Abstract

COLLINS, GUY DAVID. Defining Optimal Defoliation and Harvest Timing for Various Fruiting Patterns of Cotton in North Carolina. (Under the direction of Dr. Keith Edmisten).

Upland Cotton (*Gossypium hirsutum* L.) is a perennial plant produced as an annual crop in North Carolina. Due to high variability in net returns, and narrow profit margins, growers must focus attention not only on lint yield but also on lint quality. Implementing sound agronomic practices, such as proper defoliation timing and harvest timing, may help maximize lint yield and preserve fiber quality. Cotton is normally defoliated when 60 percent of the total harvestable bolls are open. It is hypothesized that defoliation could be initiated before 60 % OB (percent open bolls) if fruiting is compact (fruit set over 8 to 10 nodes), and in contrast, defoliation could be delayed beyond 60 % OB if fruiting is extended. Experiments were conducted in North Carolina during 2004 and 2005 at Upper Coastal Plains Research Station located near Rocky Mount to determine the effects of defoliation timing and harvest timing on three fruiting patterns of cotton. One study involved the use of a common plant growth regulator, mepiquat chloride, in three application strategies, to achieve compact, normal, and extended fruiting patterns. A second experiment was conducted using an early maturing cultivar, DP 444, a medium maturing cultivar, DP 451, and a late maturing cultivar, DP 555, to achieve the compact, normal, and extended fruiting patterns respectively. The targeted defoliation timings in each study were 50, 70 and 90 % OB and the targeted harvest timings were 14 days after defoliation and 28 days after defoliation.

According to lint yield data from the study involving mepiquat chloride application strategies, a crop with compact fruiting could be defoliated earlier than 60 % OB without sacrificing yields. Delaying harvest for early-defoliated cotton may help maximize yield and fiber length, whereas an early harvest may be more appropriate for late-defoliated cotton, especially if significant amounts of rainfall are experienced.   In 2005, micronaire values decreased 4% by delaying harvest, regardless of defoliation timing. Data also suggests that NACB (nodes above cracked boll) values equal to 3, somewhat corresponded to maximum yields, especially in cases where mepiquat chloride was used.

Data, from the study involving cultivar maturity groups, suggest that cultivar differences may be largely responsible for variations in micronaire, fiber length, length uniformity, and fiber strength. Defoliation before 60 % OB was proven to be acceptable in some cases, however harvest may need to be delayed to achieve maximum yields. In contrast, optimal yields were reached when cotton defoliated beyond 60 OBPD was harvested early. These effects were largely a result of variations in the amount of rainfall occurring during the harvest period. These data also suggested that maximum yields and fiber quality corresponded to defoliating when NACB values approached 3. Data indicated that delaying defoliation may increase yields, regardless of cultivar used. Plant mapping data suggests that fruiting patterns were different, however, all three cultivars appeared to possess an extended fruiting pattern, therefore assumptions regarding fruiting compactness can not made, based on particular cultivar maturity tendencies.

DEFINING OPTIMAL DEFOLIATION AND HARVEST TIMING FOR VARIOUS FRUITING PATTERNS OF COTTON IN NORTH CAROLINA

by

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Chair of the Advisory Committee

DEDICATION

This thesis is dedicated to my grandparents, Mr. and Mrs. Guy E. Fisher and Mr. and Mrs. Vernon W. Collins, who have instilled the love of agriculture and life-long values in me. They have provided much support throughout this degree. This thesis is also dedicated to my parents, Mr. and Mrs. V. David Collins, who have provided much encouragement and support in my achieving this degree. Lastly, but not least, this thesis is dedicated to Ms. Ashley E. Warlick, who has provided tremendous love, sacrifice, and support, of which I am truly grateful. Sincere thanks to all.

BIOGRAPHY

Guy David Collins was born to David and Joan Collins on the 11th of June, 1981 in Franklin, Virginia. He was raised in rural Northampton County, North Carolina, on a farm, owned and operated by his grandfather, Guy E. Fisher. In this rural environment, Guy enjoyed outdoor life and hobbies such as hunting and fishing, and developed a passion for agriculture. During his high school years, Guy worked on the farm, and also worked as a cotton scout for a respected agricultural consultant. Guy earned his high school diploma in May of 1999, from Ridgecroft School, in Hertford County, North Carolina.

In August of 1999, Guy attended N.C. State University to study Agronomy. During his college career, he pursued an internship in Lubbock, Texas, and was awarded numerous scholarships through the College of Agriculture and Life Sciences. Guy became involved with, and held offices in several university clubs and national honor organizations. He also became a member of Alpha Zeta Fraternity, and FarmHouse Fraternity. Guy completed the University Honors Research Program during his undergraduate career. In May of 2004, Guy was awarded the Bachelors of Science degree in Agronomy, with a minor in Agricultural Business Management, and graduated Summa Cum Laude with Honors.

Immediately following the completion of his bachelor's degree, Guy began his pursuit of a Masters of Science degree in the Cotton Extension program under direction of Dr. Keith Edmisten, and committee members, Drs. Randy Wells and David Jordan. During his Masters degree program, Guy was afforded the opportunity to speak at numerous field days and conferences, and was privileged to interact with growers, consultants, and research specialist in his own university and elsewhere. Upon completion of his Master's degree, Guy plans to pursue a Doctor of Philosophy Degree in the Cotton and Weed Science Extension Programs at N.C. State University.

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LITERATURE REVIEW

Overview

Upland Cotton (*Gossypium hirsutum* L.) is a perennial plant produced as an annual crop in North Carolina. In recent years, cotton has been produced on approximately 280,000 to 350,000 hectares in North Carolina annually, generally producing over 1 million bales (Brown, 2006). Due to high variability in net returns, and narrow profit margins, growers must focus attention not only on lint yield, but also on lint quality.

The tropical nature of the cotton plant complicates management because the growing season is relatively short in North Carolina. Because 910 to 950 (40 to 80 days depending upon the local environment) growing degree days are generally required for bolls to fully develop (Mauney, 1986), growers in this region typically want to implement a short season management strategy to maximize boll production while adequate heat units are available. Bolls set after August 15-20, or on nodes higher than 18, have reduced probability of reaching maturity, and therefore may not be harvestable (Edmisten, 2006cd). The indeterminate growth habit of cotton allows cotton to grow vegetatively and simultaneously produce flowers or fruit for approximately 8 weeks in normal conditions in North Carolina, unlike determinant plants such as corn, which flowers at a distinct point in time. As boll load (the amount of fruit on plants) increases, vegetative growth decreases because reproductive growth takes precedence over vegetative growth for photosynthetic resources. This feature allows cotton to produce some yield in extremely adverse (dry) conditions, but may also complicate management because vegetative growth can resume, and bolls may form late in the season, some of which may not be harvestable or possess very different quality characteristics compared to bolls set earlier in the season. Boll set and development occurs upward on the main stalk and outward on the sympodial branches (Edmisten, 2006e), therefore fruit at different sites (nodes or positions) on the plant may vary with respect to quality characteristics (Davidonis et al., 2000), as each may have experienced different environmental conditions (Pettigrew, 1995). Davidonis et al. (2000), observed variable fiber strength and micronaire for bolls produced at different plant positions in both rain-fed and irrigated cotton.

Growers intensively manage the bloom period (time span of flowering or anthesis) to prevent losses, and also use agronomic practices that promote crop earliness. The earliness (early fruit set and retention - and - early maturity of these fruit) of a cotton crop strongly depends on favorable environmental conditions early in the developmental process. Cool and wet conditions at planting and soon thereafter (Edmisten, 2006e), can greatly inhibit germination and growth which can delay anthesis. Drought or cool conditions may shorten the bloom period, while excess moisture, excess nitrogen, and low fruit retention may lengthen the bloom period. Delayed fruit development may result in excessive vegetative development (excessive vegetative growth), increased time to maturation, and altered quality characteristics. Problems associated with excessive vegetative growth include delayed maturity, poor boll retention, increased boll disease or rot, and difficult defoliation and harvest. In summary, cotton yield and quality can be significantly affected by environment and genetics, but several management practices may be implemented to manipulate the crop and achieve earliness, high yields, and superior quality. The use of plant growth regulators, and cultivar selection based on maturity group, are methods of manipulating cotton vegetative and reproductive growth to promote high yields and quality in North Carolina. Pin-pointing optimal defoliation and harvest timing may also maximize yields and promote high quality cotton. The following literature review summarizes and explains research findings pertaining to the effects of such management practices on yield and quality parameters of micronaire, color, staple, strength, length, and uniformity.

Quality Parameters

The quality parameters of primary concern for cotton are micronaire, staple, strength, color, length and uniformity. Fiber quality is strongly influenced by genetics (Meredith, 1984), but is also influenced by crop management and environmental factors such as soil type, insect pressure, length of growing season, weather etc.. Following the ginning process, cotton samples are taken and graded using High Volume Instrumentation Analysis (HVI) (Edmisten, 2006a) which defines these quality parameters for a specific bale. Results from this analysis provide cotton buyers with fiber quality information, and is also a partial basis for which payments are made. Cotton fiber quality is best, immediately prior to boll opening, before weathering, harvesting, and ginning take place (Anthony and Bragg, 1987). Although quality is strongly correlated to environment and genetics, proper management may also help to preserve quality. Edmisten et al. (2000) indicate that within-field seed mixtures of different cultivars that differ in quality characteristics, can increase staple length and reduce micronaire while maintaining high yield potential. Coker et al. (2001), reported improved lint uniformity and strength associated with mepiquat chloride in combination with KNO_3 treatments in two of three years.

Harvest timing, maturity at the time of harvest, harvest date, and harvester adjustments are all important factors that affect quality (Anthony and Bragg, 1987). Anthony and Bragg (1987) found that short fiber content increased from 9.1 % to 11.3 % due to weathering after boll opening. They also found that twice over harvesting yielded short fiber contents of 8.6 % and 11.8 % for the first and second harvest respectively, compared to a short fiber content of 10.1 % for the once-over delayed harvest. Overall they recommend a twice-over harvest with minimal exposure to weathering. These authors found that cotton from the second harvest contains cotton that was produced later in the growing season under sub-optimal conditions. They also concluded that fibers produced early in the growing season are less susceptible to deterioration than fiber produced later in the season.

Within-season environmental factors also affect fiber quality. Bradow et al. (1997) explain that fiber properties associated with maturity depend upon location of bolls on the plant, flowering date, and environmental conditions that occur during the maturation of each boll. Pettigrew (2004) found that higher percentage of first position bolls associated with dry-land plants may explain the increased fiber strength and micronaire in some years. In a floral removal study conducted by Heitholt (1997), fiber length and strength were unaffected by square removal, yet micronaire and maturity were greater. Pettigrew et al. (1996), reported reductions in fiber elongation, 50 % span length, uniformity ratio, micronaire, maturity, and perimeter, due to K deficiency, but no alterations occurred in 2.5 % span length and fiber strength. Pettigrew et al. (1992) in another floral removal study, reported that yield losses outweigh any improvements in fiber quality through square removal.

Micronaire is a measure of cotton "fineness" or fiber thickness. Single-cell fiber development occurs in phases, the first being elongation of the primary cell wall (Stewart, 1975) lasting for approximately 20 to 25 days (Burch and Krieg, 2002). Following fiber elongation, fibers undergo a secondary cell wall deposition which continues until the bolls are mature (Berlin, 1986). Micronaire is strongly related to cultivar or genetic predispositions (Meredith, 1984), however environmental factors also have firm influences. Heat and stress combined, often induces high micronaire because these combined stresses can result in the abscission of young bolls, which otherwise could have contributed to lower micronaire (Banks, 2005). Jones et al. (1996) found increases in micronaire and boll weight corresponding with late-season flower removal (4^{th} week and later) while no increases in micronaire, were evident for early removal of flowers. Gipson and Joham (1968) and (1969) found that fiber length and micronaire decreased when night-time temperatures decreased. High micronaire is also a result of genetic predispositions compounded by drought stress and delayed defoliation (Edmisten, 2006a), but can be managed to certain extents. Pettigrew (2004), found increases in micronaire associated with irrigation in some years, due to increases in fiber maturity. The proper use and timing of PGRs (plant growth regulators) and nitrogen inputs, along with managing stresses, can help to manage micronaire (Banks, 2005).

