Integrated Crop Management

Overview

Cotton has been part of the fabric of human existence for thousands of years. This crop's long and colorful past has shaped world history as countries expanded its production to fuel demands of the industrial revolution. The diverse and challenging conditions of cultivating this crop have provided a strong thread to the modernization of farm equipment and practices shared today by many other important commodities. The uniqueness and diversity of cotton ensures this crop's enduring importance and consistency in world markets well into the 21st Century.

Cotton not only produces the natural fibers used in textiles and clothing, but also yields a high grade vegetable oil, multiple cellulosic byproducts, and whole seeds used as a primary source of fiber and protein in animal rations. Botanically, cotton is a perennial shrub and in tropical regions, cotton grows year around. In more temperate regions such as the US Cotton Belt, cotton is grown and managed as an annual crop (Fig. 1). There are two major types of cotton grown that meet the needs of global fiber markets. The most extensively grown types are the "Upland" cottons (*Gossypium hirsutum*). The second group is the Extra Long Staple (ELS) types (*Gossypium barbadense*) also know as Pima, Sea Island and Egyptian cottons. Upland type cottons are more adaptable to growing conditions, whereas the ELS types are associated with production areas which have longer growing seasons. In the United States, ELS production has been predominantly in the irrigated western states of Texas, New Mexico, Arizona and California.

The perennial nature of cotton allows producers to manipulate its growth and development to optimize seed and fiber production. This basic principle applies to all cotton producers regardless of their location and the production strategies or technologies utilized. Strategies used to manipulate the crop can vary greatly and often allow the producer to be adaptive to local and regional conditions. However, some circumstances force decisions that can limit a producer's options. Certain decisions, besides the basics of seed selection and planting sites, must be effectively evaluated and addressed. Growers should carefully consider prices (current and future), seasonal water availability, nutrient requirements, pest control options, harvest and ginning as major production components. A good assessment of these steps prior to planting will greatly enhance the success for a given season. Errors or misjudgments in these key decisions will linger the entire season and limit potential yields (Hake *et al*., 1996).

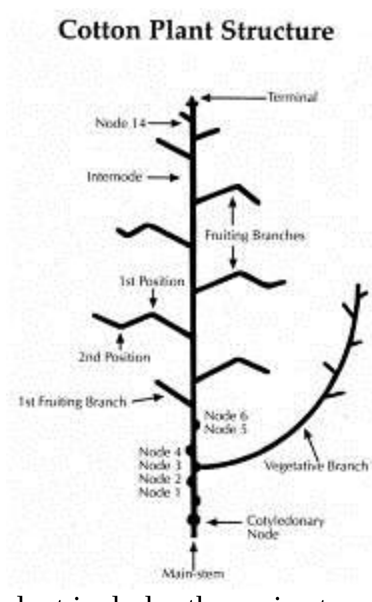

Figure 1. The basic structure of a cotton plant includes the main stem, which is made up of a series of nodes and internodes, and two types of branches, vegetative and fruiting branches (NCC, 1996).

The season can be divided into specific phases each offering different management challenges that can impact subsequent growth and final results (Fig. 2). Early-season phase is characterized by planting conditions, which is extremely important in establishing the stand. This phase represents early seedling and root growth and is entirely vegetative. Next is the reproductive phase that begins with the initiation of fruiting structures, called squares that develop into blossoms or flowers and then into bolls. This phase normally begins 35 days after planting.

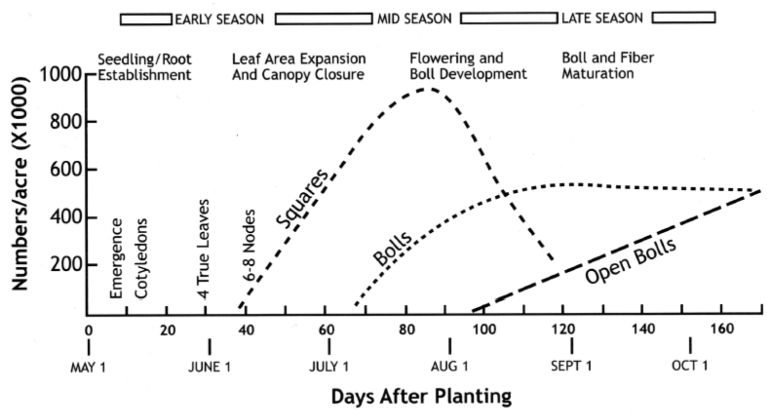

Figure 2. Seasonal development of cotton in the Mid-South with a May 1 planting date, showing typical production patterns of squares, bolls and open bolls (Oosterhuis, 1990, with permission ASA).

The reproductive phase is influenced by accumulating boll load as squares develop into mature bolls. Maturing bolls have a strong demand for photosynthate and they compete directly with vegetative growth. Important phenological distinctions that occur during this development period are “first flower”, “peak bloom” and “cutout”. First flower is determined when over 25 percent of the field’s plant population has a first position bloom. Peak bloom occurs approximately 20 to 30 days following first flower and represents the stage of growth where the plant is flowering at first, second and even third fruiting positions on the main stem branches making up the top third of the plant. Cutout is the point following peak bloom, where the plant’s photosynthic energy, going into developing bolls, exceeds that necessary to maintain vegetative growth. Following cutout, most of the plants energy is directed to maturing bolls (Kerby and Hake, 1996). The final late-season phase is characterized with the opening of mature bolls and the crop being prepared for harvest. This is often facilitated with the use of harvest aid products which enhance leaf drop and boll opening.

Establishing a stand and getting the crop off to a good start can be challenging during the early-season when above-ground growth may get off to a slow beginning. This slow establishment makes cotton a poor competitor through much of the early vegetative growth stage. However, with favorable growing conditions, vegetative growth can become excessive as the plant begins to square if growth is not managed. Maintaining the proper balance between vegetative and reproductive growth is essential for high yields, especially in situations where the length of the growing season limits production. Plant monitoring and field scouting the entire season is essential to ensuring management strategies are implemented in a timely manner (Landivar and Benedict, 1996; Oosterhuis *et al.*, 2008). Failure to accomplish the execution of many cultural practices by as little as two or three days can make the difference between a great cotton crop and a good one. During the reproductive phase it is important to maintain good square retention and vegetative growth in order to develop the plant’s structure necessary to achieve optimum yield goals. At first flower, a common management goal is to have first position square retentions above 80 percent and nine to ten nodes above first position white flower (NAWF) (Robertson *et al.*, 2008). Properly managing early square retentions at this level and potential reproductive nodal development has been closely associated with higher yields at the end of the season (Mauney, 1986; Kerby and Hake, 1996,). Square retention values prior to first flower are generally most impacted by insects (Leigh *et al.*, 1988). Plant squaring and nodal development which contributes to NAWF, prior to flowering is negatively impacted by stress. Soil fertility, moisture, and early-season pest damage are generally the dominant stress factors impacting plant structure prior to flowering (Kerby and Hake 1996; Roberts and Rechel, 1996). Square retention values less than 80 percent at first flower can often result in delayed maturity and excessive vegetative growth due to the lack of adequate fruiting forms during boll development. Boll weevil eradication efforts and insect-related transgenic technologies in some regions have helped to reduce the occurrence of low retention rates throughout squaring as well as into the flowering cycle. Retention rates of 90 percent or greater can present logistical challenges to producers because margins of error for input requirements are small. High retention values coupled with poor plant structure can result in premature cutout, which significantly impacts potential yields (Robertson *et al*., 2008). Physiological cutout is the condition where the plant's total photosynthetic production is being allocated to developing bolls and vegetative growth temporarily stops or slows significantly. Square loss as a result of environmental stress can be extenuated in situations where retention rates are very high (Mauney, 1986).

Managing inputs to achieve nine to ten NAWF at first flower will result in the plant having the growth capacity to avoid premature cutout in most instances (Oosterhuis *et al*., 2008). Fields in which NAWF values are in a range of six to seven often require more immediate action to alleviate stress to avoid premature cutout. These NAWF differences can be translated into 12 to 15 days of mid-season growth (Constable, 1991; Kerby and Hake, 1996). To optimize yields, high retention values will magnify the urgency to relieve the stress in this situation. As a rule, early or more determinate varieties are more sensitive to having adequate growth capacity or "horsepower" at first flower to achieve desired yield potential than later maturing varieties. Being on track at first flower, or taking corrective actions to get back in line shortly thereafter, is necessary to achieving high yield goals. Beginning at first flower, NAWF counts recorded weekly can help establish the last effective boll population or the last group of bolls that will contribute significantly to yield and profit (Fig. 3) (Bourland *et al*., 1992: Oosterhuis *et al*., 2008). Identifying the last effective boll population is essential for making end-of-season decisions. Cutout is reached when NAWF counts become less than five or when the probability of accumulating sufficient heat units to mature a flower falls below a user defined threshold (Kerby *et al*., 1987). Crop termination guidelines may be keyed on heat unit accumulation beyond cutout based on when bolls can be considered safe from insect damage and when terminating irrigation and the initiation of harvest aids do not significantly impact yield and quality (Helms *et al*., 2007; Leonard *et al*., 2008). It is vital for producers to continually strive to stay current with the latest research concerning the growth and development of cotton to better understand and predict the needs of the plant to produce seed and fiber more efficiently and profitably.

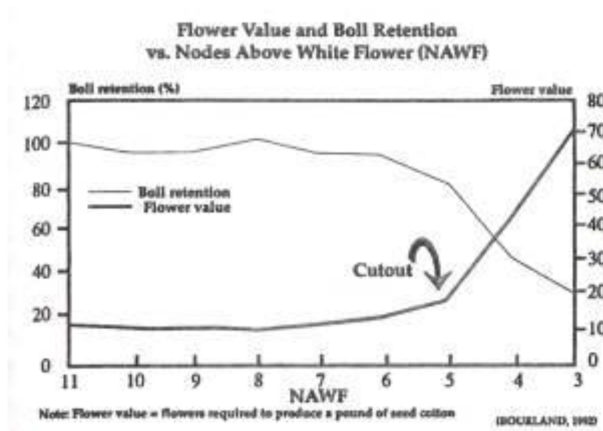

Figure 3. Identification of cutout (NAWF=5) based on boll retention rates and number of flowers a producer must protect to produce a pound of seed cotton (Bourland, 1992).

Growth and Development of a Cotton Plant

The cotton plant has perhaps the most complex structure of all major field crops. Its indeterminate growth habit and extreme sensitivity to adverse environmental conditions is unique. The growth of the cotton plant is very predictable under favorable moisture and temperature conditions. Growth follows a well-defined and consistent pattern expressed in days. Another useful and more precise way to assess crop development relies on using daily temperatures during the season to monitor progress (Table 1). The heat unit concept utilizes accumulated hours above a critical temperature rather than calendar days in describing growth and development. The growing degree days (DD) concept is based on a developmental threshold above which the crop grows. Below that temperature is where little or no development occurs. For cotton, the threshold temperature is 60˚F; therefore, the degree days are referred to as "DD60's". The basic formula for calculating heat units involves averaging the maximum and minimum temperatures for each day and subtracting the threshold temperature. Calculation of the accumulated heat units and knowledge of the heat unit requirement for any particular growth stage can be used to explain and predict the occurrence of events or duration of stages in crop development (Kerby *et al*., 1987; Landivar and Benedict, 1996; Oosterhuis, 1990).

Table 1. The average number of days and heat units required for various growth stages of cotton in the Mid-South.

Growth Stage	Days	Heat Units – DD60s
Planting to Emergence	4 to 9	50 to 60
Emergence to First Square	27 to 38	425 to 475
Square to Flower	20 to 25	300 to 350
Planting to First Flower	60 to 70	775 to 850
Flower to Open Boll	45 to 65	850 to 950
Planting to Harvest Ready	130 to 160	2200 to 2600

Modified from Oosterhuis, 1990

Stages of Growth

The developmental phases for cotton can be divided into five main growth stages: (1) germination and emergence (2) seedling establishment (3) leaf area and canopy development (4) flowering and boll development and (5) maturation (Fig. 1). The transitions between these stages are not always sharp and clear. Each stage may also have different physiological processes operating within specific requirements. If producers are aware of these stage-dependent differences in cotton growth and requirements, then many problems in crop management can be avoided, which will result in higher yields and profits.

