

**COTTON (*GOSSYPIUM HIRSUTUM* L.) RESPONSE TO PLANT DENSITY,  
INSECT PEST MANAGEMENT, AND HARVEST-AID APPLICATION  
STRATEGIES**

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## ABSTRACT

Field studies evaluated the effect of plant population and seeding configuration on cotton (*Gossypium hirsutum* L.) growth and yield. Seeding configuration did not influence plant growth and development parameters. Averaged across seeding configurations, plants grown at a density of 152,833 plants ha<sup>-1</sup> were taller than plants grown at 50,958 and 33,975 plants ha<sup>-1</sup>, and produced fewer mainstem nodes than all other populations. A 4- and 5-day (2003) and 13- and 14-day (2004) delay in peak bloom was associated with populations of 50,958 and 33,975 plants ha<sup>-1</sup>, respectively, when compared to 152,833 plants ha<sup>-1</sup>. Lint yield was not significantly reduced until plant population was lowered to 33,975 (30.5 cm plant spacing) or 50,958 (three plants per hill, 60 cm hill spacing) plants ha<sup>-1</sup>. Fiber properties were not influenced by plant population or seeding configuration.

In field experiments conducted at two Louisiana locations, the effect of late-season insect simulated defoliation (manual leaf removal) and premature harvest-aid application on cotton yield and fiber quality was evaluated. Results suggest a negative impact on yield and fiber quality should not occur when terminating management strategies for late-season bottom defoliating insects at plant development  $\geq$  NAWF5 (five nodes above the uppermost first position white flower, i.e. cutout) +550 HU (heat units), while harvest-aid application should not be initiated until plant development exceeds NAWF5+750 HU.

Data obtained from field studies conducted in both Louisiana and Tennessee, which evaluated the effect of carrier volume and nozzle type on cotton harvest-aid efficacy, determined that harvest-aids should be applied through flat fan or hollow cone

nozzles at carrier volumes of at least 93.5 L ha<sup>-1</sup>. These applications are necessary to maximize efficacy, by increasing canopy penetration by spray droplets, to achieve adequate defoliation for a once over harvest. Defoliation timing experiments in Louisiana identified 40 to 60 percent open bolls as the stage of crop maturity when harvest-aid application will result in maximum lint yields. However, a second harvest may be necessary to realize maximum lint yield. Delaying defoliation until after 75 percent open bolls may have detrimental effects on fiber quality resulting in discounts and reduced gross revenue.

# CHAPTER 1

## LITERATURE REVIEW

### Introduction

Cotton production in Louisiana has changed dramatically over the last five years. Favorable weather conditions coupled with successful boll weevil (*Anthonomous grandis grandis* (Boheman)) eradication and new stacked gene insect and herbicide resistant transgenic cultivars have resulted in state record lint yields in 2003 (1116 kg ha<sup>-1</sup>) (Anonymous 2004). However, reoccurring problems of poor fiber quality, high production costs, and low prices still plague Louisiana cotton producers and have prevented cotton production from exceeding 250,000 hectares. Even with these set backs cotton remains one of the top three row crop commodities in Louisiana.

High production costs and small profit margins have made every decision a crucial factor in surviving from year to year. In addition to adopting production practices such as no-till, which eliminate some input costs all together, producers are also trying to reduce use rates on necessary inputs to maximize the return on every dollar spent.

**Plant Population.** Choosing a seeding rate is one of the first decisions a grower must make each year and is a logical place to begin reducing input costs. Seed prices associated with recent advances in technology coupled with an increased adoption of seed protectants have made planting cotton, on a per seed basis, more expensive than ever before. However, the establishment of a good stand of cotton seedlings is paramount to obtaining a high yield (Christiansen and Rowland 1981). An acceptable plant population or what constitutes a “good” stand will vary with location, environmental conditions, cultivar, and grower preference (Silvertooth et al. 2002). Current plant density

recommendations in Louisiana are 10 – 13 plants row  $m^{-1}$  for conventionally spaced cotton (96.5 – 101.6 cm row) (Stewart et al. 2002). Boquet and Coco (1997) reported that in Louisiana maximum lint yield can be obtained with 10 and 5 plants row  $m^{-1}$  on 101.6 and 76.2 cm rows, respectively; however, these studies were conducted using older non-transgenic cultivars which are no longer popular. Advances in crop planting equipment allow growers to accurately place seed and precisely vary seeding rates. The establishment of a uniform stand can be facilitated with lower seed requirements. Planters equipped with vacuum seed metering are the current industry standard and can produce more uniform stands than mechanical seed metering (Wanjura 1980). After four years of irrigated field studies, Wanjura (1980) reported that cotton yield increased as plant spacing uniformity increased. Earlier studies reported that consistency of plant spacing was more important than total plant density (Lee 1968).

Considerable research efforts have been ongoing for the last 100 years to determine the optimum plant population for maximum yield and quality in upland cotton. Additionally, the influence of plant population on cotton growth and development has also been investigated with inconsistent or conflicting results. Several researchers have reported no significant difference in total seedcotton yield due to changes in plant density (Ray et al. 1959; Baker 1976; Jones and Wells 1998; Bednarz et al. 2000; Franklin et al. 2000), while others have reported yield decreases with excessive or deficient plant populations (Hawkins and Peacock 1970; Hawkins and Peacock 1971; Bridge et al. 1973; Fowler and Ray 1977; Smith et al. 1979; Siebert et al. 2005). A summary of these study outcomes, location, populations evaluated, and variety (if given in manuscript) is located in Table 1.1.

Table 1.1. Yield response of upland cotton to changes in plant density; studies conducted from 1959 to 2004 in the United States.

Investigator(s)	Year	Location	Variety(s)	Plant populations — plants ha <sup>-1</sup> —	Study outcome
Ray, Huspeth, Holecamp	1959	TX	Not available	37,050 – 185,250	Plant density did not affect yield.
Hawkins and Peacock	1970	GA	‘Empire WR 61’, ‘Atlas’	24,700 – 222,300	Yield reduced with populations outside the range of 96,000 – 144,000 plants ha <sup>-1</sup> .
Hawkins and Peacock	1971	GA	‘Atlas’	32,110 – 240,825	Highest yield with populations between 96,330 – 144,495 plants ha <sup>-1</sup> .
Bridge, Meredith, Chism	1973	MS	‘DP 16’	24,700 – 222,300	Highest yield with populations between 70,000 – 121,000 plants ha <sup>-1</sup> .
Baker	1976	GA	‘Coker 310’	107,489 – 358,295	Yield not influenced by population; row pattern response within a given population.
Fowler and Ray	1977	TX	‘PM 101A’, ‘C.A. 491’	38,750 – 620,000	Optimum population range for yield 79,000 – 155,000 plants ha <sup>-1</sup> .
Smith, Waddle, Ramey	1979	AR	‘Quapaw’, ‘DP 16’, ‘Rex 713’	33,969 – 169,841	Highest yield obtained with 101,573 plants ha <sup>-1</sup> .
Jones and Wells	1998	NC	‘DP 5690’	20,372 – 122,235	Population did not influence total lint yield.
Bednarz, Bridges, Brown	2000	GA	‘SG 501’	25,465 – 234,285	No difference in seedcotton yield.
Franklin, Hopper, Gannaway, Boman	2000	TX	‘PM 2200 RR’, ‘PM 232 RR’	64,531 – 129,111	No differences between populations.
Siebert, Stewart, Leonard	2005	LA	‘PM 1218 BG/RR’	38,750 – 152,833	No population influence for drill-seeded treatments; Hill spacing greater than 40 cm reduced lint yield.

