Level	% Boll Shed	Site-specific percent of first-position bolls that were shed at the latest sampling date.
	% Other Square Shed	Site-specific percent of first-position squares below the top three that were shed at the latest sampling date.
	% Small Square Shed	Site-specific percent of the top three first-position squares that were shed at the latest sampling date.
	% Square Shed	Site-specific percent of first-position squares that were shed at the latest sampling date.
	% Total Shed	Site-specific percent of first-position fruiting forms (squares plus bolls) that were shed at the latest sampling date.
	Fruiting Nodes/ Plant	Three items are included with this choice: 1. Fruiting Nodes - Site-specific average number of sympodial branches (main-stem fruiting branches) per plant on the latest sampling date for the field. 2. Squaring Nodes - Site-specific average number of main-stem sympodial branches that have not yet set a first-position flower on the latest sampling date. 3. Post-flower Nodes - Site-specific average number of main-stem sympodial branches that have already set a first-position flower on the latest sampling date.
	Height/Node Ratio	Site-specific HNR on the latest sampling date for the field. This is the average internode length in inches between main-stem branches, both sympodial and monopodial.
	Node specific % Shed	Site and node-specific percent of first-position fruiting forms that were shed at the latest sampling date. Node 1 is the upper-most sympodial/fruiting branch, Node 2 is the second highest branch, etc. Note that the higher node numbers represent branches lower on the plants.

continued

Table 1. Continued.

GROUP	ITEM	DESCRIPTION
		Rates calculated for the lower branches may be based on fewer plants than those closer to the top.
	Plant Height	Site-specific field average plant height (inches) on the latest sampling date.
	Retained Fruit/ Plant	Site-specific average number of first-position fruiting forms retained per plant on the latest sampling date for the field.
	Total Nodes/ Plant	Site-specific average number of main-stem sympodial plus monopodial branches on the latest sampling date for the field.
Growth Analysis/Nodes	Analysis/ Recommendations	Evaluations of plant development, shed rate trends and height-to-node trends. Three sets of evaluations are performed: 1. Plant developmental pace for the latest two consecutive sampling dates and the number of sympodial branches at the latest sampling date are evaluated in relation to the TDC. Consideration is also included for the square shed rate at the latest sampling date. 2. Square shed rates for the latest two consecutive sampling dates are evaluated for statistically significant increases or decreases. 3. HNR for the latest two consecutive sampling dates are evaluated for statistically significant increases or decreases.
	Field Notes	Table of date-specific notes recorded for the field. Notes are entered in the Field Notes routine located on the Farm/Field menu.

Table 2. SQAUREMAN Farm Summary Report Items.

GROUP	ITEM	DESCRIPTION
Field Info	Acreage	Field acreage
	Irrigation Status	Field irrigation status (irrigated/not irrigated)
	Last Sampling Date	Date of latest SquareMap data collection
	Planting Date	Field planting date
	Replant Percentage	Field replant percentage
	Soil Type	Soil type
	Variety	Variety (Cultivar) planted in field
Plant Structure	Boll Nodes/Plant	Average number of main-stem sympodial branches that have already set a first-position flower at the latest sampling date. This item will only have a value if SquareMap data is collected after first flower.
	Days Per Node	The average number of days for each main-stem branch added between the latest two consecutive SquareMap sampling dates. This measure is calculated for the latest two consecutive SquareMap sampling dates by dividing the change in number of main-stem branches by the number of days between sampling dates. For reference, the Target Development Curve (TDC) uses 2.7 days per node before first flower. For this measure, the effects of sampling errors can be large and erratic values may occur. This statistic is included because some users have gained confidence in it, but there are no COTMAN recommendations associated with this measure.
	Develop. Pace Analysis	Rate of main-stem sympodial branch production between the latest two sampling dates compared to the TDC. The field will be evaluated as “Fast,” “Slow,” “Normal,” or “None.” “Fast” indicates that new main-stem branches were produced more rapidly than that depicted on the TDC. “Slow” indicates that new main-stem branches were produced more slowly than that depicted on the TDC. This can indicate environmental or other stresses. “Normal” indicates that the rate of new main-stem branch production was in the range of that depicted on the TDC.

continued

Table 2. Continued.

GROUP	ITEM	DESCRIPTION
	Develop. Pace Analysis (cont.)	"None" indicates that there is only one sampling date and the rate cannot be determined.
	Elongation Rate	The average increase in height for each main-stem sympodial branch added between the latest two consecutive SquareMap sampling dates. This measure is calculated for the latest two consecutive SquareMap sampling dates by dividing the change in plant height by the change in number of main-stem branches between sampling dates. For this measure, the effects of sampling errors can be large and erratic values may occur. This statistic is included because some users have gained confidence in it, but there are no COTMAN recommendations associated with this measure.
	First Fruiting Node	Average node number of first sympodial/fruiting branch. The first fruiting node number is entered using the Add/Modify a Field routine. The data are collected only once per season so this statistic does not change across time.
	Fruiting Nodes/ Plant	Average number of sympodial branches (main-stem fruiting branches) per plant on the latest sampling date for the field.
	Height/Node Ratio	Height to node ratio on the latest sampling date for the field. This is the average internode length in inches between main-stem branches, both sympodial and monopodial.
	Node Structure Analysis	Main-stem sympodial branches at the latest sampling date compared to the TDC. The field will be evaluated as "Above," "Below," or "Target." "Above" indicates that the number of branches is greater in relation to days after planting than that depicted on the TDC. This can indicate that the field started squaring early because of optimal conditions for germination, that the first fruiting node is set low on the plant, and/or that environmental and other conditions allowed vigorous early growth. "Below" indicates that the number of branches is fewer in relation to days after planting than that depicted on the TDC. This can indicate that the field started squaring late because of unfavorable conditions for germination, that the first fruiting node is set high on the plant, and/or that environmental or other stresses have limited growth. "Target" indicates that the number of branches is within the range depicted on the TDC in relation to days after planting.
	Plant Height	Field average plant height (inches) at the latest sampling date.
	Retained Fruit/ Plant	Average number of first-position fruiting forms retained per plant on the latest sampling date for the field.
	Squaring Nodes/ Plant	Average number of main-stem sympodial branches that have not yet set a first-position flower at the latest sampling date.
	Total Nodes/ Plant	Average number of main-stem sympodial plus monopodial branches.
Population	Bolls/Acre	Number of retained first-position bolls per acre at the latest sampling date. This item will only have a value if SquareMap data are collected after first flower. Stand count data for the field are required in order to calculate this statistic.
	Fruit/Acre	Number of retained first-position fruiting forms (squares plus bolls) per acre at the latest sampling date. Stand count data for the field are required in order to calculate this statistic.
	Squares/Acre	Number of retained first-position squares per acre at the latest sampling date. Stand count data for the field are required in order to calculate this statistic.
	Plants/Acre	Number of plants per acre. Stand count data for the field are required in order to calculate this statistic. This statistic will not change across the season because stand count data are only collected once per season.

continued

Table 2. Continued.

GROUP	ITEM	DESCRIPTION
Shed Rate	% Boll Shed	Percent of first-position bolls that were shed at the latest sampling date.
	% Other Square Shed	Percent of first-position squares below the top three that were shed at the latest sampling date.
	% Small Square Shed	Percent of the top three first-position squares that were shed at the latest sampling date.
	% Square Shed	Percent of first-position squares that were shed at the latest sampling date.
	% Total Shed	Percent of first-position fruiting forms (squares plus bolls) that were shed at the latest sampling date.

Table 3. BOLLMAN Field Detail Report Items.

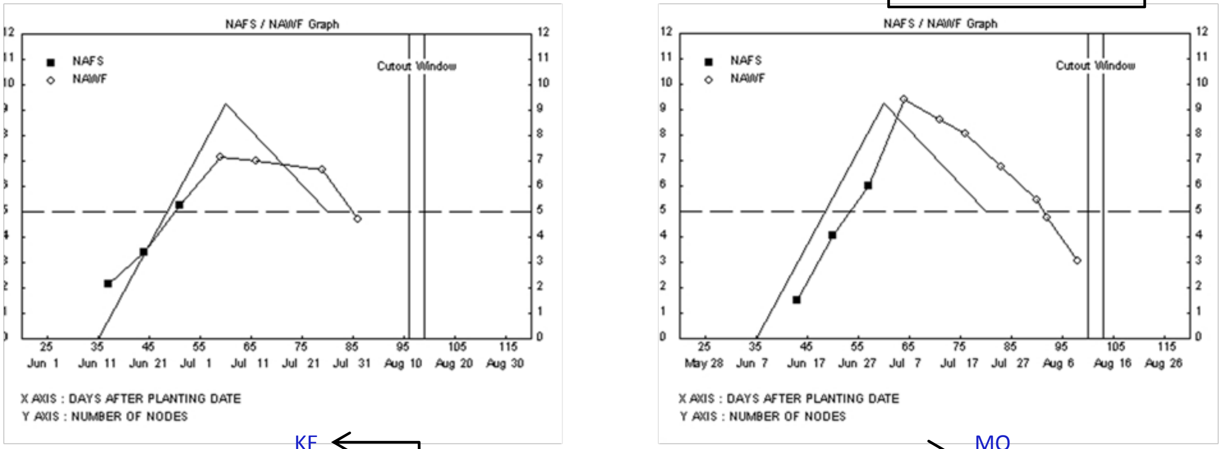
ITEM	DESCRIPTION
SN/NAWF Graph	Graph of field nodal development compared to Target Development Curve (TDC): The vertical axis displays nodes above first square pre-flower (calculated from SQUAREMAN data) and nodes above white flower (NAWF) after first flower. The horizontal axis shows Days After Planting. The TDC serves as a standard for comparing plant development. It assumes first square at 35 days after planting with the addition of one new main-stem node every 2.7 days until first flower at 60 days after planting. At first flower the TDC shows 9.25 NAWF. After first flower the production of new main-stem nodes slows and the number of NAWF declines. The TDC expects NAWF to equal 5 (physiological cutout) at 80 days after planting.
Cutout Information	Table of information related to field cutout status: 1. The first item displays information about actual or projected physiological cutout date (field average NAWF=5) relative to Latest Possible Cutout Date LPCD). The LPCD is location and risk dependent. 2. The second item gives the date or projected date of physiological cutout (NAWF=5). A projected NAWF=5 date is based on linear regression analysis. 3 The third item reports the number of days from planting to NAWF=5. 4 The fourth item reports the LPCD for the location and risk level that were selected in the Add/Modify a Farm routine. 5 The last item reports the cutout type, either “Crop Maturity” where NAWF = 5 before LPCD, or “Weather Restricted” where NAWF is above 5 at the LPCD.
Heat Unit Totals and Dates	Total heat unit (DD60) accumulation from cutout date (NAWF=5 or Latest Possible Cutout), along with a table of dates that the field reached benchmarks of 350, 450, 650, and 850 heat units (HU) after cutout. Heat units are accumulated from the earlier of NAWF=5 Date or Latest Possible Cutout Date. If the field has reached the benchmark accumulation, a date is shown in the “Actual” column. If the field has not reached the benchmark, a date based on average temperatures for the location is shown in the “Projected” column.
NAWF Information	NAWF values for each data collection date. The mean, standard deviation and number of plants are reported.
Field Management Recommendations	Crop termination guidelines based on HU accumulation from cutout. Insecticide termination and defoliation guidelines are reported.
Daily Heat Unit Accumulations	Table of cumulative daily HU (DD60s) from cutout. Information from the local weather station is used if available. An asterisk (*) next to the date indicates that the historical average is substituted. The local weather station is defined in the Add/Modify a Field routine and the local temperature data is entered using the Weather/Daily Temperatures routine. Historical average temperatures are location specific. The location is chosen in the Add/Modify a Farm routine.
Field Notes	Table of date-specific notes recorded for the field. Notes are entered in the Field Notes routine located on the Farm/Field menu.
Site Level Information	Site-specific NAWF values for each data collection date. The mean, standard deviation and number of plants are reported.

Table 4. BOLLMAN Farm Summary Report Items.

GROUP	ITEM	DESCRIPTION
Field Info	Acreage	Field acreage.
	Current NAWF Value	Average field NAWF on latest data collection date.
	Irrigation Status	Field irrigation status (irrigated/not irrigated).
	Last Sampling Date	Date of latest NAWF data collection.
	Planting Date	Field planting date.
	Replant Percentage	Field replant percentage.
	Soil Type	Soil type.
	Variety	Variety (Cultivar) planted in field.
Heat Unit Date	Date, Heat Units=350	Date, 350 HU (DD60) accumulation from cutout.
	Date, Heat Units=450	Date, 450 HU (DD60) accumulation from cutout.
	Date, Heat Units=650	Date, 650 HU (DD60) accumulation from cutout.
	Date, Heat Units=850	Date, 850 HU (DD60) accumulation from cutout.
Heat Unit Total	HU from NAWF=5	HU (DD60) accumulation from date that field average NAWF=5.
	HU from Seasonal Cutout	Heat unit (DD60) accumulation from Latest Possible Cutout Date based on historical weather (only calculated if NAWF=5 was not reached before Latest Possible Cutout Date).
	HU from User's Date	Heat unit accumulation (DD60) from User Defined Cutout Date (optional parameter specified on field definition screen and/or analysis report screen).
NAWF Info	DAP to NAWF=5	Days from planting to date that field average NAWF=5.
	Date, NAWF=5	Date that field average NAWF=5.
	NAWF Std Deviation	Standard deviation of field NAWF values from latest data collection date
	Regression Intercept	Intercept from linear regression used to project NAWF=5 date (only calculated before NAWF=5).
	Regression R Square	R-square from linear regression used to project NAWF=5 date (only calculated before NAWF=5).
	Regression Slope	Slope from linear regression used to project NAWF = 5 date (only calculated before NAWF=5).

FARM: DEMO YEAR: 2006 ANALYSIS DATE: 10/15
Grower: Demonstration Location: Arkansas Daily picker capacity: 40 Harvest days per week: 7 Total acreage: 400
Days between defoliation and harvest initiation: 14 Target harvest completion date: 11/01
Long term weather: Marianna, AR, 1948-2006 Acceptable weather risk: 50
FARM LEVEL SUMMARY REPORT

Hyperlink to view
Farm Summary Report



KE MO

Hyperlink to view
Field Detail Report

Fig. 1. Graph Thumbnail Report.