Fiber length, or upper half mean (UHM), is reported in 0.01 inches. It is better defined as the average fiber length of the upper half of a fiber bundle (Banks, 2005). Length is influenced somewhat by cultivar, but more-so by environment, as cell elongation is strongly dependent upon water and potassium supply (Banks, 2005). Short fiber is a problem in the southeastern U.S., and results primarily from cultivar predispositions (Edmisten, 2006a). However, Pettigrew (2004) found generally shorter fiber for cotton grown under moisture deficit conditions. Gipson and Joham (1969), report maximum fiber elongation rates are achieved when nighttime temperatures are a minimum of 15^{o}C and 21^{o}C for Paymaster and Acala cultivars, respectively. Heitholt et al. (1993) reported slightly longer 2.5 % span length for cotton planted in 1 meter rows compared to 0.5 m rows, although differences were small.

Fiber strength is measured in grams per tex, or the force in grams required to break the weight in grams of 1000 meters of fiber (Edmisten, 2006a). This parameter is primarily influenced by cultivar (Banks et al., 2005) as full-season cultivars generally possess higher strength than short-season cultivars (Edmisten, 2006a). Pettigrew (2004) found weaker fibers associated with irrigation in 2 of 4 years. Pettigrew (1995) reported that shade treatment produced longer span lengths and reduced fiber strength. Micronaire was influenced by the timing of the shade treatment in reference to the stage of boll development.

Color grades consist of grayness (Rd) and yellowness ($^{+}$b). Grayness describes the brightness of the fiber while yellowness describes the quantity of yellow color in the fiber

(Edmisten, 2006a). Color grades are then divided into quadrants for more precise measurements. Leaf and color grade discounts can occur if trash or stained cotton results from poor defoliation or abundant regrowth (renewed vegetative growth) at the time of harvest. Poor control of weeds and boll feeding plant bugs, may also lead to trashy or discolored lint (Banks, 2005).

Length uniformity is the parameter describing the degree of uniformity of a fiber sample (Edmisten, 2006a). Uniformity of a fiber bundle is defined as the ratio between mean length and the upper half mean length. Bolls from the top of the plant may be very different in length characteristics than bolls from the bottom of the plant. Stress during a portion of the fruiting period may increase short fiber content, for fiber elongation during this time (Banks, 2005).

Plant Growth Regulators

Mepiquat chloride (1,1-dimethyl piperidinium chloride) is a common plant growth regulator used in North Carolina cotton production. Mepiquat chloride inhibits gibberellin synthesis, which influences cell division and expansion (Reddy et al., 1992). Research indicates that mepiquat chloride helps to hasten maturity, enhance earliness and fruit retention, increase yield, and reduce plant height by inhibiting cell elongation in stems, resulting in more compact plants with shorter main stem and fruiting branch internodes (Biles and Cothren, 2001; Edmisten, 2006d; Livingston et al., 1999). Energy is diverted away from vegetative growth directed to reproductive growth. In addition, bolls that are set on upper fruiting branches contribute much less to total yield, and their development is greatly reduced by mepiquat chloride (Edmisten, 2006d). The impact of mepiquat chloride on yield is inconsistent and highly variable (Beck and Searcy, 2001), and varies depending upon environmental factors and inputs such as nitrogen and water (Reddy et al., 1992). Siddique et al. (2002) found increased seed cotton and lint yields with the application of 100 ppm mepiquat chloride, due to increases in bolls per plant and dry-matter partitioning to bolls. Davidonis et al. (2000) found that mepiquat chloride increased fiber length and maturity in first position bolls, compared to untreated plants. Zhao et al. (1999) found decreased plant height due to mepiquat chloride treatment, but the number of main-stem nodes was not affected. Other effects of mepiquat chloride include increases in net photosynthetic rate, increased leaf stomatal conductance, and improved assimilate partitioning between vegetative and reproductive organs (Zhao and Oosterhuis, 1999). Livingston et al. (1999) found that three formulations of mepiquat chloride reduced plant height, number of main-stem nodes, and internode length, and increased earliness and fruit retention.

Producers, however, face the question of when to apply growth regulators in order to maximize benefits (Landivar et al., 1996). The timing and need for mepiquat chloride may vary depending upon the specific situation. Conditions, that normally promote excessive vegetative growth and delayed maturity, usually result in positive yield responses to mepiquat chloride. Some of these conditions include late planted cotton, high plant populations, high nitrogen rates, excessive rainfall, large late maturing cultivars, and fields with a history of excessive vegetative growth, delayed maturity, or that will be defoliated first (Edmisten, 2006d). A study conducted by Davidonis et al. (2001) examined the effects of a mepiquat chloride application at first bloom on boll locations and fiber properties for three planting dates. The results indicated that boll distribution differed between planting dates, however no alterations in boll distribution patterns were found to be due to mepiquat chloride applications. However, these authors conclude that mepiquat chloride has the potential to decrease micronaire values for early planted cotton, especially if late season bolls comprise a large portion of the crop, and also increase micronaire in late planted cotton. Livingston et al. (2000) found yield advantages by applying a single application of mepiquat chloride after 850 and 1400 accumulated heat units, however, yield was decreased for treatments at match-head square and when squares were one-third full size. Turner (1996) noted that mepiquat chloride applied at match-head square can maintain a proper balance of vegetative to reproductive growth in nodes 9 through 14, where the majority of final yield is attributed. Coccaro et al. (2004) found highest yields on a mixed soil, when PGRs were applied at first bloom followed by second application two weeks later, however, there was no increase in yields when applications were made at 7-8 nodes, or to cotton grown in a heavy clay soil. Phipps et al. (1996) and (1997) found yield increases when applying mepiquat chloride in a single application, and yield reductions when mepiquat chloride was applied in multiple applications. Research conducted on Pima cotton by Munk et al. (1997) indicates that yield response to mepiquat chloride was greatest with mid to late bloom sequential applications. Ebelhar et al. (1996) found some lint increases over a four year period with the use of four sequential applications of 146 mL ha^{-1} of mepiquat chloride.

Landivar et al. (1996) suggest that mepiquat chloride should be applied when plant height is likely to be greater than the optimum, according to ALT 5 (Average length technique of the uppermost five internodes) values, where the optimum plant height is defined as 1.10 times the row spacing. Robertson and Weatherford (2003) using the COTMAN program, used growth curves to explain the timing and need of PGR applications. The authors explain that yield may be increased if PGRs are used when the growth curves of untreated plots are flatter than the targeted growth curve, and yield may be reduced if growth curves drop faster than the targeted growth curve. Hutmacher et al. (2001) used maximum internode distances to determine the need for mepiquat chloride, while taking plant vigor and fruit retention into account. They found that mepiquat chloride recommendations differ depending upon vigor, retention, and timing of measurement. Meister (2004) suggests that the maximum internode distance method may be a more accurate measure of growth response to mepiquat chloride applications during the mid and late season evaluations, compared to the height node^{-1} ratio method.

Edmisten (1994) found that a feedback approach, or a plant monitoring system, for a low rate multiple strategy recognized changes in growth more accurately and required lower rates of mepiquat chloride, than the standard low rate multiple strategy. He also observed that the plant monitoring system for the early bloom strategy (mepiquat chloride applied at 5 to 6 white flowers per 7.6 meters of row) was overly aggressive, requiring higher rates of mepiquat chloride than the standard early bloom strategy. Norton and Silvertooth (2000), in a similar study comparing low rate multiple applications, late season applications, and a feedback approach, reveal that the feedback approach was the most viable application method, and the most reliable technique associated with plant assessment in this approach, was the height node^{-1} ratio.

The application of mepiquat chloride may cause negative yield responses if growth conditions immediately following treatment are not favorable for growth (Edmisten, 2006d). Dry and/or cool weather can exacerbate the inhibition of vegetative growth while warm and/or wet weather may cause the crop to require additional applications (Beck and Searcy, 2001). If stresses occur 3 weeks or later into the bloom period, then the majority of the crop has already been set, and yield is not necessarily compromised (Edmisten, 2006d). In North Carolina, three application timing strategies are used when applying mepiquat chloride. These strategies are the Early Bloom strategy, the Modified Early Bloom strategy, and the Low Rate Multiple strategy. Usually, mepiquat chloride performs best in North Carolina when used judiciously, due to the state's less favorable environment, compared to more favorable environments found in the southern and western regions of the U.S. (Edmisten, unpublished data).

The Early Bloom strategy is the most commonly used technique. This strategy involves applications of 0.59 to 1.17 L ha^{-1} of mepiquat chloride when 5 to 6 white blooms per 7.6 meters of row are evident, and plants are 61 cm tall or greater, with no apparent stress (Edmisten, 2006d). Subsequent applications may be necessary if excessive vegetative growth prevails, but yield advantages decrease as the bloom period progresses. If cotton is greater than 71 cm tall and has not yet reached early bloom, the application of the same rate would be necessary, however, if cotton is less than 51 cm tall at early bloom, no application is necessary. No application is necessary if the internode distance between the 3rd and 4th leaves from the terminal is less than 6.4 cm. This strategy is similar to early bloom strategies involving plant monitoring, described in Edmisten (1994). The Early Bloom strategy is the most commonly recommended strategy in North Carolina to promote yield and earliness, provided it is implemented in a timely fashion (Edmisten, unpublished data).

The Modified Early Bloom strategy consists of possible applications of mepiquat chloride 10-14 days prior to bloom, at early bloom, and sometimes at 10-14 days after early bloom (Edmisten, 2006d). Applications of 0.29-0.59 L ha^{-1} should be made 10-14 days before bloom if plants range from less than 43 cm tall to greater than 51 cm tall. Applications of 0-0.88 L ha^{-1} should be made at early bloom if plants range from less than 61 cm tall to greater than 76 cm tall. Again, no application is necessary if the internode distance between the 3rd and 4th leaves from the terminal is less than 6.4 cm. Applications following early bloom are rarely necessary if earlier applications are successful (Edmisten, 2006d). The Modified Early Bloom strategy is primarily used on a smaller portion of a grower's acreage, because time constraints sometimes do not allow the Early Bloom strategy to be implemented on the entire acreage. This strategy should be implemented to the acreage that has a history of excessive vegetative growth and to the most vigorously growing cotton at the time the decision to apply mepiquat chloride is made. This approach slows the vegetative growth on the most aggressively growing cotton, and guides the plants into bloom to hopefully yield similar results as the cotton acreage receiving early bloom applications.

The Low Rate Multiple strategy should be used on productive land, preferably with access to irrigation. This strategy consists of several applications of mepiquat chloride beginning at match-head square, and subsequently in 14 day intervals if conditions remain favorable (Edmisten, 2006d). This strategy is similar to low rate multiple strategies involving plant monitoring, described by Edmisten (1994). The Low Rate Multiple (LRM) strategy is sometimes preferred by growers who wish to tank-mix mepiquat chloride with other agronomic inputs. This strategy however, has been shown to reduce yields in comparison to the Early Bloom or the Modified Early Bloom strategy, especially if dry conditions prevail (Edmisten, 1994, 1995 unpublished data).

Cultivar Selection

Numerous cotton cultivars are currently available for growers, and selection is based mainly on lint yield, fiber quality, and transgenic traits. Other factors of importance that should be considered are seed size, leaf characteristics, plant height, maturity, and the ability to retain lint in severe weather. Regardless of the criterion, growers should base their decisions on multi-year and multi-location data in cultivar comparisons (Boman, 2006).

Cultivars of different maturity groups vary in growth characteristics. Early maturing cultivars tend to yield shorter plants with more compact fruiting than later maturing cultivars that usually grow taller, and set fruit higher on the plant and later into the season. Full season cultivars generally exhibit longer growth periods requiring more heat units to fully develop its crop, compared to earlier maturing cultivars (Pustejovsky and Albers, 2003). Pustejovsky and Albers (2003) found greater final plant height, maximum internode distances, and total nodes for DP 555 compared to the earlier maturing cultivars, DP 458 and SG 215. Factors that favor excessive vegetative growth may cause delayed maturity and inhibited boll opening (Singh and Brar, 1999). These characteristics can be altered by agronomic practices such as mepiquat chloride application, planting date, nitrogen and soil moisture adjustments, and matching particular cultivars with soil types. Therefore, it is often practical for growers to plant several different maturity groups so adequate time and heat units are available to produce a crop, to avoid complications of defoliating and harvesting, and to properly schedule harvest. Also, defoliation timing and harvest timing may vary between maturity groups, as some groups have more compact fruiting and possibly more rapid boll development/boll opening characteristics.