Yield stability over a wide range of plant populations demonstrates the compensatory fruiting habit of cotton; however, increasing the number of bolls per plant does have the negative effect of delaying maturity. Heitholt (1995) reported that plant density had little effect on flower numbers (20,000 – 200,000 plants ha<sup>-1</sup>). Jones and Wells (1997) supported this by stating there were no differences in total flowers m<sup>-1</sup> or flower retention (20,000 – 120,000 plants ha<sup>-1</sup>). However, that study showed that plants in low populations had more bolls on monopodia and more distal sympodial positions, more late-season flowers, and greater retention of these bolls, which contributed to delayed crop maturity. Guinn et al. (1981) reported fewer flowers and higher boll retention in low plant populations. A delay in crop maturity associated with a low stand density (33,969 plants ha<sup>-1</sup>) was also noted in Arkansas under irrigated conditions (Smith et al. 1979).

Buxton et al. (1977) found that increases in cotton plant density increased leaf area index (LAI). However, those plants also exhibit a lower photosynthetic rate per unit leaf area due to mutual shading (Pegelow et al. 1977). Leaf area index required to maximize photosynthetic photon flux density (PPFD) interception (>90%) was obtained by cotton canopies 83 days after planting (DAP) regardless of row spacing or plant density, but the efficiency of PPFD interception per unit leaf area was greater at low plant densities (Heitholt 1994). Cotton leaves on plants in high densities have lower total available carbohydrate levels than leaves of plants in low densities (Saleem and Buxton 1976). This effect may be a result of poor assimilate partitioning due to photomorphogenic responses and the greater relative partitioning of photosynthate into

leaf biomass suggesting that cotton plants in low densities should be able to maintain higher boll retention per plant compared to plants in higher densities (Heitholt 1994).

Reducing plant density may also have implications on fiber quality, although Baker (1976), Bridge et al. (1973), and Hawkins and Peacock (1971) reported that fiber length, strength, and elongation were unaffected by plant population. Micronaire tended to increase as population decreased (Bridge et al. 1973; Jones and Wells 1998).

In addition to changes in yield performance, cotton morphology can undergo drastic changes when plants are grown under varying plant densities and configurations. Previous research indicates that cotton plant height increases as population increases to a point, thereafter intraspecific competition between plants for water, space, light, and nutrients presumably limit plant height. Bridge et al. (1973) and York (1983) reported populations in excess of 200,000 plants ha<sup>-1</sup> decreased plant height; while Peebles and Hartog (1956) found that cotton grown at populations greater than 300,000 plants ha<sup>-1</sup> under irrigated conditions were predisposed to becoming tall, rank, and subject to lodging. Siebert et al. (2005) reported a significant reduction in plant height with populations under 51,000 plants ha<sup>-1</sup> when compared to 152, 833 plants ha<sup>-1</sup>. Several researchers have also shown that plant density is inversely related to mainstem node number (Buxton et al. 1977; Fowler and Ray 1977; Galanopoulou-Sendouka et al. 1980; Heitholt 1995; Jones and Wells 1997; Kerby et al. 1990a, b; Bednarz et al. 2000; Siebert et al. 2005). These plant growth characteristics suggest that reducing plant population may be used as an additional management tool in conjunction with plant growth regulators to help control plant height.

Less dense crop canopies associated with reduced plant populations may provide opportunities for additional cost savings. Enhanced harvest-aid, herbicide, and insecticide performance/efficacy can be directly related to coverage and canopy penetration. Boll rotting pathogens may be reduced in open canopies that improve sunlight penetration and air movement. Leigh et al. (1974) reported greater insect populations (*Lygus* spp.) at higher plant densities and more frequent irrigation which they attributed to cotton canopy density. *Lygus*, formerly a secondary pest of cotton, is now ranked the second most injurious pest in the cotton yield loss estimates with 51% of the U.S. acreage infested and total yield loss of 1.06% (Williams 2005a).

Differences in varietal response to plant population have been documented in Texas (Ray and Hudspeth 1966; Fowler and Ray 1977) and Tennessee (Hoskinson et al. 1971), while Smith et al. (1979) and Galanopoulou-Sendouka et al. (1980) have reported that plant genotype does not affect plant response to plant density. Later studies by Gannaway et al. (1995) suggested that as the maturity of the selected cultivar becomes later, it becomes of increasing importance not to have excessive plant population.

Wells and Meredith (1984) reported that lint yield exhibited a linear relationship with year of cultivar release and that recent breeding efforts have altered the number of harvestable bolls to a greater extent than any other characteristic. Justification for continuing plant density research in upland cotton exists due to contradictions in the response of cotton to varying plant densities coupled with advances in plant breeding that have lead to more vigorous and higher yielding varieties than those previously studied. Additionally, many cotton cultivars currently planted are much later maturing allowing a longer bloom period and more time to compensate for reduced plant density.

**Late-Season Insect Pest Management Termination.** Insect control in the Mid-South and Southeast cotton producing states has changed dramatically with the introduction of transgenic cultivars expressing protein toxins from *Bacillus thuringiensis* Berliner (*Bt*) and successful boll weevil, *Anthonomous grandis grandis* Boheman, eradication. This has reduced the number of broad spectrum insecticide applications used in integrated pest management (IPM) programs, leading to a shift in the cotton pest spectrum.

The infestation of insects formerly considered secondary lepidopteran pests of cotton have become increasingly common in flowering cotton and are a problem in both conventional and transgenic cotton expressing a single protein toxin (Bollgard®). In 2004 40.1% of the 5,547,084 hectares of cotton grown in the U.S. were infested with a complex of late-season lepidopteran defoliators including beet armyworm (*Spodoptera exigua* (Hübner)), saltmarsh caterpillar (*Estigmene acrea* (Durey)), soybean looper (*Pseudoplusia includens* (Walker)), cabbage looper (*Trichoplusia ni* (Hübner)), and various other armyworm species (*Spodoptera* spp.) (Williams 2005a). In Louisiana alone, the cost of controlling these pests in addition to estimated yield losses exceeded \$1,391,000 in 2004 (Williams 2005b). Although this is a small portion of the total cost of insects to Louisiana producers (over \$72,000,000), these unexpected insecticide applications can severely impact profits. Application thresholds and management termination timing for these pests in southeastern cotton producing states is quite variable and vague at times (Table 1.2).

Several studies have indicated that a first position white flower located five main stem nodes below the terminal (NAWF5) is the last boll likely to develop to maturity or

contribute to yield on the plant. Flowers retained above this position contribute little to overall yield (Benson et al. 1999; Bourland et al. 1992; Jenkins et al. 1990).

Managing for early crop maturity can help avoid losses caused by adverse weather and late season insect injury (Isely 1957). Termination of late-season insect management strategies using the NAWF + accumulated heat unit (HU) method may vary

Table 1.2. Application thresholds and timing of management termination for late-season defoliating lepidopteran pests of cotton in the Southeastern United States.<sup>a</sup>

State	Application threshold	Management termination
Alabama	4 – 5 insects present per row foot	Until upper harvestable bolls mature
Arkansas	25% defoliation	Until harvestable bolls developed
Florida	If populations threaten defoliation	Until crop is “made”
Georgia	If populations threaten defoliation	Until all bolls are mature
Louisiana	30% defoliation before NAWF5 <sup>b</sup> ; 45% defoliation after NAWF5	Until crop is ready for chemical termination
Mississippi	If populations threaten defoliation	All harvestable bolls developed
North Carolina	25% defoliation	Until bolls are finished maturing
South Carolina	25% defoliation	Until bolls are finished maturing
Tennessee	25% defoliation	Until just prior to chemical defoliation

<sup>a</sup> Information based on each state’s recommendation for management of “loopers”, Lepidoptera: Noctuidae.