FARM: DEMO YEAR: 2006 ANALYSIS DATE: 10/15
Grower: Demonstration Location: Arkansas Daily picker capacity: 40 Harvest days per week: 7 Total acreage: 400
Days between defoliation and harvest initiation: 14 Target harvest completion date: 11/01
Long term weather: Marianna, AR, 1948-2006 Acceptable weather risk: 50

Table Name: NAWF **Table Title: NAWF and Heat Units** *** projected**

Field Name	Current NAWF	Date NAWF=5	HU from NAWF=5	HU from Seasonal Cutout	Date, Heat Units=350	Date, Heat Units=850
CO_1250	5.3	-	-	804.5	8/31	10/29*
KE_1134	4.7	7/31	1121.5	-	8/15	9/14
MO_1413	3.1	8/3	1050	-	8/18	9/21
PO_1180	3.85	8/2	1074	-	8/17	9/19
RU_1201	4.67	8/1	1097	-	8/16	9/16

Hyperlinks to view
Field Detail Reports

Fig. 2. Farm Summary Level Report.

Chapter 9:

Interpretation of Crop Growth Patterns Generated by COTMAN

Fred M. Bourland, Derrick M. Oosterhuis, N. Philip Tugwell, Mark J. Cochran, and Diana M. Danforth

The COTMAN™ plant growth monitoring program consists of two expert systems: SQUAREMAN (which uses SquareMap data) and BOLLMAN [which uses *nodes above white flower,* (NAWF) data] (Oosterhuis et al., 1996). Both expert systems primarily utilize one common plant measurement: the number of squaring nodes. Squaring nodes are the number of fruiting branches (sympodia) that have a square, or a shed square, in the first position from the main axis. More simply, squaring nodes refer to the number of sympodia that have not developed to the flowering stage.

Prior to first flower, squaring nodes are equal to the number of sympodia, as determined by SquareMap. After flower initiation, squaring nodes are determined by counting NAWF. In relation to first-positions on sympodia, all nodes above a first-position white flower will potentially bear a square, while all nodes below the white flower will potentially bear a boll. As boll load increases, development of new main-stem nodes in the plant terminal slows, causing first-position flowers to occur progressively closer to the plant apex. Thus, the number of squaring nodes is an indicator of the fruiting dynamics of the plant throughout the effective fruiting period (Bourland et al., 1992).

Interpretation Standards

A growth curve based on fruiting dynamics is formed when squaring nodes obtained from sequential sampling dates are plotted by *days after planting* (DAP). When interpreting crop growth, the user must consider three standards: 1) square retention, 2) the *Target Development Curve* (TDC), and 3) the latest possible cutout date.

Square Retention

High or low square retention can greatly influence the interpretation of a particular growth curve slope. SQUAREMAN summarizes total square shed and shed rate by main-stem nodal position for all first-position squares. Evaluation of square retention is not available in BOLLMAN.

Target Development Curve (TDC)

The TDC assumes that first square appears at 35 DAP, first flower at 60 DAP with NAWF=9.25, and physiological cutout (defined as NAWF=5) at 80 DAP. Tharp (1960) indicated that a cotton square requires 25 days to develop into a white flower and that the vertical squaring interval (i.e., the average number of days for successive main-stem nodes to develop) is about 2.7 days. Thus, the NAWF apogee (NAWF=9.25, determined by dividing 25 by 2.7) indicates the number of main-stem nodes differentiated by the plant during the time required for the first square to develop into a white flower. TDC is assumed to represent a crop that combines an optimal degree of early maturation and high yield. Actual growth patterns measured in fields can then be compared to the TDC.

Latest Possible Cutout Date (LPC)

Latest possible cutout date (LPC) is the latest date from which a population of flowers has a high probability of developing into bolls having acceptable size and quality. COTMAN assumes that 850 heat units (DD60s) are required for a flower population to develop into mature bolls. Based on historical weather and a user-defined risk level, LPC is the latest date from which 850 DD60s can be expected to be accumulated prior to a pre-determined harvest completion date. If a field reaches physiological cutout (NAWF=5) prior to LPC date, then end-of-season management is based on crop maturation, and heat units (HU) are accumulated from the physiological cutout date. Otherwise, end-of-management is based on weather restraints and HU are accumulated from the LPC date.

Factors to Consider When Interpreting Crop Growth Patterns

1. Square retention (high or low).
2. Alignment of curve relative to TDC (left, near, or right).
3. Slope of curve relative to TDC (flatter, similar, or steeper).
4. Apogee of curve relative to TDC (less, near, or above).
5. Change in slope between consecutive sample dates.
6. Physiological cutout date relative to LPC date.

Generalized Growth Pattern Interpretations

Alignment of Curve with Slopes Equal to Target

Left of Target: Early and/or rapid development of plant structure. If accompanied with high square retention in SQUAREMAN, anticipate high demands for water and nutrients by the developing fruit load. In BOLLMAN, plants may be approaching cutout too early and stress may reduce yield.

Near Target: Development at pace for an optimal combination of earliness and yield.

Right of Target: Delayed and/or slow development of plant structure, often associated with late planting or low seedling vigor. High retention in early fruiting positions should be attained to avoid further delay in maturation and excessive vegetative growth.

Apogee (peak) of Curve at First Flower

Less than Target: Stress has reduced plant structure. If stress is not relieved (or if other stresses occur), premature cutout will occur. For optimal yield in situations with a low apogee, curve should flatten or temporarily increase (indicating additional terminal growth) before declining to physiological cutout.

On Target: Plants are growing at optimal pace with about 10 fruiting branches, which is ample structure for high yields if fruit is retained and an additional five main-stem nodes (non-productive nodes at top of mature plant) are added.

Above Target: Plants have attained vigorous nodal development. If accompanied by relatively high fruit retention and development, high yields are likely. Excessive vegetative growth may occur if a good fruit load is not maintained.

Slopes of SQUAREMAN Growth Curve (prior to apogee)

Slope Ascent Flatter than Target: Stressed plant growth, intensity of stress is indicated by flatness of curve and fewer squaring nodes.

Slope with Steeper Ascent than Target: Excess plant growth (often associated with fruit shed).

Slope Ascent Flattens Between Sampling Dates: Plants have become stressed, often associated with moisture deficiency.

Slope Ascent Steepens Between Sampling Dates: Plant stress relieved, e.g. rain/irrigation if water is deficient.

Slopes of BOLLMAN Growth Curve (after apogee)

Slope Descent Flatter than Target: Boll load (accumulative number and size of bolls) is low relative to vegetative growth of plant. Maturity is progressively delayed as curve flattens.

Slope Descent Steeper than Target: Boll load (accumulative number and size of bolls) is high relative to vegetative growth of plant. Steep descent is often associated with small plant structure and/or excessive stress. Time to crop maturity is progressively shortened as rate of descent increases.

Slope Descent Flattens Between Sampling Dates: Reduced rate of boll load accumulation has occurred due to loss of fruit and/or enhancement of vegetative growth (relieving stress conditions).

Slope Descent Steepens Between Sampling Dates: Boll load relative to vegetative growth has increased due to increased fruit development and/or stress conditions that slow terminal growth.

Curve Ascends after Declining Past NAWF=5: The ascent (sometimes going above NAWF=5) may indicate second growth of individual plants after they ceased terminal growth, or that the sample includes late-maturing plants after the more dominant plants have matured. Neither second growth nor the late-maturing plants should dictate end-of-season decisions. Ceasing NAWF sampling when average NAWF drops below 5 eliminates confusion caused by either of these situations.

SQUAREMAN to BOLLMAN Transition

An inconsistency in number of squaring nodes may be attained during the transition from last SquareMap and first NAWF count. This transition, particularly obvious when the last SquareMap and first NAWF are taken on the same day, is related to variation in sampling. Samples for SquareMap include consecutive plants, while only plants with first-position white flowers are included in the NAWF sample. Thus, only plants that have initiated flowering, rather than all plants, are sampled for NAWF during early initiation of flowering.

SquareMap Squaring Nodes Relatively Same as NAWF: Relatively uniform plants within the field, such that most plants have initiated flowering near the same time.

NAWF>SquareMap Squaring Nodes: Non-uniform plant population. Early flowering plants are more dominant and vigorous than the rest of the plant population. The late, less dominant plants can cause flattening or ascent of the BOLLMAN curve as they begin to flower.

NAWF<SquareMap ***Squaring Nodes****:* Non-uniform plant population. Early flowering plants are less dominant and vigorous than rest of plant population. Bimodal fruiting curve may occur as the more dominant, late plants begin flowering.

Interpretation Examples

The 16 curves in Figures 1 through 4 provide a range of likely scenarios that may be experienced with crop growth patterns generated by COTMAN. Four SQUAREMAN curves are compared to TDC, a likely associated cause is proposed, and actions for high and low square retention situations are suggested (Fig. 1). BOLLMAN curves include situations where ascents of the curves derived by SQUAREMAN were on target (Fig. 2), above target (Fig. 3), and below target (Fig. 4). Each BOLLMAN curve is described and a likely cause is proposed. Comparison with an arbitrarily established LPC date is used to determine whether crop- or weather-oriented rules would be used, and physiological cutout date (i.e. days to NAWF=5) is determined. Finally, a production efficiency index—a subjective appraisal of potential yield and production risks—is assigned to each BOLLMAN curve. Rather than attempting to predict yields, this index should serve as a signal of growth pattern situations that are likely to be problematic.

Final Remarks

COTMAN provides a dynamic, interactive process to evaluate plant growth development throughout the fruiting period. These generalizations and examples should help users to better understand this dynamic process. Specific knowledge of growing conditions, including planting date, plant density, cultivar, soil, weather, pest problems, etc., within a field will greatly enhance the ability of the user to interpret growth curves. Each of these factors directly and indirectly (interacting with other factors) influences plant growth and development. A better understanding of these influences will provide insight for remedying in-season problems and minimizing risks associated with factors that cannot be adjusted within the season. The growth curve provides a composite picture of all direct and indirect influences that affect plant development. With experience, the user should be able to quickly evaluate and properly react to the growth curve.

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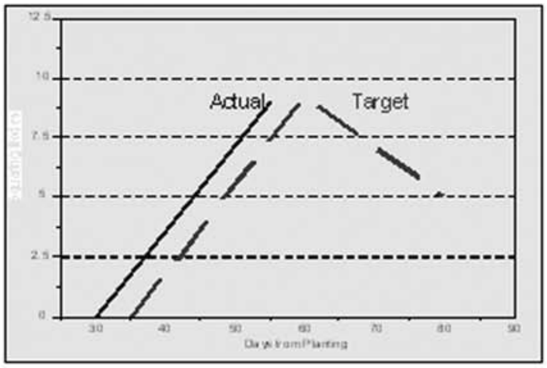
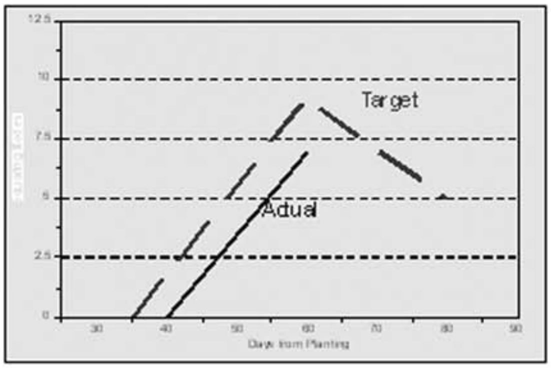
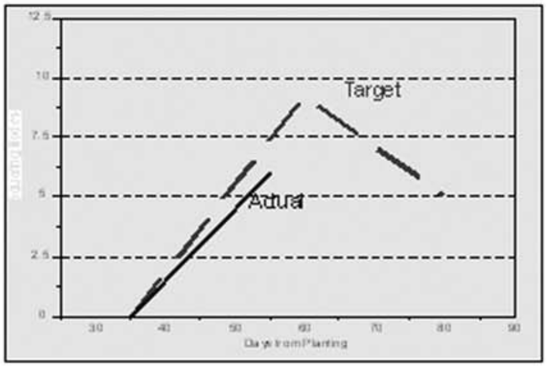


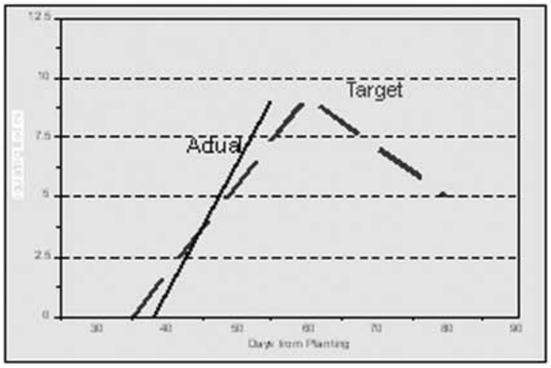
Description	Slope equal to target but nodal development is early
Likely cause	Optimum conditions after planting, usually accompanied by low first
Action:	
High retention	Anticipate very high fruit demands
Low retention	Anticipate relatively low demands, monitor & control vegetative



Description	Slope equal to target but nodal development delayed
Likely cause	Slow emergence (check seedlings for root damage); 1st fruiting node at main-stem node 7 or higher
Action:	
High retention	Maintain growth rate to achieve acceptable maturity
Low retention	Remedy as quickly as possible to avoid late maturity

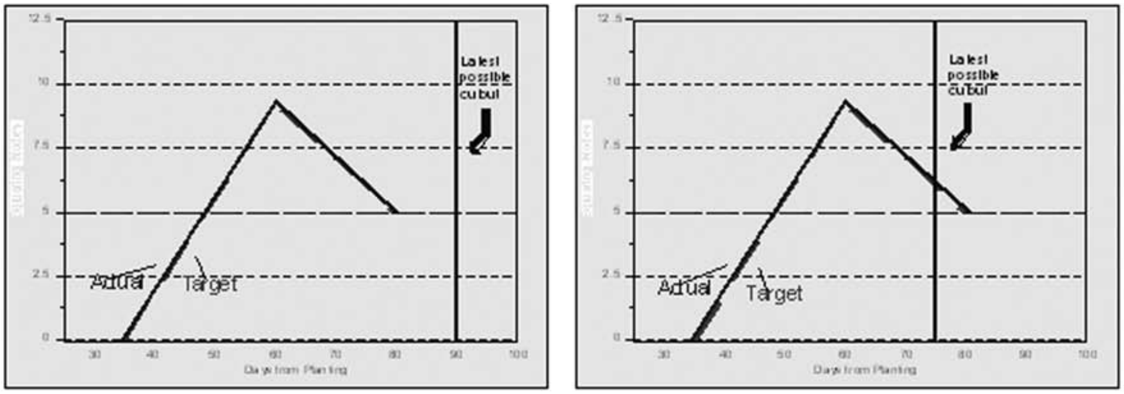


Description	Slope flatter than target
Likely cause	Chronic plant stress due to insufficient water, nitrogen deficiency, fine-textured soil, etc.
Action:	
High retention	Immediately relieve stress to avoid premature cutout
Low retention	Less critical to immediately relieve stress; continue to monitor plant growth and fruit retention



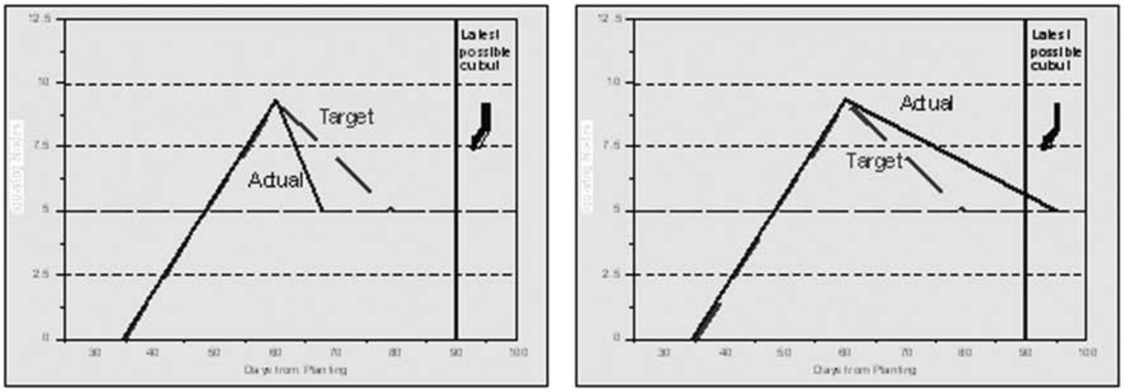
Description	Slope steeper than target after slow start
Likely cause	Loss of fruit accompanied by good growing conditions
Action:	
High retention	Not likely to occur; monitor & control vegetative growth
Low retention	Control cause of fruit loss, monitor & control vegetative growth

Fig. 1. Examples of Crop Growth Curves Derived from SQUAREMAN.