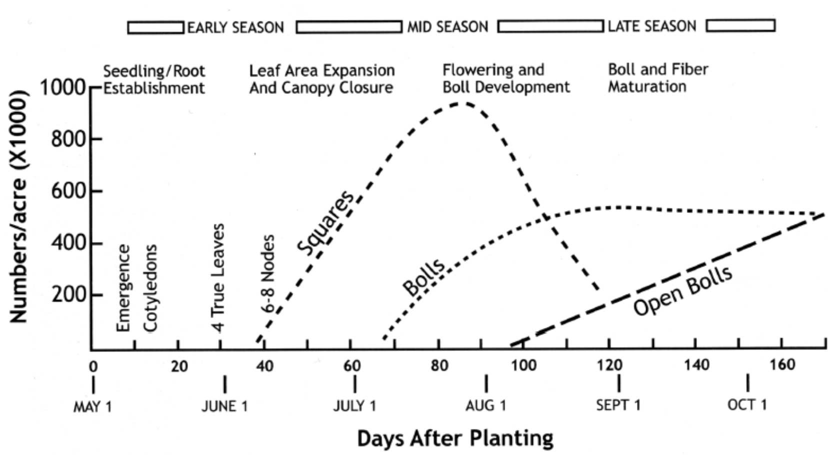

Figure 1. Seasonal development of cotton in the Mid-South with a May 1 planting date, showing typical production patterns of squares, bolls and open bolls (Oosterhuis, 1990, with permission ASA).

Root Development

Under favorable germination conditions, the radicle (root) emerges within two to three days. The radicle becomes the taproot that grows downward into the soil. The taproot penetrates the soil rapidly after germination and may reach a depth of up to 10 inches or more by the time the cotyledons unfurl (5 to 7 days, 50 DD60s) (Fig. 2). Root development during the early vegetative stage may proceed at the rate of 0.5 to 2.0 inches per day, depending on soil temperature and moisture conditions (Huck, 1970; McMichael, 1986).

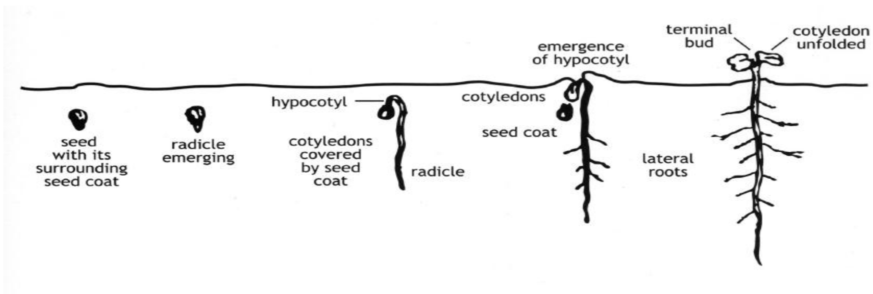

Figure 2. Stages of germination and seedling emergence (Oosterhuis, 1990, with permission ASA).

The roots may be 3 feet deep in some soils when the above ground portion of the plant is only about 14 inches (Fig. 3). The taproot may penetrate the soil from less than 1.5 feet to as much as 9 feet while the lateral roots remain fairly shallow, less than 3 feet (McMichael and Quisenberry, 1993). On deep alluvial and irrigated soils in California, roots reach a depth of 3 to 4 feet when the young plants are only 8 to 10 inches high, with a final depth at maturity of 9 feet (Grimes *et al*., 1972). The bulk of the root system is located in the upper 3 feet, but this is dependent upon the soil moisture, soil physical structure and vigor of the individual plant (Taylor and Ratliff, 1969; Pearson *et al*., 1970; Taylor and Gardner, 1983). The total root length continues to increase as the plant develops until the maximum plant height is achieved and fruit begins to form. Total root length begins to decline as older roots die. Furthermore, root activity begins to decline as the boll load develops and carbohydrates are increasingly directed toward developing the fruit (McMichael, 1986).

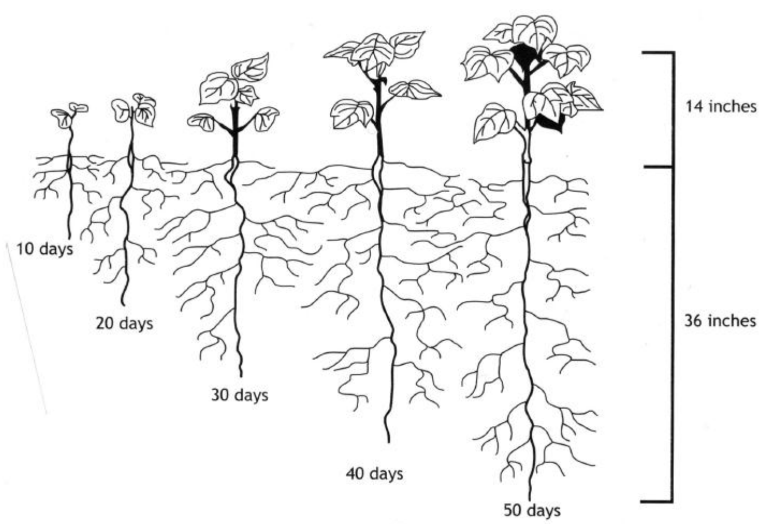

Figure 3. Early-season root development of cotton (Oosterhuis, 1990, with permission ASA).

Vegetative Development

Under favorable conditions for germination, cotton seedlings emerge five to ten days after planting or after 50 to 60 DD60s are accumulated. The fully expanded cotyledons are 1 to 2 inches above the soil surface and are arranged directly opposite the main stem. The cotton plant has a very prominent main stem, which results from the elongation and development of the terminal bud or apical meristem. The main stem consists of a series of nodes and internodes and has an indeterminate growth habit (Fig. 4). Much of the early development of the cotton plant is directed by the development of a substantial root system while growth of the first true leaves is relatively slow. The number of nodes and the length of the internodes are influenced by genetics and environmental factors such as climate, soil moisture, nutrients, disease and insects. The appearance of a new node for relatively non-stressed cotton occurs after an additional accumulation of 50 to 60 DD60s (Kerby *et al*., 1987; Oosterhuis, 1990).

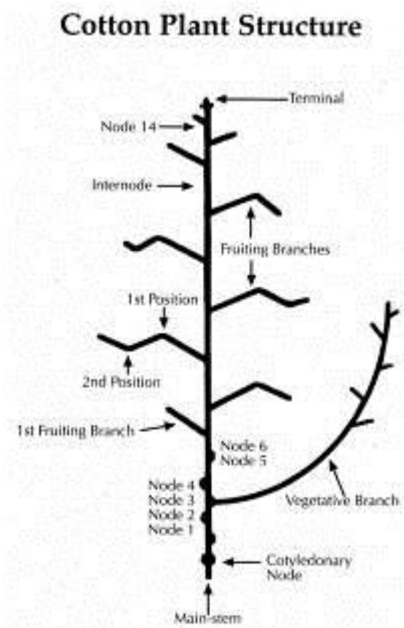

Figure 4. The basic structure of a cotton plant includes the main stem, which is made up of a series of nodes and internodes, and two types of branches, vegetative and fruiting branches (NCC, 1996).

The developmental rate of a new node is significantly slower when the plant is water stressed. Typically this produces shorter stature plants. Nodes give rise to main stem leaves and branches. Main stem leaves and branches are spirally arranged on the stem in a three-eighths phyllotaxy above the cotyledonary node. Two types of branches are produced: monopodial are the vegetative branches and sympodial are the fruiting branches. Monopodial branches are structurally similar to the main stem. Growth is from a single terminal bud and tends to grow in an upright position. Sympodial branches are produced by the main stem and monopodial branches and grow at an acute angle to the main stem. Every sympodial branch has a main stem leaf associated with the branch. As the branch extends from the main stem, each new fruiting node has an extending leaf and a fruiting structure or square at each node. Elongation of the internode behind the flower bud and leaf causes them to extend away from the main stem. The development of this branch terminates in a square, but a second leaf and square develop in the axil of the first leaf and similarly extend away from the first leaf and square by internode elongation. Repetition of this process produces several squares and leaves resulting in the typical zigzag appearance of the fruiting branch. The flowers are opposite the leaves on the sympodial branches and develop more rapidly than monopodial branches.

Final plant height is also a function of the extension of main stem nodes. Within cotton varieties, the seasonal total numbers of main stem nodes is strongly influenced by determinacy and growing environment. Cotton breeding and selection for earliness has favored shorter statured, more determinant cotton varieties. However, management factors such as excessive nitrogen fertilizer and excessive square loss from insect feeding can cause even moderate stature plants to grow excessively tall and rank (Siebert *et al*. 2006).

Reproductive Development

Signs of reproductive growth begin to appear about four to five weeks after planting with the formation of the floral buds or squares in the terminal of the plant (Table 1). Cotton has a distinctive and predictable fruiting pattern. Once fruiting begins, fruiting branches tend to be produced at each successive main-stem node. The first fruiting branch is often produced at the sixth or seventh node on the main stem. Approximately three days elapse between fruit on a given fruiting branch and the same relative position on the next higher branch. The time interval for the development of two successive fruiting forms on the same sympodial branch is approximately six days (Fig. 5). Squaring is followed about three weeks later by flowering and the start of boll development. The time requirement for a square to develop into a white flower is not influenced significantly by external conditions or plant stress. Throughout the remainder of the season, the cotton plant, due to its indeterminate growth habit, will continue adding vegetative growth at the same time as the reproductive development. The occurrence of the first position white flower moves closer to the terminal of the plant as the developing bolls become the major sink for photosynthate, which in turn also results in the slowing of new node or square development (Robertson *et al*., 2007a).

Table 2. Timing of various events during square development relative to the flowering date of an individual fruiting structure.

Days Before Flower	Size of Bud	Comments
40	Microscopic	Square initiation can occur as early as 2nd true leaf expansion. Hot weather induces four-bract squares, cool weather delays square initiation.
32	Microscopic	Lock numbers determined. Carbohydrate stress decreases number from 5 to 4.
23	2 mm PHS	Ovule number determined. Carbohydrate stress decreases potential seed number.
22	2 mm PHS	Pollen cells divide.
19	3 mm MHS	Pollen viability reduced by high nighttime temperatures.
5	13 mm	Squares start expanding rapidly
3	17 mm	Fibers begin to form
0	Flower opens White flower	Pollen sheds and fibers start to elongate. Extremes of humidity or water disrupts pollen function

Modified from Stewart, 1986

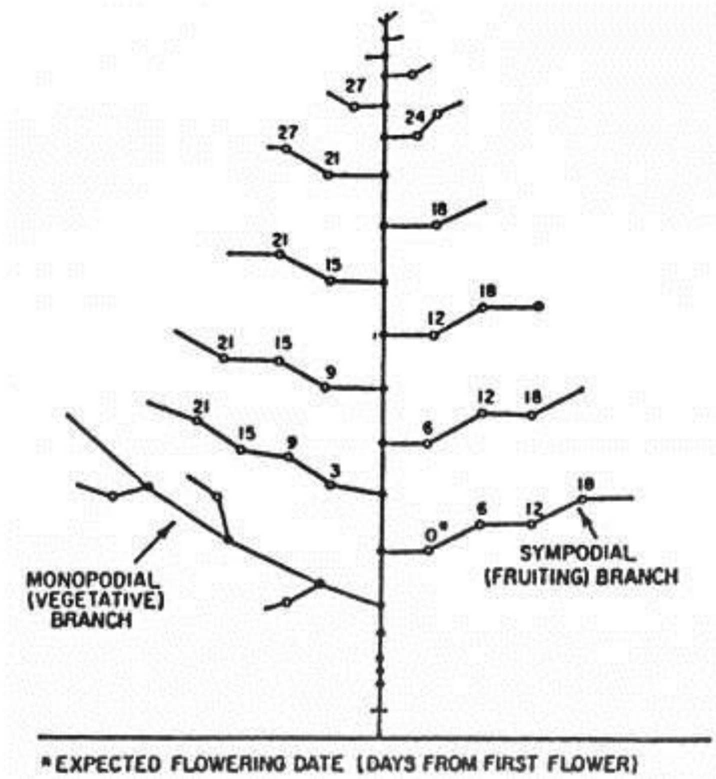

Figure 5. Expected flowering interval in days beyond first flower illustrating the three day age difference in flowering dates of the same fruiting position on the next higher fruiting branch and the six day difference in age between fruiting positions on the same branch (Oosterhuis, 1990, with permission ASA).

The boll develops rapidly after fertilization and reaches its full size within three weeks (Fig. 6). An additional four to five weeks are required for boll maturation. Seeds attain their full size about three weeks after fertilization, but do not reach maturity until shortly before the boll opens. Fibers attain their full length in about 25 days after fertilization with the maximum growth rate occurring during the first 10 to 15 days of this period. Thickening of the fiber begins at about 16 days after fertilization and continues until the boll is mature.