<sup>b</sup> Abbreviation: NAWF5, node above white flower five, when a first position white flower is located five mainstem nodes below the terminal, i.e. cutout.

with insect pest species, variety, and the environment (Torrey et al. 1997). Multi-state evaluations of insecticide termination rules supported by the cotton modeling program

COTMAN generally show that insecticide applications beyond NAWF5 + 350 HU in Arkansas are not economically feasible (Bryant et al. 1999; Cochran et al. 1998).

However, a range of boll maturities confer tolerance to cotton insect pests (Table 1.3).

Several studies have reported the effects of removal of various plant parts on cotton yield and fiber quality. Jones et al. (1996) found that cotton plants could compensate from early season square removal by shifting fruit production to upper fruiting branches on the main stem and at distal sites on all fruiting branches. Moreover, delayed photosynthetic decline has been associated with floral bud removal (Wells 2001; Holman and Oosterhuis 1999). These studies indicate that cotton has the ability to either delay photosynthetic decline in relation to cutout, or alter the source-sink relationship in response to the removal of fruiting structures.

Little data exists regarding crop yield and fiber quality effects from late-season foliage removal before the crop reaches physiological maturity. Foliage injury or complete leaf removal can indirectly affect yield by reducing leaf area that provides photosynthate to mature bolls (Mascarenhas et al. 1999). Cotton plants can withstand  $\leq 57\%$  simulated defoliation before first square without a significant reduction in lint yield (Kerby et al. 1988). However, Russell et al. (1993) found that defoliation  $>20\%$  during boll maturation stages could significantly impact yield by reducing the production of photosynthate necessary for maximum boll development. Torrey et al. (1997) reported significant yield loss associated with removal of all foliage from the bottom 66% of the cotton canopy when plant development was at NAWF  $\leq 5 + 350$  HU.

Table 1.3. Boll ages conferring tolerance to cotton insect pests<sup>a</sup>.

Investigator(s)	Year	Insect pest	Boll age (HU <sup>b</sup> )	
			non- <i>Bt</i>	<i>Bt</i> <sup>c</sup>
Bagwell and Tugwell	1992	boll weevil - <i>Anthonomous grandis</i> <i>grandis</i> Boheman	350	n/a <sup>d</sup>
Adamczyk, Mascarenhas, Church, Leonard, Graves	1998	beet armyworm - <i>Spodoptera exigua</i> (Hübner)	360	390
	1998	fall armyworm - <i>Spodoptera</i> <i>frugiperda</i> (J.E. Smith)	> 850	
Russell	1999	tarnished plant bug - <i>Lygus lineolaris</i> (Palisot de Beauvois)	n/a	327
Gore, Leonard, Church, Russell, Hall	2000	bollworm - <i>Helicoverpa zea</i> (Boddie)	426	299
Greene, Herzog, Roberts	2001	southern green stink bug - <i>Nezara</i> <i>viridula</i> (L.)	n/a	559
Willrich, Leonard, Temple	2004	brown stink bug - <i>Euschistus servus</i> (Say)	n/a	550

<sup>a</sup> Boll age determined by calculating heat unit accumulation after anthesis.

<sup>b</sup> HU, heat unit = average daily temperature – 60.

<sup>c</sup> *Bt* – transgenic cotton containing foreign genes from *Bacillus thuringiensis* Berliner.

<sup>d</sup> Abbreviation: n/a, not available.

A review of plant physiology literature suggests that cotton plants could withstand substantial defoliation of the lower canopy with little impact on photosynthate production and minimal yield reduction due to carbon reallocation. It is likely that the photosynthetic contribution of leaves low in the crop canopy is negligible by the end of the growing season. Asynchrony between carbon assimilation and utilization occurs in flowering cotton. At anthesis, the subtending leaf is approximately 17 d old (Wullschleger and Oosterhuis 1990a) and peak photosynthesis in that leaf occurs 13 to 16 d after it unfolds.

These peak photosynthetic rates are maintained for approximately 12 d. A linear decline occurs beyond that point until the leaf is 70 d old and stabilizes at 20% of the maximum (Constable and Rawson 1980). The subtending leaf is not operating at peak photosynthetic capacity during the majority of the boll filling period and carbon must be allocated from other plant parts. Lower position sympodial bolls on the plant (node eight) collectively require > 60% import of carbon to sustain optimum growth rates during the season (Wullschleger and Oosterhuis 1990b). These bolls rely heavily on carbon allocation from leaves higher up on the mainstem, in addition to photosynthate supplied by the bracts and boll walls (Bhatt 1988; Elmore 1973; Ashley 1972; Brown 1968). Furthermore, leaves lower in the canopy exhibit accelerated deterioration of the photosynthetic system, possibly due to mutual shading (Wullschleger and Oosterhuis 1990b).

Additional cost savings could be realized by better understanding the impact of these pests and eliminating applications that could be unnecessary and potentially beneficial. Jones et al. (1981) suggested that open canopy architecture of okra-leaf cotton varieties increased air movement and sunlight penetration making the canopy environment less favorable for boll infection by pathogens. A similar change in canopy architecture can be achieved from leaf removal by defoliating insects.

**Harvest-aid Application.** Increasing acceptance of the mechanical cotton picker in the 1950s and 1960s brought about a need for effective cotton defoliant to increase harvest efficiency by allowing for a cleaner harvest of seedcotton. Therefore, chemical defoliant were developed to remove much of the cotton foliage prior to harvest. Chemical defoliation is a cultural practice which induces abscission of cotton foliage

earlier than normal (Cathey 1986). The ultimate goal of harvest-aid use is to facilitate mechanical harvest and protect fiber and seed quality by allowing earlier harvest, thus reducing field weathering losses, and minimizing trash content and staining of the lint (Vales and Bragg 1996). Numerous factors must be taken into consideration when choosing a proper harvest-aid combination, application method, and timing. These choices play a large role in determining the final economic value of the crop. Premature chemical defoliation caused reductions in fiber quality and leaf grades when compared to cotton defoliated at a later date (Larson et al. 2002, Whitwell et al. 1987). Although fiber strength and length may be higher with defoliation prior to 60% open bolls, the reduction in yield and micronaire can possibly offset any potential benefits (Snipes and Baskin 1994).

Timing of harvest-aid application must be based on the compromise between degradation of open bolls and allowing time for maturation of green bolls. Currently there are several accepted techniques of timing cotton defoliation; however, no single technique is foolproof and more than one should be used to help verify or confirm another. Timing cotton defoliation using on the COTMAN decision aid is based on the accumulated heat units past cutout. This method states that fields monitored with the COTMAN (Tugwell et al. 1998) recommend defoliation at 850 heat units beyond NAWF = 5 (Bourland et al. 1992). Benson et al. (1999) showed that in one of three fields tested using the Arkansas defoliation timing according to COTMAN occurred seven days earlier than the producer standard and resulted in significantly lower yields. Timing defoliation using the COTMAN system may not be suited for locations outside Arkansas

where longer growing seasons and different cultural practices may require more heat unit accumulation before harvest-aid application in order to maximize yield.