Description	On-target fruiting pattern attaining physiological cutout prior to latest possible cutout date
Likely cause	Optimum combination of factors producing early maturation and yield
End-of-season mgt.	Crop-oriented rules
Physiol. Maturity	80 DAP
Prod. Eff. Index	100% TDC

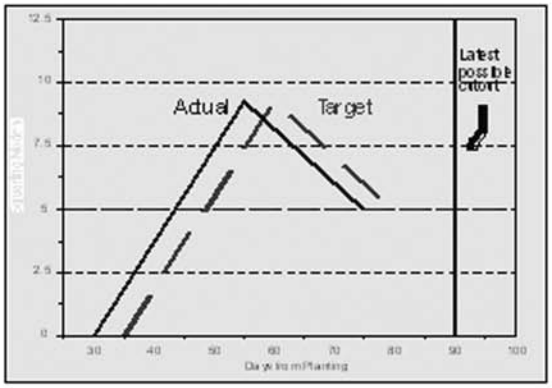
Description	On-target fruiting pattern, but physiological cutout after latest possible cutout date
Likely cause	Late planting
End-of-season mgt.	Weather-oriented
Physiol. Maturity	80 DAP
Prod. Eff. Index	90% TDC



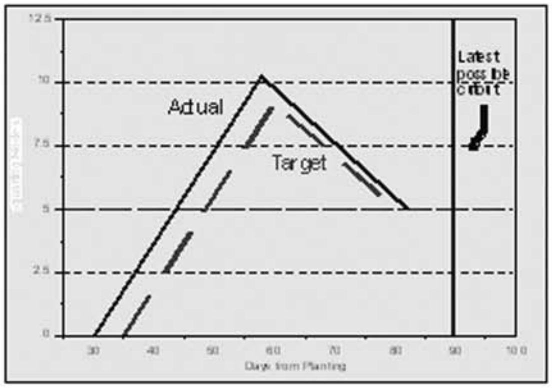
Description	Rapid decline in NAWF
Likely cause	Severe chronic stress, for example, water deficit
End-of-season mgt.	Crop-oriented rules
Physiol. Maturity	68 DAP
Prod. Eff. Index	75% TDC

Description	Slow decline in NAWF
Likely cause	Loss of bolls to physiological shed and possibly insects; excess vegetative growth
End-of-season mgt.	Weather-oriented rules
Physiol. Maturity	95 DAP
Prod. Eff. Index	90% TDC

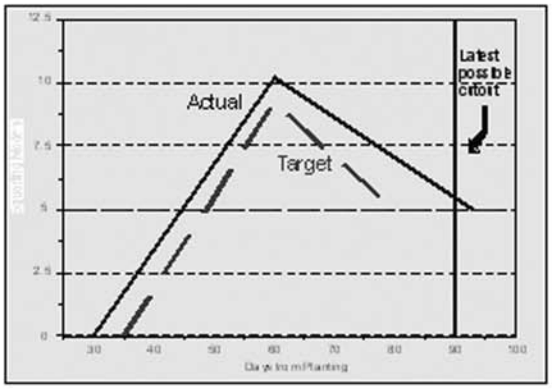
Fig. 2. Examples of BOLLMAN Curves when SQUAREMAN was On Target.



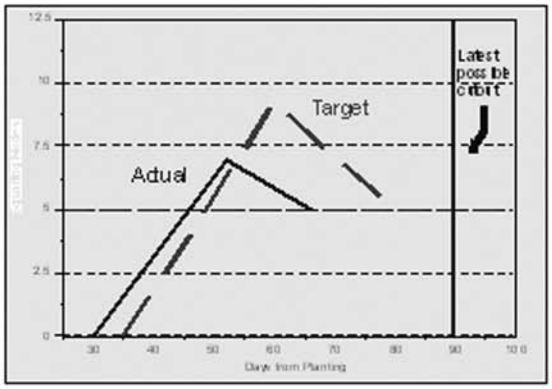
Description	Early fruiting with slopes similar to target
Likely cause	Early plant and fruit development with fruiting initiated on low main-stem no
End-of-season mgt.	Crop-oriented rules
Physiol. Maturity	75 DAP
Prod. Eff. Index	105% TDC



Description	Early and extended fruiting pattern with slopes similar to target, but higher apogee
Likely cause	Vigorous early growth with satisfactory boll retention, followed by good growing conditions
End-of-season mgt.	Crop-oriented rules
Physiol. Maturity	82 DAP
Prod. Eff. Index	110% TDC

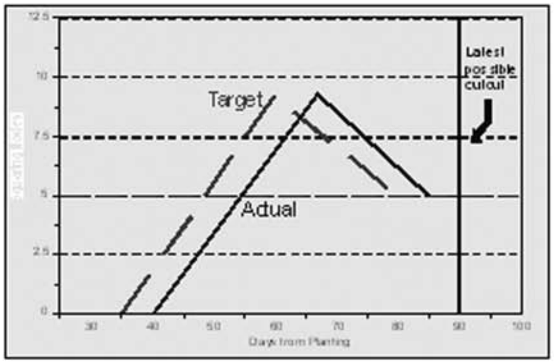


Description	Prolonged fruiting pattern with slow NAWF decline
Likely cause	Vigorous early growth with relatively low boll retention
End-of-season mgt.	Weather-oriented rules
Physiol. Maturity	93 DAP
Prod. Eff. Index	95% TDC

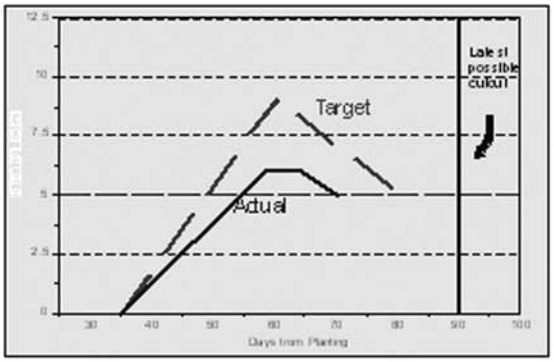


Description	Very early initiation of flowering followed by premature cutout
Likely cause	Low first fruiting node followed by high boll retention and chronic stress
End-of-season mgt.	Crop-oriented rules
Physiol. Maturity	65 DAP
Prod. Eff. Index	70% TDC

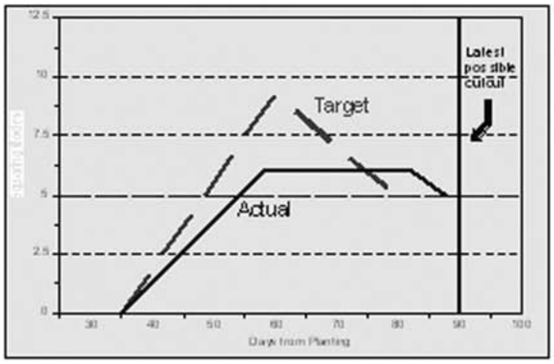
Fig. 3. Examples of BOLLMAN Curves when SQUAREMAN was Above Target.



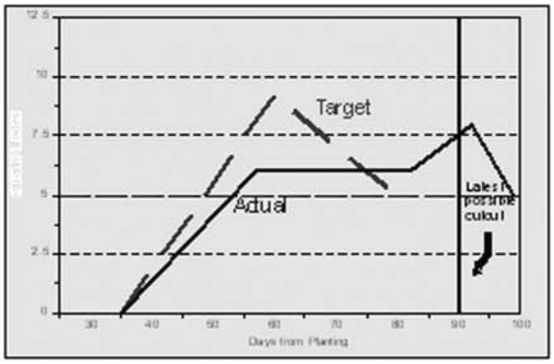
Description	Optimum growth pattern, but delayed squaring node
Likely cause	Adverse conditions causing slow emergence or conditions causing high first fruiting
End-of-season mgt.	Crop-oriented rules
Physiol. Maturity	85 DAP
Prod. Eff. Index	95% TDC



Description	Slow development of squaring nodes, low squaring nodes at first flower and premature cutout
Likely cause	Chronic stress through-out fruiting period
End-of-season mgt.	Crop-oriented rules
Physiol. Maturity	70 DAP
Prod. Eff. Index	50% TDC



Description	Slow development of squaring nodes, low squaring nodes at first flower and delayed
Likely cause	Early & mid-season stress, followed by sustained vegetative and fruit development
End-of-season mgt.	Crop-oriented rules
Physiol. Maturity	88 DAP
Prod. Eff. Index	85% TDC



Description	Slow development of squaring nodes; low apogee at first flower, and excess late-season growth
Likely cause	Early & mid-season stress, followed by relief of stress - often accompanied by low fruit retention
End-of-season mgt.	Weather-oriented rules
Physiol. Maturity	98 DAP
Prod. Eff. Index	80% TDC

Fig. 4. Examples of BOLLMAN Curves when SQUAREMAN was Below Target.

Chapter 10:

Using COTMAN to Manage Defoliation and Harvest Efficiency

Derrick M. Oosterhuis, N. Philip Tugwell, Dan D. Fromme, and Fred M. Bourland

Defoliation effectively marks the end of the cotton growing season; it is the final in-season management practice before harvest. A common goal is to reach an acceptable yield potential, defoliate, and harvest in the shortest period from planting for an early crop. The ability to exploit earliness greatly depends upon the timely recognition of the final stages of plant development and boll maturity. Harvesting cotton as early as possible increases the likelihood of more ideal weather conditions and higher lint quality during the first part of the harvest season. It is important to apply harvest aids early enough to take advantage of the benefits of early harvest, while avoiding application so early that yield and quality of the cotton are decreased. Furthermore, if the last effective boll population and its degree of maturity are not recognized promptly, insect pests may be treated to protect fruit that contributes little or no value to the crop.

Historical Development

The COTMAN™ program was developed over the past 20 years with input and testing by many researchers, extension workers, consultants, farmers, and graduate students. The founding principles of COTMAN are based on concepts of cotton plant growth and development and insect control, which began forming in the early 1900s. During that time, scientists recognized the need to establish early maturity in cotton to avoid the ravishing effects of the boll weevil, a newly introduced pest. Predictable and sequential development of cotton fruiting was soon realized, and concepts of crop maturity in cotton began to emerge. COTMAN initially focused on following the order and development of the cotton plant fruiting and predicting when to terminate insecticide application based on recognizing cutout and the time in heat units (HU) thereafter needed to protect the last effective boll population from insect attack. However, the idea of using the same principles was soon adopted to establish when to safely defoliate the crop without forfeiting yield or quality.

Timing Defoliation

When harvest aids first were introduced, they were applied according to historical harvest dates. However, factors such as weather, heat unit accumulation, and variation in cotton cultivars made this technique largely undependable. Traditional timings of defoliation include percent open bolls at 60% to 65%, cut boll technique, nodes above cracked boll (NACB)=4 or less, and heat unit accumulation beyond cutout. COTMAN provides growers with a more reliable timing of defoliation based on the actual development of the fruit load that is to be harvested. The program provides a means of defoliating as early as possible, which increases the likelihood of more ideal weather conditions and higher lint quality during the harvest season.

Timing of harvest aids continues to be a difficult decision for producers. Producers and crop advisors often are tempted to wait as long as possible on young immature bolls in the top of the plant before making the decision to defoliate. These bolls are often insect damaged, small, and account for little additional gain—but the perception of additional lint yield is difficult to overcome. The validation of the heat unit concept of timing defoliation beyond the last effective boll population, as defined by COTMAN, allows producers to make this decision with greater confidence and often provides for an earlier harvest.

Defoliation Timing Using COTMAN Based on Heat Units Beyond Cutout

The defoliation timing guidelines in COTMAN are based on heat unit (DD60) accumulation beyond physiological cutout (NAWF=5) or seasonal cutout (last date from which 850 HU can be expected prior to desired harvest completion date). White flowers at cutout represent the *last effective boll population* or the youngest cohort of bolls that will contribute significantly to yield and profit. Defoliation can be timed by the maturity of the last effective boll population or from the date a field has reached cutout. To achieve maximum yield and revenue, 850 HU should be accumulated from the date of cutout before defoliation (application of first defoliation) is initiated. The use of cutout (NAWF=5 or seasonal cutout) + 850 HU as a prediction of when to defoliate has been based on numerous field research trials over the past 15 years. Although results varied slightly from year to year, it is generally accepted that 850 HU after cutout are required to ensure earliness and the protection of the yield and quality potential.

Examples of Research to Verify the Cutout + 850 Heat Units Rule

Texas: Results from ten defoliation timing studies from 1998–2005 along the Texas Upper Gulf Coast to validate the COTMAN defoliation timing concept based on NAWF=5 + 850 HU showed that yields generally plateau between NAWF=5 + 850 and NAWF=5 + 1050 HU (Fig. 1A). In these studies, the traditional timings of defoliation (percent open bolls, cut boll technique, and nodes above cracked boll) were approximately equivalent to NAWF=5 + 1050 HU – 8 to 10 days later than COTMAN defoliation timing. COTMAN assists producers in defoliating as early as possible, which increases the likelihood of more ideal weather conditions and higher lint quality during the harvest season.