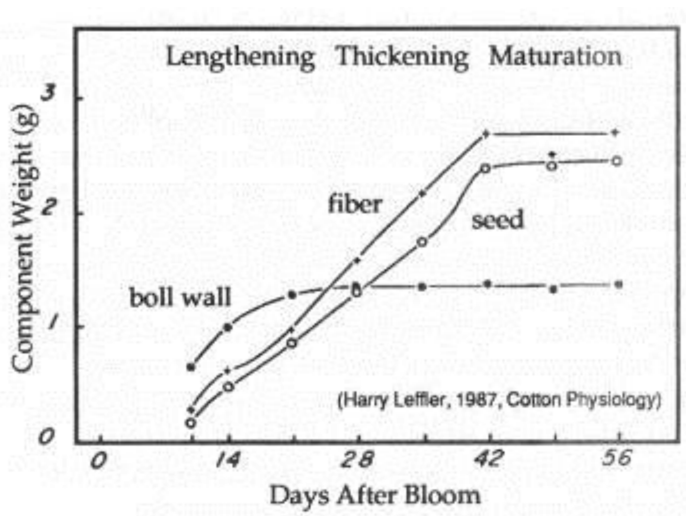

Figure 6. Although bolls are full size 21 days after flowering, fiber and seed development requires an additional 28 to 35 days (NCC, 1996).

Fiber thickening occurs by the daily deposition of consecutive layers of cellulose on the inner wall of the fiber in a spiral fashion. The degree of thickening and the angle of the spirals affect fiber strength and maturity. Fiber elongation and maturity can be impacted by numerous factors from fertilization to maturity (Table 3). Until the boll opens, the fiber is a living cell, but upon opening the fiber is exposed to the air and soon dries out and becomes twisted (Seagull, 2001). In addition to the long fibers, most commercial cultivars (excluding *Gossypium barbadense*) have very short white or colored fibers on the seed called linters or fuzz fibers.

Table 3. Timing of various events during boll development relative to flowering and primary factors influencing the event.

Days After Flower	Event	Primary Factors Influencing the Event
-2 to 12	Fiber density on seed surface	Temperature and carbohydrate status
0	Pollen shed	Temperature and relative humidity
0 to 3	Rate of fiber initiation	Temperature and potassium status
0 to 3	Pollen tube growth and seed fertilization	Temperature and relative humidity
1 to 14	Boll abscission	Plant water and carbohydrate status
3 to 25	Fiber length and seed number	Temperature and potassium status
15 to 45	Fiber cellulose (fiber thickening)	Temperature
25 to 50	Protein and oil accumulation	Temperature, plant water, nitrogen and potassium status
49 to 50	Boll opening	Temperature and relative humidity

Modified from Stewart, 1986

Cotton quality is defined by the length, maturity, strength and micronaire of the fiber. These qualities are determined by the genetic makeup of specific plant varieties, the climatic conditions experienced by the crop, and the management of the crop through production and harvest (Table 4). For example, bolls maturing late in the season, when temperatures are lower, require a longer period for fiber growth and development and usually produce less lint often of lower quality.

Table 4. The degree of variability in fiber quality parameters as influenced by the genetic makeup of the variety and the environment (weather and management) during the growing season (NCC, 1996).

Fiber Quality Parameter	Genetics (%)	Environment (%)
Staple	82	18
Micronaire	41	59
Color	21	79
Strength	90	10

The relative importance of the fruiting positions oriented from the main stem along a sympodial branch varies, i.e., the first, second and third sympodial positions contribute about 60, 30, and 10 percent of the total seed cotton yield, respectively (Bednarz *et al*., 2000; Jenkins *et al*., 1990). The lint quality tends to also decrease away from the main stem. The likely production problems occurring during the maturation stage include low temperatures and slow upper-canopy boll development, which can increase boll rot, delay harvesting, reduce the efficacy of defoliants and boll openers, and lower quality lint.

The growth and development of the cotton plant follows a typical sigmoid curve with a relatively slow start during emergence and root growth, followed by an exponential increase in growth rate during canopy formation, flowering, boll development and slowing down during the boll maturation phase (Fig. 7). Both genotype and environment affect this pattern. Nevertheless, a general and predictable pattern of growth exists for the cotton plant (Hearn, 1994, Jones and Wells, 1997).

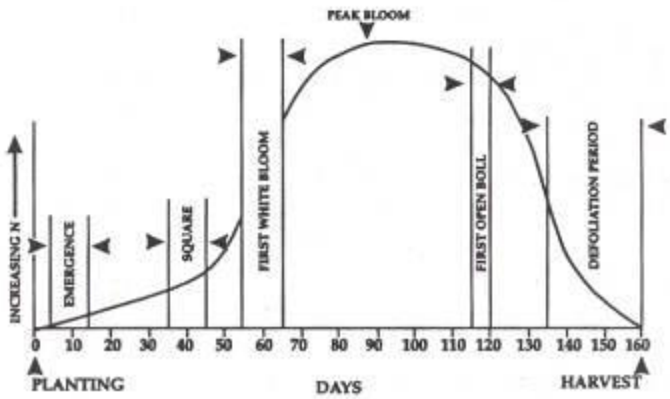

Figure 7. The growth and development of the cotton plant follows a typical sigmoid curve (NCC, 1996).

Understanding cotton growth and development is critical in order to implement sound management strategies for maximum yields and profits. Cotton is a perennial plant with an indeterminate growth habit and has a very dynamic growth response to environment and management. Site-specific management strategies need to be taken into consideration to optimize yields. Furthermore, management strategies should be flexible to allow for changing environmental conditions.

Establishing the Crop

Establishing a healthy stand of cotton is the first step toward a successful season. Cotton does not tolerate difficulties encountered during its first weeks of growth. An important accomplishment toward a successful season is achieved when cotton actually begins to grow the first true leaf. Advances in planting equipment, improved cultural practice techniques and technological improvements in seed quality and chemical protectants have enhanced the potential to obtain a healthy and uniform stand of seedling cotton. Nonetheless, lack of attention to detail, poor planting conditions or overconfidence is a formula for failure.

Getting a Good Start

Decisions regarding equipment, tillage systems and row spacing for cotton can be influenced at the farm level depending on rotation and other cultural practices employed. Other decisions such as variety selection and plant population can be field specific. Regardless of production strategies in place, substantial costs are often incurred by the producer before a seed has been planted. Doing the right thing at the right time is important. However, having a good plan does not ensure success as soil moisture and temperature levels influenced by weather conditions following planting can be unpredictable.

Equipment and Tillage Systems

Modern equipment offer growers a way to better match tillage systems to soils which allow for timelier soil preparations and planting in various soil types. For example, new planters are capable of precise placement of the seed. No-till, strip-till, and stale seedbed systems enable producers to plant when soil conditions are closer to optimum, rather than having to wait until fields can be tilled conventionally for planting. Additionally, winter cover crops are often used in no-till and strip-till systems to provide seedlings with protection from wind and sand. Establishing a uniform cover crop with few skips is important to ensure that the cover crop is weed-free and more easily terminated.

In most no-till and strip-till systems, burndown herbicide applications are made in early spring to facilitate planting into fields with a cover crop. A follow-up herbicide (post-plant pre-emergence) is often required at or immediately after planting to manage escapes and newly emerged vegetation. Early season insect pest problems, sometimes associated with cover crops such as wheat or rye, are often the result of pest populations increasing on broadleaf weeds found in the cover crop. Timely burn-down herbicide applications can be effective in eliminating the buildup of pests in weeds while continuing to allow cover crop residue to provide wind and sandblasting protection as well as preserve soil moisture for planting. After emergence, weed control is similar to that used in conventional tillage methods except that mechanical cultivation is avoided, if possible (National Cotton Council of America, 2007).

Stale seedbed producers prepare beds in the fall following harvest and leave them fallow until spring planting. The objective is to prevent planting delays that can occur when spring tillage is done on heavy soils. Tillage operations are avoided after the fields are bedded in the fall until planting time in the spring. Burndown herbicides are the sole means of native vegetation control. The lack of compaction from tillage operations improves soil structure and internal drainage which is often one of the most limiting factors for cotton on heavy soils. At planting, a thin layer of dry soil is removed from the top of the bed for optimum seed placement and planter operation. Producers sometimes can plant directly on the stale seedbed depending on moisture conditions.

Subsoiling fields that have plow pans can improve water and root penetration. This practice is generally done prior to fall bedding or in the spring before planting. Subsoiler shanks set to a depth of 16 to 18 inches will loosen compacted layers. Subsoilers are available that will address problem plow pans while minimizing disturbance to surface residues.

Reducing tillage trips in conventional systems can save fuel and lessen the potential for compacting soils. If fields are not rutted excessively at harvest, producers may re-shape the old beds for planting the following season if plow pans are not a problem. Excavating the cotton roots of the previous crop can provide clues as to the existence of a plow pan.

Cultural practices aimed to prevent the over-wintering of pink boll worms in some areas require the post-harvest destruction and incorporation of cotton stalks every fall. This requirement is mandated by law and every field is inspected to meet plow-down specifications. The adoption of reduced tillage practices has forced some changes in the degree of incorporation allowed. Stalks must be shredded and undercut to insure no spring regrowth will occur. The fall plow-down plus a legal planting date insures a 90 day host-free period to prevent the overwintering of this major cotton pest.

Row Spacing

Altering row spacing from a wider conventional spacing of 38 to 40 inches to a narrow row pattern of 15 to 30 inches can offer an alternative approach to enhance earliness and help the crop make more efficient use of light in fields that typically grow smaller plants. Shifting row spacing may also allow producers, who grow grain crops, to use the same equipment across the entire farm. However, a shift in row spacing can represent a significant investment in new equipment if necessary to accommodate new row spacing.

Variety Selection and Seed Quality

Variety selection and seed quality have a lasting effect on the crop's early-season vigor and on overall plant health which is critical in establishing high yield potentials. Less vigorous varieties are more susceptible to stresses caused by inadequate moisture, cool temperatures, thrips feeding, seedling diseases, nematodes and other pests. In addition, varieties exhibit varying levels of resistance or tolerance to high temperatures, diseases and pests, such as fusarium or verticillium wilt, root-knot nematode and bacterial blight. Consider planting resistant varieties, or those that have at least some tolerance when possible.

Yield still is the ultimate measure for a cotton crop, although the ever-increasing demand for higher fiber quality makes this factor a close second in priority. When selecting varieties for planting, don't simply choose the top yielding variety at any single testing location or year, but look at the averages of several seasons. Varieties that consistently produce yields near the top are often easier to manage than those that produce at the top in some locations and in the middle or near the bottom at others. Also, some varieties perform more consistently across different seasonal conditions and locations (Sadras *et al*. 1997). Pay particular attention to yield ranking in irrigated as well as dryland locations. This will help identify varieties that may tolerate stress better than others.

Each variety has strengths and weaknesses. The challenge is to identify these characteristics and adjust management strategies to enhance strengths while minimizing the weaknesses. Ultimately, the best experience is based on first-hand, on-farm knowledge. Evaluate yield and quality parameters of unbiased testing programs to learn more about new varieties. Three-year averages are much more meaningful in evaluating the performance of a variety. If three-year averages do not exist for the varieties in which you are most interested, evaluation across locations can be useful.

Producers should try new varieties on some of their land. However, planting the entire farm in new varieties is not recommended. Plantings of new varieties should be limited to no more than 10 percent of the farm. Acreage of a variety may be expanded slightly if it performs well the first year. Consider planting the bulk of the farm to three or four proven varieties of differing maturity to reduce the risk of weather interactions and to spread harvest timings. Producers should always evaluate more than one year's worth of data prior to planting more than trial acreage of a new variety on their farm. Be very cautious in terms of acres planted to newer varieties if multi-year testing is not available.

Select the highest quality seed for planting. Rapid field germination and emergence is best because it narrows the window for seedling diseases and minimizes the impact of pests. In addition to the standard warm germination test, a cool germination test is also recommended. When cool and warm germination numbers are added together, high-quality seed will have a vigor index of at least 160 (e.g., a warm germination value of 90 plus a cool germination value of 70 equals 160) (Table 1) (Hopper *et al*., 1988). Early planting into cool soils requires a high vigor index. When planting early, plant the best vigor index available in the variety you are planting. Under less than optimal conditions, it is inadvisable to plant cotton seed with a combined (warm and cool) germination percentage of less than 150 (Hake *et al*., 1996).

Table 1. Planting seed rating based on vigor index calculated by adding the standard warm germination and the cool germination test percentages (Hopper *et al.*, 1988).

Rating	Vigor Index (Standard + Cool germination)
Excellent	160 or greater
Good	140 to 159
Fair	120 to 139
Poor	Less than 120

Planting

Plant uniformly spaced seeds (drilled or hill-drop pattern) with good seed-to-soil contact in warm moist soil with temperatures of at least 60 to 65˚F. Planting with precision, not speed has a proven payoff. The trend in reduced seeding rates reflects the availability of precise planters and the producer's desire to manage high-value seed costs by reducing the number of seeds per acre. An efficient, well-timed planting operation can result in a 10 to 25 percent savings of seed, seed treatment costs and if planting licensed seeds, technology fees (Robertson *et al*., 2007b).