Previous research has shown the close relationship between temperature and boll development (Hesketh et al. 1968; Gibson and Ray 1970) that supports HU accumulation beyond cutout as the best method of determining crop maturity. However, this method is not practical in commercial production due to the intensive monitoring required to determine when the majority of plants reach NAWF5. The percent open boll technique specifies that defoliant application should occur when 65 to 90% of harvestable bolls on the plant are open. However, this technique does not allow for gaps in the fruiting pattern or differences in boll maturity (Brecke et al. 2001). The cut boll technique refers to timing defoliation when the uppermost harvestable boll is mature enough to be opened either naturally or chemically. In this technique a boll is referred to as “mature” when a cross section reveals seeds with well defined cotyledons and black seed coats (Cothren 1999).

Nodes above cracked boll (NACB) is a technique that uses principles of plant monitoring and average heat unit accumulations to determine when a plant is ready for harvest-aid application. Data generated by Kerby et al. (1992) from field tests in California, Oklahoma, Texas, and Mississippi surmised that defoliation of cotton at NACB equal to or less than four resulted in a yield loss of less than one percent with no reduction in fiber quality. However, for the NACB method to be accurately used the number of fruiting branches and contribution of each position must be noted.

In addition to timing of harvest-aid application (based on weather and harvest scheduling, and harvest-aid selection) adjuvant usage, spray volume and pressure, off-

target movement and application equipment are critical aspects of obtaining adequate defoliation (Bader et al. 2001). The efficacy of a harvest-aid is directly related to plant condition and weather at the time of application (Cathey 1986). Spray coverage, canopy penetration, volatilization, photodecomposition, absorption, and translocation can also impact harvest-aid performance (Oosterhuis et al. 1991). Spray coverage and canopy penetration can be manipulated through carrier volume and nozzle selection. Womac et al. (1992) documented a 4.8% increase in the coverage of water sensitive paper when carrier volume was increased from 47 to 94 L ha<sup>-1</sup> using flat fan nozzles. In the same study defoliation ratings increased from 58.8 to 74.1% with an increase in carrier volume from 47 to 187 L ha<sup>-1</sup>, respectively.

Several types of nozzles exist, however, flat fan and cone nozzles are most often used in agricultural applications. Flat fan nozzles, with their small droplet size (volume median droplet diameter 330 - 640 microns), provide excellent coverage, moderate canopy penetration, but are prone to drift (off-target movement) (Anonymous 1996). Cone nozzles increase canopy penetration with equal coverage and greater drift potential than that of flat fan nozzles, because of median droplet diameter of 200 – 280 microns (droplets < 200 microns are considered potential drift contributors) (Anonymous 1996). Air induction or venturi type nozzles introduce air into the nozzle body prior to the nozzle orifice resulting in larger droplets and reduced drift potential (Griffin et al. 2003).

Changes in carrier volume can affect leaf runoff, canopy penetration, drift potential, and chemical concentration per unit leaf area (Monaco et al. 2002). In general, reducing droplet size and increasing carrier volume provides greater weed control, but results vary with weed species, herbicide rate, and mode of action (Buehring et al. 1973).

Fuel prices have more than doubled in the last two years and show no sign of decreasing in the near future, making an adequate defoliation for a once over harvest even more important. Proper selection of carrier volume and nozzle type can increase harvest-aid efficacy and may eliminate the need for a second harvest-aid application. Precise defoliation timing can also be used to protect fiber quality and maximize harvester efficiency in an effort to take full advantage of premiums to boost gross farm revenue.

Although previous research has focused on seeding rates, insect pest management termination, and harvest-aid application strategies; further data must be obtained to keep up with changes in technology and production practices to refine recommendations. Objectives of this research were: 1) to evaluate the effect of plant population and seeding configuration on cotton growth, development, and yield; 2) to determine the effect of late-season simulated insect pest defoliation on cotton yield and physical fiber properties and establish guidelines for terminating management of late-season defoliating insects; 3) to determine the combination of nozzle type and carrier volume to optimize efficacy of herbicidal and hormonal cotton harvest-aids; 4) to examine defoliation timing effects on cotton lint yield, fiber quality, and gross revenue using three accepted defoliation timing methods (HU accumulation after NAWF5, NACB, and open boll percentage at defoliation (OBPD)); and to determine which of these methods is the most consistent for maximizing revenue in Louisiana and if any correlations exist between them.

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## CHAPTER 2

### PLANT POPULATION AND SEEDING CONFIGURATION EFFECTS ON COTTON GROWTH AND YIELD

#### Introduction

The establishment of a good stand of cotton seedlings is paramount to obtaining a high yield (Christiansen and Rowland 1981). However, the definition of an acceptable plant population will vary with location, environmental conditions, cultivar, and grower preference (Silvertooth et al. 1999). Current plant density recommendations in Louisiana are 10 to 13 plants row m<sup>-1</sup> for conventionally spaced cotton (96.5 to 101.6 cm row) (Stewart et al. 2002). Research conducted in Louisiana from 1992 to 1995, prior to the release and widespread acceptance of transgenic cultivars, stated that maximum lint yield was obtained with 10 and 5 plants row m<sup>-1</sup> on 101.6 cm and 76.2 cm rows, respectively (Boquet and Coco 1997).

A single cotton seed can be an effective delivery system for a wide range of pest control products, transgenic traits, and genetics. Recent advances in technology coupled with the increased adoption of seed treatments have made planting cotton, on a per seed basis, more expensive than ever before. Seed specific in-furrow application systems are currently being developed can spray 5.1 cm bands with > 84% accuracy over planted seeding spaces of 10.2 cm, respectively, resulting in material savings of 50% (Wilkerson et al. 2004). This suggests that reducing seeding rates may have implications beyond simply saving seed.

Considerable research has been conducted on the influence of plant population on cotton growth, development, and yield; however, results are inconsistent. Several researchers have reported no significant difference in total seedcotton yield due to

changes in plant density (Ray et al. 1959; Hawkins and Peacock 1973; Baker 1976; Buxton et al. 1977; Jones and Wells 1998; Bednarz et al. 2000; Franklin et al. 2000), while others have reported yield decreases with excessive or deficient plant populations (Hawkins and Peacock 1971; Bridge et al. 1973; Smith et al. 1979).

There are numerous contradictions on the effect of plant population on cotton growth and yield in the literature, justifying further research with current production practices. However, it is just as important to consider the interaction of plant population and new cultivars with vigorous growth habits and greater yield potential. Wells and Meredith (1984) reported that lint yield exhibited a positive linear relationship with year of cultivar release. Recent breeding efforts have altered the number of harvestable bolls to a greater extent than any other characteristic. In addition to modern cultivars, advances in crop planting equipment allow growers to accurately place seed and precisely vary seeding rates. This facilitates the establishment of a uniform stand with lower seed requirements. Planters equipped with vacuum seed metering are the current industry standard and can produce more uniform stands than mechanical seed metering (Wanjura 1980). In a four year irrigated field study, Wanjura (1980) reported that cotton yield increased as plant spacing uniformity increased. Earlier studies reported that consistency of plant spacing was more important than total plant density (Lee 1968).

Reducing plant population may have other management implications. For example, Leigh et al. (1974) reported higher numbers of *Lygus* spp. with increased plant populations. Formerly secondary pests of cotton, *Lygus* spp. now require multiple insecticide applications per season to achieve adequate control. Reduced plant populations can possibly decrease insecticide inputs without sacrificing yield to increase

farm profit. The objective of these studies was to 1) evaluate plant population and seeding configurations on cotton growth, development, and yield; 2) to isolate a specific combination of plant population and seeding configuration that minimize seed use without sacrificing yield using modern cultivar.