Defoliation Timing

Defoliation of cotton is a common practice used in North Carolina acreage to promote leaf abscission, boll opening, and to inhibit regrowth (renewed vegetative growth) in preparation for harvest. Defoliation can improve yields, lint grades, and promote earlier harvest. Singh and Tripathi (1976) noted that maturity was reached 10 to 15 days earlier, due to chemical defoliation. Defoliation is usually accomplished by using a combination of hormonal and herbicidal defoliants along with boll opening compounds, such as ethephon. Hormonal and herbicidal defoliants increase ethylene production, and therefore induce senescence mechanisms that lead to leaf abscission (Yang et al., 2003). Dessicants cause rapid moisture loss and drying of leaves (Yang et al., 2003) which decreases metabolic activity, thus interfering with the abscission process. The efficiency of defoliants is strongly dependent upon the plant's physiological condition and the environment at the time of application and soon thereafter. Plants should be physiologically mature and vegetatively dormant. Optimally, these conditions are met under environmental conditions that promote faster metabolic activity, such as warm temperatures, high atmospheric water content, sufficient leaf turgor, and adequate sunlight (Snipes and Wills, 1994).

Defoliation, if properly and timely implemented, can reduce trash content, allow faster or more efficient harvest, increase hours of harvest by allowing dew to dry quicker, straighten lodged plants, decrease boll rot or disease, and stimulate boll opening. Deciding when to defoliate is a complicated matter because crop maturity, crop condition, current and expected weather conditions, and harvest scheduling, all must be considered (Edmisten, 2006b). Proper timing of defoliation can significantly increase yields and quality. Premature defoliation may decrease yields (Phipps et al., 2002) while delayed defoliation may increase boll rot or the likeliness of damage or loss of lint due to weathering (Edmisten, 2006b). Although micronaire can be reduced through early defoliation (Faircloth et al., 2004a), yield can also be reduced, therefore defoliation decisions are a compromise between late season yield gains and a timely harvest (Snipes and Baskin, 1994). Defoliant activity may also be inhibited by cooler temperatures associated with later defoliation (Edmisten, 2006b). Growers are sometimes tempted to wait until the uppermost bolls are mature before deciding to defoliate, however these upper bolls contribute little to additional gain (Robertson et al., 2003).

Defoliation timing also affects quality parameters. Early defoliation can decrease yield and micronaire (Kelley et al., 2000), however delayed defoliation can result in yield or quality losses due to adverse weather conditions (Faircloth et al., 2004a). Snipes and Baskin (1994) found that defoliation as early as 20 and 40 % OB (percent open bolls) reduced yield and micronaire, and recommend defoliating after 60 % OB. Bednarz et al. (2002) found that length uniformity decreased when harvest aids were applied after 90 % OB in 1999 and 2000, and HVI-UHM was greatest when harvest aids were applied before 80 % OB in 2000. They also observed that AFIS fiber length was greatest when harvest aids were applied at 48 % OB in 1999, and 42 % OB in 2000. Maximum lint yields in this study, were achieved when harvest aid application occurred at 76.5 % OB in 1999, and at 89 % OB in 2000, although both HVI and AFIS fiber length, was optimized when harvest aid application occurred at 40 to 60 % OB. Therefore, proper defoliation timing is an economic balance between optimizing yields while preserving quality.

Methods currently used in North Carolina to time defoliation are the percent open boll method (% OB) and the nodes above cracked boll method (NACB). It is generally safe to defoliate when the majority of the plants in a field are 60 % OB (Edmisten, 2006b). However, variability in crop development may alter this recommendation. The boll population may be in various stages of maturity near the time of harvest, due to the indeterminate growth habit of cotton (Stewart et al., 2000b). Fields where the crop is set over a short period of time may possibly be defoliated earlier (40-50 % OB) while fields where the crop is set over a longer period of time may require delayed defoliation (70-80 % OB) because bolls set higher on the plant may not be sufficiently mature if defoliated at 60 % OB (Edmisten, 2006b; Hake et al., 1990). Defoliation could occur before 60 % OB if the flowering period is short and the crop is compact, however if the flowering period occurs over a long time, defoliation would possibly be more effective later than 60 % OB because more time may be needed for all bolls to develop, as these bolls are distributed throughout the plant (Kerby et al., 1992). High early season square retention, in North Carolina, causes the majority of the crop to be set over 8 to 10 nodes, which is closer in maturity than a crop set over 12 to 14 nodes, therefore may be defoliated earlier in terms of % OB and NACB (Stewart et al., 2000a). Faircloth et al. (2004a) found an increase in lint yield of 75 kg ha^{-1} across cultivars, by delaying defoliation from 40 % OB to 60 % OB, however UHM was unaffected by % OB changes, across cultivars. In another study concerning defoliation timings in cotton containing interrupted fruiting, Faircloth et al. (2004b) found data that defoliating after 60 % OB may help achieve optimal yields, in cotton containing a fruiting gap. However, these researchers also suggest that defoliating before 60 % OB may help avoid discounts due to high micronaire while avoiding yield losses, in cotton without a fruiting gap. A study conducted by Bednarz (2001) shows that timing defoliation at 60 % OB produced the highest maximum net returns in 1998, and highest lint yields and adjusted gross income were achieved when harvest aid application occurred at 80 % OB in 1999. Snipes and Baskin (1994) observed increased strength and length when defoliating at 20 % OB, but also found decreased yields resulting from early defoliation, therefore recommend defoliating after 60 % OB. However, Kelley et al. (2000) found no significant differences in yield or micronaire between 30 and 60 % OB defoliation timings. Singh and Tripathi (1977) found decreased seed cotton yield by defoliating at 20 % OB, and maximum yield was observed when defoliation occurred at 40 to 60 % OB.

The nodes above cracked boll method (NACB) is conducted by counting the number of nodes from the highest first position cracked boll to the highest harvestable boll. The current recommendation suggests that 4 NACB is a safe timing for defoliation, however lower plant population may have more bolls residing on vegetative branches, and 3 NACB may be a better timing for these situations (Edmisten, 2006b). Supak et al. (1993) suggest that NACB is an appropriate method in initiating defoliation, given that emergence is uniform, with normal fruit initiation and retention. Using the NACB method may also be more economical than the % OB method, due to the reduced time required to take these measurements (Faircloth et al., 2004b).

Heat unit accumulation beyond cut out (normally when NAWF = 4 or 5) is also used as a trigger for defoliation in some areas of the cotton belt. Robertson et al. (2003) found yield penalties for defoliating prior to 850 HU, and yields were similar when defoliation occurred between 850 HU and 1050 HU. However, loan values for quality were the greatest when defoliating at 850 HU. Fromme et al. (2003) also noted that yields were similar between the 850 HU timing (55 % OB) and the 950 HU (70 % OB) or 1050 HU (80 % OB) timings. Other studies conducted by Fromme et al. (2004) show yield increases by defoliating at 950 HU at some locations, while another location showed no yield advantage from defoliating after 750 HU. Bynum et al. (2004) found yield increases by defoliating at 950 HU and 1050 HU timings compared to earlier timings. Benson et al. (2001) also support the 850 HU timing as the optimal timing for defoliation in Arkansas. Fromme (1999) found that defoliation can be initiated between 750 HU and 850 HU, while Witten and Cothren (2002) found that defoliating at 850 HU after cutout is not practical without reducing yields, and also suggest that cutout can not be defined as NAWF = 5 in all cotton producing areas. Gonzalez-Garcia et al. (2005) also refute the 850 HU timing as the optimal defoliation timing, and make similar suggestions regarding the definition of cutout. Holman et al. (2000), and Fromme et al. (2005) found yield advantages differed between the various HU timings depending upon location and year. This method strongly depends on accuracy in defining cutout, and climatic conditions that determine cutout, during the production season.

Harvest Timing

Harvest should be conducted when all harvestable bolls are open, so losses of yield and quality is avoided (Supak, 1996). However, the time required for all bolls to open may differ depending upon crop maturity even if defoliants and boll openers are used. The rate of boll opening depends on environmental conditions, cultivar maturity group, and timing and use of plant growth regulators, among other factors. Earlier harvest can be promoted by proper use of defoliants (Supak, 1996). Defoliants improve leaf grades by reducing trash content, while ethephon products accelerate opening of mature bolls, therefore allowing harvesting to be conducted earlier (Supak, 1996). While twice-over harvesting is common in other areas of the cotton belt, a once-over strategy is generally recommended in most situations in North Carolina. Exposure of lint to weather can alter cotton fiber properties (Barker et al., 1979), and result in lower quality, therefore harvest should be performed soon after harvestable bolls are open. Valco (2005) explains that harvesting when cotton is too wet may reduce picking efficiency and cause reductions in fiber quality during subsequent storage. He therefore recommends harvesting when dew is absent and when relative humidity is below 60 %.

In addition to quality, lint yield can also be reduced due to environmental conditions. Faircloth (2002) found that seedcotton losses were correlated to rainfall greater than 0.5 cm and winds greater than 9 m s^{-1}. Williford (1992) found that 50 mm of rainfall is required to significantly reduce yields, whether rainfall occurs in one event or multiple events. He also notes grade losses associated with delayed harvests in 1983 and 1985, and both once-over and delayed harvest in 1984. He concluded that rainfall of 50 mm or more also appears to be the point of significant grade loss. Williford (1992) also suggests that the highest yields and quality are obtained when harvesting as soon as bolls are open, and when exposure of open bolls to rainfall is minimized (Williford, 1992). The twice-over strategy resulted in the highest yields and quality, but the author says economics of this strategy must be considered. However, Valco (2005) explains that early harvest may decrease yield, reduce micronaire, and increase short fiber content. Hague et al. (1999), found that fiber stickiness was greatest when harvest occurred after a killing frost. Duncan et al. (2003), conducted studies in Kansas, where harvest dates were separated by 14 day intervals, and found no yield decreases between the first three harvest dates, but found a significant decrease between the third and the fourth harvest date in 2001. Also, Duncan et al. (2003) noted changes in reflectiveness and yellowness as harvest was delayed, in 2001. In 2002, they found a significant yield reduction between the second and the third harvest date, due to a snowfall event, and a decrease in micronaire when harvest was delayed. Bednarz et al. (2002) found profit reductions of \$74 ha^{-1} $week^{-1}$ as harvest was delayed. Kelley et al. (2002) found decreases in color grade, staple length, strength, and uniformity as harvest was delayed, but found no differences in micronaire due to field exposure, and therefore concluded that yield and quality reductions can occur if harvest is delayed past an early optimum, and if 7.6 cm of precipitation occurs during the later harvest period. Although boll opening rates may vary depending upon genetics, environment, and management, harvest should be conducted soon after all harvestable bolls are open, with minimal exposure to weathering.

Conclusion

As supported by previous research, defoliation timing and harvest timing varies depending upon the crop's development and prevailing environmental conditions. The incorporation of management practices, such as the use and timing of plant growth regulators, and the planting of cultivars of different maturity groups, may alter the earliness, development, and fruiting pattern of the crop. These alterations may possibly affect the methods in which the crop should be defoliated and harvested. This research will examine the effects of defoliation timing and harvest timing on early, medium, and late plant growth regulator timings and cultivar maturity groups. This research will also hopefully define an optimal economic defoliation and harvest timing for each plant growth regulator strategy and maturity group.

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CHAPTER II

DEFINING OPTIMAL DEFOLIATION TIMING AND HARVEST TIMING FOR COMPACT, NORMAL, AND EXTENDED FRUITING PATTERNS OF COTTON ACHIEVED BY PLANT GROWTH REGULATOR APPLICATIONS

Abstract

Cotton (*Gossypium hirsutum* L.) in North Carolina is normally defoliated when 60 percent of the total bolls are open. It is hypothesized that defoliation could be initiated before 60 % OB (percent open bolls) if fruiting is compact, and in contrast, defoliation could be delayed beyond 60 % OB if fruiting is extended. Experiments were conducted in North Carolina during 2004 and 2005 at Upper Coastal Plains Research Station near Rocky Mount, to determine the effects of defoliation and harvest timings on crops of various levels of maturity or fruiting patterns. Mepiquat chloride was applied using the modified early bloom strategy, the early bloom strategy, and a non-treated control, to achieve compact, normal, and extended fruiting patterns, respectively. Targeted defoliation timings were 50, 70, and 90 % OB. Actual defoliation timings included 45, 61, and 77 % OB in 2004, and 57, 78, and 92 % OB in 2005. Harvest timings included 14 ± 3 days after defoliation and 28 ± 3 days after defoliation. In 2004, delaying harvest decreased length uniformity and fiber strength values by 2% and 9% respectively. In 2004, fiber strength was greater at the early and mid defoliation timings, when harvested early, and fiber strength was also increased due to mepiquat chloride applications. In 2005, data indicated that a crop with compact fruiting could be defoliated early, in terms of % OB, without sacrificing lint yield, indicating that nodes above cracked boll (NACB) measurements may be equally accurate as % OB measurements in timing defoliation, and therefore should be incorporated into defoliation decisions. Delaying harvest for a crop defoliated early may help maximize yield and fiber length, whereas an early harvest may be more appropriate for a crop defoliated late,

especially if significant amounts of rainfall are experienced. In 2005, micronaire values decreased 4% by delaying harvest, regardless of defoliation timing.