Arkansas: Results of field tests in northeast, central, and southeast Arkansas from 2001 to 2002 (with defoliation timings scheduled on 750, 850, 950, and 1050 HU beyond cutout) showed that yield tended to increase numerically as defoliation was delayed. However, yields generally reached a plateau between 850 and 1050 HU (Fig. 2B). Loan values calculated from HVI values (value per acre was calculated by multiplying pounds of lint produced by the calculated loan value) were greatest at the 850 HU timing. Defoliation prior to 850 HU resulted in lower yields and loan values. Defoliation at 850 HU resulted in the numerically greatest returns per acre.

Defoliation to Enhance Fiber Quality and Lessen Loss of Yield

Of the fiber quality parameters, micronaire (coarseness of fiber) and grade (trash and color) are most affected by timing of defoliation and subsequent harvest. Depending on expected micronaire, defoliation should be either moved forward or delayed to obtain optimal (i.e., non-penalty) micronaire. Expected micronaire is dependent upon the genetic potential of the cultivar (high or low micronaire cottons), specific fruit retention (bolls in early positions tend to have higher micronaire), and environmental conditions (complex interactions involving night temperatures and boll development). Micronaire of a field can be predicted by early sampling (e.g., via the Lewis method).

Trash may be increased by poor defoliation and/or by regrowth (resumption of vegetative growth after defoliation). When lush plant growth is present (e.g., tall, rank cotton), a more aggressive defoliation program is required to obtain proper leaf shed. However, an aggressive program may “stick” leaves (i.e., leaves die but fail to drop because the abscission layer is not formed) when temperatures are warm. Dead leaves that adhere to the plant will substantially increase trash. Regrowth causes additional green leaf material to be present at harvest, and may cause staining of fiber and/or increase leaf content in ginned cotton. The potential for regrowth increases as time between defoliation and harvest increases (i.e., delayed harvest).

Delaying harvest also increases the probability that cotton fibers will deteriorate and increases the likelihood of storm damage. Repetitive wetting of fibers in open bolls causes fibers to deteriorate. Deterioration of fibers disrupts the protective primary wall of fibers and increases microbial growth on fibers. Subsequently, fibers become discolored (thus, reduced color grade) and weight of individual fibers decline (thus, reduced yield). Storm damage because of wind and/or rain may also reduce yield by causing seedcotton to be detached from the boll and fall to the ground. Field management to lessen fiber deterioration and storm damage is primarily dependent on reducing the time between defoliation and harvest. COTMAN assists with reducing this time by aligning fields by their crop maturation date. Multiple fields may then be defoliated based on their relative maturity, picking capacity of the producer, and expected weather conditions.

Sampling

COTMAN is a very sensitive measure of plant growth and development and can be linked to all late-season growth changes. The measured growth is an integration of all environmental and management conditions, i.e. a composite picture of that integration. Therefore, the value of COTMAN depends on the investment in the exact reading of the plant from the start to the end. For the COTMAN program to work effectively, it is important to understand the whole crop growth pattern (*See* Chapter 3) and follow it closely with careful recordings of SQUAREMAN and BOLLMAN (*See* Chapter 5). In this way, cutout can be accurately determined and the timing of defoliation accurately predicted. It is not sufficient to merely take a few NAWF measurements close to cutout as this practice may produce a distorted estimate of the actual cutout date, which then may cause misapplication of COTMAN principles. It is imperative to have a sound sampling method for plant fruiting development (*See* Chapter 5) in order to get a true representation of the development of the boll load so as to be able to reliably determine the last effective boll cohort (physiological or seasonal cutout). The timing of defoliation can then be determined with confidence without any loss of yield or fiber quality.

Summary

Defoliation timing based on heat units beyond cutout is an effective and easy way of determining the most economical time to terminate the crop without suffering from yield loss or discountable fiber qualities. Research over the past 20 years has shown that 850 HU after cutout for timing defoliation allow the cotton crop to be terminated in a timely manner without yield loss. Validity of physiological cutout (NAWF=5) and time between flower and open boll (850 HU) has been confirmed on a wide range of cultivars and growing conditions. Some conditions may merit adjustment of these rules, yet they can always serve as a baseline for making specific defoliation and harvest decisions.

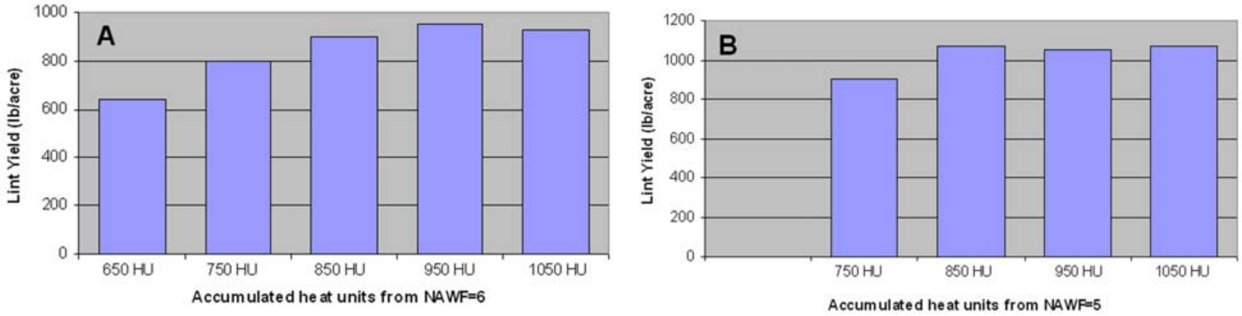


Fig. 1. Effect on lint yield from defoliation timing based on the number of heat units accumulated after cutout in (A) Texas and (B) Arkansas.

Chapter 11:

Utilization of COTMAN to Enhance Yield and Revenue of Cotton

William C. Robertson, Derrick M. Oosterhuis, N. Ray Benson,
Frank E. Groves, and Fred M. Bourland

COTMAN™ is a crop management system based on in-season plant monitoring. The COTMAN computer software makes it easy to enter data and generate the reports used to make management decisions. The program is divided into two parts, SQUAREMAN and BOLLMAN. SQUAREMAN is used to monitor crop development up to the time of first flower. Monitoring with BOLLMAN begins at first flower and is used to monitor boll-loading stress and to assist with end-of-season crop termination decisions. The overall program was designed to facilitate crop management, protect yield potential, and increase profits.

At First Square

SQUAREMAN, the first part of the COTMAN program, is primarily used to monitor pre-flowering plant development. At or near first square, plant stand counts and average first-fruiting node numbers are recorded. During squaring, 10 plants at each of 4 sites per field are monitored weekly for presence or absence of first-position squares. Reports provide feedback on square retention and plant stress based on nodal development. Square shed information alerts growers to possible pest problems and augments insect scouting reports. A quick comparison to the *Target Development Curve* (TDC) shows if the actual pace of crop development is too slow, too fast, or just right for an early crop and high yields.

At Flowering

BOLLMAN, the second part of the COTMAN program, is used to monitor post-flowering plant development. Monitoring with BOLLMAN begins when the crop starts to flower and is used to monitor boll-loading stress and to assist with end-of-season crop termination decisions. Beginning at first flower, *nodes above white flower* (NAWF) counts are recorded weekly from 10 plants at each of 4 sites per field. Establishing the last effective boll population—the last group of bolls that will contribute significantly to yield and profit—is essential for making end-of-season decisions. Cutout is reached when NAWF counts become less than 5 or when accumulating sufficient heat units (850 DD60s) to mature a flower is unlikely to occur. From cutout until defoliation, daily high and low temperatures are recorded from a local weather source. Crop termination guidelines are based on heat unit accumulation beyond cutout.

Monitoring and Ensuring Good Crop Growth and Development

The perennial and indeterminate nature of cotton often forces managers to manipulate growth and development to optimize seed and lint production. Maintaining the proper balance between vegetative and reproductive growth is essential to optimize yield and earliness. During squaring it is important to maintain good square retention and to develop the plant structure necessary to achieve yield goals. A realistic goal at first flower is to achieve a range of square retention from 80 to 85% and nodes above first-position white flower of 8 to 10. Square retention values prior to first flower are generally impacted greatest by insect pressures. COTMAN allows producers to follow crop growth during the season, detect potential problems, make timely in-season management decisions, determine end-of-season termination of inputs, protect yield and fiber quality potential, and increase revenues.

Detecting Crop Stress

The development of plant structure prior to flowering is impacted negatively by stress. Fertility and moisture are the dominant factors contributing to plant structure prior to flowering. Square retention values less than 80% will often result in delayed maturity and excessive vegetative growth because of the lack of fruiting forms during boll development. Boll weevil eradication efforts and *Bt* technologies have helped to reduce the occurrences of low retention rates through squaring as well as into flowering. Retention rates of 90% or greater can present logistical challenges to managers in that margins of error for input timings are small. Delays in timing can result in excessive square shed. High retention values coupled with poor plant structure will result in premature cutout, significantly impacting yields. Shed as a result of environmental stresses is often greater in situations where retention rates are very high.

Managing inputs to achieve 8 to 10 NAWF at first flower will result in the plant having the necessary "horsepower" to avoid premature cutout in most instances. Fields in which NAWF values are in a range of 6 to 7 will require immediate action to alleviate stress to avoid premature cutout. High retention values will magnify the urgency to relieve the stress in this situation. As a rule, early or more determinate cultivars are more sensitive to having adequate growth vigor at first flower to achieve desired yield potential than later-maturing or less determinate cultivars. Being on track at first flower or taking corrective actions to get back in line shortly thereafter is necessary to achieve both high yield goals and profitable production.

The BOLLMAN component of COTMAN is much less labor intensive than the SQUAREMAN component. BOLLMAN provides the manager great insight about the crop with little additional time requirements to collect NAWF data. Tracking NAWF from first flower to cutout and evaluating the slope of the resulting growth curve can help managers identify fields that are potentially early- or late-maturing so that management practices can be used to help preserve existing yield potential. The target for comparison during flowering is a value of NAWF=9.25 at first flower or 60 days after planting and NAWF=5 at 80 days after planting. The actual growth curve from the field does not necessarily have to match the TDC exactly but should run parallel to it. The rate at which this curve declines is a measure of stress.

Two types of stress may occur. A great boll load stresses the plant and is thought of as a good stress. Lack of moisture and fertility also stresses the plant and is thought of as a bad stress. Excessive stress will generally produce a crop development curve that declines much faster than the TDC. Lack of stress, good or bad, will result in a line that runs flatter than the TDC. Fields experiencing slopes of NAWF values that are parallel to the TDC and with high retention values are most often the fields that will respond favorably to additional inputs to preserve the crop.

Insecticide Termination

The decision of when to terminate late-season insect-pest management strategies has been a persistent problem for the cotton industry. Returns through increased yields and improved fiber quality must exceed the cost of these control strategies to justify late-season insecticide treatments. BOLLMAN provides an estimate of the critical time to terminate insect-pest management strategies at the end of the growing season. The program uses *cutout* (NAWF=5) as the endpoint for flowering of the last effective boll population set on the plant (Oosterhuis, 1990; Bourland et al., 1992). Bolls produced by the plant after cutout often do not have enough time remaining in the season to produce mature cotton fibers (Bernhardt et al., 1986). As a general rule, after cutout has occurred and the crop has accumulated 350 to 450 heat units (HU), harvestable bolls are considered safe from attack by all fruit-feeding insect pests (Oosterhuis and Kim, 2004). Physiological cutout is a key factor that must be defined accurately for each situation to eliminate late-season treatments used to protect cotton bolls that may abscise or produce lower quantities of less-mature fiber than earlier bolls.

Once the last effective boll population or cutout is established, HU or DD60s are accumulated to aid in insecticide termination decisions. Termination guidelines are as follows:

- Insecticide termination for lepidopterous and lygus species - NAWF=5 + 350 HU;
- Insecticide termination for stink bug - NAWF=5 + 450 HU;

- Insecticide termination for fall armyworm - NAWF=5 + 500-550 HU; and
- Insecticide termination for defoliating insects - NAWF=5 + 650 HU.

Irrigation Termination

The decision of when to stop irrigation has been a persistent problem for the cotton industry, and rather arbitrary rules or calender days have been used with mixed success. The COTMAN crop monitoring program provides a scientifically based method of timing the last irrigation. The cotton crop requires adequate water during flowering and boll development (from 0.25 inch/day to 0.4 inch/day) for boll growth and fiber development, but timing the termination of watering is essential in order to allow the crop sufficient time to mature prior to defoliation and harvest.

Using COTMAN to time the last irrigation relies on the identification of the last effective boll population at NAWF=5 (i.e., physiological cutout) and the subsequent accumulation of an additional 350 to 500 HU to determine the timing of the final irrigation. After cutout and when the required heat units accumulation is met, the field should be irrigated for the last time if the soil is not already sufficiently moist. The required number of HU after NAWF=5 (i.e., 350 to 500) depends on the location as well as the rainfall and temperature conditions experienced. In “moderate” summer conditions with deep soil moisture availability, the accumulation of 350 HU after NAWF=5 is sufficient for all the state, but an extra week of irrigation is appropriate out to 500 HU under extreme conditions—e.g., in the summer of 2007 when there was almost zero rain in July and August, and temperatures of 100°F were common (and very high yields were obtained). Achieving field capacity was difficult under the conditions in 2007. The following termination guidelines are offered for location, but the weather experienced also needs to be considered to modify these:

- Irrigation termination for North Arkansas NAWF=5 + 350-400 HU;
- Irrigation termination for Central Arkansas NAWF=5 + 400-450 HU; and
- Irrigation termination for South Arkansas NAWF=5 + 450-500 HU.

Defoliation and Harvest

Use of the COTMAN program allows producers to decide with some confidence, and on a scientific basis, when to initiate defoliation. The defoliation timing guidelines in COTMAN are based on heat unit (DD60) accumulation beyond physiological cutout (NAWF=5) or seasonal cutout (last date from which 850 HU can be expected prior to desired harvest completion date). White flowers at cutout represent the last effective boll population or the youngest cohort of bolls that will contribute significantly to yield and profit. Defoliation can be timed by the maturity of the last effective boll population or from the date a field has reached cutout.

To achieve maximum yield and revenue, 850 HU should be accumulated from the date of cutout before defoliation (application of first defoliation) is initiated. The use of cutout (NAWF=5 or seasonal cutout) + 850 HU as a prediction of when to defoliate has been based on numerous field research trials over the past 15 years. Although results varied slightly from year to year, it is generally accepted that 850 HU after cutout are required to ensure earliness and the protection of the yield and quality potential. Overall, the use of COTMAN should allow more precise and confident timing of defoliants, often with improved results and a savings of chemicals.

Early Crop Maturity

Early crop maturity refers to the ability to grow and mature the crop within the confines of the season prior to the onset of adverse weather while ensuring a high yield potential. Crop maturity is related to a field population of plants (in relation to their environmental potential) that has developed to the point that no additional inputs are required, not to be confused with physiological cutout at NAWF=5 (*See* Chapter 14, Terminology). COTMAN provides a method to achieve early maturity provided the program is followed and the resulting data correctly interpreted and used in management.