Increase the seeding rate slightly when planting early into cooler soils. The minimum plant population in the final stand should be about two plants per foot of row for row spacing of 38 to 40 inch rows, or approximately 30,000 plants per acre. Research has shown that due to the compensating nature of cotton, uniform populations between 30,000 and 60,000 thousand plants per acre can produce similar yields (Siebert *et al*., 2006). In some regions where 30-inch rows are standard, higher populations 45,000 to 60,000 thousand plants per acre is the norm. Planting less than 2 seeds per foot of row on 38 to 40 inch rows can significantly delay maturity, as cotton tends to develop more bolls on outer positions and on higher nodes in less dense populations (Siebert *et al*., 2006). Consider the plant's architecture, by variety, when adjusting planting rates. Plants with a tendency to produce more vegetative growth will perform better with lower plant populations. Planting density and environmental factors can affect final plant heights (Kerby *et al*., 1990, Sadras *et al*., 1997, Siebert *et al*., 2006).

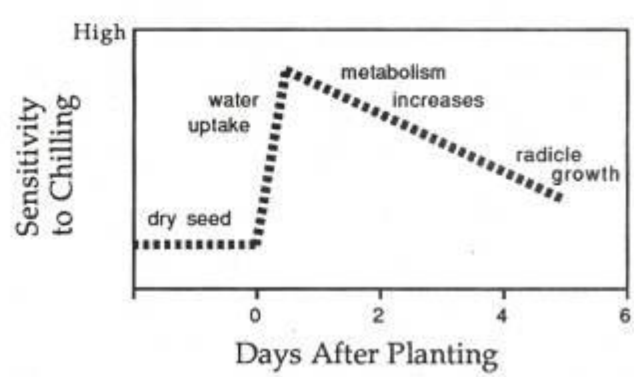

Figure 1. Sensitivity to chilling injury in relationship to days after planting (NCC, 1996).

Soil and air temperatures should be at optimum levels when planting. A mid-morning soil temperature of 68˚F at the planting depth for three consecutive days and a favorable five-day forecast following planting is best, but not always realistic for early planting (Table 2) (Kerby *et al*., 1996). Soil temperatures below 50˚F have been associated with chilling injury of pre-emerged seedlings (Fig. 1) (Christiansen, 1964; Wanjura and Buxton, 1972). A favorable five-day forecast will help avoid potential chilling injury getting the seedling off to a good start which can pay dividends at the end of the season (Fig. 2).

Table 2. Temperature guidelines to determine favorability of a five-day forecast.

Outlook for Planting	Five Day DD60 Accumulation
Very Good	50 or greater
Good	26 to 49
Marginal	16 to 25
Poor	11 to 15
Very poor	10 or less

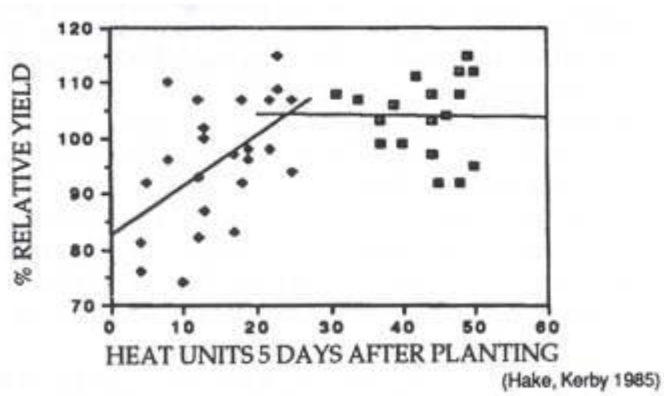

Figure 2. Impact of heat unit accumulation during the first five days after planting (NCC, 1996)

Although dependent on growing conditions, a delay in planting early in the planting window can have little impact on the date of flowering as cotton planted under optimum conditions will often catch up to earlier planted cotton that struggled with cool temperatures. Adequate soil temperature for a vigorous plant is critical. Make sure adequate soil moisture is available for optimum results and that seedbeds are firm to ensure good seed-to-soil contact.

Prior to planting it is important to create a pest-free seedbed environment. Pre-plant, burndown herbicide applications should be made at least three weeks prior to planting to ensure no green matter is on the seedbed (Fig. 3). Control all potential host plants/weeds in and around fields to eliminate sources of insect and mite pests. Most of the pest problems in cotton originate in other crops or on native vegetation surrounding cotton fields. Plant the highest quality seed variety available if planting conditions are less than favorable. The planting depth should be within the 0.25 to 1.5 inch range depending on soil characteristics to optimize emergence. For the duration of the season, it is very important to manage weedy host plants on field borders in an ongoing effort to reduce pest problems in adjacent cotton fields, but take care to avoid off-target pesticide problems.

Figure 3. Planting into pest-free seedbed environment with a terminated cover crop containing no green matter is recommended to avoid pests.

Replant decisions

Regardless of location, cotton producers have one experience in common – replanting – especially when they push the limits on earlier-than-advised planting. Experience has shown that planting early does not necessarily result in earliness. In many years, first fields planted are not necessarily the first fields ready for harvest.

Since the optimum soil temperature for cotton germination is near 85°F, it is understandable that soil temperatures less than 60˚F can lead to stand failure. Cold weather slows cotton growth, increasing its vulnerability to fungal pathogens which grow well at 65°F. The coldest soils are fine textured, poorly drained, flat-planted, light colored soils, which can lead to slow germination. The presence of sodium and other salts in these soils will slow germination even more, especially when soil calcium is low. When planting into cold soils it is imperative to use the highest quality seed. As seed size decreases, seed quality becomes more critical when planting in marginal conditions.

When determining if replanting is necessary, many factors should be considered. First, it is important to evaluate the current stand of plants that will survive (Fig. 4). This may not be evident for a few days after a storm if evaluating hail damage. Nonetheless, it is crucial to evaluate the population, uniformity and health of the existing stand. Establishing the occurrence of skips greater than three-foot in length, especially when this occurs simultaneously in adjacent rows is critical. The calendar date is also important. A thin stand is much more acceptable near the end of the planting window. The ability of cotton to adapt and maintain yield potential at lower plant populations is often underestimated. Most recommendations state, “If the decision to replant is difficult, then there are probably enough plants to keep the stand.” (Robertson and Lorenz, 2003)

Figure 4. Inspect both above and below ground plant tissue when evaluating damage.

Close attention to planting correctly the first time may prevent having to become familiar with replanting recommendations. Most advisors recommend that planting be delayed until mid-morning soil temperatures reach 68°F, 58°F California and Arizona, Kerby *et al*., 1989) at the desired planting depth for three consecutive days, and the five-day forecast calls for dry weather and a minimum of 25 DD60s (Robertson *et al*., 2007b).

Protecting the Plant

Producers should plant seed that has been treated with two or more fungicides, since most materials have activity against only one species of seedling disease pathogens. These materials also have different control mechanisms. Some protectants provide surface defense from disease organisms carried on the seed or in the nearby soil. Other products are systemic and are absorbed through the seed coat and then taken up by the seedling. Since practically all seed treatments are applied by a commercial seed processor, make sure recommended fungicides are being used that offer protection against more than one type of fungi.

Seed treatments can provide only so much protection as high rates might injure the seed. In fields with a history of seedling disease or in areas which can experience cool, wet conditions at planting, the use of one or more in-furrow fungicide may be recommended. Planting on raised beds can also improve soil warming and drainage, creating less favorable conditions for seedling disease.

Nematodes and insects/mites can compound the severity of seedling diseases by slowing plant growth. Plants suffering from foliar damage caused by insects/mites or root damage from nematodes are not able to grow as rapidly. Also consider that it may be the seedling disease that sets up the plant for more injury by nematodes and insect/mite pests.

Producers should choose an at-planting systemic insecticide/miticide capable of providing long residual efficacy. Some choose to omit systemic insecticides/miticides at planting because of the added expense and time requirements during the planting operation. However, problems may arise if adverse weather conditions prevent producers from making timely applications of foliar sprays, adding to the time the plant is subjected to insect/mite feeding.

Whether or not systemic products are used to protect the plants, cotton must be scouted in the early season for insects/mites or signs of their feeding (Fig. 5). Lack of soil moisture or a damaged root system can impact the efficacy of systemic products. When damage does occur above threshold levels, it is best to select insecticides/miticides that are not phytotoxic to the cotton seedling or harmful to beneficial insects. Cotton can overcome some damage by pests if the plant is actively growing. An example is thrips damage to cotton. Cotton is less susceptible to feeding by thrips after the plant has five true leaves and is growing vigorously (Layton and Reed, 1998). However, prior to this more tolerant stage, heavy earlier thrips feeding has been shown to be detrimental to early root development and final yields (Roberts and Rechel, 1996).

Figure 5. Illustration of three equal age plants with varying levels of thrips protection (NCC, 2007).

Adverse weather conditions in the early season can upset the best-laid weed control strategies. If pre-emergence herbicides are not activated due to lack of moisture or if excessive rains cause delays in applying post-directed or over-the-top herbicides in the early season, excessive weed competition can impact maturity, yield potential, and fiber value from contamination.

Establishing a healthy stand of cotton, which is free from damaging levels of pests, is the first step toward a successful season. As stated previously, cotton is a poor competitor during the early season. Weed, insect and disease pests often impact maturity and yield potential if left unchecked early in the season. Field scouting should be initiated at emergence, setting up the first line of defense, to protect the cotton crop during this vulnerable time of the season.

In-season Management

Meeting the basic needs of the cotton plant is the goal of producers regardless of their location or the production strategies employed. Getting the crop off to a good start is an important step in managing the crop. However, a good start does not guarantee high yields or profitability. A timely, well managed approach to meeting the in-season needs of the crop can help overcome a less than optimal start and help improve yield potential.

Some cotton growing regions present greater challenges to the producer and crop than others. These challenges include, but are not limited to, one or a combination of pests, soil structure, soil chemistry and environmental conditions. Regardless of the nature of the challenges, the crop's response to the growing conditions becomes apparent and often interpreted by evaluation of the roots, rate of node production, internode length, size of fruit abscission scars and fruit present on the plant at the end of the season.

Producers can benefit from guidelines for in-season management to establish criteria for making decisions. Expert recommendations of best management practices such as those found in the publication, "The First 40 Days™ and Fruiting to Finish™" can be a valuable resource for cotton producers (National Cotton Council of America, 2007). Additionally, guidelines can often help producers evaluate feedback from the plant in response to cultural practices. Successful producers have learned to read the plants and respond to the interactions of practices with one another and with the particular limitations inherent to specific fields.

Monitoring the Crop

By quantifying several growth parameters of the cotton plant, producers can identify potential problems and reconsider their management decisions while there is still time to address issues (Landivar and Benedict, 1996). This management approach requires growers to set aside the time and effort to collect and interpret data. Early approaches to plant mapping were very labor intensive and often required every fruiting site on the plant to be recorded. Plant mapping does not have to be complicated to provide useful information. In fact, the simpler it is, the more likely it will be used.

From emergence to flowering, the producer's greatest concerns often center on having an acceptable growth rate and adequate fruit retention once squaring begins. After flowering, NAWF values provide producers insight to boll-loading stress and assists with end-of the-season crop termination decisions (Oosterhuis *et al*., 2008). Plant mapping offers producers the ability to track and summarize this information and identify fields that may need additional attention.

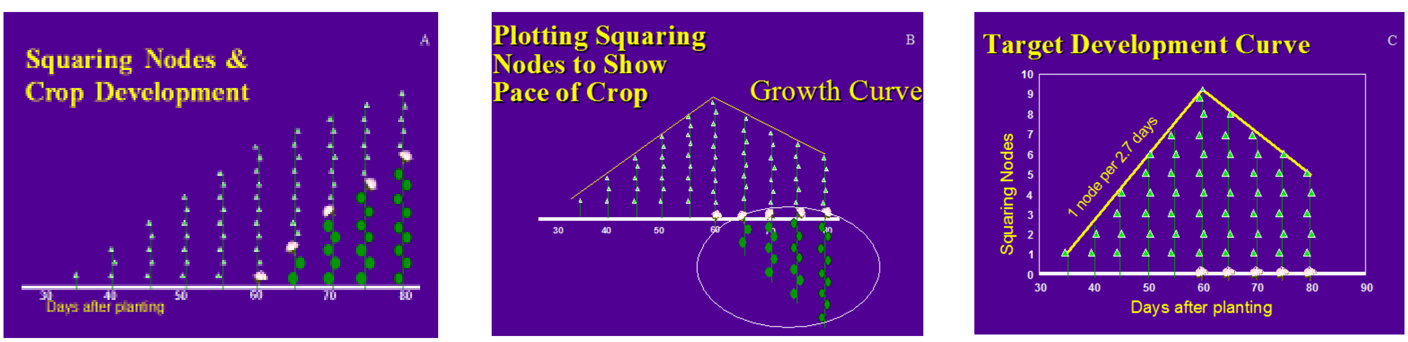

Figure 1. The COTMAN computerized cotton management program instructs users to collect presence or absence of first position squares beginning at first square which generally occurs 35 days after planting. Prior to flowering all fruiting nodes are squaring nodes. At first flower, 60 days after planting, users collect node above white flower (NAWF) data. This data also represents squaring nodes on the plant. Cutout, NAWF=5, generally occurs 80 days after planting. The graph shape of squaring nodes from first square to cutout represents the Target Development Curve of COTMAN (Teague and Danforth, 2008).