Introduction

Defoliation of cotton is a common practice used in North Carolina to promote leaf abscission, boll opening, and to inhibit regrowth (renewed vegetative growth) in preparation for harvest. Chemical defoliation can improve lint yield, lint grades, and promote earlier harvest. Defoliation, if properly and timely implemented, can reduce trash content, allow faster and more efficient harvest, increase hours of harvest by allowing dew to dry quicker, straighten lodged plants, decrease boll rot, and stimulate boll opening (Edmisten, 2006b).

Deciding when to defoliate is a complicated matter because crop maturity, crop condition, current and expected weather conditions, and harvest scheduling must be considered (Edmisten, 2006b). Proper timing of defoliation can significantly increase yields and quality. Premature defoliation may decrease yields (Phipps et al., 2002) while delayed defoliation may increase boll rot or the likeliness of damage or loss of lint and fiber quality due to weathering (Edmisten, 2006b). Although micronaire can be reduced through early defoliation (Faircloth et al., 2004a), yield can also be reduced, therefore defoliation decisions are a compromise between late season yield gains and a timely harvest (Snipes and Baskin, 1994). Defoliant activity may also be inhibited by cooler temperatures associated with delayed defoliation (Edmisten, 2006b). Growers are sometimes tempted to wait until the uppermost bolls are mature before deciding to defoliate, however these upper bolls often contribute little to additional yield gain (Robertson et al., 2003).

Defoliation timing also affects quality parameters. Early defoliation can decrease yield and micronaire (Kelley et al., 2000), however, delayed defoliation can result in yield or quality losses due to adverse weather conditions (Faircloth et al., 2004a). Snipes and Baskin (1994) found that defoliation as early as 20 and 40 percent open bolls (% OB) can reduce yield, and therefore recommend defoliating after 60 % OB. Bednarz et al. (2002) found that length uniformity decreased when harvest aids were applied after 90 % OB in 1999 and 2000, and HVI-UHM was greatest when harvest aids were applied before 80 % OB in 2000. They also observed that AFIS fiber length was greatest when harvest aids were applied at 48 % OB in 1999, and 42 % OB in 2000. Maximum lint yields in this study were achieved when harvest aid application occurred at 76.5 % OB in 1999, and at 89 % OB in 2000, although both HVI and AFIS fiber length was optimized when harvest aid application occurred at 40 to 60 % OB. Therefore, proper defoliation timing is an economic balance between optimizing yields while preserving quality.

Methods currently used in North Carolina to time defoliation are the percent open boll method (% OB) and the nodes above cracked boll method (NACB). It is generally safe to defoliate when the majority of the plants in a field are 60 % OB (Edmisten, 2006b). However, variability in crop development may alter this recommendation. A study conducted by Bednarz (2001) shows that timing defoliation at 60 % OB produced highest maximum net returns in 1998, and highest lint yields and adjusted gross income were achieved when harvest aid application occurred at 80 % OB in 1999. Snipes and Baskin (1994) observed increased strength and length when defoliating at 20 % OB, but also found decreased yields resulting from early defoliation. Singh and Tripathi (1977) found decreased seed cotton yield by defoliating at 20 % OB, and maximum yield was observed when defoliation occurred at 40 to 60 % OB. However, Kelley et al. (2000) found no significant differences in yield or micronaire between 30 and 60 % OB defoliation timings.

The boll population may be of various stages of maturity near the time of harvest, due to the indeterminate growth habit of cotton (Stewart et al., 2000b). Fields where the crop is set over a short period of time may possibly be defoliated earlier (40-50 % OB) while fields where the crop is set over longer period of time may require delayed defoliation (70-80 % OB) because bolls set higher on the plant may not be sufficiently mature if defoliation occurs at 60 % OB (Edmisten, 2006b; Hake et al., 1990). Defoliation could occur before 60 % OB if the flowering period is short and the crop is compact, however if the flowering period occurs over a long time, defoliation would possibly be more effective later than 60 % OB because more time may be needed for all bolls to develop, as these bolls are distributed throughout the plant (Kerby et al. 1992). In North Carolina, early season square retention is usually high, resulting in the majority of the bolls set over 8 to 10 nodes, which results in a more narrow range in boll maturity than a crop set over 12 to 14 nodes. Therefore, a crop with a narrow range in maturity, may be defoliated earlier in terms of % OB (Stewart et al., 2000a). Faircloth et al. (2004a) found an increase in yield of 75 kg ha^{-1} across cultivars, by delaying defoliation from 40 to 60 % OB, however UHM was unaffected by % OB changes, across cultivars. In another study concerning defoliation timings in cotton of interrupted fruiting, Faircloth et al. (2004b) suggested that defoliating before 60 % OB may possibly help avoid discounts due to high micronaire while avoiding sacrifices in yields, provided that the crop has no fruiting gap. Likewise, these researchers also claim that delaying defoliation may be appropriate for achieving optimal yields in cotton containing a fruiting gap.

Compact fruiting can be achieved through the application of plant growth regulators, and more-so through proper timing of these growth regulators. Mepiquat chloride (*1,1*-dimethyl piperidinium chloride) is a common plant growth regulator used in North Carolina cotton production. Research indicates that mepiquat chloride helps to hasten maturity, enhance earliness and fruit retention, increase yield, and reduce plant height by inhibiting cell elongation in stems, resulting in more compact plants with shorter main stem and fruiting branch internodes (Biles and Cothren, 2001; Edmisten, 2006d; Livingston et al., 1999). The impact of mepiquat chloride on yield is inconsistent and highly variable (Beck and Searcy, 2001), and results are dependent upon environmental factors and inputs such as nitrogen and water (Reddy et al., 1992). The timing and need for mepiquat chloride treatment may vary depending upon the specific situation. Conditions, that normally promote excessive vegetative growth and delayed maturity, are more likely to result in positive yield responses to mepiquat chloride. Some of these conditions include late planted cotton, high plant populations, high nitrogen rates, excessive rainfall, large late-maturing cultivars, and fields with a history of excessive vegetative growth, delayed maturity, or that will be defoliated first (Edmisten, 2006d). Usually, mepiquat chloride performs best in North Carolina when used judiciously, due to the state's less favorable environment, compared to more favorable environments found in the southern and western regions of the U.S. (Edmisten, unpublished data).

Meister (2004) suggests that the maximum internode distance method may be a more accurate measure of growth response to mepiquat chloride applications during the mid and late season evaluations, compared to the height $node^{-1}$ ratio method. Livingston et al. (2000) found yield advantages from a single application of mepiquat chloride after 850 accumulated heat units, however yield was decreased for treatments applied at match-head square and when squares were one-third full size. Turner (1996) noted that mepiquat chloride applied at match-head square can maintain a proper balance of vegetative to reproductive growth in nodes 9 through 14, where the majority of final yield is attributed. Coccaro et al. (2004) found highest yields on a mixed soil, when PGRs (plant growth regulators) were applied at first bloom followed by second application two weeks later however, there was no increase in yields when applications were made at 7-8 nodes, or to cotton grown in a heavy clay soil. Edmisten (1994) found that a feedback approach, or a plant monitoring system, for a low rate multiple strategy recognized changes in growth more accurately and required lower rates of mepiquat chloride, than the standard low rate multiple strategy. He also observed that the plant monitoring system for the early bloom strategy was overly aggressive, requiring higher rates of mepiquat chloride than the standard early bloom strategy. A study conducted by Norton and Silvertooth (2000) comparing low rate multiple applications, late season applications, and a feedback approach, reveals that the feedback approach was the most viable method, and the most reliable technique associated with plant assessment in this approach, was the height node^{-1} ratio. Phipps et al. (1996) found yield increases when applying mepiquat chloride in a single application, and yield reductions when mepiquat chloride was applied in multiple applications.

Harvest should be conducted when all harvestable bolls are open, so that losses of yield and quality are avoided (Supak, 1996). However, the time required for all bolls to open may differ depending upon crop maturity, even if defoliants and boll openers are used. The rate of boll opening depends on environmental conditions, cultivar maturity group, and timing or use of plant growth regulators, among other factors. Earlier harvest can be promoted by the use of defoliants (Supak, 1996). Defoliants reduce trash content and therefore improve leaf grades, while ethephon products accelerate opening of mature bolls, therefore allowing harvesting to be conducted earlier (Supak, 1996). Exposure of lint to weathering can alter fiber properties (Barker et al, 1979), and result in inferior quality, therefore harvest should be conducted soon after harvestable bolls are open. Faircloth (2002) found that seedcotton losses were correlated to rainfall greater than 0.5 cm and winds greater than 9 m s^{-1}. Williford (1992) found that the highest yields and quality are obtained when harvesting as soon as bolls are open, and when exposure of open bolls to rainfall is minimized. He found that 50 mm of rainfall is required to significantly reduce yields, whether rainfall occurs in one or several events. He also found grade losses associated with delayed harvests in 1983 and 1985, and both once-over and delayed harvest in 1984. He concluded that rainfall of 50 mm or more also appears to be the point of significant grade loss. Kelley et al., (2002) found decreases in color grade, staple length, strength, and uniformity as harvest was delayed, but found no differences in micronaire due to field exposure, and therefore concluded that yield and quality reductions can occur if harvest is delayed past an optimum, and if 7.6 cm of precipitation occurs during the later harvest period. Although boll opening rates may vary depending upon genetics, environment, and management, harvest should be conducted soon after all harvestable bolls are open, with minimal exposure to weathering.

The objectives of this research were to determine if defoliation timing differs for three fruiting patterns, accomplished by plant growth regulator application, and to define optimal defoliation and harvest timing for cotton of various fruiting patterns.

Materials and Methods

The experiment was conducted in North Carolina during 2004 and 2005 on a Goldsboro fine sandy loam soil (Fine-loamy, siliceous, subactive, thermic, Aquic Paleudult) at the Upper Coastal Plains Research Station (UCPRS) near Rocky Mount. A medium maturing cultivar, DP 451, was planted at a rate of 12.5 seeds meter^{-1} on 10 May 2004, and 3 May 2005 using a 2-row White vacuum planter in 2004, and a 4-row John Deere 6700 planter in 2005. Plots contained eight 12.2 m long rows, spaced 0.97 m apart. Treatments represented three plant growth regulator application strategies to accomplish various fruiting patterns, each defoliated at three stages of maturity based on a targeted %

OB (percent open bolls), with two harvest timings. Each plant growth regulator strategy was conducted in accordance to North Carolina Cooperative Extension recommendations (Table 2.1). The three plant growth regulator strategies used, were an early strategy (Modified Early Bloom), a standard strategy (Early Bloom), and a non-treated control. Targeted defoliation timings included 50 (early), 70 (mid), and 90 (late) % OB. Harvest timings included an early harvest (14 days after defoliation ± 3 days), and a late harvest (28 days after defoliation ± 3 days). Treatments were arranged in a modified split-block, split-plot design containing latin squares, with four replications. The three MC strategies were arranged in a Latin square structure, with defoliation timings randomly stripped across blocks, and the sub-plot factor as harvest timing. All other production and pest management practices were conducted according to the North Carolina Cooperative Extension recommendations for the particular region (Bacheler, 2006; Crozier, 2006; Koenning, 2006; York and Culpepper, 2006).

The Modified Early Bloom treatments received mepiquat chloride {*N,N*-dimethyl piperidinium chloride} (Mepex®, Griffin LLC., Valdosta GA.) at a rate of 0.59 L ha^{-1} during the pre-bloom (10 to 14 days before early bloom) period, on 30 June 2004 and 7 July 2005, followed by mepiquat chloride at a rate of 0.59 L ha^{-1} at the early bloom (5 to 6 white blooms per 7.6 m of row) growth stage, on 12 July 2004 and 18 July 2005. The first application of mepiquat chloride was delivered when plant height, total nodes, and uppermost fully expanded internode distances were 59 cm, 12, and 6.5 cm respectively in 2004, and 52 cm, 13, and 6 cm respectively in 2005. The second application of mepiquat chloride was delivered when plant height, total nodes, and uppermost fully expanded internode distances were 79 cm, 14, and 6 cm respectively in 2004, and 60 cm, 14, and 5.5 cm respectively in 2005 (Table 2.1).