### **Materials and Methods**

Two experiments evaluating plant population and seeding configuration were conducted at the Dean Lee Research Station near Alexandria, LA during 2003 and 2004 on a non-irrigated Norwood silt loam soil (fine-silty loam, mixed calcareous, thermic Typic Udifluent). The seeding configuration study (experiment 1) was a randomized complete block with four replications (Table 2.1). The plant population by seeding configuration study (experiment 2) was a randomized complete block with an unbalanced factorial treatment arrangement (factor A: population; factor B: seeding configuration) and four replications. Plot size in both studies was four 96.5 cm rows 12.15 m long. All treatments were planted with cotton (cv. PayMaster 1218 BR) seed using a four row John Deere Max Emerge II vacuum planter (Moline, IL) with either 5.1 cm between seeds for drill seeded treatments or 20 cm between hills (four seeds per hill) for hill-drop seeded treatments. Plots were hand thinned three weeks after emergence to their respective plant population. All data were recorded from the center two rows of the four-row plot. The entire experimental area was maintained using standard cultural practices based on extension recommendations by the Louisiana State University AgCenter.

Plant height and number of mainstem nodes were recorded from five randomly selected plants within each plot weekly (post thinning). Cotyledons were counted as

node 0 and the uppermost node with a mainstem leaf > 25 mm wide was considered the terminal node. Plant height and number of mainstem nodes per plant were used to

Table 2.1. Seeding configurations and plant populations of studies conducted at Alexandria, LA in 2003 and 2004.<sup>a</sup>

Seeding configuration study			Population $\times$ seeding configuration study		
Population	Seeding configuration	Intra-row Spacing <sup>b</sup>	Population	Seeding configuration	Intra-row spacing
plants ha <sup>-1</sup>		cm	plants ha <sup>-1</sup>		cm
101,929	drilled	10	152,883	drilled	6.8
101,929	hill-drop	20 (2/hill) <sup>c</sup>	152,883	hill-drop	20 (3/hill)
101,929	hill-drop	40 (4/hill)	76,466	drilled	13.5
67,952	hill-drop	60 (4/hill)	76,466	hill-drop	40 (3/hill)
-	-	-	50,958	drilled	20
-	-	-	50,958	hill-drop	60 (3/hill)
-	-	-	33,975	drilled	30.5

<sup>a</sup> Studies planted May 24, 2003 and May 26, 2004.

<sup>b</sup> Distance between plants for drill seeded treatments and distance between hills for hill-drop seeded treatments.

<sup>c</sup> Number of plants hill<sup>-1</sup> for hill-drop seeded treatments.

calculate height: node ratio (average plant height / average # nodes). After anthesis, the number of white flowers per plot and the number of mainstem nodes above the uppermost first position white flower (NAWF) on five randomly selected plants per plot was recorded twice a week. White flower counts were terminated when NAWF = 5 (i.e., cutout). When all plots reached approximately 60% open bolls the experimental area was chemically defoliated with a tankmix of thidiazuron (N-phenyl-N'-1,2,3-thiadiazol-5-ylurea), tribufos (S,S,S-Tributyl phosphorotrithioate), and ethephon (2-Chloroethyl phosphonic acid). Following defoliation, ten consecutive plants per plot were mapped to

determine retention of fruiting forms by node and branch location. Fruiting positions were characterized as having either aborted or retained fruit.

The center two rows of each plot were harvested with a commercial two – row spindle picker fitted with a weigh cell capable of being tared between plots. An approximate 0.9 kg sub-sample of seedcotton was retained from each plot and ginned on a 12-saw research gin to determine lint percentage. Treatment effects on lint percentage were not significant and all treatments were within 3% of the average for the entire experiment in both years (data not shown). Therefore, an average lint percentage was used to calculate lint yields. Physical fiber properties were determined using High Volume Instrumentation (HVI) method at the Louisiana State University AgCenter Fiber Laboratory, Department of Agronomy, Baton Rouge, LA (Sasser 1981).

Plant height, number of mainstem nodes, and white flower counts were each plotted as a function of time (weeks after planting). The profiles of the lines generated from the plant height, number of mainstem nodes, and white flower counts were each subjected to repeated measures analysis. Treatments were separated using pairwise comparisons with a Tukey-Kramer adjustment (PROC MIXED, SAS Institute 1998). Plant mapping, lint: seed ratio, lint yield, and fiber data were subjected to analysis using the SAS MIXED procedure and means separated with Fishers' Protected LSD ( $\alpha = 0.05$ ) (PROC MIXED, SAS Institute 1998). Significant interactions prevented combining data for plant height, mainstem nodes, and appearance of white flowers across years. Data for all other variables were combined over years. Differences are attributed to a 25 cm increase in rainfall from 15 May to 31 Aug. in 2004 in comparison to 2003 (Figure 2.1).

## Results and Discussion

Repeated measures analysis indicated that seeding configuration was not significant across plant populations for all growth and development parameters measured both years (Table 2.2). Limited information is available on the effect of intra-row seeding configuration at a given population on growth and development parameters. Hawkins and Peacock (1970) reported that plant population, as long as the stand is of uniform density, may be a more important factor than either spacing or number of plants per hill; and that boll and fiber characteristics were relatively stable over a wide range of planting patterns (Hawkins and Peacock 1971).

**Plant Height and Mainstem Nodes.** Results show that in 2003, plant height was lower for populations of 50,958 and 33,975 plants ha<sup>-1</sup> compared to 152,883 plants ha<sup>-1</sup> (Figure 2.2). This was evident at the end of the season and was reflected in final plant height measurements in which plants grown at a density of 33,975 plants ha<sup>-1</sup> produced plant heights shorter than that of 152,883 plants ha<sup>-1</sup>, respectively. In 2004, these variables were not influenced by plant population.

Differences between years were attributed to early season stresses from excessive rainfall and possibly poor root development. Contradictory effects of plant population on cotton height have been reported. Bridge et al. (1973) and York (1983) reported populations in excess of 200,000 plants ha<sup>-1</sup> decreased plant height. In Arizona, irrigated cotton grown in populations greater than 300,000 plants ha<sup>-1</sup> became tall, rank, and predisposed to lodging (Peebles and Hartog 1956). Research with ultra-narrow row cotton ( $\leq 50.8$  cm) at extremely high plant populations ( $\leq 620,000$  plants ha<sup>-1</sup>) has been

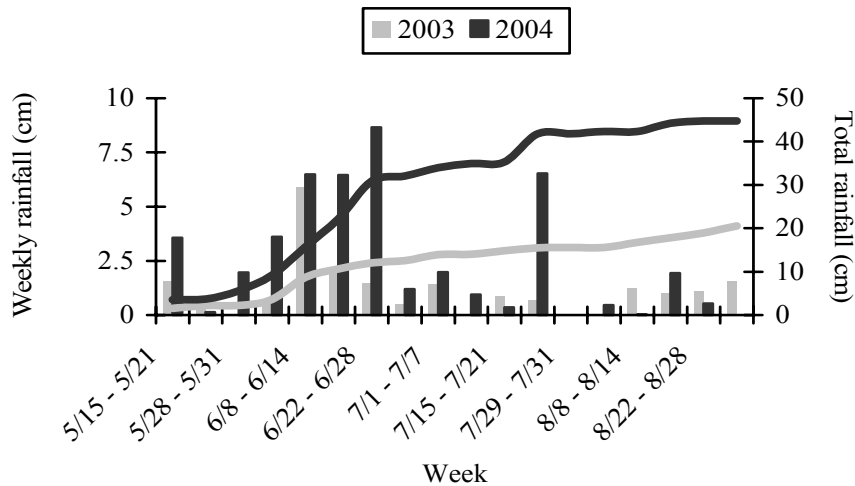


Figure 2.1. Weekly (bars) and total (lines) rainfall for May – August, 2003 and 2004. Weather data collected at the Dean Lee Research Station near Alexandria, LA.