It is important to promote earliness so as to avoid expensive late-season battles with insects (particularly high bollworm moth counts in late August) to reduce late-season insect control costs and also to reduce selection pressure for insect resistance.

Additional benefits of an early crop include the ability to harvest prior to the advent of bad weather, resulting in greater picking efficiency and improved grades. With the onset of bad weather, harvesting is slowed and requires more fuel and repairs. Less field work is generally required after harvest of dry fields compared to wet fields that may have significant ruts. These factors can provide the producer additional time to do needed field work, collect fertility and nematode soil samples, allow for better cover crop results, and create less producer stress.

A testimonial from a producer: *"I am sure glad we had COTTON-MAN (COTMAN) information on my farm. I am finished with harvest, have my stalks cut, fields ripped and most everything bedded. Most of my neighbors still have several hundred acres to harvest and their pickers are parked…… they have gaps in their defoliation,"* Bob Ramey, Blytheville, Ark.

Scheduling Fields for Harvest

An additional benefit of the COTMAN crop monitoring program is the scheduling of fields for mechanical harvest based on the maturity of the individual fields. In this way, producers can make the best use of their time and harvesting equipment.

Financial Rewards

We continue to see that the BOLLMAN component allows the producer to save money on input costs (chemicals and irrigation water) and overhead (to manage more acres with the aid of COTMAN) while the SQUAREMAN component may have potential to increase net revenue through insights leading to increased square retention and early detection of problems in plant structure. Perhaps the biggest cost saving comes from the ability to predict, with some confidence, when to terminate insecticide applications and irrigation. Research has shown a $15 per acre savings in northeast Arkansas. With the advent of *Bt* cotton and the boll weevil eradication program, the value of BOLLMAN to reduce insecticide costs due to budworm and boll weevil damage has been greatly reduced. However, savings with regard to other cotton pests still exist. In addition, precise determination of irrigation termination and its impact on defoliation timing can result in better or more consistent results of a harvest aid program. Furthermore, COTMAN crop monitoring data can also be used to determine when to start irrigating, to see if irrigation is sufficient during the squaring and flowering stages, and also to help producers know when to stop irrigating.

COTMAN as an Overall Management Tool

COTMAN is an effective management tool. Better information means better decision making. Each field has its own report. COTMAN provides users timely information on square retention as well as plant and fruit numbers per acre. The graph of crop development pace reveals much about the "horsepower" of the crop. Flowering dates of the last effective boll population (cutout) provide the benchmark of all end-of-season decisions. COTMAN reduces end-of-season guesswork. It helps users determine when bolls are safe from insect pests, when irrigation can be safely terminated, and when to defoliate for optimal yield and quality. The cost of full-season crop monitoring is more than offset by savings on late-season insecticide. Timely feedback on crop development pace and stress gives growers the ability to take prompt corrective actions. This program is easily integrated into management systems and helps tie everything together to enhance overall profitability.

Other Benefits of COTMAN

Prevention of Reduced Fiber Quality and Lowered Yield

The proper use of the COTMAN program can reduce the potential of reduced fiber quality and the likelihood of yield losses due to storm damage. Field management to lessen fiber deterioration and storm damage is primarily dependent on an early harvest and reducing the time between defoliation and harvest. COTMAN assists with reducing this time by aligning fields by their crop maturation date for mechanical harvest. Multiple fields may then be defoliated based on their relative maturity, picking capacity of the producer, and expected weather conditions. Timely defoliation and subsequent harvest will also help to ensure acceptable micronaire (fineness of fiber) and grade (trash and color). Timely harvest also reduces the potential for regrowth, which increases as time between defoliation and harvest increases (i.e., delayed harvest). Significant levels of regrowth that require additional harvest aid applications will increase costs and/or reduce fiber quality (color).

Qualifying for Conservation Programs

In conservation programs, which use a point system to demonstrate conservation, COTMAN can be a valuable tool. The use of COTMAN records has made application to the watershed program easier by showing that crop growth was used to help develop the fertility program, that insecticide was not used in excess, and that NAWF data were used to demonstrate that crop maturity was used to terminate irrigation so as not to waste water. Basically, use of the COTMAN program has helped producers qualify for the watershed conservation program, which means additional revenue.

Summary

The COTMAN program has numerous real benefits for cotton management. Money savings from insecticide termination have turned out to be only a means to “spark” interest in COTMAN. However, the ability to clearly follow crop development with relatively simple and easy practical measurements allows producers “to see” if the crop is on track or showing stress symptoms, and this provides the major benefit in crop management. Early crop maturity and timely defoliation help prevent fiber quality and yield losses. The overall benefit of COTMAN is knowledge of the crop development that allows timely management inputs and decisions for higher yield and substantial economic savings.

For more information on COTMAN, visit the following site: http://www.cotman.tamu.edu/index.htm

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Chapter 12:

Costs and Benefits of COTMAN

Robert Hogan, Mark J. Cochran, Diana M. Danforth, William C. Robertson, and Kelly Bryant

Many potential benefits may be realized through the use of COTMAN™. Decision rules contained in BOLLMAN are primarily directed toward the management decisions of insecticide and irrigation termination and harvest initiation. Harvest initiation rules can be employed at both field and farm level. In fact, many experienced users find much of the value of BOLLMAN rules to be in ranking fields by physiological maturity so that harvest can be sequenced and pickers used more efficiently. SQUAREMAN rules can be used to assist in critical management decisions of irrigation initiation, early-season insect control, plant growth regulators, and foliar fertilization. These rules are diagnostic in nature and are designed to identify fields that are under stress. Considerations to remedy these stresses are listed to assist growers in determining a course of action.

Evaluations of the insecticide termination rules have been structured to identify:

1. any yield losses from terminating boll weevil, bollworm, and plant bug control at NAWF=5 + 350 additional heat units (HU);
2. performance of the rules in actual grower fields with significant late-season pest infestations;
3. potential insect-control cost savings by eliminating insecticide applications that do not protect bolls to be harvested; and
4. costs of data collection.

Yield Losses Associated with Insecticide Termination

A series of small-plot research trials in the states of Arkansas, Louisiana, Mississippi, Virginia, and Texas was conducted in 1995 and 1996 to examine the impact on lint yields of various termination thresholds varying from NAWF=5 (physiological cutout) to NAWF=5 + 650 HU (Cochran et al., 1996, 1998). The following conclusions from these multi-state small plot trials can be reached:

- in no small plot trial was there ever a significant yield loss observed by terminating insecticide applications at the recommended NAWF=5 + 350 HU;
- in 6 of 7 1995 trials, the numerically highest yield was associated with termination at either NAWF=5 + 200 HU or NAWF=5 + 350 HU; however, these yield advantages were not always statistically significant; and
- in 1996 trials in Arkansas, Louisiana, and Mississippi, no significant differences in lint yields were observed between termination at NAWF=5 + 350 HU and later termination. In 5 of 7 trials, lint yields were highest with termination at NAWF=5 + 350 HU.

Validity of Insecticide Termination Rules Under Heavy Infestations

Performance of the COTMAN termination rule in grower fields was monitored in 1995 and 1996 in Arkansas, Mississippi, and Texas. These fields were selected because they were felt to present strong challenges to early termination. Net revenues were contrasted for the COTMAN rule and full-season control following grower's normal action thresholds. Therefore, differences in yields and control costs were considered. In 1995, when data from all fields were analyzed as a group, regression analysis showed that the termination rule of NAWF=5 + 350 HU resulted in statistically higher net revenues, between $46 and $53 per acre. Eight grower fields were monitored in 1996. No statistically significant differences were observed between COTMAN termination and full-season insect control for lint yields, revenue adjusted for fiber quality discounts/premiums, or net revenues above insect control costs.

Potential Insecticide Treatment Savings

In 1995, insecticide application data were collected across three states: Arkansas, Louisiana, and Mississippi. COTMAN information was also collected so inferences could be drawn on potential cost savings that could arise from adoption of the termination rule. Cost savings were defined as the cost of insecticide applications made after a field reached NAWF=5 + 350 HU. Based upon the small-plot trial information, yields were assumed to be unaffected by terminating at NAWF=5 + 350 HU. The potential savings varied by region of the state and reflected differences in late-season insect pressure. In the Northeast, cost savings were estimated at $7.77/acre. In the Eastern/Central region and Southeast region, the savings were calculated to be $13.54/acre and $21.20/acre, respectively (King et al., 1996).

Harris et al. (1997) summarized results from experiments on insecticide termination in Mississippi from 1993 through 1996. On average, 2.1 additional insecticide applications were applied after NAWF=5 + 350 HU at a cost of $14.62/acre/application, resulting in an additional production cost of $30.70/acre with no increase in yield and thus a reduction in income. These costs could have been avoided by following the COTMAN termination rules.

Over a four-year period from 1995 through 1998, insecticide application data were collected in Arkansas, Louisiana, Mississippi, and Texas to validate insecticide termination at NAWF=5 + 350 HU and define cost savings to producers from using the termination rule (Cochran et al., 1999). Cost savings were defined as the cost of applications made after a field reached NAWF=5 + 350 HU. Based upon small-plot trial information, yields were assumed to be unaffected by terminating at NAWF=5 + 350 HU (20 out of 20 trials yields were unaffected after 350 HU). Thirty-three large-plot research trials were conducted in Arkansas, Mississippi, and Texas over the same four-year period. Over all these large-plot trials, a difference of less than 2 pounds of lint/acre was observed between full-season treatment and termination at + 350 HU. An average of $19.62/acre was spent on additional control costs not resulting in increased yields (Cochran et al., 1999).

An economic analysis was conducted in 2004 using anecdotal data (not a replicated experiment) from producer and consultant records over a period of four years from 2000 through 2003 and extending across a total area of 63,615 acres of cotton (Hogan and Robertson, 2004). The ad hoc analysis indicated an average $18.23 would have been spent in additional production costs that did not contribute to increased yields. This analysis assumed an additional 1.68 pesticide applications would be made after cutout + 350HU (Cochran et al., 1999). These producer and consultant records included wages and salaries of plant mappers/scouts, related federal and state employee costs (federal and state withholding, FICA, Medicare, unemployment, etc.), daily travel expenses to and from fields, radio and computer equipment, bonuses, and miscellaneous expenses incurred.

Costs of COTMAN Data Collection

To contrast projected benefits from using COTMAN with costs of collecting the data, a study was conducted by the Arkansas Cooperative Extension Service (Robertson et al., 1997). Efforts were made to record the amount of time that data collection, travel, and analysis for COTMAN can take. Data were obtained from one grower and three crop advisors. Each group collected data in a slightly different manner, particularly in regard to frequency of plant monitoring and coordination with insect scouting. This study showed approximately 16 to 23 minutes per field per week are required to collect data. Cost per acre across the four operations ranged from a low of $1.06/acre/yr to a high of $3.08/acre/yr. The higher estimate included time for both COTMAN and insect scouting. If it is assumed that personnel assigned to scout insects are also assigned to do plant monitoring and that all travel costs are allocated to insect scouting, then the cost of data collection for COTMAN is reduced from $3.08/acre/yr to $0.88/acre/yr. Further results from the above-mentioned ad hoc analysis showed an increase in data-gathering costs to $1.65/acre/yr by the end of 2003. Although these costs have increased in an absolute sense, percentage cost savings from using the COTMAN system are still quite high.

Irrigation Termination Cost Savings

Research was initiated in 2000 to determine if a COTMAN relationship could be established that would specify irrigation termination at NAWF=5 + certain accumulated HU. Evidence has accumulated to suggest, in Arkansas at least, that NAWF=5 + 350 additional HU is a good rule of thumb for irrigation termination in the northeast; + 400 to 450 additional HU in the central section; and + 450 to 500 additional HU in the south and southeastern portions of the state. Furthermore, if it is a dry year or if projected cotton prices for harvest are high, termination could be delayed by as much as 50 to 100 HU from the above rule of thumb. A wet year or low projected cotton prices would indicate the need for a shortened irrigation season.

Individual producers have various systems to determine when to terminate irrigation on their own operations in a manner that works for them. With that in mind, cost savings through irrigation termination utilizing COTMAN rules can be fairly spectacular. Each additional acre-inch of water that is applied above the minimum required will cost $2.72 per acre-inch and $5.67 per acre-inch when applied with furrow and center-pivot irrigation, respectively.

Defoliation

Economic evaluations of COTMAN have focused primarily on the BOLLMAN recommendations. Harvest initiation rules have been addressed in Chapter 10 and are based on the determination of the flower date of the last effective boll population and the number of additional HU necessary for these bolls to mature. Both lint yields and gross revenues begin to plateau at 850 HU so that in most cases little will be gained (yield or revenue) by delaying harvest to accumulate additional HU past this point. However, much can be gained through the benefits of earliness.

Miscellaneous Benefits

Additional anecdotal evidence continues to accumulate that suggests:

- Some farm managers are able to oversee a greater total cotton acreage with the use of COTMAN technology than without it.
- COTMAN can be used to target the crop to a specific, desired harvest window. Benefits of this could include:
  - » Better harvest weather.
  - » Better lint quality and a better loan price received.
  - » Less field work after harvest (repairing damaged fields).
  - » Increased likelihood of finishing all fall field work.
  - » Time provided to plant fall cover crops.
- Good COTMAN records could add credibility in dealing with conservation issues —i.e., runoff, Total Maximum Daily Loads (TMDLs) as stipulated in the Clean Water Act—and quantity of water use (irrigation termination is decided by what the plant needs rather than by a less scientific method).
- Earliness and tracking crop development have become the major benefits of COTMAN, while insecticide and irrigation savings are just added benefits.

Concluding Remarks

With the advent of *Bt* cotton and the boll weevil eradication program, the value of BOLLMAN to reduce insecticide costs has been somewhat reduced. However, savings with regard to other cotton pests still exist.

Most economic data have been compiled from BOLLMAN observations. We continue to see that the BOLLMAN component allows the producer to save money on input costs (chemicals and irrigation water) and overhead (to manage more acres with the aid of COTMAN), while the SQUAREMAN component may have potential to increase net revenue through insights leading to increased square retention and early detection of problems in plant structure.

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Chapter 13:

Recurring Questions About COTMAN

Fred M. Bourland, N. Philip Tugwell, Thomas A. Kerby, N. Ray Benson, and Diana M. Danforth

Principles of COTMAN™ are robust and apply to most cotton growing conditions. Yet, some recurrent misunderstandings have plagued COTMAN since its conception. Most of the misunderstandings and questions have been associated with 1) the *Target Development Curve* (TDC), 2) physiological and seasonal cutout, 3) plant stress, and 4) the utility of COTMAN data.