The Early Bloom treatments received mepiquat chloride at a rate of 1.17 L ha^{-1} at the early bloom growth stage (5 to 6 white blooms per 7.6 m of row), on 12 July 2004 and 18 July 2005. The application of mepiquat chloride for all early bloom treatments, was delivered when plant height, total nodes, and uppermost fully expanded internode distances were 93 cm, 15, and 7.5 cm respectively in 2004, and 70 cm, 15, and 6 cm, respectively, in 2005 (Table 2.1).

Mepiquat chloride was applied using a CO_2-pressurized backpack sprayer, calibrated to deliver 140 L ha^{-1} using regular flat-fan nozzles. Plant heights, nodes, and uppermost fully expanded internode length (distance between 4^{th} and 5^{th} true leaf from the top of the plant) were recorded for six plants in the center two rows receiving defoliation treatment. Mid-season data, including heights, nodes, and nodes above white flower, were recorded for six plants per defoliation treatment in all plots on 4 August 2004, and on 8 August 2005. Plant mapping data were collected for 18 plants per defoliation treatment on 13 September 2004, and on 11 October 2005.

Percent open boll measurements were recorded on six adjacent plants chosen randomly in each plot within the designated strip assigned to a specific defoliation timing, and the average was taken across all plots within the strip. All plots within the designated strips were defoliated each year when this average reached the targeted % OB. A standard mixture of tribufos {*S,S,S*-tributyl phosphorotrithioate} (Def®, Bayer Crop Science, Research Triangle Park N.C.) at the 0.59 ml ha^{-1} rate, thidiazuron {*N*-phenyl-*N*'-1,2,3-thiadiazol-5-ylurea} (Dropp® 50 WP, Bayer Crop Science, Research Triangle Park N.C.) at the 0.22 kg ha^{-1} rate, and ethephon {2-chloroethyl phosphonic acid} (Prep®, Bayer Crop Science, Research Triangle Park N.C.) at the 2.34 L ha^{-1} rate, was used in each year, across all application timings. On 22 September 2005, an extra application of ethephon plus AMADS {(2-chloroethyl phosphonic acid) plus (1-aminomethanamide dihydrogen tetraoxosulfate)} (CottonQuick® , Dupont, Wilmington DE.) at the 4.7 L ha^{-1} rate, and tribufos at the 0.44 L ha^{-1} rate, was applied after all designated defoliation timings, to defoliate leaves that were not defoliated by the first application, and to prevent potential contamination of lint. The early defoliation treatments were defoliated on 13 September 2004 and 6 September 2005. The mid defoliation treatments were defoliated on 20 September 2004 and 13 September 2005. The late defoliation treatments were defoliated on 27 September 2004 and 19 September 2005. The actual defoliation timings were 45, 61, and 77 % OB in 2004, and 57, 78, and 92 % OB in 2005. Defoliation treatments were applied using a CO_2-pressurized backpack sprayer, calibrated to deliver 140.3 L ha^{-1} using regular flat-fan nozzles. At each defoliation timing, percent open bolls, total bolls, and nodes above cracked bolls (nodes between highest first position cracked boll and highest harvestable boll) were recorded.

The center two rows of each experimental unit were harvested with a 2-row John Deere spindle picker. The early harvest (14 days after defoliation $\pm$ 3 days) was conducted on rows 2 and 3 in all plots within each defoliation strip. The late harvest (28 days after defoliation ± 3 days) was conducted on rows 6 and 7 in all plots within each defoliation strip. Seedcotton weights for each plot were recorded and sub-samples were collected for HVI analysis and lint percentage. Data included lint yield, micronaire, length, length uniformity, and strength.

Data for lint yield and fiber quality parameters were subjected to analysis of variance using PROC GLM (Mixed procedure) in SAS version 9.1.3 (SAS Inst., 2005). Due to strong interactions with year, and consideration of F-tests, lint yield and quality data were reported separately by year. Means of significant main effects and interactions were separated using Fisher's Protected LSD at $p \leq 0.05$.

Results and Discussion

Interactions with year were significant for most yield and quality parameters, therefore means were reported separately in 2004 and 2005. The harvest timing main effect for lint yield was significant in 2004 (data not shown). In 2004, lint yields increased 61 kg ha^{-1} as harvest was delayed from 14 days after defoliation to 28 days after defoliation.

The MC strategy (mepiquat chloride treatment strategy) main effect for lint yield was significant in 2004 (data not shown). In 2004, lint yields of the modified early bloom strategy were 160 kg ha^{-1} higher than the yields of the non-treated control. The means for the early bloom strategy were numerically less than the yields of the modified early bloom and greater than the yields of the non-treated control, however these differences were not significant. The downward trend in lint yields from the compact fruiting (MEB) to the extended fruiting (NTC) MC strategies, indicate a yield response to mepiquat chloride applications. In 2005, there were no significant differences between the three MC strategies.

The defoliation timing by MC strategy interaction for lint yield was significant in 2005 (Table 2.2). The modified early bloom strategy yielded significantly higher than the non-treated control at the early defoliation timing, indicating that early defoliation may not be plausible for crops with extended fruiting patterns. At the mid defoliation timing, the non-treated control yielded significantly higher than the early bloom strategy. The reverse effect occurred at the late defoliation timing, as the early bloom strategy yielded significantly higher than the non-treated control. At both medium and late defoliation timings, yields of the modified early bloom strategy were not different from either the non-treated control or the early bloom strategy.

When comparing lint yields across defoliation timings for each individual MC strategy, yields of the non-treated control decreased, but not significantly, as defoliation was delayed from the early to the late defoliation timing. Yields of the modified early bloom strategy were significantly higher when defoliated at the early defoliation timing compared to the medium or late defoliation timings. Yields of the early bloom strategy defoliated at early and late defoliation timings, were not significantly different, however yields at these defoliation timings were both significantly higher than yields of the mid defoliation timing.

The defoliation timing by harvest timing interaction for lint yield was significant in 2005 (Table 2.3). Yields of the delayed harvest defoliated at the early defoliation timing were significantly higher than the yields of the early harvest, but were not different from the yields of the early harvest of the late defoliation timing. At the early defoliation timing, lint yields increased significantly as harvest was delayed, however, the reverse effect occurred at the late defoliation timing. At the mid defoliation timing, there was no differences in lint yields between the two harvest dates. Heat unit accumulation during the defoliation and harvest periods, was greater in 2005 compared to 2004 (Table 2.4), possibly allowing more bolls to open between the early and delayed harvests. Also, the significant rainfall events occurring between defoliation and harvest in 2005 (Table 2.5), were more extensive for the medium and the late defoliation timings, and to a lesser extent for the early defoliation timing. Yields of either harvest timing at the mid defoliation timing, and were not different from the yields of the early harvest defoliated at the early defoliation timing, and late harvest of the late defoliation timing. These trends indicate that achieving an early harvest may be more important when defoliation is delayed, due to increased weathering potential.

The harvest timing main effect for micronaire was not significant in 2004, however, it was significant in 2005 (data not shown). Micronaire decreased by 4 % as harvest was delayed in 2005, indicating that delaying harvest may help reduce micronaire values in years subject to yielding high micronaire. This effect is also possibly a result of either the increases in opening of less mature bolls, or the significant rainfall events that occurred between defoliation and harvest in 2005 (Table 2.5). All values were in the discount range in 2005, but not in 2004.

The harvest timing by MC strategy interaction was significant for fiber length in 2004 (Table 2.6), but not in 2005. Length values of each MC strategy all decreased numerically as harvest was delayed, but only significantly for the early bloom strategy. This indicates that delaying harvest could reduce fiber length, however, all length values were above the 2.7 kN mg kg^{-1} discount benchmark.

The defoliation timing by harvest timing interaction for length was significant in 2005, but not in 2004 (Table 2.7). Length values increased as harvest was delayed for the early and mid defoliation timings, possibly due to extensive heat unit accumulation, but the reverse effect occurred at the late defoliation timing, likely a result of significant amounts of rainfall (Table 2.5). Differences between harvest timings defoliated at the medium or late defoliation timings, were not significant. Maximum fiber length values were achieved by defoliating early and delaying harvest, or defoliating late and harvesting early. These trends, again, indicate that achieving an early harvest may be more important when defoliation is delayed, due to increased weathering potential.

The defoliation timing by MC strategy interaction was significant for length in 2005 (Table 2.8). No statistical differences between defoliation timings were evident for the non-treated control, however, length values numerically increased as defoliation was delayed from the early to the mid defoliation timing, and slightly decreased as defoliation was delayed from the medium to the late defoliation timing. Again, heat unit accumulation and rainfall events are the likely reasons for these results (Table 2.4, 2.5). Length values of the modified early bloom strategy defoliated at the early defoliation timing were significantly greater than when defoliated at the mid defoliation timing, however, values corresponding to the late defoliation timing were not different from either the early or the mid defoliation timings. As defoliation was delayed from the medium to the late defoliation timings, length values of the early bloom strategy increased, but neither values were different from that of the early defoliation timing. Length values of the modified early bloom strategy were significantly greater than the values of the non-treated control, but were not different than that of the early bloom strategy, at the early defoliation timing. There were no statistical differences in fiber length between each of the MC strategies within each of the medium or late defoliation timings. This suggests that mepiquat chloride use may be more important, in terms of fiber length, if the crop is to be defoliated early. Also, the absence of significant relationships between MC strategies and defoliation timing, for the medium and late defoliation timings, is probably a result of partial fiber development due to environmental influences.

The harvest timing main effect was significant for length uniformity, in 2004 (data not shown). Uniformity values decreased 1 % as harvest was delayed in 2004. This decrease in uniformity, between harvests, is possibly caused by boll opening of lesser mature bolls, during the 14 day interval.

The defoliation timing by MC strategy interaction was significant for length uniformity in 2005 (Table 2.9). At the early defoliation timing, values of the modified early bloom strategy were significantly higher than the values of the non-treated control, but neither value was different from the values of the early bloom strategy. The non-treated control yielded higher uniformity than the modified early bloom or the early bloom strategy, at the mid defoliation timing, but there were no differences in values between the MC strategies at the late defoliation timing. Values of the modified early bloom and the early bloom strategies, decreased significantly as defoliation was delayed from the early to the mid defoliation timing, but increased when defoliation was delayed from the medium to the late defoliation timing.

The harvest timing main effect for strength was significant in 2004 but not in 2005 (data not shown). Fiber strength decreased by 9 %, or 28 kN mg kg^{-1}, as harvest was delayed in 2004, and only numerically in 2005, possibly due to prolonged field exposure and degradation by rainfall (Table 2.5).

The defoliation timing by MC strategy interaction for strength was significant in 2004 (Table 2.10). Strength values of the non-treated control and the early bloom strategy were significantly less than the values of the modified early bloom strategy at the mid defoliation timing, however all strength values of the mid defoliation timing were not different from those of either the early or late defoliation timings, indicating that there is no strength penalty associated with early defoliation.

The defoliation timing by harvest timing interaction for strength was significant in 2004 (Table 2.11). In 2004, at the late defoliation timing, strength values of the early and delayed harvests were not different statistically, whereas strength values decreased significantly as harvest was delayed for both the early and mid defoliation timings. Strength values of the late defoliation timing, regardless of harvest timing, were significantly less than the early harvest strength values of the early and mid defoliation timings, but were significantly greater than the late harvest values of either defoliation timing. Prolonged field exposure to weathering is likely responsible for these effects (Table 2.5).

The harvest timing by MC strategy interaction was significant for strength in 2004 (Table 2.12). All strength values of the early harvest were significantly greater than those of the delayed harvest. Within the early harvest, the modified early bloom yielded higher strength than the non-treated control, however the values of the early bloom strategy were not significantly different from either of the non-treated control nor the modified early bloom strategies. There were no significant strength differences between MC strategies when harvest was delayed.

The defoliation timing by harvest timing by MC strategy interaction was significant for strength in 2005, however no explainable trends were evident, and results are best explained by the interactions previously explained, therefore data for the defoliation timing by harvest timing by MC strategy interaction are not reported.

Interactions with year were insignificant for most parameters, so analyses for plant mapping parameters were combined over 2004 and 2005 (Table 2.13, 2.14). At midseason, both the non-treated control and the early bloom strategies were greater in plant height than the modified early bloom strategy, but were not significantly different from each other (Table 2.14). Total nodes were greatest for the non-treated control, followed by the early bloom strategy, and lastly, the modified early bloom strategy. Nodes above white flower values were greatest for the non-treated control compared to both the early bloom and the modified early bloom strategy. These data indicate the desired levels of fruiting compactness was achieved, and that physiological maturity would like occur earliest for the modified early bloom strategy, followed by the early bloom strategy and lastly, the non-treated control.