Table 2.2. Response of cotton plants to seeding configuration (drill- vs. hill-drop seeded) within a given plant population, studies conducted at Alexandria, LA in 2003 and 2004.

Population	Variable <sup>a</sup>	Population X seeding configuration study	
		2003	2004
plants ha <sup>-1</sup>		<i>P</i> > <i>t</i> <sup>b</sup>	
152,883	plant height	0.2635	0.3896
	mainstem nodes	0.9998	0.3624
76,466	plant height	0.8986	0.9999
	mainstem nodes	0.9999	0.9999
50,958	plant height	0.0814	0.8999
	mainstem nodes	0.9741	0.8099
		Seeding configuration study	
101,929	plant height	0.8107	0.0536
	mainstem nodes	0.7391	0.2991

<sup>a</sup> Data collected weekly 30 DAP – 80 DAP (2003) or 87 DAP (2004).

<sup>b</sup> Seeding configurations within a population compared using repeated measures analysis ( $\alpha = 0.05$ ).

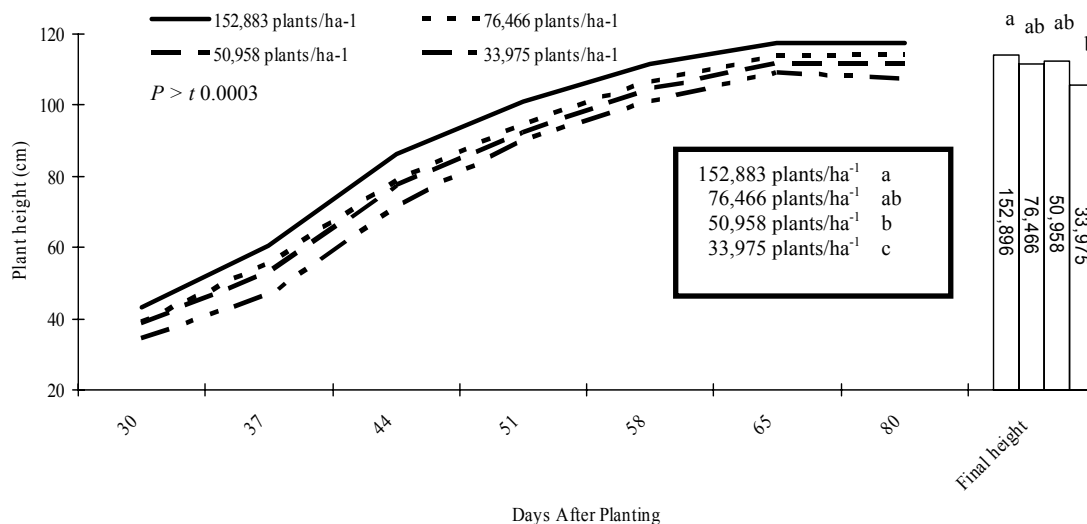


Figure 2.2. Effect of plant population on cotton plant height, Alexandria, LA, 2003. Plant populations (plants ha<sup>-1</sup>) are averaged across drill and hill-drop seeding configurations. The p-value represents repeated measures analysis of plant height over the duration of data collection with the table representing treatment separation for repeated measures analysis, populations followed by the same letter are not significantly different ( $\alpha= 0.05$ ). Bars from left to right represent populations of 152,883; 76,466; 50,958; and 33,975 plants ha<sup>-1</sup>, respectively; final plant height of treatments followed by the same letter are not significantly different ( $\alpha= 0.05$ ).

shown to decrease plant height (Fowler and Ray 1977). Cotton plant height increases with increasing populations only to a point, after which intraspecific competition between cotton plants for water, nutrients, and space presumably limit plant size. Total number of mainstem nodes was significantly lower for plant populations of 152,883 plants ha<sup>-1</sup> than that of any other population evaluated in 2003 (Figure 2.3). Buxton et al. (1977) and Kerby et al. (1990 a, b) demonstrated that increasing plant density decreased the number of mainstem nodes per plant.

Lower plant populations with their shorter plant height and increased number of nodes per plant resulted in a reduced height: node ratio and may reduce plant growth regulator usage requirements, thus resulting in less intensive crop management. In a

study addressing cotton response to mepiquat chloride application, yield progressively decreased with increasing plant populations due to excessive vegetative growth (York 1983); however, variations in plant response to mepiquat chloride at different plant densities with respect to plant height was not investigated.

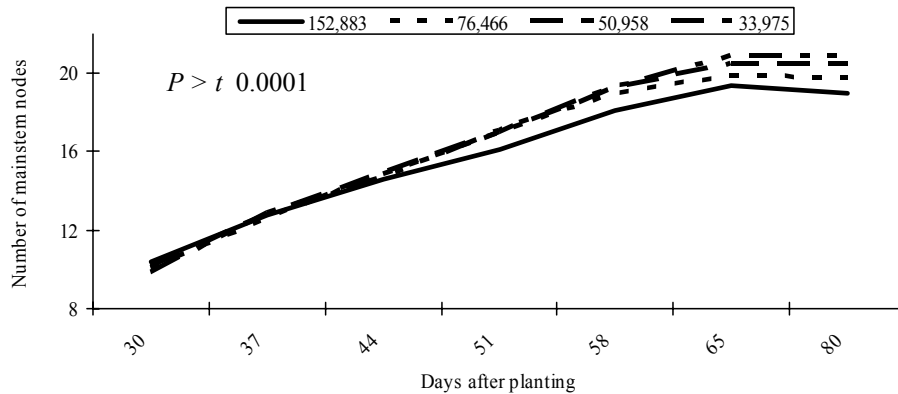


Figure 2.3. Effect of plant population on total number of main stem nodes per plant, Alexandria, LA 2003. Plant populations (plants ha<sup>-1</sup>) are averaged across drill and hill-drop seeding configurations. The p-value represents repeated measures analysis of plant height over the duration of data collection; 33,975; 50,958; and 76,466 plants ha<sup>-1</sup> do not significantly differ and are significantly greater than 152,833 plants ha<sup>-1</sup> ( $\alpha=0.05$ ).

**Earliness.** No significant differences were detected for number of white flowers ha<sup>-1</sup> during the bloom period for populations evaluated (data not shown). However, the date of peak bloom demonstrated a delay in maturity in the lower plant populations (Table 2.3). Using the period of days after planting (DAP) to peak bloom, a 4- and 5-day (2003) and 13- and 14-day (2004) delay in peak bloom was associated with 50,958 and 33,975 plants ha<sup>-1</sup>, respectively, when compared to 152,883 plants ha<sup>-1</sup>. Heitholt (1995) reported that plant density had little effect on flower numbers (20,000 to 200,000 plants ha<sup>-1</sup>) and Jones and Wells (1997) supported this by stating there were no differences in total flowers m<sup>-1</sup> or flower retention (20,000 to 120,000 plants ha<sup>-1</sup>). Jones and Wells (1997) also showed that plants in low populations had more bolls on monopodia and

more distal sympodial positions, more late-season flowers, and greater retention of these bolls which contributed to delayed crop maturity. A delay in crop maturity associated with a low stand density (33,969 plants ha<sup>-1</sup>) was also noted in Arkansas under irrigated conditions (Smith et al. 1979).

**Boll Distribution.** The effects of plant population on delaying maturity can be explained by variations in fruiting patterns (Table 2.3). As plant population decreased; total bolls per plant, first position bolls per plant, and second, third, and monopodial bolls per plant increased. Averaged across both years, there was a 2.25 fold increase in the total number of bolls per plant at 33,975 plants ha<sup>-1</sup> compared with 152,883 plants ha<sup>-1</sup>.