Target Development Curve

Does the Target Development Curve represent optimal cotton growth?

Use of the term "target" has caused much confusion, because "target" suggests the establishment of a goal or optimum. The TDC does not necessarily establish the optimal or best growth pattern for a specific growing situation. Instead, the TDC simply establishes a standard for comparisons. The standard was based on long-established principles of cotton plant growth as summarized in Chapter 3. Actual crop development curves may, and often do, deviate from the TDC. Actual crop growth curves that deviate from the TDC only suggest that the pace of crop development is different than the accepted standards reported for cotton growth and development. Deviations from the TDC should not be viewed as a definite change in potential yield.

Since the Target Development Curve was developed in Arkansas, is it applicable to other cotton-growing regions?

Although the TDC was developed in Arkansas, it is not tailored to fit any specific growing situation. Since the TDC is simply a standard, there is no need to establish different standards for various cotton-growing regions or conditions. In the absence of disease and/or water stress, heat unit (HU) requirement for squaring node development is fairly standard. Expected (as well as optimal) growth patterns are not the same for different growing regions or conditions. Certainly, growth patterns for water-stressed and well-watered cottons will differ greatly. Comparison of plant development to the TDC can be used to interpret plant response in each situation.

Does the Target Development Curve represent a growth curve for maximum cotton yield?

Cotton plants mimicking the TDC should produce cotton in a highly efficient, short-season production manner. Maximum yield could be attained by a growth curve above the TDC (i.e., start fruiting earlier, higher apogee of curve, and/or longer, effective flowering period). However, production costs and risks associated with such a growth curve would often be greater than with plants following the TDC. With a three-day vertical and a six-day horizontal flowering interval, a cotton plant may potentially produce 16 flowers on main-stem fruiting branches in less than 21 days and may produce additional flowers on fruiting branches arising from vegetative branches. Assuming 40,000 uniformly developed plants per acre and a 20-day effective flowering period, cotton has a yield potential of over five bales per acre. Therefore, high and efficient cotton yields are possible with a crop having 20 days of effective flowering. Plant mapping data show that the development of nine to ten effective fruiting branches (i.e., main-stem nodes bearing a fruiting branch with a harvestable boll) is common in U.S. Mid-South cotton. Since cotton plants require at least 24 days to develop this plant structure, growers are producing plants with increased ability to compensate for fruit loss and for variation among plants.

Should there be different Target Development Curves for newly developed fast-fruiting cultivars?

Some have suggested that the TDC should be different for newly developed "fast-fruiting" cultivars. However, many of the newly developed cultivars (with the advent of *Bt* cotton and boll weevil eradication) are less determinate and tend to be later maturing than the most popular cultivars being grown when COTMAN was developed. It should also be noted that the growth parameters summarized by Tharp in 1960 were established on cultivars that predated breeding efforts to develop short-season cultivars and even predated development of old standards such as "Stoneville 213" and "Deltapine 16." Varieties express only minor differences in node development as well as vertical and horizontal flowering intervals. Variation in early- and late-maturing varieties is usually attributed to node number of the first fruiting branch (lower is more determinate) and/or the slope of the NAWF curve (steep descent associated with early maturity and this is usually a function of fruit retention).

Why is Target Development Curve based on days after planting rather than on heat units after planting?

The TDC establishes a standard for main-stem nodal development relative to *days after planting* (DAP) and does not attempt to model or predict plant development. Initiation of fruiting might be more closely synchronized with the curve if nodal development were charted by *days after emergence* (DAE). Yet, charting by DAE rather than DAP would disregard a major plant develop criterion, namely, days required to emerge. Slow emergence is usually indicated by SQUAREMAN growth curve occurring to the right of the TDC. Also, an even better fit to a standard curve might likely occur if the development were charted by heat unit accumulation. Again, COTMAN is not modeling plant development—a fit to a curve would not provide any diagnostic function. Comparison of main-stem nodal development by DAP to the TDC provides a dynamic evaluation of plant development throughout effective flowering.

Physiological and Seasonal Cutout

What is the difference between physiological and seasonal cutout?

End-of-season decisions in COTMAN are based upon the maturation of the last effective population of bolls. The flowering date of the last effective population of bolls is determined by either the plant's ability to set and mature a population of bolls (physiological cutout) or by simply running out of time at the end of the season (seasonal cutout), whichever comes first. Physiological cutout is related to the carrying capacity of the plant. As boll load increases relative to the plant's carrying capacity, white flowers progress toward the plant apex. We have determined that physiological cutout is identified by NAWF=5 (white flower occurring within 5 nodes of the plant apex). Flowers retained after NAWF=5 often result in bolls that produce less lint and are of poorer quality than bolls set lower on the plant.

The only time that physiological cutout does not identify the flowering date of the last effective flower population is when boll maturation is limited by late-season weather. The latest possible cutout dates have been determined for various cotton growing locations by assigning each location a harvest completion target date (primarily based on historical weather data). From various experiments, we know that 850 heat units (DD60s) are required from flower to mature a boll. Using long-term daily averages for heat unit accumulations, latest possible cutout date was defined as the last date from which a person can expect to achieve 850 HU prior to harvest completion target date (i.e., harvest completion date minus 850 HU). Obviously, neither boll weevil eradication nor *Bt* cotton changes the weather, and thus they have no effect on the latest possible cutout date.

Does NAWF=5 signal physiological cutout for all cotton varieties?

Identification of NAWF=5 as a signal of physiological cutout was simultaneously determined by the University of Arkansas group and Dr. Tom Kerby's group in California during the early 1990s. At the time, neither group knew that the other was working on the concept, and each group used different approaches. Finding the same conclusion independently in contrasting environments with contrasting varieties increased our confidence. Since then, the validity of NAWF=5 for identifying physiological cutout has been proven throughout the Cotton Belt over multiple years in nearly all conceivable insect pest situations with all classes of cotton varieties.

In certain circumstances, is NAWF=4 a better signal of physiological cutout than NAWF=5?

The only time that NAWF=4 becomes a better signal of cutout than NAWF=5 is when cotton has experienced severe plant stress. Such stress typically causes short plant structure and small boll load. Conditions that may incite such stress include prolonged drought, competition among plants (as found in ultra-narrow row cotton), hard pans, root-knot nematode, nitrogen deficiency, etc. In such cases, flowers occurring at NAWF=4 tend to have proportionately more value. However, plants under such stress require very few days to progress from NAWF=5 to NAWF=4. Thus, changing physiological cutout to NAWF=4 has little practical value.

Can date of physiological cutout be estimated by a one-time examination of plants?

Date of physiological cutout is typically determined by the interpolation of 2 points of NAWF that encompass NAWF=5 (i.e., dates that are above and below NAWF=5). One-time examination of plants seldom will provide an accurate measurement of physiological cutout. A greater danger of a one-time examination is that the user may be measuring second growth. In this case, physiological cutout date has already occurred, and the user will be monitoring flowers that will not contribute to profitable yield.

Should physiological cutout be re-defined since boll weevil eradication and *Bt* cotton permits maturation of the "top crop?"

Boll weevil eradication and *Bt* cotton will have no effect on the physiological capacity of the plant. As its name implies, physiological cutout (NAWF=5) is a plant-based, physiological phenomenon. The validity of NAWF=5 as a signal of physiological cutout has been confirmed in several tests with *Bt* cotton and in environments void of boll weevils (including eradication zones). Since normally growing plants are unable to maintain and mature populations of bolls derived from flowers after NAWF=5, injury to the late fruit by boll weevils or the bollworm/budworm complex will not adversely affect yield of *Bt* (or non-*Bt*) cotton grown with or without boll weevils.

The seemingly logical conclusion that higher yields can always be made with more nodes and time ("chasing a top crop") is enticing but can have severe consequences. Each time that new tools to control insect pests become available, short-season concepts of cotton production tend to be abandoned. The removal of the boll weevil and the insertion of *Bt* genes do not change the basic physiology of the plant or negate the benefits of short-season cotton production. The promise of increased yield with little additional costs invariably increases risks, costs money, and provides little or no increase in yield.

Can optimal yields be obtained if physiological cutout occurs before latest possible cutout date (i.e., plants cutout too early)?

The suggestion that optimal yields cannot be obtained if physiological cutout occurs prior to the latest possible cutout date encourages growers to add inputs with hopes of increasing yields. This approach may pay off occasionally, but the risks of disaster associated with late-season weather are always increased with delayed production. Certainly, if all fields were pushed to the latest possible cutout date, then harvest could not be completed by the target date. Numerous studies have proven that cotton plants have enough fruiting sites to make ample yield in a short-season approach. In the past century, short-season concepts of producing cotton have seemed to appear and disappear at regular intervals. In the early 1900s, early production of cotton was seen as a way to escape ravages of the boll weevil, a new pest of U.S. cotton. Using short-season concepts, yields were increased and production costs declined. When new, more effective insecticides were developed, short-season concepts were abandoned—until the insects became resistant and lessened the effectiveness of the insecticide. Each time, the return to using short-season concepts to grow cotton provided increased yields with lower production costs.

Is the latest possible cutout date for effective flowering accurate for all years?

Latest possible cutout date is an average based on long-term weather data. It predicts the latest date that a flower can be expected to have enough heat units (850 DD60s) to develop into a mature boll. Since it is an average, the absolute date for latest possible effective flowering may differ in any year. If late-season weather is warmer than usual, effective flowering may occur later than the latest possible cutout date. Conversely, if cooler conditions occur (usually from an early cold front) then effective flowering may cease prior to the latest possible cutout date. Although not verified, less than 850 HU may be needed in areas where better "quality" of late-season heat units (e.g., higher light intensity, wider diurnal temperature fluctuation) is attained.

Plant Stress

What is the difference between good and bad plant stress?

Cotton plants grow in an indeterminate fashion. They continue vegetative growth after initiation of fruiting (both squares and flowers). Consequently, maintenance of a good balance of vegetative to fruiting growth is important. Typically, stress will impact vegetative growth more quickly than fruit development. Stress may occur because of bad factors (e.g., lack of moisture, temperature extremes, lack of nutrients, hard pans, diseases, root-knot nematode, etc.) or good factors (e.g., large fruit load). The impact of the bad factors is to limit vegetative growth, which will reduce the carrying capacity (fruit load) of the plant. Plants will selectively favor the demands of increasing fruit load over the demand of the vegetative growth, causing plants to progress to physiological cutout.

Does COTMAN differentiate or signal the type of stress plants are undergoing?

Slopes of observed plant growth relative to the TDC can be used to detect plant stress. The TDC tracks typical effects of good stress on plant growth. Bad stress factors will cause a very slow ascent (flatter than TDC) before flowering or a rapid descent (steeper than TDC) after flowering. Although COTMAN does not specify the type of stress, users can typically determine the source of stress by measures of fruit retention and plant vigor and by knowledge of the incipient environmental conditions.

Can COTMAN predict plant stress?

Although COTMAN does not extrapolate growth curves beyond observed data, plant growth conditions that are vulnerable to plant stress can be identified. For example, plants with very high square retention or relatively slow main-stem nodal development (i.e., few NAWF at first flower) are very vulnerable to plant stress. Such plants may cutout prematurely if hot, dry weather is experienced.

Will plant stress managed by COTMAN influence micronaire?

Plant stress may contribute to low or high micronaire. Chronic stress, which limits vegetative growth throughout the season, would likely limit maturation of bolls and cause immature (low micronaire) fiber. Acute stress, which effectively ceases vegetative growth and incites fruit abortion, may result in high micronaire. The specific effects of acute stress on micronaire depend upon the timing of the acute stress and environmental conditions following the acute stress. With early cutout, warm temperatures (especially at night) facilitate the flow of carbohydrates to support sustained fiber development, resulting in high micronaire. Plants that follow the normal development patterns of the TDC should produce inherent micronaire values associated with the cotton variety grown.

Utility of COTMAN Data

Why should a grower be interested in use of COTMAN?

Users of COTMAN should be able to reap the benefits (increased or equal yields with reduced costs and less risks) associated with short-season cotton production (*See* Chapters 10 and 11). It has been suggested that BOLLMAN provides opportunities to save money (i.e., reduce production costs) while SQUAREMAN provides opportunities to make money (i.e., increase yields). The advents of *Bt* cotton and boll weevil eradication have lessened the direct value of BOLLMAN in reducing cost of insect control. Yet, savings with regard to control of other insect pests still exist. More importantly, BOLLMAN provides information regarding end-of-season plant management and relative maturation of different fields. Although users can gain important information from SQUAREMAN, research is needed to be able to fully utilize the economic benefits of this information.

How much time does it require to collect COTMAN data?

Collection of BOLLMAN/NAWF data requires 16 to 23 minutes per field per week. Moving between sampling sites usually takes more time (and effort) than collection of NAWF data at one site. Time requirements for SQUAREMAN data are greater than for BOLLMAN data. As plants get larger, more time is required to collect SQUAREMAN data. Conversely, as plants progress to cutout, less time is required to collect BOLLMAN.

The cost of gathering COTMAN (SQUAREMAN and BOLLMAN) data has been estimated to be $1.65 per acre per season.

Can COTMAN data collected in different fields be compared?

COTMAN provides a very strong tool for comparing plant development in different fields. Variation in growth patterns may be associated with different planting dates, plant densities, soil types, varieties, irrigation, etc. An aberrant growth pattern is “normal” if abnormal conditions are experienced. Thus, fields showing aberrant or unusual growth patterns can be examined for contributing conditions. Comparison of relative maturity of different fields is an important attribute of COTMAN, because it assists with scheduling groups of fields for defoliation and harvest.

Is the role of second- and third-position fruit ignored by the COTMAN program?

The COTMAN program focuses on the first-position squares and bolls. First-position bolls typically account for at least 60% of yield and encompass the full range of fruit age (i.e., oldest and youngest fruit). Therefore, sampling based on first-position squares and bolls should provide correct management for all fruit. Fruit in second and third positions will directly affect the vegetative-to-fruiting balance of the plant and will be reflected in the observed COTMAN growth curve.

Can COTMAN be used to determine time and rate of mepiquat chloride?

The COTMAN curve tends to reflect, rather than detect, the effects of uncontrolled vegetative growth. By the time the curve suggests excessive vegetative growth, it may be too late to effectively control the growth. Direct measures of plant height in SQUAREMAN may be used to assist with plant growth regulator management (*See* Chapter 3).

How can COTMAN be used to time irrigation?

Undue, bad plant stress will likely occur if irrigation is delayed until the COTMAN curve reflects drought conditions. Therefore, other irrigation timing techniques should be utilized to time irrigation. Considerable research has been done to utilized COTMAN data to time to the last irrigation (*See* Chapter 11).

Can COTMAN’s utility be increased through additional research?