Final plant height, and height node^{-1} ratio, were significantly less for the modified early bloom strategy compared to the non-treated control and the early bloom strategies, which were statistically the same (Table 2.13). Total position 1 bolls for the non-treated control strategy were significantly greater than values of the early bloom strategy, but the values of the modified early bloom strategy were not different from either the non-treated control or the early bloom strategies. Total bolls on positions 11 through 19, were significantly greater for the non-treated control, compared to either the modified early bloom or the early bloom strategies, and the values of the latter two strategies were not significantly different from each other. The non-treated control yielded significantly greater position 1 bolls on nodes eleven through nineteen, than the modified early bloom strategy, however, the values of the early bloom strategy were not significantly different from either of the other two strategies. These data also indicate that the desired level of fruiting compactness was achieved through plant growth regulator applications.

Conclusions

The success of any defoliation and harvest strategy depends upon the crop condition, and prevailing environmental conditions. Growers must balance influences of plant growth regulators and defoliation with yield and quality attributes. Similar to the findings of Kelley et al. (2002), and Williford (1992), lint yields may vary with harvest timing, and may be strongly correlated to the extent and intensity of rainfall events that occur following defoliation. Yield response to mepiquat chloride also varies, as positive responses to growth regulators often depend on environmental conditions following the application. Similar to statements of Kerby et al. (1992) and Stewart et al. (2000a), early defoliation for cotton with compact fruiting, accomplished through mepiquat chloride applications, is plausible according to our lint yield results in 2005. These data also suggest that delaying harvest for a crop defoliated early, may enhance yields, whereas an early harvest strategy could result in higher yields of a crop defoliated beyond 60 % OB. Micronaire may also be reduced to target values by delaying harvest, which may be an effective management tool in years that tend to produce high micronaire cotton. Data from 2004 suggest that harvesting early may maximize potential fiber length, whereas length could be reduced by delaying harvest. However, data from 2005 suggest that delaying harvest for a crop defoliated early, and vice versa for a crop defoliated later than

60 % OB, can maximize length, although most values were above the discount benchmark.

Applications of mepiquat chloride also lead to increases in fiber length and in length uniformity, as seen in 2005, especially at earliest defoliation timing. Data shows that delaying harvest may decrease length uniformity and fiber strength values, potentially to discount levels. Similar to the findings of Snipes and Baskin (1994), fiber strength increased through the application of mepiquat chloride, and by implementing an early harvest, especially when the crop is defoliated at 60 % OB and before. Midseason and endseason plant mapping data, combined over both years of this study, demonstrate that compact and extended fruiting was accomplished, in terms of plant heights, nodes, and fruiting position, however, conducting a similar study in areas more prone to excessive vegetative growth could result in more pronounced distinction between fruiting patterns. Data from this study suggest that defoliation and harvest may vary depending upon the fruiting pattern of the crop, and nodes above cracked boll may be a useful tool in deciding when to defoliate, and should be used in combination with % OB measurements. In terms of yield, defoliating when NACB is equal to 3, regardless of percent open values, appears to be an accurate threshold to initiate defoliation (Table 2.15). Regardless of the situation, growers must consider crop condition and weather forecasts, when making a defoliation decision.

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Table 2.1. Heights, nodes, and internode distance data at time of mepiquat chloride application for each MC strategy in 2004 and 2005.

MC strategy	Heights		Nodes		Internode distances	
	2004	2005	2004	2005	2004	2005
	cm		no.		cm	
MEB[z] 1st application	59	52	12	13	6.5	6.0
MEB 2nd application	79	60	14	14	6.0	5.5
EB	93	70	15	15	7.5	6.0

[z]MEB denotes the modified early bloom strategy; EB denotes the early bloom strategy.

Table 2.2. Defoliation timing by MC strategy interaction effects on lint yield in 2005.[z]

Defoliation timing	MC strategy	Lint yield
—— % OB ——		—— kg ha^{-1} ——
57	NTC[y]	1290bcd
	MEB	1410a
	EB	1320abc
78	NTC	1280bcd
	MEB	1180de
	EB	1150e
92	NTC	1220cde
	MEB	1250bcde
	EB	1340ab

[z]Data are pooled over harvest timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at α = 0.05.
[y]NTC denotes the non-treated control; MEB denotes the modified early bloom strategy; EB denotes the early bloom strategy.

Table 2.3. Defoliation timing by harvest timing interaction effects on lint yield in 2005.[z]

Defoliation timing	Harvest timing	Lint yield
——— % OB ———		—— $kg\ ha^{-1}$ ——
57	Early[y]	1300bc
	Late	1380a
78	Early	1210cd
	Late	1190cd
92	Early	1400ab
	Late	1140d

[z]Data are pooled over MC strategies. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.
[y]Early denotes the harvest at 14 days after defoliation; Late denotes the harvest at 28 days after defoliation.

Table 2.4. Degree Day 60 (DD 60) accumulation for specified intervals in 2004 and 2005.

Time interval	Early Defoliation		Mid defoliation		Late Defoliation	
	2004	2005	2004	2005	2004	2005
	DD 60s					
Planting-defoliation	2131	2000	2199	2099	2267	2219
Planting-early harvest	2266	2252	2352	2352	2358	2449
Planting-late harvest	2358	2449	2357	2513	2369	2516
Defoliation-early harvest	146	267	155	271	107	251
Defoliation-late harvest	237	464	160	432	118	318

Table 2.5. Rainfall accumulation (cm) for specified intervals in 2004 and 2005.

Time interval	Early Defoliation		Mid defoliation		Late Defoliation	
	2004	2005	2004	2005	2004	2005
	cm					
Planting-defoliation	52	39	55	40	55	41
Defoliation-early harvest	3	4	1	4	1	3
Defoliation – late harvest	4	5	4	12	4	10
Early harvest- late harvest	1	1	3	8	3	8

Table 2.6. Harvest timing by MC strategy interaction effects on fiber length (UHM) in 2004.[z]

Harvest timing	MC strategy	Length
		——— cm ———
Early[y]	NTC[x]	2.95ab
	MEB	2.99a
	EB	3.00a
Late	NTC	2.92bc
	MEB	2.96ab
	EB	2.87c

[z]Data are pooled over defoliation timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.
[y]Early denotes the harvest at 14 days after defoliation; Late denotes the harvest at 28 days after defoliation.
[x]NTC denotes the non-treated control; MEB denotes the modified early bloom strategy; EB denotes the early bloom strategy.

Table 2.7. Defoliation timing by harvest timing interaction effects on fiber length (UHM) in 2005.[z]

Defoliation timing	Harvest timing	Length
—— % OB ——		—— cm ——
57	Early[y]	2.70b
	Late	2.81a
78	Early	2.69b
	Late	2.73ab
92	Early	2.81a
	Late	2.75ab

[z]Data are pooled over MC strategies. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.

[y]Early denotes the harvest at 14 days after defoliation; Late denotes the harvest at 28 days after defoliation.

Table 2.8. Defoliation timing by MC strategy interaction effects on fiber length (UHM) in 2005.[z]

Defoliation timing	MC strategy	Length
—— % OB ——		—— cm ——
57	NTC[y]	2.70c
	MEB	2.81a
	EB	2.76abc
78	NTC	2.74abc
	MEB	2.72bc
	EB	2.68c
92	NTC	2.73abc
	MEB	2.80ab
	EB	2.81a

[z]Data are pooled over harvest timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.
[y]NTC denotes the non-treated control; MEB denotes the modified early bloom strategy; EB denotes the early bloom strategy.

Table 2.9. Defoliation timing by MC strategy interaction effects on uniformity index (UI) in 2005.[z]

Defoliation timing	MC strategy	Uniformity
——— % OB ———		—— % ——
57	NTC[y]	80.9bc
	MEB	83.0a
	EB	81.7abc
78	NTC	82.5ab
	MEB	80.6c
	EB	80.5c
92	NTC	82.2abc
	MEB	83.0a
	EB	83.2a

[z]Data are pooled over harvest timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.
[y]NTC denotes the non-treated control; MEB denotes the modified early bloom strategy; EB denotes the early bloom strategy.

Table 2.10. Defoliation timing by MC strategy interaction effects on fiber strength (STR) in 2004.[z]

Defoliation timing	MC strategy	Strength
—— % OB ——		—— kN mg kg^{-1} ——
45	NTC[y]	301ab
	MEB	294ab
	EB	294ab
61	NTC	290b
	MEB	308a
	EB	293b
77	NTC	298ab
	MEB	291b
	EB	304ab

[z]Data are pooled over harvest timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.
[y]NTC denotes the non-treated control; MEB denotes the modified early bloom strategy; EB denotes the early bloom strategy.

Table 2.11. Defoliation timing by harvest timing interaction effects on fiber strength (STR) in 2004.[z]

Defoliation timing	Harvest timing	Strength
—— % OB ——		—— kN mg kg^{-1} ——
45	Early[y]	317a
	Late	276c
61	Early	315a
	Late	280c
77	Early	302b
	Late	293b

[z]Data are pooled over MC strategies. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.
[y]Early denotes the harvest at 14 days after defoliation; Late denotes the harvest at 28 days after defoliation.

Table 2.12. Harvest timing by MC strategy interaction effects on fiber strength (STR) in 2004.[z]

Harvest timing	MC strategy	Strength
		——— kN mg kg^{-1} ———
Early[y]	NTC[x]	304b
	MEB	316a
	EB	314ab
Late	NTC	289c
	MEB	280c
	EB	280c

[z]Data are pooled over defoliation timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at α =0.05.
[y]Early denotes the harvest at 14 days after defoliation; Late denotes the harvest at 28 days after defoliation.
[x]NTC denotes the non-treated control; MEB denotes the modified early bloom strategy; EB denotes the early bloom strategy.

Table 2.13. MC strategy main effect for plant mapping parameters combined over 2004 and 2005.[z]

MC strategy	Heights	Height node^{-1} ratio	Postion 1 Total bolls	Total bolls on nodes 11-19	Postion 1 bolls on nodes 11-19
	— cm —		——— no. ———		
NTC[y]	90a	5.6a	6.1a	2.9a	2.7a
MEB	69b	4.7b	5.4ab	2.0b	1.9b
EB	82a	5.4a	5.1b	2.1b	2.1ab

[z]Data are pooled over years, defoliation timings, and harvest timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.

[y]NTC denotes the non-treated control; MEB denotes the modified early bloom strategy; EB denotes the early bloom strategy.

Table 2.14. MC strategy main effect for midseason plant mapping parameters combined over 2004 and 2005.[z]

MC strategy	Heights	Nodes	Nodes above white bloom
	——— cm ———	——————— no.	———————
NTC[y]	87a	16a	1.1a
MEB	71b	14c	0.4b
EB	82a	15b	0.6b

[z]Data are pooled over years, defoliation timings, and harvest timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.
[y]NTC denotes the non-treated control; MEB denotes the modified early bloom strategy; EB denotes the early bloom strategy.

Table 2.15. Nodes above cracked boll measurements for each MC strategy at each defoliation timing in 2004 and 2005.

MC strategy	Early Defoliation		Mid defoliation		Late Defoliation	
	2004	2005	2004	2005	2004	2005
	no.					
MEB[y]	2.9	2.8	1.3	1.3	1.7	0.4
EB	2.7	2.4	1.7	1.0	1.6	1.2
NTC	4.7	3.5	2.1	2.3	3.0	1.1
Average	3.4	2.9	1.7	1.5	2.1	0.9

[y]MEB denotes the modified early bloom strategy; EB denotes the early bloom strategy; NTC denotes the non-treated control.