Table 2.3. Plant population effect on peak bloom and boll distribution at Alexandria, LA in 2003 and 2004.

Population plants ha <sup>-1a</sup>	Peak bloom <sup>b</sup>		Boll distribution by position <sup>c</sup>		
	2003	2004	1 <sup>st</sup>	2 <sup>nd</sup> , 3 <sup>rd</sup> , & Mon <sup>d</sup>	Total
	-----DAP -----		----- bolls plant <sup>-1</sup> -----		
152,883	74	77	6.7	4.9	10.7
76,466	77	82	7.3	7.4	14.2
50,958	78	90	8.6	10.5	19.1
33,975	79	91	9.9	14.6	24.1
LSD (0.05)	4	8	0.6	1.8	1.9

<sup>a</sup> Plants per hectare averaged across drill and hill-drop seeding configurations.

<sup>b</sup> Abbreviations: DAP, days after planting; Mon, monopodial bolls. Planting dates: 5/24/03 and 5/26/04.

<sup>c</sup> Plant mapping data averaged across both 2003 and 2004 experiments.

<sup>d</sup> Number of second and third position sympodial and monopodial bolls combined.

This increase in total bolls is mainly attributed to a 3.0 fold increase in the number of second and third position sympodial and monopodial bolls per plant, but the number of first position sympodial bolls increased only 1.5 fold, respectively. These results are

similar to those of Jones and Wells (1998) who also documented increased an increased number of bolls per plant and more bolls at distal sympodial and monopodial positions. The higher number of bolls at distal locations from the mainstem may result in an appreciable delay in maturity. During the end of the season bolls require more time to accumulate heat units as average daily temperatures decline.

Guinn et al. (1981) reported fewer flowers and higher boll retention in low plant populations with no appreciable delay in maturity. Staggenborg and Krieg (1993) found plant population had little or no effect on boll retention. Our results suggest the higher number of bolls per plant associated with lower plant densities are related to leaf area index (LAI), photosynthetic photon flux density (PPFD), and efficiency of solar radiation utilization. Buxton et al. (1977) noted that increases in cotton plant density increased LAI. However, those plants also exhibit a lower photosynthetic rate per unit leaf area due to mutual shading (Pegelow et al. 1977). LAI required to maximize PPFD interception (>90%) was obtained by cotton canopies by 83 DAP regardless of row spacing or plant density, but the efficiency of PPFD interception per unit leaf area was greater at low plant densities (Heitholt 1994). Cotton leaves on plants in high populations have lower total available carbohydrate levels than leaves of plants in low densities (Saleem and Buxton 1976). This effect may be a result of poor assimilate partitioning due to photomorphogenic responses and the greater relative partitioning of photosynthate into leaf biomass (Heitholt 1994). Therefore, cotton plants in low densities should maintain higher boll retention per plant compared with plants in higher densities.

**Lint Yield and Fiber Properties.** No year by treatment interactions were present and data were combined across years. In the seeding configuration study, yield

reductions were not observed with a population of 67,952 plants ha<sup>-1</sup> (four plants per hill, 60 cm hill spacing) compared to 101,929 plants ha<sup>-1</sup> planted in drill- or hill-drop seeding configurations (Table 2.4).

Table 2.4. Plant population and seeding configuration effect on lint yield and physical fiber properties at Alexandria, LA in 2003 and 2004 (seeding configuration study).<sup>a</sup>

Population	Seeding	Intra-row	Lint				
	configuration	Spacing <sup>b</sup>	yield	Micronaire	UHM	Strength	Uniformity
plants ha <sup>-1</sup>		----- cm -----	kg ha <sup>-1</sup>	- units -	-- cm --	grams tex <sup>-1</sup>	--- % ---
101,929	drilled	10	1181	4.5	2.82	29.7	83.3
	hill-drop	20 (2/hill) <sup>c</sup>	1271	4.5	2.79	29.6	83.4
	hill-drop	40 (4/hill)	1311	4.3	2.82	29.7	83.3
67,952	hill-drop	60 (4/hill)	1117	4.4	2.79	29.4	83.4
LSD (0.05)			NS	NS	NS	NS	NS

<sup>a</sup> Studies harvested September 29, 2003 and October 26, 2004.

<sup>b</sup> Distance between plants for drill seeded treatments and distance between hills for hill-drop seeded treatments.

<sup>c</sup> Number of plants hill<sup>-1</sup> for hill-drop seeded treatments.

In the population by seeding configuration study, highest lint yields were obtained with 152,883 plants ha<sup>-1</sup> (3 plants per hill, 20 cm hill spacing) at 1465 kg ha<sup>-1</sup> (Table 2.5). Lint yields were not different among drill seeded treatments regardless of population.

Yield of the lowest population (33,975 plants ha<sup>-1</sup>, drilled, 30.5 cm between plants) was below that of the highest yielding treatment (152,883 plants ha<sup>-1</sup>, 3 plants per hill, 20 cm hill spacing), 1264 and 1465 kg ha<sup>-1</sup>, respectively, but was not different to yields from the equivalent density (152,883 plants ha<sup>-1</sup>) in a drill seeded configuration (1399 kg ha<sup>-1</sup>).

Yield was similar for hill spacing of 20 and 40 cm, but was reduced at 60 cm spacing.

Hawkins and Peacock (1971 and 1970) also reported higher yields with 20 and 40 cm hill spacing than with plants on 60 cm hills. Although not significant, yields increased as the

number of seed per hill increased from three to five seed when hills were spaced 60 cm (Hawkins and Peacock 1970). This may explain why 60 cm hill spacing with four plants per hill was not significantly different from other treatments in the seeding configuration study, but a significant yield reduction did occur with 60 cm hill spacing with only three plants per hill in the population by seeding configuration study. Recent studies in Texas (Franklin et al. 2000), Georgia (Bednarz et al. 2000), and North Carolina (Jones and Wells 1998) have shown no differences in yield due to plant population (64,531 – 129,111 plants ha<sup>-1</sup>, 38,623 – 276,983 plants ha<sup>-1</sup>, and 21,518 – 129,111 plants ha<sup>-1</sup>, respectively). Our studies evaluated “stacked” gene transgenic cotton varieties; which, although very similar to their recurrent parent cultivars, are not genetically identical and yield “drag” or decreased performance of cultivars after gene introgression was an initial concern (York et al. 2004). Recent studies by Nichols et al. (2004) have

Table 2.5. Plant population and seeding configuration effect on lint yield and physical fiber properties at Alexandria, LA in 2003 and 2004 (population by seeding configuration study).<sup>a</sup>

Population	Seeding	Intra-row		Lint yield	Micronaire	UHM	Strength	Uniformity
	Configuration	Spacing <sup>b</sup>						
plants ha <sup>-1</sup>		----- cm -----	kg ha <sup>-1</sup>	- units -	----- cm -----	grams tex <sup>-1</sup>	----- % -----	
152,883	drilled	6.8	1399	4.5	2.82	29.3	83.7	
	hill-drop	20 (3/hill) <sup>c</sup>	1465	4.5	2.82	29.6	83.4	
76,466	drilled	13.5	1344	4.6	2.84	29.4	83.3	
	hill-drop	40 (3/hill)	1388	4.6	2.79	29.2	83.2	
50,958	drilled	20	1418	4.7	2.82	29.0	83.5	
	hill-drop	60 (3/hill)	1177	4.6	2.79	29.2	83.5	
33,975	drilled	30.5	1264	4.7	2.82	28.9	83.4	
LSD (0.05)			166	NS	NS	NS	NS	

<sup>a</sup> Studies harvested September 29, 2003 and October 26, 2004.