A simple approach is to break the growing season down into stages. When mapping cotton it makes sense to break the season into presquare (from emergence to first square), squaring (from first square to first bloom), flowering (from first flower until cutout) and cutout (from cutout to harvest). After dividing the season, it is important to prioritize the parameters to measure during each stage. Experienced field scouts that use plant monitoring as a tool are reluctant to invest time in collecting data that is difficult to interpret or not useful in making management decisions for specific stages. However, when monitoring tools are useful in making more efficient decisions at the farm level, these techniques are readily used by more progressive field scouts. The benefits of monitoring generally outweigh the costs (Hogan *et al*., 2008).

The number of sites and sampling locations is an important and sometimes overlooked decision. Sample locations for mapping should be representative of the field conditions. The number of sites and the number of plants sampled at each site should be sufficient to obtain reliable data to base management decisions. The objective of plant mapping is different than that of sampling or scouting a field for pests as insect pests may first enter or build to damaging populations in field margins or in areas not always representative of the field. As a result, sample site selection for mapping may need to differ from scouting site locations.

Presquare

Easily measured plant growth parameters include plant population, plant height and the number of nodes. Additional observations that can be noted are root health, herbicide damage, wind or hail damage and poor drainage areas. Depending on location, more or less factors can be included. These parameters can be measured very quickly. The data can give indications of plant stand, stand uniformity and growth rate or vigor. The rate of plant growth, as measured by the production of new nodes, over time can be a very sensitive measure of stress, which can delay the production of new nodes. Moisture stress is generally the dominant factor impacting plant structure at this stage of growth. Regardless of the cause of stress, further investigation into the cause and potential alleviation of this stress should be undertaken, especially in growing regions where the length of the growing season is limited.

Squaring

Many measureable parameters related to vegetative and reproductive development exist and can become overwhelming. It is important to consider parameters that can be rapidly and accurately measured. Some of the most important plant parameters to be considered for measurement during this growth stage are plant height, number of nodes, node of first fruiting branch and square retention at the first position. Stress during this stage of growth can be easily detected by evaluating nodal production over time. Plant structure prior to flowering is negatively impacted by stress. Fertility and moisture are generally the dominant factors impacting plant structure prior to flowering (Foshee *et al*., 1999).

Square retention is not generally impacted by stress during this stage. However, larger than expected squares in the terminal and upper branches is a clear sign of stress and is a signal pointing to a slowdown in terminal growth. Percent retention for squares prior to bloom should remain very high, since squares only need small quantities of carbohydrate for their survival. Physiological square shed generally doesn't occur until the demand for carbohydrate has peaked by growing bolls. Square shed prior to first bloom may be caused by insect feeding. If square loss before bloom is noticed, a closer look at insect pressure is advised.

Excessive vegetative growth can also occur under the most favorable conditions. The length of the upper five internodes can be a direct measure of the current state of the plant as these are the only internodes on the main stem where elongation is occurring. The length of the third internode from the terminal or the combined length of the top five internodes can be used to gauge vigor. Plants in which the third internode exceed 3 to 4 inches or if the top five internodes exceed 7 to 9 inches may be experiencing excessive vegetative growth. These conditions may require the application of a plant growth regulator. Square size can also be a sign of vigorous growth if smaller than expected squares are observed in the first positions of the upper fruiting branches on the plant (Bourland *et al*., 1992).

During squaring, it is important to maintain good square retention and to develop the plant structure necessary to achieve yield goals. A realistic goal is to achieve a range of square retention from 80 to 85 percent and maintain nine to ten nodes above the first position white flower.

Flowering

Producers may benefit the greatest from plant monitoring during the flowering stage. During the effective fruiting period, or the time between first flower and cutout, important parameters to monitor include plant height, number of nodes, the number of nodes above the uppermost first position white flower (NAWF), first position squares retained above the white flower and first position bolls retained below the white flower. If detailed records are being collected, then plant height should be taken from the same plants from which nodes and fruit counts are made (Kerby and Hake, 1996; Gwathmey *et al*., 2004; MSUCARES.com, 2009)

Young bolls, 10 days or less beyond white flower, are very sensitive to physiological shed when carbohydrate supplies are limited (Fig. 2). Factors limiting carbohydrate supplies may include cloudy weather, high temperatures, water stress, leaf damage or a heavy boll load. During this stage, management options should include practices that help the crop maintain an optimum carbohydrate supply to the boll load to ensure best conditions for growth. Avoid problems that can reduce carbohydrate supply by timely irrigation, good fertility, pest control and avoiding any stress that would reduce the canopy size (Holman and Oosterhuis, 1999).

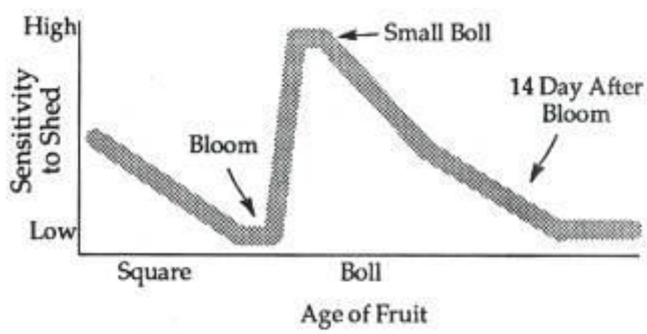

Figure 2. Sensitivity of various fruiting forms to shed (NCC, 1996).

Another major factor in boll retention is varietal sensitivity to heat-stress. Even under irrigated conditions where soil moisture levels are not a limiting factor, high temperatures can adversely affect boll retention due to pollen sterility (Radin *et al*. 1994, Gerik *et al*. 1996, Kakani *et al*. 2005). Breeding for heat stress tolerance has improved the world selection of available cultivars classified as tolerant, moderately tolerant, and susceptible to high temperatures (Liu *et al*., 2006). Identification of specific heat stress indicators will continue to advance the development of heat tolerant varieties for planting in arid and hot climates (Voloudakis *et al*. 2002, Kosman *et al*. 2006, Wu *et al*. 2007). Even thought the optimum temperatures for pollen germination is defined (Burke *et al*. 2004) during the flowering period, day and night temperatures are out of the control of cotton producers. In production areas that experience excessive temperatures selection of heat tolerant varieties will be of greater importance (Singh *et al*. 2007).

Perhaps the simplest single measurement that can provide an overall status of plant well being is NAWF. The NAWF measurement is an indication of the available energy of the plant. The concept of NAWF coupled with a measure of fruit retention, is a powerful tool when conducting plant monitoring and is one of the components of COTMAN, a computerized program for cotton management (Oosterhuis *et al*., 2008). Beginning at first flower, NAWF counts recorded weekly can help establish the last effective boll population or the last group of bolls that will contribute significantly to yield and profit. Identifying the last effective boll population is essential for making end-of-season decisions (Gwathmey *et al*., 2004).

Cutout

The first position white flower present at cutout represents the last effective boll population or the last cohort of bolls that will contribute significantly to overall yield and profit. It is this group of bolls that growers should base their decisions for terminating the crop.

Tracking the progression of NAWF values across time can be useful in predicting the date of cutout. Many end of the season termination guidelines are based on heat unit accumulation or DD60s beyond cutout. With COTMAN, historical weather data used in conjunction with projected cutout dates can be very useful in targeting insecticide and irrigation termination dates while also projecting harvest aid application and harvest dates (Robertson *et al*., 2008). These projections can be updated periodically with actual temperatures to establish more accurate dates for crop termination of harvest aid initiation dates. Having target dates for harvest aid applications and harvest dates can be a very useful planning tool. Careful evaluation of the time needed to harvest the crop in conjunction with target harvest completion dates can help identify a date that harvest must be initiated (Supak *et al*., 2001).

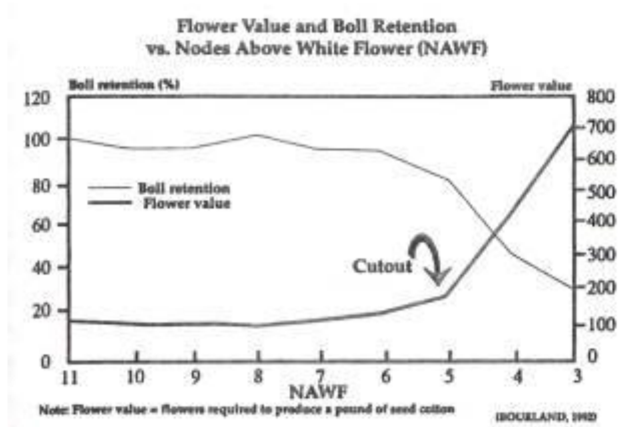

Figure 3. Identification of cutout (NAWF=5) based on boll retention rates and number of flowers a producer must protect to produce a pound of seed cotton (Bourland, 1992).

Evaluation of nodes above cracked boll (NACB) has been developed to help determine harvest aid application timing. This simply tracks the progress of the first position cracked boll relative to that of the uppermost harvestable boll. The percentages of open bolls, NACB, and DD60s beyond cutout are useful tools to time harvest aid applications (Bynum and Cothren, 2008).

Integrated Pest Management

Integrated pest management (IPM) is simply using the right tools at the right time to attack common pests. Its principles include utilizing an array of alternatives, rather than focusing on only one or two methods of pest control. This practice depends largely upon knowledge of the crop and information about a pest or potential pests and includes an analysis of the pest population, a survey of the economic severity of the pest, the surrounding environment, and the various tools that are available to control pests.

The objective of using an IPM cotton program focuses on producing an early, high quality and high yielding crop. This requires a systems approach of using recommended practices for soil preparation, variety selection and planting dates, followed by a balanced fertility and water management program. These and other cultural practices often interact with one another affecting plant growth and development and can affect the occurrence of pests and the producer's ability to manage them. Keeping pest damage to a minimum is the main objective of an IPM program. This includes using cultural, biological, mechanical and chemical management options. Cultural practices can impact natural predators, parasites and diseases, which play an important role in the biological control of many cotton pests. Effective cultural and biological control strategies can, in some instances, effectively reduce the dependence on chemical control of pests. To minimize the impact of pests and pest control costs, it is recommended that producers apply pesticides only when needed based on careful monitoring of the crop and pest populations and use the most cost effective and efficacious treatments for the targeted pests. Consideration of the pesticide of choice should also include the potential to induce or intensify secondary pests and resistance. One of the most costly pesticide applications a producer can make is one that doesn't work. Proper product selection, application timing and spray coverage including droplet size and output volume is essential to ensuring the success of chemical control methods as well as avoiding drift or other off target movement of pesticides. Producers are also responsible for ensuring that the intended use complies with current regulations and conforms to the product label. It is recommended that the most current information be read and follow all label recommendations before applying any product (National Cotton Council of America, 2007).

Figure 1. Field scouts using a shake sheet (right) or a sweep net (left) to monitor insect beneficial and pest populations (NCC, 2007).

Producers should scout their fields to detect possible pest problems before pest populations reach an economic or action threshold (Fig. 1 and 2). An action threshold is the point at which pest populations or environmental conditions indicate that pest control action must be taken. Sighting a single pest does not mean control is or will be needed. The level at which pests become an economic threat is critical to guiding future pest control decisions. Information concerning scouting techniques, thresholds for specific pests and recommendations for chemical control of pests can often be obtained locally. IPM continues to evolve as new tools become available, but the basic concepts remain economically and environmentally sound. IPM has significantly reduced the cost of production and has helped to drastically reduce the risks posed by pesticides.

Figure 2. A cotton field with a significant population of weeds. Cotton is a poor competitor at this stage of growth. Irreversible loss of yield potential has likely occurred (NCC, 2007).

Soil Fertility

Proper fertilization of cotton is of paramount importance to meet the nutritional needs of the crop. However, this can be difficult to determine because many variables can affect development and production. Anything that causes plant stress will affect nutrient uptake. Some factors include soil texture, drainage, field preparation, weather, variety, time of planting, plant populations, emergence and stand, previous crop and carry-over fertility and/or chemicals. A current soil test is still the best tool for taking the guesswork out of fertilization. Knowing what you have is critical in calculating what you need to apply in order to deliver a balanced nutrient program to achieve desired yield and quality goals (Table 1). Over fertilization is costly to the producer and to the environment. It is also undesirable to the crop, which may result in maturity delays and increased attractiveness for insect pests and diseases.

