Chapter 2:

Initial Development of the COTMAN Program

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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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