CHAPTER III

DEFINING OPTIMAL DEFOLIATION TIMING AND HARVEST TIMING FOR COMPACT, NORMAL, AND EXTENDED FRUITING PATTERNS OF COTTON ACHIEVED BY CULTIVAR MATURITY GROUPS

Abstract

In North Carolina, cotton (*Gossypium hirsutum* L.) defoliation is usually initiated when 60 percent of the total bolls are open. Within season environmental conditions, such as rainfall and heat unit accumulation, vary greatly from year to year, as this region is located in the northern region of the cotton belt. Final results could yield compact or extended fruiting patterns for a particular area, depending on heat unit and rainfall combinations that prevail. Recent evidence suggests that defoliation could be initiated before 60 % OB (percent open bolls) if fruiting is compact (fruit set over 8 to 10 nodes), however, a crop with extended fruiting may require delayed defoliation to reach optimal yields and quality. Experiments were conducted in North Carolina during 2004 and 2005 to observe the effects of defoliation and harvest timings on crops of various levels of maturity or fruiting patterns. Compact, normal, and extended fruiting patterns were achieved via planting early, medium, and late maturing cultivars, respectively. The three cultivars, DP 444, DP 451 and DP 555, were used to achieve the compact, normal and extended fruiting patterns, respectively. Targeted defoliation timings were 50, 70, and 90 % OB. Actual defoliation timings included 46, 69, and 83 % OB in 2004, and 50, 66, and 82 % OB in 2005. Harvest timings included 14 ± 3 days after defoliation and 28 ± 3 days after defoliation. Yields of each of these cultivars varied in 2004, possibly due to differences in moisture and heat unit accumulation. Data also suggest that cultivar differences may be largely responsible for quality variations in micronaire, fiber length, length uniformity, and fiber strength. Micronaire was reduced by 3% when harvest was delayed in both years, which may

be an effective quality management tool in years likely to result in high micronaire, however, in 2005 strength was also reduced, possibly due to the rain events that occurred during the harvest period in this year. Defoliation before 60 % OB was proven to be plausible however harvest should be delayed to achieve maximum yields, for this scenario. In contrast, optimal yields were reached when cotton, defoliated beyond 60 % OB, was harvested early. These effects were largely a result of variations in the amount of rainfall occurring during the harvest period. Data indicated that delaying defoliation may increase yields, regardless of cultivars. Plant mapping data suggest that fruiting patterns were different, however, all three cultivars seemed to possess an extended fruiting pattern, therefore assumptions regarding fruiting compactness can not made based on a particular cultivar maturity group. Also, the use of nodes above cracked boll (NACB) measurements may be equally effective as % OB measurements, and therefore should be incorporated into defoliation decisions. A similar study conducted in environments that promote excessive vegetative growth, could result in larger variation in fruiting patterns and thus more conclusive results.

Introduction

Numerous cotton cultivars are currently available for growers. Cultivar selection is usually based on lint yield, fiber quality characteristics, and transgenic traits. Other factors of importance that should be considered are seed size, leaf pubescence, plant height, and maturity as well as stormproofness and ginout. Regardless of the criterion, growers should base their decisions on multi-year and multi-location data in cultivar comparisons (Boman, 2006).

Cultivars of different maturity groups vary in growth characteristics. Early maturing cultivars tend to yield shorter plants with more compact fruiting than later maturing cultivars that usually grow taller, and set fruit higher on the plant and later into the season. Full season cultivars generally exhibit longer growth periods, requiring more heat units to fully develop its crop, compared to earlier maturing cultivars (Pustejovsky and Albers, 2003). Pustejovsky and Albers (2003) found greater final plant height, maximum internode distances, and total nodes for DP 555 compared to the earlier maturing cultivars, DP 458 and SG 215. Factors that favor excessive vegetative growth may cause delayed maturity and inhibited boll opening (Singh and Brar, 1999). These characteristics can be altered by agronomic practices such as mepiquat chloride application, planting date, nitrogen and soil moisture adjustments, and matching particular cultivars with soil types. Therefore, it is often practical for growers to plant several different maturity groups so adequate time and heat units are available to produce a crop, to avoid complications of defoliating and harvesting, and to properly schedule harvest. Also, optimal defoliation timing and harvest timing may vary between maturity groups, as some groups have more compact fruiting and possibly more rapid boll development or boll opening characteristics.

Cotton defoliation promotes leaf abscission, boll opening, and inhibits regrowth (renewed vegetative growth). Crop maturity, crop condition, current and expected weather conditions, and harvest scheduling, all must be considered when deciding when to initiate defoliation (Edmisten, 2006b). Premature defoliation may decrease yields (Phipps et al., 2002) while delayed defoliation may increase the likeliness of damage or loss of lint due to weathering (Edmisten, 2006b; Faircloth, 2002). Although micronaire can be reduced by defoliating early (Faircloth et al., 2004a), yield reductions may occur, therefore defoliation decisions are a balance between a timely harvest and late season yield increases (Snipes and Baskin 1994). Growers are sometimes tempted to wait until the upper portion of bolls are mature before deciding to defoliate, however these upper bolls may contribute little to additional yield increases (Robertson et al., 2003). Delayed defoliation can possibly result in yield or quality losses due to adverse weather conditions (Faircloth et al., 2004a). Snipes and Baskin (1994) found that defoliation as early as 20 to 40 % OB (percent open bolls) reduced yield and micronaire, and recommend defoliating after 60 % OB. Bednarz et al. (2002) found that length uniformity decreased when harvest aids were applied after 90 % OB in 1999 and 2000, and HVI-UHM was greatest when harvest aids were applied before 80 % OB in 2000.

In North Carolina, it is generally safe to defoliate when the majority of the plants in a field have reached 60 % OB (Edmisten, 2006b). However, variability in crop development may alter this recommendation. The boll population may be of various stages of maturity near the time of harvest, due to the indeterminate growth habit of cotton (Stewart et al., 2000b). Fields where the crop is set over a short period of time, may possibly be defoliated earlier (40-50 % OB) while fields where the crop is set over a longer period of time may require delayed defoliation (70-80 % OB) because bolls set higher on the plant may not be sufficiently mature at 60 % OB (Edmisten, 2006b, Hake et al., 1990). Defoliation could occur before 60 % OB if the flowering period is short and the crop is compact, however if flowering occurs over a long period of time, defoliation beyond 60 % OB would possibly be more effective because more time may be needed for younger, or less mature, bolls to develop (Kerby et al. 1992). High early season square retention, in North Carolina, causes the majority of the bolls to be set over 8 to 10 nodes, which is closer in maturity than a crop with bolls set over 12 to 14 nodes, therefore may be defoliated earlier in terms of % OB and NACB (Stewart et al., 2000a). Cultivars that differ in maturity, may also exhibit different fruiting patterns, fruiting compactness, or spread of fruit throughout the plant. Faircloth et al. (2004a) found yield increases, by delaying defoliation from 40 to 60 % OB across cultivars (Faircloth et al., 2004a). Faircloth et al. (2004b) suggest that defoliating before 60 % OB may help avoid discounts due to high micronaire while avoiding yield losses, provided the crop has no fruiting gap. The authors also suggest that delayed defoliation may be appropriate for achieving optimal yields in cotton containing a fruiting gap.

The rate of boll opening depends on environmental conditions, cultivar maturity group, and timing and use of plant growth regulators, among other factors. Proper defoliation can improve leaf grades and lead to earlier harvest by accelerating boll opening with the use of ethephon products (Supak, 1996). Lint exposure to weathering, alters fiber characteristics (Barker et al., 1979) and reduce quality grades, therefore cotton should be harvested soon after all harvestable bolls are open. However, boll opening rates may differ between fields or cultivars, and depend upon crop maturity and weather, even if defoliants and boll openers are used. Williford (1992) suggests that harvest should be initiated when harvestable bolls are open, with minimum exposure of open bolls to rainfall. Faircloth (2002) found that seedcotton losses were correlated to rainfall greater than 0.5 cm and winds greater than 9 m s^{-1}. The benchmark in which rainfall begins to reduce yields and grades, according to the findings of Williford (1992) is 50 mm of rainfall whether rainfall occurs in one event or multiple events. He also noted that grade losses were associated with delayed harvests in two of three years, and both once-over and delayed harvest only in one year. Kelley et al. (2002) found that delayed harvest resulted in several quality penalties, except for micronaire, and also concluded that 3 inches of precipitation during the later harvest period, is the threshold where yield and quality reductions begin. Although boll opening rates may vary depending upon genetics, environment, and management, harvest should be conducted soon after all harvestable bolls are open, with minimal exposure to weathering.

The objectives of this research were to determine if defoliation timing differs for three cultivar maturity groups, and define optimal defoliation and harvest timing, in terms of yield and fiber quality, for various fruiting patterns of cotton.

Materials and Methods

The experiment was conducted in North Carolina during 2004 and 2005 on a Goldsboro fine sandy loam soil (Fine-loamy, siliceous, subactive, thermic, Aquic Paleudult) at the Upper Coastal Plains Research Station (UCPRS) near Rocky Mount. Using a 2-row White vacuum planter in 2004, and a 4-row John Deere 6700 planter in 2005, cotton seed of each cultivar was planted at a rate of 12.5 seeds linear meter^{-1} on 12 May 2004, and 3 May 2005. Treatments represented three cultivar maturity groups or fruiting patterns, each defoliated at three stages of maturity based on targeted % OB (percent open bolls) measurements, and two harvest timings. The three cultivar maturity groups included an early maturing cultivar (DP 444), a medium maturing cultivar (DP 451), and a late maturing cultivar (DP 555). Targeted defoliation timings included 50 (early), 70 (mid), and 90 (late) % OB. Harvest timings included an early harvest (14 days after defoliation $\pm$ 2 days) and a late harvest (28 days after defoliation $\pm$ 2 days). Plots contained eight rows 12.2 m long, spaced 0.97 m apart. Treatments were arranged in a modified split-block, split-plot design containing Latin squares, with four replications. The three cultivars were arranged in a Latin square structure, with defoliation timings randomly stripped across blocks, and the sub-plot factor as harvest timing. All other production and pest management practices were conducted according to the North Carolina Cooperative Extension recommendations for the particular region (Bacheler, 2006; Crozier, 2006; Koenning, 2006; York and Culpepper, 2006).

Percent open boll measurements were recorded on six adjacent plants chosen randomly in each plot within the designated strip assigned to a specific defoliation timing, and the average was taken across all plots within the strip. All plots within the designated strips were defoliated each year when this average reached the targeted % OB. A standard mixture of tribufos {*S,S,S*-tributyl phosphorotrithioate} (Def®, Bayer Crop Science, Research Triangle Park N.C.) at the 0.59 ml ha^{-1} rate, thidiazuron {*N*-phenyl-*N*'-1,2,3-thiadiazol-5-ylurea} (Dropp® 50 WP, Bayer Crop Science, Research Triangle Park N.C.) at the 0.22 kg ha^{-1} rate, and ethephon {2-chloroethyl phosphonic acid} (Prep®, Bayer Crop Science, Research Triangle Park N.C.) at the 2.34 L ha^{-1} rate, was used in each year, across all application timings. On 22 September 2005, an extra application of ethephon plus AMADS {(2-chloroethyl phosphonic acid) plus (1-aminomethanamide dihydrogen tetraoxosulfate)} (CottonQuick® , Dupont, Wilmington DE.) at the 4.7 L ha^{-1} rate, and tribufos at the 0.44 L ha^{-1} rate, was applied after all designated defoliation timings, to defoliate leaves that were not defoliated by the first application, and to prevent potential contamination of lint. The early defoliation treatments were defoliated on 13 September 2004 and 6 September 2005. The mid defoliation treatments were defoliated on 20 September 2004 and 13 September 2005. The late defoliation treatments were defoliated on 27 September 2004 and 19 September 2005. Actual defoliation timings were 46, 69, and 83 % OB in 2004, and 50, 66, and 82 % OB in 2005. Defoliation applications were applied using a CO_2-pressurized backpack sprayer, calibrated to deliver 140.3 L ha^{-1} using regular flat-fan nozzles. At each defoliation timing, percent open bolls, total bolls, and nodes above cracked bolls (nodes between highest first position cracked boll and highest harvestable boll) were recorded. Plant mapping data were collected for 18 plants per defoliation treatment.

The center two rows of each experimental unit were harvested using a 2-row John Deere spindle picker. The early harvest (14 days after defoliation $\pm$ 3 days) was conducted on rows 2 and 3 in all plots within each defoliation strip. The late harvest (28 days after defoliation $\pm$ 3 days) was conducted on rows 6 and 7 in all plots within each defoliation strip. Seedcotton weights for each plot were recorded and sub-samples were collected for HVI analysis and lint percentage. Data included lint yield, micronaire, length, length uniformity, and strength.

Data were subjected to analysis of variance using PROC GLM (Mixed procedure) in SAS version 9.1.3 (SAS Inst., 2005). Due to strong interactions with year, and consideration of F-tests, lint yield data were reported separately by year. The harvest timing main effect for strength and uniformity index were also reported separately by year. Means of significant main effects and interactions were separated using Fisher's Protected LSD at $p<0.05$.

Results and Discussion

Interactions with year were significant for yield, and plant mapping parameters, so analyses are reported separately by year. The harvest timing main effect for strength is also reported by year, however all other main effects for quality parameters are reported with years combined, due to the lack of significant year interactions.