Considerable research is being conducted to validate and extend the utility of COTMAN. Some areas that have great potential to increase the utility of COTMAN are:

1. *Improved use of SQUAREMAN data*. At present, pre-flower COTMAN data are used to monitor square retention and nodal development. Little attention has been given to investigating possible remedial and enhancement treatments associated with early-season growth patterns.
2. *Incorporation of COTMAN into precision agriculture*. Precision agriculture provides the opportunity to greatly improve COTMAN sampling techniques so that variability in a field can be more accurately accessed and managed.
3. *Incorporation of COTMAN and remote sensing*. Some evidence indicates that remote-sensing techniques may someday be used to monitor plant growth. If a remote-sensing parameter that closely monitors NAWF can be found, BOLLMAN principles could be applied without physically monitoring fields.

Chapter 14:

Terminology and Concepts Related to the COTMAN Crop Monitoring System

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COTMAN™ is a computerized decision aid that integrates information on plant growth patterns, current and historical weather data, and farm and field parameters to enhance cotton crop management. Basically, COTMAN is a crop monitoring system that utilizes selected plant indicators to follow plant development and fruit load from initiation of squaring through effective flowering. COTMAN consists of two expert systems, SQUAREMAN (primarily used to monitor pre-flowering plant development) and BOLLMAN (used to monitor post-flowering plant development). This glossary of terminology and concepts associated with the COTMAN crop monitoring system is provided to explain some of the key terms used, to clarify misunderstandings, and to make the overall concept easier to understand and implement.

Terminology and Concepts

Abortion: *See* shed/shedding, damaged terminals.

Abscission: Loss of a plant structure from an abscission zone. *See* Fruit shedding, Shed/shedding.

Abscission zone: Area at the base of a leaf petiole or peduncle of a square or boll where the structure may separate from the mother plant. The abscission zone, site, or layer consists of a transverse layer of specialized cells in which the cell walls loosen and the cells expand to initiate the abscission process.

Acceptable weather risk: A choice in the BOLLMAN component of COTMAN that determines the level of risk that the user is willing to accept relative to the late-season weather. Risk is expressed as a percentage of years (based on historical weather) in which heat unit accumulation is not sufficient to mature the last effective boll population. Percentage options include 15 and 50% of years. Changing the acceptable weather risk will shift the latest possible cutout date. By accepting more weather risk (e.g., 50%), the latest possible cutout date can be shifted to a later date. However, this increases the risk that the last effective boll population will not receive sufficient heat units to mature before harvest.

Anthesis: Developmental stage of a flower when pollination occurs which leads to fertilization, generally associated with white flower.

Average internode length: Height (length) of the main stem divided by the number of main-stem nodes. *See* height-to-node ratio, internode, vigor index.

Axil: The upper angle between the petiole of a leaf and the stem from which it grows.

Boll count: Average number of bolls per sampled unit. Boll counts times boll weight provides an indication of yield potential and may be used to indicate when a desired economic boll load has been set. Bolls set on fruiting positions nearest the main stem tend to contribute most to yield, and be of a higher quality when they are retained.

Boll/fruit load: Cotton plant's capacity to retain and develop fruit within limits of its genetic constitution and the prevailing environmental conditions. As boll loading progresses, available resources are partitioned in favor of boll development and diverted from vegetative development. The genetic constitution governs the vegetative/boll relationship, and the environment governs the available resources. The term is also used to indicate when a desired economic level of bolls has been set or when additional boll set is limited by the prevailing environmental and physiological conditions of the crop. *See* Boll count.

Boll maturity: *See* Maturity.

Boll opener: A chemical, such as ethephon or Prep®, that increases the rate of boll opening at crop maturity. Boll openers are commonly used to promote efficient mechanical harvesting.

Boll retention: *See* Fruit retention.

Boll shedding: *See* Fruit shedding.

BOLLMAN: The component of the COTMAN system that focuses on management of the boll development period. BOLLMAN is an expert system that identifies the relative maturity of fields and recommends when insect control can be terminated and harvest preparation initiated. Decision rules employ the flowering date of the last effective boll population. Fields within a farm can be scheduled for harvest using BOLLMAN by comparing their respective maturity. Inputs for BOLLMAN include NAWF counts, long-term weather patterns, local heat unit accumulations, farm-specific data on harvest capacity, cotton acreage, and the user's selection of acceptable weather risk.

Canopy: The covering formed by the leaves of the plant population in a crop. Full canopy refers to the stage when the leaves of the plants in adjacent rows meet in the inter-row and shade the soil surface.

Compensation: The cotton plant's response to fruit loss in terms of new growth, additional development, or adjusted fruit retention. The nature of the compensatory response is related to the age and growth stage of the plant, and the actual mechanism is associated with carbon partitioning and the dynamics of resource allocation within the plant.

Cotyledonary node: Opposite nodes at the base of the plant where cotyledons (seed leaves) attach to the plant. When counting first fruiting node in SquareMap, the cotyledonary node is counted as node zero.

Cracked boll: First visual sign of boll opening, when the carpel walls separate along sutures.

Crop maturity: *See* Maturity.

Crop-oriented rules: Decision rule base in BOLLMAN, which is implemented when cotton is maturing early enough that end-of-season management will be based on physiological cutout rather than on seasonal cutout. Crop-oriented rules depend on the development of the crop rather than on calendar dates associated with long-term weather. *See* Weather-oriented rules.

Crop termination: A general term for the cessation of active crop growth in preparation for harvest. The termination of vegetative and reproductive growth is usually achieved with the use of chemical plant growth regulators or defoliants. *See* Cutout, Defoliant.

Cutout: A general 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. In BOLLMAN, cutout designates the end of the effective fruiting period, which may be related to the physiology of the plant (referred to as physiological cutout) or to the end-of-season growing conditions (seasonal cutout).

- **Physiological cutout:** Crop development stage characterized by an average NAWF=5. Without end-of-season constraints, physiological cutout signals the flowering date of the last effective boll population, i.e., NAWF=5 occurs before the latest possible cutout date.
- **Seasonal cutout:** When the flowering date of the last effective boll population is determined by end-of-season weather constraints rather than crop maturity. Seasonal cutout is determined in COTMAN from long-term weather patterns and called "the latest possible cutout date."
- **Premature cutout:** Early cutout associated with excessive stress, e.g., drought or nitrogen deficiency. Premature cutout will occur earlier than physiological cutout.

Damaged (aborted) terminals: Damaged main-stem tissue in the plant apex resulting in a loss of apical dominance. Plants having terminals aborted prior to first flower are avoided when using SquareMap, but will cause no procedural change for NAWF. However, NAWF counts should not be taken on a plant having an aborted terminal above the uppermost white flower.

Data logger: An electronic device for entering plant monitoring data in the field. Data are then transferred to a computer for compilation and analysis.

DD60s: *See* Heat units.

Defoliant: Any of a variety of chemicals that induce leaf abscission when sprayed on the cotton plant. Defoliants are frequently used to facilitate spindle-picking of cotton. COTMAN suggests that defoliants be applied at NAWF = 5 plus 850 heat units. *See* Crop termination, Defoliation.

Defoliation: Removal of the leaves of a plant or entire crop by abscission induced by a defoliant, crop development, weather, mechanical means, or certain insects and diseases. *See* Crop termination, Defoliant.

Degree day: *See* Heat units.

Earliness: An imprecise term used to represent the rapid development or maturation of the harvestable cotton crop relative to the available growing season. *See* Growth pattern, Maturity.

Early crop: In COTMAN, a crop that develops within the restriction of crop-oriented rules. Also, an early crop may refer to an early-planted crop.

Effective fruiting period: In COTMAN, the time between first square and cutout. Flowering will continue beyond this point, but the resulting bolls are not economical to manage, i.e., may not have acceptable retention, size, or quality.

First flower (in a field): The time when about one-half of plants in a population have developed at least one white flower, rather than when the first flower appears in the field. First flower, thus, refers to an average flowering date, and is often referred to as "50% flower." The first flower on an individual plant will normally occur on the first fruiting position from the main-stem axis on the lowest sympodium and can generally be expected to occur about 55 to 65 days after planting.

First flower (in COTMAN): The earliest time that 10 white flowers can be easily detected within a sampling site in the field. Since first flower is a signal of the change from squaring to boll development, it is important to determine when initiation has begun rather than wait until the majority of the plants are flowering (i.e., 50% first flower in a field as defined above). Interpretation of plant growth can then be made by comparing NAWF at first flower to the pinnacle of the Target Development Curve. *See* Target Development Curve.

First fruiting branch: Earliest (lowest) formed sympodial branch on the main stem, not necessarily the first sympodium with a retained fruit.

First fruiting node: Lowest main-stem node above the cotyledonary node from which a sympodial branch develops. Usually occurs at main-stem nodes 5 to 7, although this is influenced by temperature and cultural practice. Typically, the first square on the plant will appear on this sympodium at the fruiting position nearest the main stem.

First position bolls: Bolls on sympodial branches at the nodal position nearest to the main stem. Bolls in these positions usually account for at least 60% of the total yield and have the highest lint quality.

First square: The first fruiting bud to appear on a cotton plant. In COTMAN the stage of growth when approximately 33% of the plants have a visible square. The first square should appear on the fruiting position of a sympodium closest to the main stem. It is recorded as the first visible appearance of the square, although the young developing square was present in the terminal much earlier. Appearance of the first square signals the commencement of SquareMap measurements. *See* First fruiting node.

Flowering interval: The time in days or heat units between the appearance of white flowers either at adjacent fruiting positions along the same sympodium (horizontal flowering interval) or at the same fruiting position on the next higher sympodial branch (vertical fruiting interval).

Fruit load: *See* Boll/fruit load.

Fruit retention: Presence of a square or boll at a fruiting position. It is often used to refer to accumulative square or boll retention by a plant. Fruit retention refers to normal growth and development of a fruiting structure, and is the opposite of square/boll abscission, abortion, or shedding.

Fruit shedding: Physiologically induced separation of a square or boll from a plant, usually induced by some damage to squares/bolls or stress on the plant. Often referred to as abscission. Occasionally, in reference to squares or bolls, the term "abortion" is used in the same context.

Fruiting branch: *See* Sympodium.

Fruiting node: Refers to main-stem nodes producing sympodia or fruiting branches. Not to be confused with nodal positions on a sympodial branch. *See* Fruiting position, Node.

Fruiting position: A specific nodal position on a sympodium where a reproductive structure may be produced. A fruiting position may have a square, a flower, a boll, or a scar (where fruit has aborted). The majority of the yield usually comes from the first- and second-fruiting positions (prime fruiting sites) along a sympodial branch. Boll size and lint quality decrease with each fruiting position away from the main stem.

Growing degree day: *See* Heat units.

Growth pattern: Crop growth patterns in cotton are categorized by COTMAN based on the number of squaring nodes (y-axis) and days from planting (x-axis). Insight into progress of a crop may be made by comparing realized growth pattern to the standard Target Development Curve. *See* Target Development Curve.

Growing point: A mass of meristematic tissue located at a node on a main stem, monopodia, or sympodia that may give rise to a branch, branch segment, or a square. Each growing point on a cotton plant has an associated leaf (either true leaf or prophyll leaf).

Harvest (picking) capacity: An estimate, used in the BOLLMAN component of COTMAN, of the number of acres of cotton that can be picked per day.

Harvest completion date: The target date in BOLLMAN when harvest should be completed based on local perception (i.e., individual experience of the specific farm) and experience with weather patterns. *See* Historical weather database

Harvest initiation: The time when sufficient bolls are open to begin picking fields. Harvest initiation is generally sequenced among fields based on maturity.

Harvestable boll: A mature or immature boll that will open before the end of the growing season to permit mechanical harvest. Boll opening may be prevented if boll development is arrested by some factor such as excessively cool weather. Also, a harvestable boll may become non-harvestable because of boll rot, wind and/or rain damage, insect damage, or mechanical damage. A general sense of which bolls are harvestable is important in order to limit management inputs designed to protect non-harvestable bolls late in the cropping season. *See* Maturity, Open boll.

Heat units (HU): Also known as growing degree days or DD60s. A concept that utilizes temperature rather than calendar days in describing growth and development of a crop. The concept is based on a developmental temperature threshold (usually 60°F for cotton) above which the crop grows and below which little or no development occurs. Assuming no upper threshold, the basic formula for calculating heat units involves adding the maximum and minimum temperatures for each day, dividing by 2 and subtracting the threshold temperature. Calculation of the accumulated heat units and a knowledge of the heat unit requirement for any particular growth stage can be used to explain and predict the occurrence of events or the duration of stages in crop development, i.e., as a general physiological time scale of development during the season. The expected range of heat units for any particular growth stage may be influenced by deficiencies of nutrients or water, insect infestations, disease, or physical damage by weather or chemicals.

Heat units from NAWF=5: A method in BOLLMAN used to assist with end-of-season management decisions (timing final insecticide application, final irrigation, and defoliation) based on the development of the last effective boll population sequenced by heat unit accumulation. *See* Defoliant, Insect-safe bolls, Last effective flower/boll population.

Height-to-node ratio (HNR): Average internode length determined by dividing the total plant height in inches by the total number of main-stem nodes. Plant height is measured from the cotyledonary node to the uppermost main-stem node with an unfurled leaf. Number of main-stem nodes is determined by counting the main-stem node immediately above the cotyledonary node to the highest main-stem node with an unfurled leaf, or by the number of sympodia plus first fruiting node (less one) in SquareMap. The height-to-node ratio is used as an index of plant vigor. The developing fruit load reduces the height-to-node ratio.

Historical weather database: The long-term weather data used in decisions in COTMAN.

Daily temperatures from at least 30 years at a location are analyzed to determine latest possible cutout dates to allow 850 heat unit accumulation as well as average daily heat unit accumulation that can be used to project dates that the crop will achieve target heat unit accumulation after cutout is determined. *See* Heat unit, Latest possible cutout.

Insect-safe bolls: Bolls tolerant to insect feeding. The point in development when a boll becomes safe from insects. After a boll had accumulated 350 heat units, the endocarpal layer of the boll was rarely penetrated by boll weevil (*Anthomonus grandis* Boheman) or third-instar bollworm (*Helicoverpa zea* Boddie) larvae. Thus, the last effective boll population is projected to be resistant to these insects as soon as 350 heat units have accumulated from physiological or seasonal cutout.

Internode: The stem section between two consecutive nodes, i.e., the space between two successive true leaves on the main stem or a branch. *See* Average internode length.

Last effective flower/boll population: The latest developing population of fruit that has a high probability of being retained and developing into bolls having adequate size and fiber properties to substantially contribute to harvest. Flowering date of this population can be identified by NAWF=5 (physiological cutout) or by the latest possible cutout date (seasonal cutout). Management inputs to protect later flowers and bolls are usually wasted with little or no return on the investment.