Table 1. Typical nutrient contents (lbs) required to produce one bale of lint (NCC, 1996).

Element/ Nutrient	Above Ground Plant (leaves, stems, & fruit)	Seed Cotton	Lint
Oxygen	2100	700	250
Carbon	1650	550	190
Hydrogen	360	120	35
Nitrogen	62	35 to 40	1
Potash (K_20)	61	15	3
Phosphate (P_20_5)	22	13 to 20	0.3
Calcium	27 to 62	1	0.2
Magnesium	11 to 27	5	0.3
Sulphur	8 to 16	1 to 2	trace
Other Nutrients	‹3	trace	trace

Tools such as plant tissue analysis, soil testing, and other laboratory techniques are necessary to diagnose a problem once it occurs. Practical guidelines such as “Be Your Own Cotton Doctor” from the Potash & Phosphate Institute, 2005, USA can be of great benefit to field practitioners. Most state’s Cooperative Extension programs offer producers regional guidelines.

Soil nutrients are taken up in direct proportion to growth and temperature. Total nutrient uptake for nitrogen, phosphorus and potassium tracks cumulative heat units. During the spring growing months, when heat units are low, cotton grows slowly and takes up only limited amounts of nutrients. It is during the peak growing months when nutrients need to be most readily available to the crop (Fig.1). Fertilizer applications should be scheduled in a timely fashion so that nutrient availability is synchronized with plant demands (Fig. 2).

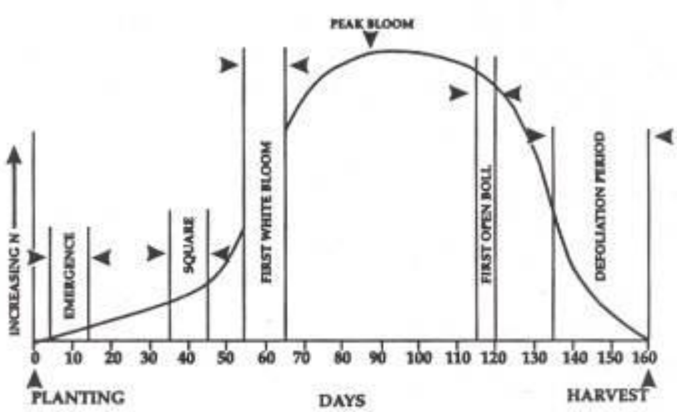

Figure 1. The growth and development of the cotton plant follows a typical sigmoid curve. This curve is representative of nutrient and water demands during the season (NCC, 1996).

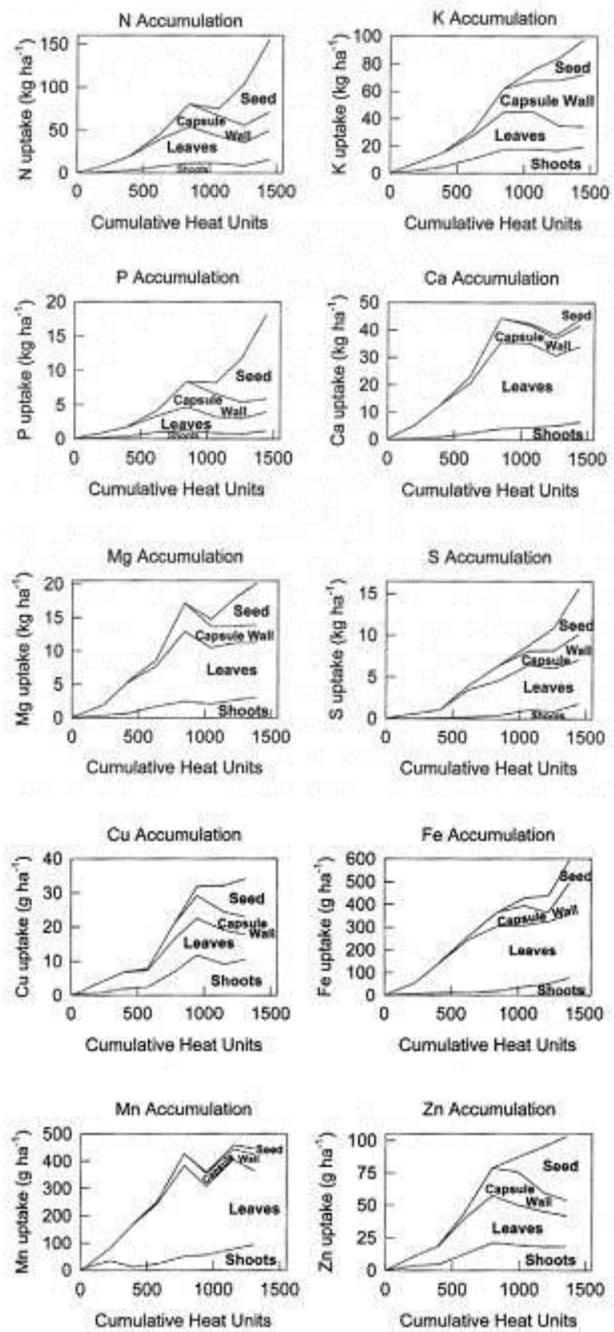

Figure 2. Seasonal demands for various macronutrient and micronutrients (Mullins and Burmester, 1991, 1992, 1993a, 1993b).

Soil Sampling

Soil sampling is the best way to determine the soil pH and level of residual nutrients. It is often beneficial to establish a base level of residual nutrients in the soil over time. The ability to make sound fertility decisions are enhanced when producers apply best available sampling techniques for nitrogen, phosphorus, potassium and trace elements.

Cotton absorbs highly soluble and less soluble nutrients by different methods. The highly soluble nutrients in the oxidized form of nitrate, sulfate and borate are readily available for plant uptake in the soil solution, but can also be leached from the soil. Mobility in soil solution reduces the value of soil sampling for soluble nutrients (nitrogen, sulfur and boron), but soil sampling is useful at any time of the year for less mobile nutrients (phosphorus, potassium, calcium and magnesium) and soil acidity.

Sampling depths of 6 inches is satisfactory for pH, other nutrients and trace elements. A deep sample is required for more accurate nitrogen recommendations. A sampling depth of 18 to 24 inches is often recommended. Issues related to mobility in the soil solution dictate deep sampling for residual nitrates are done at planting. The sampling procedure is also very important. Nutrients tend to be more concentrated near the surface and in the drill row on established beds in reduced and no-till production. Consistent sample collection in relationship to the bed is essential for accurate assessment of the nutritional status of the field and for long-term nutritional evaluation regardless of tillage systems used.

Producers often schedule soil sampling activities in the fall. This allows them to get the results in time to plan a soil fertility program for each field. If lime is needed, fall applications are recommended since lime can require several months to react fully with the soil. The time and cost invested in a good soil test, followed by incorporating the recommendations is considered one of the most cost-efficient practices a grower can implement.

Soil pH

Cotton grows best in soil with a pH between 5.8 to 8.0. Yield decreases are usually not severe until the soil pH drops below 5.5 to 5.2 on sandy loam and silt loam soils respectively, or above 8.5 for western irrigated soils in the USA. When the soil pH falls beyond this range, soil amendments are recommended. To raise soil pH, lime is recommended and to lower soil pH, gypsum, or forms of sulfur are the most common amendments applied. For best results, incorporate amendments into the soil several months before planting. In most soils, amendments reach maximum effectiveness 5 to 6 months after application.

Macronutrients

Macronutrients can be broken into two more groups: primary and secondary nutrients. The primary nutrients are nitrogen, phosphorus, and potassium. These major nutrients usually are lacking from the soil first because plants use large amounts for their growth and survival. The secondary nutrients are calcium, magnesium, and sulfur. There are usually enough of these nutrients in the soil so fertilization is not always needed.

Nitrogen (N)

For economic yields, cotton must have the right amount of N in all phases of growth and fruit development (Fritschi *et al*., 2004). Excessive N delays maturity, causes rank growth, can intensify insect infestations, encourages diseases and increases the risk of boll rot and reduced lint quality. On the opposite side of the spectrum, allowing N deficiency to continue will result in small stalks, pale green leaves, small bolls, fruit shed, and low yields.

Very little N is used by the cotton plant in the seedling stage. The heaviest demand for N is during the fruiting stages of squaring and boll formation, but the amount of N required for optimum yields will vary with the situation. High yielding cotton can contain as much as 180 pounds N per acre in the root system and above ground plant parts. Plant available N is subject to loss during the season due to conditions such as leaching, volatilization and denitrification. Field scouting for visible problems and petiole nitrate analysis should be used frequently to monitor nutritional status.

Nitrogen is mobile in both the soil and the plant. In cotton, N is translocated from older to newly developing plant parts. Thus, nutrient deficiencies first appear on older leaves as yellowing, or in severe cases, reddening of the leaf blade. Plants deficient in N tend to be spindly, mature too early and result in reduced boll retention and yield. Research also reveals that a shortage of sulfur can result in inefficient use of available N by cotton. Thus, balanced plant nutrition is a sound best management practice for high yield, high quality cotton production (Mullins, 1998).

An excess or an improperly timed application of N can result in late season vegetative growth and defoliation problems. Too much N can cause delayed maturity, damage fiber quality, increase the likelihood of regrowth after defoliation and reduce yields. Larger leaves, plant lodging, higher pest damage and delayed fiber maturity and boll opening are often observed with excessively high N rates.

Plan a fertility program based on past field production levels and realistic expectations. Only small amounts of N are needed in the seedling stage, and split applications are often recommended. If higher than expected yield potentials are apparent into the flowering stage, and soil and plant monitoring indicate a need, there is still time to supplement the plants with extra N prior to cutout (Fig. 3) (Silvertooth *et al*., 2001; Robertson *et al*., 2002). The correct amount of seasonal N will produce a timely N deficiency and fruiting cutout, which helps mature the crop for defoliation and harvest.

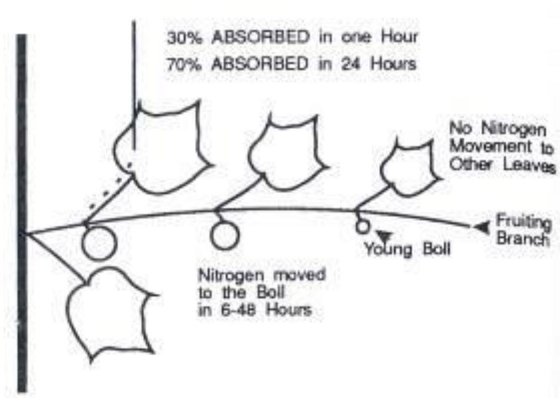

Figure 3. Uptake and movement of foliarly applied nitrogen (Miley and Oosterhuis, 1989).

Phosphorus (P)

Solubility of P in the soil is the opposite extreme of nitrogen. Phosphorus has low mobility in the soil and leaching is not a problem. Instead, mobility to the roots is the prime limitation to uptake. Because of the low mobility of P, root interception is the prime method of uptake, regardless of soil pH. Cotton roots are aided in the uptake of soil P by mycorrhizal fungi.

Phosphate is tightly bound in the soil, especially at either low or high pH, which reduces its solubility. Cold soils further decrease P uptake due to the slow root growth and reduced solubility of phosphate in cold water. Despite cotton's peak consumption of P during the summer months, deficiencies often occur in seedling cotton when the plant outgrows the stored P in the seed (Duggan *et al*., 2009).

Field observations are an important part of the total management process in producing high-yielding, high-quality cotton. However, cotton does not always display visible symptoms of P deficiency. Phosphorus performs throughout the growing season starting with promotion of a rapidly developing root system. It also promotes the movement of growth substances within the plant, such as sulfate transport into leaf chloroplasts.

When P deficiency symptoms occur in cotton they are usually not as clearly defined as with most other nutrients. Symptoms may include smaller, very dark green leaves with purplish reddening. Other possible symptoms are overall stunting, poor boll retention and delayed flowering. Regardless of how the in-season symptoms are expressed, the ultimate consequence of P deficiency is yield reduction.

Potassium (K)

All nutrients are needed during the crop's entire growth cycle, but the need for K increases dramatically when bolls are set on the plant. Bolls are major points of utilization for K, and high concentrations of K are required to maintain sufficient water pressure for fiber elongation (Read *et al*., 2006). Potassium is also involved in enzyme activation and pH balance in the cell, which is important for plant health and disease suppression.

Potassium mobility in soils is intermediate between N and P, but is not easily leached because it has a positive charge (K^+) which causes it to be attracted to negatively charged soil colloids. Roots have to grow near the source of K, but micorrhizae are not required for K uptake. Potassium is stored in leaves for use later by developing bolls, just like nitrogen. The peak need for K is during boll filling. To be available at this time, K must be in solution when late-season roots are less active.