The cultivar main effect was significant for lint yield in 2004 (data not shown). Yields of DP 555 were 327 kg ha^{-1} higher than DP 451 and 356 kg ha^{-1} higher than DP 444, although the yields of the latter two cultivars were not significantly different from each other. Heat unit and rainfall accumulation between planting and defoliation was greater in 2004 than in 2005, allowing the full season cultivar to approach its yield potential to a greater extent in this year (Table 3.1, 3.2).

The harvest timing by cultivar interaction was significant for lint yield in 2005, but not in 2004 (Table 3.3). Yields of the early harvest for DP 444 were significantly higher than all other harvest timings and cultivars, probably due to earlier maturity and minimum exposure to rainfall events compared to the other two cultivars. Lint yields of the late harvest for DP 444 and both harvest timings for DP 451 and DP 555 were not significantly different from each other, although there was a downward numeric trend in lint yields as harvest was delayed, for all cultivars, possibly due to rainfall events occurring in the latter harvesting period (Table 3.2).

The defoliation timing by harvest timing interaction was significant for lint yield in 2005 (Table 3.4). Yields increased significantly as harvest was delayed, when cotton was defoliated at the early defoliation timing, however yields decreased numerically as harvest was delayed when defoliated at the mid defoliation timing, and significantly when defoliated at the late defoliation timing, likely a result of significant rainfall events occurring between defoliation and harvest for the latter two defoliation timings (Table 3.2). Yields of both harvest timings of the mid defoliation timing were not statistically different from yields of the early harvest defoliated at early defoliation timing, and the yields of the early harvest defoliated at mid defoliation timing were significantly higher than the yields of the late harvest defoliated at late defoliation timing. Yields of the early harvest defoliated at the late defoliation timing were not significantly different from the yields of the late harvest defoliated at early defoliation timing, but the latter scenario was not significantly different from yields of either harvest timing defoliated at mid defoliation timing. These data indicate that an early harvest may be of more importance when defoliation is delayed, due to increased weathering potential.

The harvest timing main effect was significant for micronaire (data not shown). In both years, micronaire values decreased by 3 % as harvest was delayed. Appreciable rain events between the two harvests, especially in 2005, are likely responsible for this effect (Table 3.2).

The cultivar main effect was significant for micronaire (Table 3.5). The medium maturing cultivar, DP 451, had significantly higher micronaire values than DP 555 and DP 444, however values of DP 444 were significantly less than that of DP 555. Micronaire values of DP 451 were in the discount range, whereas values of DP 444 and DP 555 were not.

The cultivar main effect was significant for fiber length (Table 3.5). Length values of DP 451 were significantly higher than both DP 444 and DP 555, and the values of the latter two cultivars were not significantly different from each other.

The cultivar main effect was significant for length uniformity index (Table 3.5). Uniformity values of DP 451 and DP 444 were not significantly different however, values of both cultivars were significantly higher than values of DP 555.

The harvest timing main effect was significant for fiber strength in 2005 (data not shown). Fiber strength decreased by 2 % as harvest was delayed in 2005, possibly due to extended field exposure and rain events (Table 3.2).

The cultivar main effect was significant for strength (Table 3.5). Strength values of DP 451 and DP 444 were not significantly different, however, values of both cultivars were significantly less than values of DP 555.

Interactions with year were significant for most parameters, so analyses for plant mapping parameters were reported separately over 2004 and 2005 (Table 3.6, 3.7, 3.8, 3.9). In 2004 (Table 3.6), total bolls on nodes 4-7 and position 1 bolls on nodes 4-7 were highest for DP 444, followed by DP 451 and lastly DP 555. Position 2 bolls on nodes 4-7 for DP 444 and DP 451, were not significantly different, however values of DP 555 were significantly less than the other two cultivars. DP 555 yielded higher values than both DP 451 and DP 444, with respect to total bolls, position 1 bolls, and position 2 bolls, on nodes 11-19.

In 2004 (Table 3.7),values of DP 555 were significantly greater than both DP 451 and DP 444, with respect to total nodes, nodes of first sympodial branch, total position 2 bolls, outer bolls on nodes 8-10, and outer bolls on nodes 11-19. DP 555 yielded significantly more sympodial bolls that DP 444, while values of DP 451 were not significantly different from either of the other cultivars.

In 2005 (Table 3.8), DP 444 yielded significantly less values than both DP 451 and DP 555, with respect to total bolls, sympodial bolls, total position 1 bolls, position 1 bolls on nodes 11-19, and total bolls on nodes 11-19. With respect to position 1 bolls on nodes 4-7, DP 555 yielded significantly lower values than both DP 451 and DP 444.

In 2005 (Tables 3.9), with respect to total nodes and sympodial nodes, DP 555 was higher than DP 451 or DP 444. Also, values of DP 451 exceeded that of DP 444. With respect to final plant height, DP 555 had higher values than DP 451 and DP 444, however, DP 444 yielded significantly higher height node^{-1} ratio values.

Conclusions

Proper implementation of a successful and profitable defoliation or harvest program, requires timing defoliation and harvest to balance potential yield gains with quality losses, or vice versa. Regardless of how well agronomic strategies are implemented, the success of a particular defoliation and harvest program is strongly dependent upon favorable environmental and crop conditions that prevail during and following defoliation and harvest. Data from this study indicate that cultivar yield potential varies from year to year. In one year of this study, evidence supports that higher yields may be obtained by implementing an early harvest for an early maturing cultivar. As previously suggested by Faircloth et al. (2004b) regardless of cultivar maturity group that is planted, data also supports that defoliation before 60 % OB is plausible, however harvest for a crop in this situation may need to be delayed for maximum yields to be achieved. However, if defoliation is delayed past 80 % OB, and early harvest strategy may be needed to reach maximum yields.

In North Carolina, discounts for high micronaire are likely, therefore management practices that can potentially decrease micronaire without sacrificing yields, should be considered. These data suggest that delaying harvest may help reduce micronaire values to an optimal (no discount) range, regardless of defoliation timing or cultivar planted. However, as seen in previous studies, micronaire may be strongly influenced by cultivar, along with environmental conditions. Differences in fiber length, length uniformity, and fiber strength may also be due to varietal tendencies, however, fiber strength may also be influenced by environmental conditions following boll opening. Similar to findings of Kelley et al. (2002) and Williford (1992) significant rainfall as seen in 2005 can result in yield loss and quality penalties (Table 3.2).

Similar to varietal differences found in previous studies by Pustejovsky and Albers (2003), plant mapping data suggest that compact, normal, and extended fruiting patterns were achieved through planting early, medium, and late maturing cultivars respectively. Although differences in plant fruiting were evident, all three cultivars possessed somewhat of an extended fruiting pattern. Regardless of cultivar maturity, early or delayed defoliation may be plausible depending upon fruiting pattern, however other factors such as harvest scheduling, and prevailing environmental conditions should be considered foremost before making a defoliation decision. Also, proper defoliation and harvest timing may be used to avoid discounts in fiber quality. Some data supports the idea that defoliation timing may differ for crops of varying fruiting patterns, and that the NACB should be used in combination with % OB measurements. In terms of yield, defoliating when NACB is equal to 3, regardless of percent open values, appears to be an accurate threshold to initiate defoliation (Table 3.10). Perhaps, similar studies conducted in environments, where fruiting patterns are more distinctly different, may yield more conclusive results, as to the optimal defoliation and harvest timing for cultivar maturity groups.

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Table 3.1. Degree Day 60 accumulation for specified intervals in 2004 and 2005.

Time interval	Early defoliation		Mid defoliation		Late defoliation	
	2004	2005	2004	2005	2004	2005
	DD 60s					
Planting-defoliation	2103	2000	2170	2099	2238	2219
Planting-early harvest	2238	2252	2323	2352	2329	2449
Planting-late harvest	2329	2449	2328	2513	2341	2516
Defoliation-early harvest	146	267	155	271	107	251
Defoliation-late harvest	237	464	160	432	118	318

Table 3.2. Rainfall accumulation (cm) for specified intervals in 2004 and 2005.

Time interval	Early defoliation		Mid defoliation		Late defoliation	
	2004	2005	2004	2005	2004	2005
	cm					
Planting-defoliation	52	39	55	40	55	41
Defoliation-early harvest	3	4	1	4	1	3
Defoliation – late harvest	4	5	4	12	4	10
Early harvest- late harvest	1	1	3	8	3	8

Table 3.3. Harvest timing by cultivar interaction effects on lint yield in 2005.[z]

Cultivar	Harvest timing	Lint yield
		—— kg ha^{-1} ——
DP 555	Early[y]	1360b
	Late	1360b
DP 451	Early	1400b
	Late	1390b
DP 444	Early	1580a
	Late	1440b

[z]Data are pooled over defoliation timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.

[y]Early denotes the harvest at 14 days after defoliation; Late denotes the harvest at 28 days after defoliation.

Table 3.4. Defoliation timing by harvest timing interaction effects on lint yield in 2005.[z]

Defoliation timing	Harvest timing	Lint yield
—— % OB ——		—— kg ha^{-1} ——
50	Early[y]	1320cd
	Late	1470ab
66	Early	1440bc
	Late	1410bcd
82	Early	1580a
	Late	1300d

[z]Data are pooled over cultivars. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.
[y]Early denotes the harvest at 14 days after defoliation; Late denotes the harvest at 28 days after defoliation.

Table 3.5. Cultivar main effect for micronaire (MIC), length (UHM), Uniformity (UI), and strength (STR) for both years combined.[z]

Cultivar	Micronaire	Length	Uniformity	Strength
	— units —	— cm —	— % —	– kN mg kg^{-1} –
DP 555	4.9b	2.81b	82.3b	298a
DP 451	5.2a	2.84a	83.4a	287b
DP 444	4.6c	2.80b	83.2a	290b

[z]Data are pooled over years, defoliation timings, and harvest timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.

Table 3.6. Cultivar main effect on fruit numbers and position in 2004.[z]

Cultivar	Total bolls on nodes 4-7	Position 1 bolls on nodes 4-7	Position 2 bolls on nodes 4-7
	——	no.	——
DP 555	0.8c	0.4c	0.3b
DP 451	2.8b	1.5b	1.1a
DP 444	4.0a	1.8a	1.5a
	Total bolls on nodes 11-19	**Position 1 bolls on nodes 11-19**	**Position 2 bolls on nodes 11-19**
	——	no.	——
DP 555	5.2a	3.3a	1.4a
DP 451	2.1b	1.8b	0.3b
DP 444	1.6b	1.6b	0.1b

[z]Data are pooled over defoliation timings and harvest timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.

Table 3.7. Cultivar main effect on nodes and fruit position in 2004.[z]

Cultivar	Node of 1st Sympodial branch	Total nodes	Sympodial bolls	Position 2 bolls	Outer bolls on nodes 8-10	Outer bolls on nodes 11 -19
	no.					
DP 555	8a	16a	11a	4a	0.4a	0.5a
DP 451	6b	14b	8b	3b	0.1b	0.0b
DP 444	6b	14b	9ab	3b	0.1b	0.0b

[z]Data are pooled over defoliation timings and harvest timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at α = 0.05.

Table 3.8. Cultivar main effect on fruit numbers and position in 2005.[z]

Cultivar	Total bolls	Sympodial bolls	Total bolls on position 1	Position 1 bolls on nodes 4-7	Position 1 bolls on nodes 11-19	Total bolls on position 11-19
	no.					
DP 555	7a	7a	6a	0.5b	3a	3a
DP 451	7a	7a	6a	1.0a	2a	3a
DP 444	6b	5b	4b	1.0a	1b	1b

[z]Data are pooled over defoliation timings and harvest timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.

Table 3.9. Cultivar main effect on plant heights and nodes in 2005.[z]

Cultivar	Height	Height $node^{-1}$ ratio	Total nodes	Sympodial nodes
	— cm —		—— no. ——	
DP 555	84a	4.7b	18a	10a
DP 451	76b	4.8b	16b	9b
DP 444	78b	5.4a	14c	8c

[z]Data are pooled over defoliation timings and harvest timings. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.

Table 3.10. Nodes above cracked boll measurements for each cultivar at each defoliation timing in 2004 and 2005.

Cultivar	Early Defoliation		Mid defoliation		Late Defoliation	
	2004	2005	2004	2005	2004	2005
	no.					
DP 444	3	4	1	2	0	2
DP 451	4	3	1	3	1	2
DP 555	5	4	2	4	3	1
Average	4	4	1	3	1	2