Late crop: A subjective term that refers to bolls produced on the upper and outer periphery of the plant canopy, usually developed late in the season. These bolls may experience increased inclement weather and insect risks and are often small and have low fiber and seed quality. In COTMAN, bolls developed after physiological cutout or seasonal cutout are considered a late crop. Late crops can result from late planting or from excessive early fruit shedding.

Latest possible cutout date: Latest date from which accumulation of heat units required for boll maturation is probable, based upon the historical weather database and harvest completion date within a specific geographical region. This date becomes later as the user assumes a higher acceptable weather risk or more southern locations.

Main stem: The central axis of the plant consisting of a terminal meristem and a series of internodes with growing points and one main-stem leaf at each node. A typical branching pattern associated with main-stem nodes would consist of inactive growing points (i.e., no branches) at the first one to four nodes (above the cotyledonary node), monopodia on the next one to three nodes and sympodia on all subsequent nodes. In cotton, the nodes, main-stem leaves and associated sympodial branches typically arise in a three-eighth phyllotaxy around the main stem, i.e., a new leaf or branch arises every three-eighths of the circumference of the main stem.

Main-stem node: The part of the stem at which a main-stem leaf is attached. In the axil of the leaf, a monopodial or sympodial branch may arise from an axillary bud. A second axillary bud also exists in the axil and occasionally generates a second branch from the main-stem node. The highest main-stem node for practical counting purposes is considered to be where the most recent main-stem leaf has unfolded. *See* Monopodium, Sympodium.

Maturity: A term used to describe the completion of natural growth and development.

- **Boll maturity:** A mature boll is one that has sufficient nutrition (carbohydrates and mineral nutrients) to open normally if the subtending leaf is removed. The boll slicing technique may be used to determine if a boll is mature. A boll that resists cross-sectional slicing by a sharp knife (due to fiber development) is considered mature. A dark seed coat is also an indication of boll maturity.
- **Crop maturity:** Crop maturity is related to a field population of plants (in relation to their environmental potential) that has developed to the point that no additional inputs are required.
- **Fiber maturity:** Fibers that have developed sufficient secondary wall thickening so that spinning and dying processes are not adversely affected. Bolls with immature fibers may open normally and be harvested.

Monopodium (plural, monopodia): A continuous, non-segmented, vegetative branch typically arising from lower nodes of the main-stem axis (as opposed to the fruiting branch or sympodium). Monopodia do not directly bear fruit but can give rise to sympodia that may bear fruit. A vegetative branch continues to produce leaves until some stress causes it to cease growth. The number of monopodia on a plant normally varies from zero to 4 depending on plant density, cultivar, planting date, and other factors. If the terminal of a main stem is damaged, particularly early, a monopodium may assume the role of the main stem. Unless a large percentage of the crop suffers terminal abortion, these plants should be avoided in plant monitoring.

Node: A point of attachment of a plant structure (leaf or fruit) to the main stem or branches of a plant. For plant mapping/monitoring, nodes on the main stem are referred to as main-stem nodes, and nodes on the sympodia are referred to as fruiting positions.

Node of first fruiting branch: *See* First fruiting node.

Nodes above first square (NAFS): In SQUAREMAN, a measure of the number of main-stem nodes above the first fruiting node or first square. *See* Squaring nodes.

Nodes above white flower (NAWF): A measure of the number of main-stem nodes above the uppermost white flower in the first fruiting position. More precisely, NAWF is a measure of the number of squaring nodes after first flower. Used in BOLLMAN as an indication of the maturity of the boll load by reference to the amount of vegetative growth (above the uppermost white flower) relative to the reproductive growth below. The upper highest node on the main stem, for practical counting purposes, is considered to be the node at which the most recent main-stem leaf has unfolded (others have used a leaf size of 1 inch). *See* Squaring nodes.

Open boll: A boll in which the carpel sutures have dehisced and allowed the seedcotton to become exposed and dry.

Physiological cutout: *See* Cutout.

Pick: The harvest of the mature seedcotton by a spindle-type picker. Originally cotton was picked by hand, but now cotton in the United States is exclusively harvested mechanically.

Plant mapping: One of several methods used to characterize plant structure and fruiting behavior of plants by recording the location of fruiting and/or vegetative structures on the plant. Mapping techniques tend to be a single evaluation of crop status rather than a sequential series of crop characterizations, as in plant monitoring, for following crop progress.

Plant monitoring: A general term used for one or a series of interactive measurements on the plant or crop, usually made sequentially during the growing season. Management decisions are based upon thresholds and changes over sampling dates. Plant monitoring includes vigor indices, SquareMap, NAWF, petiole nutrient analysis, certain aspects of insect scouting, etc.

Plant population: An estimate of the number of plants per unit area. In COTMAN, plant population is determined by counting the number of plants in 3-foot sections of row. *See* Stand.

Premature cutout: *See* Cutout.

Prophyll: A small (about 0.2 to 0.4-inch-long by 0.1-inch-wide) petiole-less leaf formed in leaf axils, and associated with secondary axillary buds.

Regrowth: The resumption or continuation of growth that may occur after application of a harvest-aid chemical. Not to be confused with second growth.

Sample site: Location in the field where samples are to be taken. Typically, COTMAN uses 4 or more sample sites randomly selected for each field or stratum.

Sampling: Process of selecting a subset of the field population of plants to monitor for estimating the status of the entire field. Usually a fixed number of consecutive plants with relevant properties (e.g., white flowers in the first fruiting position) is sampled at each sample site.

Scar: A mark left on the stem or branch where a leaf square or boll abscised.

Seasonal cutout: *See* Cutout.

Second growth: The resumption of growth and production after cutout. Occurs primarily in regions with a long growing season. *See* Regrowth.

Shed/shedding: Separation of a leaf, square, or boll from a plant, usually induced by some stress. Occasionally, when referring to squares or bolls, the term "abortion" is used in the same context. *See* Abscission.

Simulation (crop simulation): Use of computer models, such as GOSSYM/COMAX, to mimic crop development. May be used to aid in predictions and management decisions. COTMAN does not utilize crop simulation. Instead, crop development is monitored. Various crop growth pattern scenarios relative to available growth time can be then postulated.

SQUAREMAN: The component of COTMAN that principally covers management from first square until first flower and provides a direct reflection of plant response to incipient pest and environmental stress. SQUAREMAN quantitatively measures progression of fruiting node development, fruit retention, and plant vigor. The program monitors the number of squaring nodes, plant vigor, and fruit status (number, retention, and distribution). Using SquareMap data combined with information on row spacing and date of planting, the program generates measures of plant population: total nodes; squaring nodes; fruit retention rates; vigor indices, including plant height and height-to-node ratios; days per node and elongation rates; and a graph of nodal development compared to the Target Development Curve.

SquareMap: An in-season plant monitoring technique used to assess fruiting node development and fruit retention. The data are used in SQUAREMAN. SquareMap is primarily used from first square to first flower but may be continued until cutout. Required inputs include once-per-season measurements of stand density and first fruiting node number and sequential (once or twice per week) plant maps denoting the presence or absence of squares in the first fruiting positions and plant heights.

Squaring nodes: Collective term for NAFS (prior to first flower) and NAWF (after first flower). Squaring nodes are a measure of the number of sympodia above the first-position oldest square/youngest flower throughout the effective fruiting period and is equal to the number of sympodia arising from the main stem that are too young to have developed first-position flowers. Monitoring of squaring nodes may begin after the first squares become visible and continue until cutout. As the first square progresses to the white flower stage, the pace of plant structural development can be charted and compared to the target development curve. *See* Target Development Curve.

Square shedding: *See* Abscission, fruit shedding.

Stand (effective stand): Stand generally refers to the number of plants per area, e.g., plants per acre. Effective stand must consider not only the number of plants, but also uniformity of plant distribution, length of skips, and plant health. *See* Plant population.

Stratum: Division of a field to enhance sampling designs. For representative sampling, each field may be divided into 4 or more strata with larger samples taken from strata with the greatest production management problems and/or plant diversity.

Sympodium (sympodia): A segmented fruiting branch in cotton upon which the flowers and resulting bolls arise. This is in contrast to monopodia, which are vegetative stems, including the main stem, that do not give rise to bolls directly. A sympodium is "zig-zag" shaped with each section terminating in a node with a true leaf and a potential fruit.

Target Development Curve (TDC): A benchmark or standard growth development curve in COTMAN, which is based on number of squaring nodes plotted by days from planting. It is used in COTMAN as a standard for comparing actual growth curves. The TDC assumes 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 and reaches NAWF=5.0 at 80 days after planting, with an average descent of 0.2125 nodes per day. Inferences regarding plant growth status and management decisions can be determined by comparing monitored patterns of squaring nodes to the TDC.

Terminal: Usually refers to the growing point in the plant apex but may also include the outer growing points of monopodia and, in some cases, sympodia. These growing points consist of meristematic tissue of multiple main-stem, monopodial, and sympodial nodes.

Terminal node: Uppermost main-stem node on which the main-stem leaf is unfurled.

Unfurled leaf: The condition when a young developing leaf expands such that the unfolding edges no longer touch each other. The upper highest node on the main stem, for practical counting purposes, is considered to be the node at which the most recent main-stem leaf has unfolded. Others have used a leaf diameter of 1 inch.

Vegetative branch: *See* Monopodium.

Vegetative node: Main-stem nodes between the cotyledonary node and the first fruiting node. When a vegetative node infrequently arises above the first fruiting node, the plant should be excluded from SquareMap. *See* Fruiting node.

Vigor index: A measure of early-season growth of cotton plants, typically by evaluating plant height over time or plant height in relation to the number of main-stem nodes, e.g., height-to-node ratio. Other parameters used in assessing vigor index include elongation rate (change in height occurring between two sample dates divided by change in number of main-stem nodes) and length of the uppermost 5 main-stem nodes. These parameters are attempts to determine the rate of growth of the most recently developed nodes.

Weather-oriented rules: Decision rule base in BOLLMAN used when physiological cutout does not occur prior to the latest possible cutout date. End-of-season management must then be based on calendar dates associated with long-term weather data (seasonal cutout) rather than the physiological development of the crop (physiological cutout). *See C*rop-oriented rules.

White flower: A cotton flower with white petals that occurs on the day of anthesis (pollination). On the day prior to anthesis, the unopened flower is referred to as a candle; on the day following anthesis, the flower petals turn pink, then red.

Appendices

Diana M. Danforth

A. COTMAN Software: Request for Modification

B. COTMAN 2004 Order Form, Version 2 (4.3.18)

C. First Fruiting Node (FN) Data Collection Form

D. Nodes Above White Flower (NAWF) Data Collection Form

E. SquareMap Data Collection Form

F. Stand Density Collection Form

G. Heat Unit Chart

COTMAN Software: Request for Modification

Person/group Request date

E-mail Phone

Type of modification

☐ Add/change user options or interface

☐ Add/change a report calculation or evaluation

☐ Add/change data requirements

☐ Add/change a guideline

Brief change description:

Fully describe requested change, including data requirements and calculation details. Provide illustrations where appropriate. Attach additional documentation if necessary.

Provide justification for request. If requesting a calculation or evaluation change, provide supporting research results.

COTMAN™ 2004 Order Form, Version 2 (4.3.18)

Please take a moment to update our records. Accurate reporting is critical for our ability to continue providing the COTMAN software free of charge. We ask that you don't share the software. Instead, make a separate request for other users. If you must share, please provide registration information for the additional users.

Return to COTMAN Order 2004
University of Arkansas
Department of Agricultural Economics and Agribusiness
Agriculture 217
Fayetteville, AR 72701

FAX: (479) 575-5306

User contact information

Name ____________________________ Title ____________________________

Organization ______________________________________

Mailing Address ____

____

City ______________________________ State ____________ Zip _____________

Phone (   ) FAX (   )

Email: ____

COTMAN experience of primary user *(choose only one answer)*

- ○ Evaluating for possible use
- ○ New user (first season)
- ○ Experienced user (1–3 years)
- ○ Veteran user (4 or more years)
- ○ Other ________________________
____

2004 planned COTMAN use *(answer all that apply)*	**2003 COTMAN use** *(answer all that apply)*
☐ Research trials, public sector # trials _____	☐ Research trials, public sector # trials _____
☐ Research trials, private sector # trials _____	☐ Research trials, private sector # trials _____
☐ Individual farm # acres ______ # fields___	☐ Individual farm # acres ______ # fields ____
☐ Private consulting # acres _____ # farms ___	☐ Private consulting # acres _____ # farms ___
☐ Extension consulting # acres _____ # farms ___	☐ Extension consulting # acres _____ # farms ___
☐ Extension demonstration # farms ___	☐ Extension demonstration # farms ___
☐ Classroom, workshop and other formal education	☐ Classroom, workshop and other formal education
☐ Will not use in 2004 (evaluating only)	☐ Did not use in 2003

Comments:

First Fruiting Node (FN) Data Collection Form

		Row 1: Plant Number					Row 2: Plant Number					Site Mean FN (sum/10)
	Site	1	2	3	4	5	1	2	3	4	5	
Farm	1											
	2											
Field	3											
	4											
Date	5											
	6											
	7											
	8											
	Field Mean FN (sum of site means/number of sites)											
Farm	1											
	2											
Field	3											
	4											
Date	5											
	6											
	7											
	8											
	Field Mean FN (sum of site means/number of sites)											
Farm												
Field												
Date												
	Field Mean FN (sum of site means/number of sites)											

NAWF Data Collection Form

		Plant Number									
	Site	1	2	3	4	5	6	7	8	9	10
Farm	1										
	2										
Field	3										
Date	4										
	5										
	6										
	7										
	8										
Farm	1										
	2										
Field	3										
Date	4										
	5										
	6										
	7										
	8										
Farm	1										
	2										
Field	3										
Date	4										
	5										
	6										
	7										
	8										

SquareMap Data Collection Form

	Site-Row	Ht (in.)	Plant 1 1 2 12345678901234567890	Plant 2 1 2 12345678901234567890	Plant 3 1 2 12345678901234567890	Plant 4 1 2 12345678901234567890	Plant 5 1 2 12345678901234567890
Farm	1-1						
	1-2						
Field	2-1						
	2-2						
	3-1						
Date	3-2						
	4-1						
	4-2						
	5-1						
	5-2						
	6-1						
	6-2						
	7-1						
	7-2						
	8-1						
	8-2						

Stand Density Collection Form

Farm:				
Field:	Date:			
	Site			
Row	1	2	3	4
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				

Stand Density Collection Form

Farm:				
Field:	Date:			
	Site			
Row	1	2	3	4
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
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20				
21				
22				
23				
24				

Heat Unit Chart

	Temperature		Daily	Fields, list sequentially as cutout is reached									
Date	High	Low	DD60 [1]										

---

[1] *DD60 = [(High +Low) / 2] - 60; Values <0 should be noted as "0"*

COTMAN™

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DIVISION OF AGRICULTURE

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