When fruit retention is low, crop demand for K is less. Foliar K has been successfully used in some areas to partially satisfy K demand for high yield conditions, but soil applications is one of the best ways to supply all fertilizer nutrients, including this nutrient.

Potassium deficiency symptoms appear as a yellowish-white mottling of the foliage and changes in leaves to a light-yellowish-green color with yellow spots appearing between the veins. The centers of these spots die and numerous brown specks occur at leaf tips around margins and between veins. The tips and margins break down first and curl downward. As symptoms progress, the whole leaf becomes reddish brown, dries and becomes scorched and blackened in appearance. Premature dropping of leaves is also characteristic and may affect boll development resulting in bolls not maturing or only partially opening and containing poor quality fiber (Cassman *et al*., 1990)

Secondary Nutrients

Secondary nutrients include calcium (Ca), magnesium (Mg) and sulfur (S). These nutrients are sometimes referred to as "the synthesizers." They play key roles that are essential for plant growth and health. Cotton plants take up Mg and S in about the same quantities as P, a major nutrient. Calcium is required in even greater amounts.

Calcium functions to strengthen cell walls, which prevent collapse, enhancing cell division and plant growth, protein synthesis, carbohydrate movement and balancing cell acidity. Increased susceptibility to seedling diseases and poor stalk strength are possible effects of Ca deficiency. All Ca is taken up from the soil.

Magnesium is essential for the production of the green pigment in chlorophyll. The need for both Ca and Mg is best determined by taking routine soil tests and applying lime (calcitic or dolomitic) as needed. As a nutritional disorder becomes more severe, cotton may first experience a shortage of Mg without showing visual deficiency symptoms or hidden hunger. As the deficiency becomes more severe, older leaves on the plant will often show visible deficiency symptoms.
Sulfur is essential for the production of three amino acids, which are the building blocks in the synthesis of proteins. Assessing the need for S is difficult. A soil test is of limited value since sulfate (SO_4), the form used by plants, can be readily leached or moved out of the root zone. Sulfur deficiencies sometimes are seen in cotton planted on sandy soils that has formed from parent material low in sulfur with low organic matter levels. Sulfur deficiencies look much like N deficiencies, pale-green leaves on the upper part of the plant. Sulfur deficiency appears on new growth first; whereas N deficiency appears on older leaves first.

Micronutrients

The essential micronutrients are elements that are needed in only small amounts. There are seven of these: Boron (B), Molybdenum (Mo), Zinc (Zn), Iron (Fe), Manganese (Mn), Copper (Cu) and Chlorine (Cl).

Plants can suffer from a deficiency or an excess of any of these nutrients, depending on their soluble concentrations in the root zone. Micronutrient availability is influenced by soil pH. As soil pH increases from 4.0 to 7.0, the solubility of boron, zinc, iron, manganese and copper decreases. In contrast, the solubility and availability of molybdenum increases as the pH increases. As a result, liming to a pH of 6.0 to 6.5 is generally recommended.

Regular soil tests will provide most of the information that is necessary to build an efficient fertilization program. However, a separate B analysis is needed for certain suspect fields when low organic matter, excess lime, sandy texture, severe fruit drop and/or delayed maturity has been observed.

Cotton is considered a B responsive crop. However, B is a more important supplemental micronutrient in the Delta, Mid-South and Eastern regions of the U.S. cotton belt than in the arid West where B can be a problem from excessive levels. Boron plays an essential role in the development and growth of new cells in the growing meristems. Boron is also required for protein synthesis where N and carbohydrates are converted into proteins. It also performs key functions in pollination and reproduction. In the Delta region, B is more critical in the northern areas of production. This is due to a shorter season and lower temperatures during the latter part of the fruiting season (Albers *et al*., 1993).

A distinguishing feature of B is that it is not mobile within the plant. Therefore, B deficiencies occur in newly developing plant tissue. The terminal bud often dies, resulting in development of many lateral branches. Young leaves of B deficient cotton are yellowish green in color. At low B levels, flower buds become chlorotic and bracts flare open. Many of the fruiting forms become dried out and shed from the plant. Bolls that survive often are deformed, presenting a flat-sided or hook-billed appearance. A dark discoloration will be inside the boll and inside the boll petioles.

Soils can be tested for micronutrients, but generally the expense to conduct the tests is not needed. Instances where a micronutrient deficiency might exist would be: sandy soils low in organic matter; subsoils exposed due to grading or land leveling; cold and wet weather with slow breakdown of organic matter; alkaline soils; and very high levels of other nutrients (high phosphate levels can induce zinc deficiency).

Summary

An efficient fertilizer program can be developed by keeping in mind the time when different nutrients are needed and the fate of those nutrients when applied to the soil. Cotton's N requirement is greatest during boll filling, but carry-over into harvest is detrimental. Phosphorus is needed all season long, but the ability of roots to extract P is reduced in cool spring soils, justifying "at planting" fertilizer applications for increased availability. The heaviest demand for K and B occurs during boll filling. Phosphorus, K, Ca and MG stay where they are placed until that soil zone is disturbed; but N, B and S are vulnerable to leaching losses from the root zone prior to plant uptake.

Soil testing should be conducted every two to three years to establish residual nutrient levels. More frequent sampling can provide seasonal decisions on fertilizer recommendations when large yields are being produced. An understanding of soil nutrient levels combined with attainable yield goals will improve nutrient recommendations. Base application timings to meet crop needs. Calibrate application equipment and avoid fertilizer applications on wet soil to minimize compaction, runoff, leaching and denitrification. Using grass filter strips along ditches and waterways will help reduce soil erosion, runoff and nutrient loss. These practices are not only a part of a good stewardship program, but help reduce costs and improve fertilizer efficiency.

Water Management

Cotton's water requirement is determined by the location and environment where it is being grown. The dryer and hotter the environment, the more water the plant requires. A desert-like environment with high temperatures and low humidity will result in high water requirements ranging from 40 to 50 inches of water per year. A more humid and temperate environment often results in lower water requirements anywhere between 20 to 30 inches.

Cotton is a drought-tolerant crop and in many parts of the Cotton Belt where summer precipitation is adequate, it can be grown without supplemental irrigation. In more arid regions, where irrigation is required to make the crop, growers have several application methods to choose from depending on their location and cultural methods available. The most common irrigation method is flood irrigation where water is diverted down furrows or the entire surface area is flooded. Other methods include sprinklers and subsurface drip systems. Low pressure drip irrigation systems can provide an economic alternative to traditional subsurface drip and conventional irrigation systems (Robertson *et al*., 2007c). Water quantity, quality and drainage are important considerations in determining the best method to irrigate cotton. In some regions and years, having the ability to remove or drain surface water from fields is as important to maintaining high yield and fiber quality as adding water through irrigation. In arid regions where water quantity and availability is limited more reliance on sprinkler and drip irrigation systems are utilized.

Having an adequate supply of moisture is critical to establishing and maintaining high yield and quality potential (Table 1). Avoidance of water-deficit stress, beginning at first square, is critical to establishing adequate plant structure and fruiting forms to set high yield and quality potentials, especially with early-maturing varieties grown in locations with a limited growing season. Being at or near field capacity at early bloom and maintaining adequate water supplies at least through cutout is recommended. This requires constant monitoring of crop water use and soil moisture conditions, and irrigating before the crop stresses to maintain high yield and fiber potentials. A soil profile full of moisture at first open boll will often meet the water requirements necessary to mature the crop (Gerik *et al*., 1996).

Table 1. Estimated impact of severe deficit moisture stress on fruit and fiber development (Hake and Grimes, 2010).

		Impact on:	
Fruit Stage	Retention	Fiber Quality	Yield
Presquare	Minimal	Minimal	Minimal
Square initiation	Moderate	Minimal	Loss - Fewer and smaller bolls
Boll – 0 to 30 days of age	Severe	Severe	Loss - Short staple and high micronaire
Boll – 31 to 60 days of age	Minimal	Moderate	Loss - Immature fiber
Boll opening	None	Minimal	Hasten maturity

Moisture stress resulting from the lack of or an excess of water early in the growing season will restrict root and crop development (Pace *et al*. 1999). Cotton is particularly sensitive to moisture stress (deficit) just prior to and during squaring through the end of the effective flowering window. Abrupt changes in soil moisture will adversely affect growth and cause fruit shed. Severe water deficits can essentially stop terminal growth. Growth, both vegetative and reproductive, will resume as moisture levels improve. The shed of fruit as a result of stress will not usually occur until growth resumes as abscission is an active process (Voloudakis *et al*. 2002). Although growth starts again after severe water deficits, a significant delay in maturity can occur as square production must resume replacing shed fruiting forms (Pettigrew, 2004, Karam *et al*. 2006). Bolls greater than tens days of age generally do not shed as a result of stress. Time requirements from square initiation to a ten-day old boll can exceed four weeks. Square loss during this fruiting period can significantly reduce yield potential or increase the length of time necessary to produce desired yields. Delays generally result in higher production costs due to the extended fruiting period.

Irrigation scheduling

Using local guidelines for irrigation scheduling is recommended as the foundation for making important decisions for initiating, scheduling and terminating irrigation. Irrigation initiation and termination decisions are difficult and can greatly impact yield and quality in a positive or negative manner. Irrigation scheduling guidelines often include criteria based on the soil moisture as a result of actual measurements. More subjective soil moisture evaluations can be derived from the look and feel of the soil. Observations of the cotton plant will reveal that a change in leaf color toward a slight bluish tinge occurs before wilting. In the drier spots in the field, the color appears somewhat darker than the remainder of the field. These spots can be used year to year as a diagnostic indicator to initiate irrigation. However, these spots don't often provide a great deal of advanced warning that yield limiting moisture stress is imminent. Bookkeeping methods are utilized to keep a running inventory of plant available water by adding effective rainfall and irrigation to account for water entering the soil profile and subtracting soil water losses. Plant water use based on daily high and low temperatures and estimated evapotranspiration rates is determined by crop growth and other factors accounting for water leaving the soil profile. Computer programs allow producers to input data from various measurements to schedule irrigation based on plant, soil and environmental data generally collected onsite.

The thresholds in which irrigation is recommended and amounts to apply will vary during the season based on factors including crop growth stage, environmental conditions, soil characteristics, water quality and quantity. The plant's water use and the sensitivity to stress in maintaining high yield and quality potentials vary throughout the growing season. Monitoring plant development, particularly nodal development from the appearance of the first true leaf to first flower, can be useful in providing feedback to the effectiveness of irrigation scheduling as nodal development is very sensitive to moisture stress. The increasing demands for energy by the developing bolls significantly impact nodal development rates. This change causes observations of nodal development rates to be much less reliable for providing feedback for irrigation scheduling after the onset of flowering. Nodes above white flower measurements reveal much about the levels of stress the plant is experiencing and can provide a benchmark from which irrigation termination can be made. However, this measure does not differentiate between good stress (heavy boll load) and bad stress (deficit soil moisture stress). Nonetheless, monitoring plant development is useful in evaluating the effectiveness of irrigation scheduling. Knowledge of boll retention rates coupled with how the plant is responding vegetatively to reproductive stress can provide the producer a better understanding of the current status and future needs of the plant (Robertson *et al*., 2008).

Plant Growth Regulators (PGRs)

The cotton plant's perennial and indeterminate growth habit is perhaps the most complex of all major row crops. The plant is very responsive to management and changes in the environment. The change in both vegetative and reproductive growth in response to stress or the lack of stress is predictable. However, the ability of the cotton plant to compensate for fruit loss or to recover from stress can be surprising. Producers use PGRs and other cultural practices as a means to manage the balance between vegetative and reproductive growth for efficient cotton production

The use of PGRs encompasses a broad category of compounds that promote, inhibit or otherwise modify plant physiological or morphological processes. Some PGRs are plant hormones or their analogues; others are simply metabolic regulators. These products are classified as organic compounds that alter the growth and development of plants. Unlike plant hormones that are endogenously produced by the plant, PGRs may be considered chemical compounds either produced naturally by the plant or synthetically. They are biologically active at very low concentrations and elicit responses similar to those observed from plant hormones. Since most plant growth and development processes are regulated by natural plant hormones, these processes may be manipulated by either altering the plant hormone level or changing the capacity of the plant to respond to its natural hormones. All PGRs should be considered as management tools in the producer's arsenal to alter cotton growth and development in an attempt to control growth and improve productivity (Jost *et al*., 2006)

Commercially available PGRs can often be divided into two basic groups: growth inhibitors and promoters. The growth inhibiting PGRs generally provide consistent height reduction and often enhance earliness. Yield increases may be a bonus if it occurs. However, growth-promoting PGRs offer no direct height reduction and generally provide little advantage, if any, toward enhancing earliness and must provide yield increases to be profitable (Biles and Cothren, 2001).

Excessive vegetative growth can also occur under optimum conditions. The length of the upper five internodes can be a direct measure of the current status of the plant as these are the only internodes on the main stem where elongation is occurring (Bourland *et al*., 1992). The length of the fourth internode from the terminal or the combined length of the top five internodes can be used to gauge vigor. Plants in which the third internode exceeds 3 to 4 inches or the top five internodes exceed 7 to 9 inches may be experiencing excessive vegetative growth and should be evaluated for using a growth inhibiting PGR. Smaller than expected square size can also be a sign of vigorous growth if this is observed in the first positions of the upper fruiting branches.

Figure 1. Identification of the fourth internode for the purpose of evaluating plant vigor.

Growth inhibiting PGR applications should be well-timed in anticipation of excessive growth rates to more effectively manage vegetative growth and plant height. These compounds will not shrink cotton plants, but will only slow growth of actively growing tissue after application. It is important to monitor the crop for growth, square size and fruit retention when scouting as well as evaluating the current and future potential for stress. The evaluation of stress should also take into account pressure from nematodes and diseases. Growth inhibiting PGRs are generally not recommended for use on stressed cotton. Once the need for this type of product has been established, the application rate should include consideration of the environment and the size of the plant. It is important to read and follow label guidelines for all products.

Harvest Management

Harvest management is more than applying harvest aid products. Fertility, water management and weed control play an important role in the success of a harvest aid program. The goal should be to supply the crop with adequate fertility and moisture levels to meet realistic yield goals. Any excessive fertility or moisture remaining in the soil at the end of the season, beyond what is necessary to maintain an active plant, represents more potential costs or inputs the producer could have avoided. Excess fertility and moisture coupled with favorable temperatures for plant growth at the end of the season will complicate harvest aid programs as well as increase costs of both producing the crop as well as preparing it for harvest (Gwathmey *et al*., 2001). On the other hand, failure to meet the plants nutritional or moisture needs will negatively impact yield potential and plant activity. The success of a harvest aid program is highly dependent on having adequate plant activity as leaf defoliation and boll opening is an active process. Inadequate weed control programs will present challenges with harvest and possibly impact fiber quality. This is in addition to loss of yield potential as a result of weed competition during the season. Having relatively weed-free fields at the end of the season coupled with low residual fertility and moisture levels will help lower production costs while providing great flexibility in designing economical harvest aid programs to help maintain existing yield and fiber quality (Supak *et al*., 2001).

Harvest aid programs often include the use of compounds that result in leaf defoliation, boll opening or tissue desiccation. Components of a harvest aid prescription are often dependent of the production strategy and harvest method employed. A universal goal of cotton producers is to harvest as early as possible to minimize environmental risks without sacrificing lint yield or fiber quality. Guidelines for harvest aid products, rates and timing can often be obtained locally. These guidelines generally take normally expected plant status and environmental conditions for a specific region into account in developing recommendations. Products and use rates can vary greatly from region to region and even within a region or country based on grower preference and experience. However, the basic concepts apply to improve efficacy of pre-harvest preparations prior to harvest.

The two primary categories of harvest aid products, hormonal and herbicidal, are based on their mode of action. These products provide a broad range of results and are often tank mixed. Hormonal materials generally fall into the categories of defoliants or boll openers. As a general rule, these tend to be more temperature sensitive than herbicidal defoliants. Increasing rates of herbicidal products, in turn, makes them desiccants. Select products and rates appropriate to the local field environment and crop condition. Previous experience and confidence in treatments should be a major factor in determining choice. Consider weather forecasts when selecting treatments. Some products are more temperature sensitive than others. The yield and fiber quality potential of the field will often dictate the harvest aid budget.

There are several ways to determine when to treat cotton with a harvest aid product. An old rule of thumb is to defoliate when 60 percent of the bolls are open. Another method involves counting the nodes above the uppermost first position cracked boll (NACB) and the uppermost first position harvestable boll. When NACB values average four or less, the fields can be defoliated without significant weight or quality loss. Both of these measures of maturity assume a typical level of plant senescence as bolls mature. In situations where conditions for growth are very favorable, plants don’t senescence as rapidly as expected. As a result, the occurrence of boll opening slows while fiber development within the boll does not. Thus, field evaluations involving boll opening can sometimes greatly underestimate maturity. Perhaps the most reliable method of determining boll maturity is to slice open bolls with a knife (Fig. 1). Mature bolls will be too hard to dent when squeezed and cannot be easily cut with a sharp knife. Lint will string out when a mature is sliced, seed coats will be dark or black in color, and cotyledons will be well formed.

Figure 1. Boll slicing of first position bolls beginning with a mature cracked boll on the far right to the least mature boll in this image on the far left (NCC< 2007).

Timing of harvest aids can pose a difficult decision to growers since they are often encouraged to use at least two methods to determine maturity of the crop in an effort to time applications. However, producers are often tempted to wait as long as possible for young immature bolls to open near the top of the plant before defoliating. These last bolls can be insect damaged and often are smaller, which account for little additional yield gains, but the perception of yielding more lint is difficult to overcome. A heat unit concept of timing defoliation beyond the last effective boll population as defined by COTMAN would allow producers to make this decision with greater confidence as it is much less subjective than other measures of maturity and possibly allow for an earlier harvest (Fig. 2) (Gwathmey *et al*., 2001; Helms *et al*., 2007).

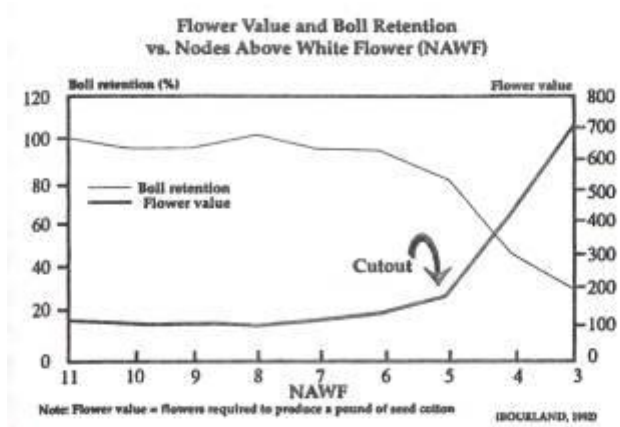

Figure 2. Identification of cutout based on boll retention rates and number of flowers a producer must protect to produce a pound of seed cotton (Bourland, 1992).

Harvest aid products generally are not translocated in the plant, therefore coverage is a very important part of the process. Successful defoliation requires uniform canopy coverage. Total spray volumes of 5 to 7 gallons per acre by air or 12 to 15 gallons per acre by ground are typical recommendations to ensure good coverage. Coverage also depends on spray droplet size, atmospheric conditions and the canopy density. Generally, smaller spray droplets provide better coverage and canopy penetration but are more likely to drift in windy conditions or evaporate in high-temperature, low-humidity conditions. Larger spray droplets experience less drift and evaporation, but provide poor coverage and canopy penetration. Medium-sized droplets are generally recommended (Fig 3). Increased spray volumes help enhance coverage thus improving defoliation, especially on rank plants with lush foliage (Bader *et al*., 2001).

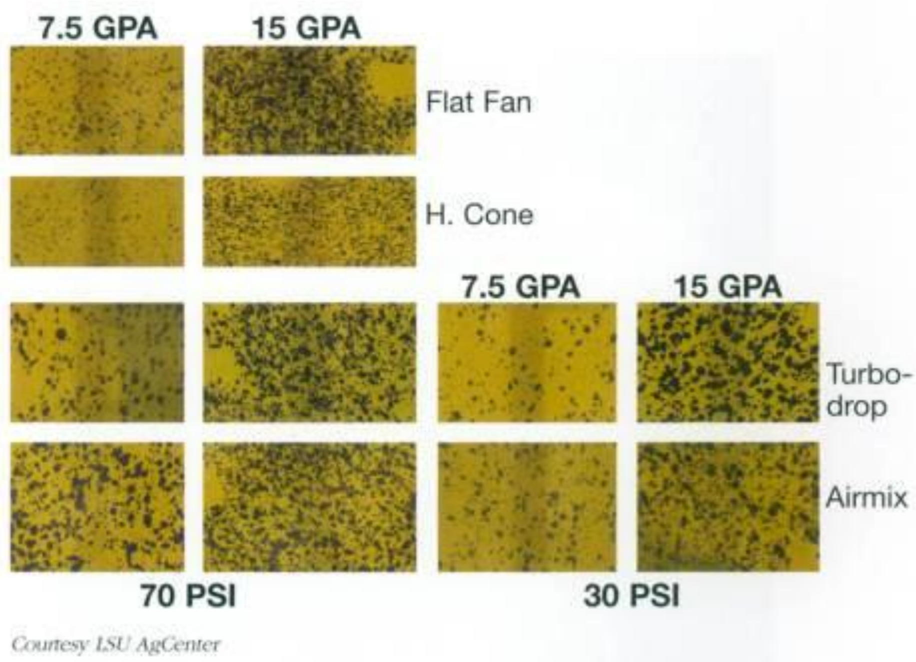

Figure 3. Water sensitive spray cards illustrating droplet size and coverage of various spray tips, spray volumes, and pressures (NCC, 2007).

Harvest aid applications should be coordinated with harvest progress. Applications should be timed in a manner so fields will be harvest-ready to meet a defined schedule. It is common for producers who mechanically pick cotton to treat only as much acreage as can be harvested in 7 to 12 days. Early treatment of excess acreage can decrease yields, expose lint to weather and increase the likelihood of significant regrowth. Moisture entering the boll just as it begins to crack open can allow fungal pathogens to enter the boll colonizing on the locks of seedcotton. These locks often fail to fully open and are referred to collectively as a hardlock boll. Boll openers promote and synchronize the opening of bolls regardless of boll age or maturity. Cotton bolls are much more tolerant to wind, rain or other forces which can cause seedcotton to fall to the ground when the leaves are on the plant.

Figure 4. A typical hardlock boll. Seed and fiber quality of a hard lock boll is generally poor

Producers who mechanically strip cotton sometimes have the option to wait on a killing frost to desiccate plant tissue as opposed to using chemical desiccants. Stripper harvest of cotton requires that minimal green tissue be present in the field for efficient operation of the harvester.

Harvest aid products generally work better on mature cotton under warm, humid, sunny conditions. Cool temperatures at the time of application or immediately afterward can retard the activity of defoliants and boll openers often resulting in less than desirable results. If possible, harvest aids should not be applied during or immediately preceding a significant cooling or drop in temperature. More desirable results are often obtained if treatment is delayed until temperatures are allowed to warm or stabilize for at least three to four days (Gwathmey *et al*., 2001).

Defoliation is not always required for mechanical picking. Cotton that is completely cutout with "tough" leaves and little regrowth present may not need defoliation if harvested and ginned quickly. In this situation, it is important not to pick too early or late in the day as green leaf in the seedcotton provides an additional source of moisture. It is also recommended that the producer contact the gin prior to harvest to ensure that timely ginning of the seedcotton can be achieved. Ginners can often make adjustments in the ginning process to help preserve fiber quality if they are aware of issues that may require special attention (Roberts *et al*., 1996).

Summary

Due to increasing production costs cotton producers must be able to critically evaluate every input. An understanding of the development of the cotton plant is crucial for making strategic management decisions and maintaining profitable production. Advancements in modification of plant earliness and determinacy have lead to varieties with shorter final main stem nodes and overall shorter plant heights.

Decisions regarding row spacing, tillage equipment and systems to use for production may be an all encompassing farm-wide decision that is based on rotation crops and other cultural practices employed. Other decisions such as variety selection, plant population and many early-season pest control strategies are made prior to planting and can vary with each field. The financial investment in a cotton crop incurred prior to planting can be significant. The monetary costs alone echo the importance of doing the right thing at the right time. Production budgets are available for many cotton growing regions and serve as a tool to help producers and lenders customize one with realistic yield goals to match individual circumstances. While having a plan does not guarantee success, having one does provide the producer a way to chart a course of action toward achieving success and offers a means to evaluate decisions at the end of the season. An experienced producer once stated that he had 30 experiences in producing cotton as opposed to having 30 years experience growing cotton as each year was different. Many times management decisions are based on what went wrong the previous year. A better understanding of the cotton plant can allow producers the ability to better predict the needs of the plant and utilize that information in the decision making process as opposed to what worked or didn't work last year.

Management improvements will be an ongoing challenge as cotton producers face market realities. A producer's understanding and knowledge of the crop and ability to read the plant is critical in developing strategies to meet the anticipated needs. Developing an integrated management approach to increase the efficiency of every input and output of production will be an essential element of a successful enterprise. Cotton producer will be expected to produce quality fiber and cotton products under increasing demands for environmental stewardship. Integrating management practices into an efficient system will be the best approach to sustaining the future of cotton production.

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