<sup>b</sup> Distance between plants for drill seeded treatments and distance between hills for hill-drop seeded treatments.

<sup>c</sup> Number of plants hill<sup>-1</sup> for hill-drop seeded treatments.

shown that glyphosate resistant transgenic cultivars grown in ultra-narrow row spacing (< 38 cm) had lint yields equal to or higher than conventional (non-transformed) cultivars in 2 of 3 years. Our studies have addressed the response of transgenic cultivars grown at varying plant densities in conventional row spacing in the lower Mississippi delta (96.5 cm) environment.

Physical fiber properties including micronaire, staple length, fiber strength, and uniformity were not influenced by plant population or seeding configuration. Baker (1976), Bridge (1973), and Hawkins and Peacock (1971) reported that fiber length, strength, and elongation were unaffected by plant population; however, micronaire tended to increase as population decreased (Bridge et al. 1973; Jones and Wells 1998), a similar trend was noted here as well.

### **Summary**

Considerable research efforts have been ongoing for over 100 years to determine the optimum plant population for maximum yield and quality in upland cotton. Many studies report highest yields occur in plant populations ranging from 49,000 to 256,000 plants ha<sup>-1</sup> (Kittock et al. 1986). Our results show that maximum yields can be obtained with plant densities between 33,975 and 152,883 plants ha<sup>-1</sup> if planted in a drill seeded configuration or hill-drop configuration with hill spacing not to exceed 40 cm. Yield stability across populations is attributed to a greater number of bolls per plant at lower populations, the majority of which are monopodial and outer position sympodial bolls. Shorter plant height and a greater number of mainstem nodes associated with lower plant densities may reduce plant growth regulator requirements resulting in less intensive crop management. However, a greater number of outer position bolls can result in delayed

maturity and may cause problems with heat unit accumulation in a short growing season. The compromise between easier crop management and the delay in maturity must be made when selecting an appropriate seeding rate to achieve a desired final plant population.

As seed and technology costs continue to rise, it is likely that producer interest in reducing seeding rates will also increase. Adverse weather conditions coupled with reduced seeding rates will inevitably result in extremely low plant populations and increase the likelihood of replanting to obtain an acceptable plant density. These data indicate that cotton plant populations can be lowered with no adverse effects on yield. Future investigations need to address the importance of plant distribution in sub-optimal or “skippy” stands.

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## CHAPTER 3

### COTTON YIELD AND QUALITY RESPONSE TO PREMATURE DEFOLIATION: INSECTS AND HARVEST-AIDS

#### Introduction

Management of late-season defoliating insects in mid-south and southeastern cotton, *Gossypium hirsutum* L., producing states has changed dramatically with the introduction of transgenic *Bacillus thuringiensis* cotton, the use of selective insecticides, and boll weevil, *Anthonomous grandis grandis* (Boheman), eradication. These technologies have dramatically reduced the number of broad spectrum insecticide applications applied per season.

Soybean looper, *Pseudoplusia includens* (Walker), and cabbage looper, *Trichoplusia ni* (Hübner), are generally considered secondary pests of cotton, however late-season infestation and defoliation prior to physiological maturity of the last harvestable boll population may negatively impact yield. Soybean looper populations in Georgia are significantly higher in cotton - soybean [*Glycine max* (L.)] agroecosystems when compared to a soybean monoculture (Beach and Todd 1986). In Mississippi, populations of soybean looper and cabbage looper adults are highest from early – mid August, and generally decline in September (Jost and Pitre 2002). Weir and Boethel (1995) determined soybean looper to be the most serious defoliating pest of cotton and soybean in Louisiana. In Louisiana, soybean looper is characterized by dense larval populations in cotton and soybean ecosystems during late August or September (Burleigh 1972).

Several studies have indicated that a first position white flower located five main stem nodes below the terminal (NAWF5) is the last boll likely to develop to maturity or

contribute to yield on the plant. Flowers retained above this position contribute little to overall yield (Benson et al. 1999; Bourland et al. 1992; Jenkins et al. 1990).

Managing for early crop maturity can help to avoid losses caused by adverse weather and late season insect injury (Isely 1957). Termination of late-season insect management strategies using the NAWF + accumulated heat unit (HU) method may vary with insect pest species, variety, and the environment (Torrey et al. 1997). Multi-state evaluations of insecticide termination rules supported by the cotton modeling program COTMAN generally show that insecticide applications beyond NAWF5 + 350 HU are not economically feasible (Bryant et al. 1999; Cochran et al. 1998).

A range of boll maturities confer tolerance to cotton insect pests. Bagwell and Tugwell (1992) reported boll weevil damage to cotton bolls decreased dramatically at 350 HU after anthesis. Bollworm, *Helicoverpa zea* (Boddie), has been shown to significantly reduce yield of conventional and transgenic *Bt* cotton until bolls have accumulated >426 HU and >299 HU after anthesis, respectively (Gore et al. 2000). Beet armyworm, *Spodoptera exigua* (Hübner), can penetrate the endocarp of bolls, for conventional and transgenic *Bt* cotton, until bolls accumulate >360 HU and >390 HU, respectively (Adamczyk et al. 1998). In the same study, fall armyworm, *Spodoptera frugiperda* (J.E. Smith), successfully penetrated >60% of conventional bolls that had accumulated 852 HU, but <10% of transgenic *Bt* bolls that had accumulated 864 HU (Adamczyk et al. 1998). Cotton bolls are generally safe from significant yield losses due to tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), (Russell 1999); brown stink bug, *Euschistus servus* (Say), (Willrich et al. 2004; Fromme 2000); and southern

green stink bug, *Nezara viridula* (L.), (Greene et al. 2001) injury at 327 HU, 550 HU, and 559 HU beyond anthesis, respectively.

Several studies have reported the effects of removal of various plant parts on cotton yield and fiber quality. Jones et al (1996) found that cotton plants could compensate from early season square removal by shifting fruit production to upper fruiting branches on the main stem and at distal sites on all fruiting branches. Moreover, delayed photosynthetic decline has been associated with floral bud removal (Wells 2001; Holman and Oosterhuis 1999). These studies indicated that cotton has the ability to either delay photosynthetic decline in relation to cutout, or alter the source-sink relationship in response to the removal of fruiting structures. However, little data exists regarding crop yield and fiber quality effects from late-season foliage removal before the crop reaches physiological maturity. Foliage injury or complete leaf removal can indirectly affect yield by reducing leaf area that provides photosynthate to mature bolls (Mascarenhas et al. 1999). Cotton plants can withstand  $\leq 57\%$  simulated defoliation before first square without a significant reduction in lint yield (Kerby et al. 1988). However, Russell et al. (1993) found that defoliation  $>20\%$  during boll maturation stages could significantly impact yield by reducing the production of photosynthate necessary for maximum boll development. Torrey et al. (1997) reported significant yield loss associated with removal of all foliage from the bottom 66% of the cotton canopy when plant development was at NAWF  $\leq 5 + 350$  HU. The objective of this study was to determine the effects of late-season simulated insect pest defoliation on cotton lint yield and physical fiber quality compared to premature harvest-aid application, and to establish guidelines for managing late-season bottom defoliating insect pests of cotton.

## **Materials and Methods**

**Site Location and Management Practices.** Experiments were conducted at the Dean Lee Research Station in Alexandria, LA (Norwood silt loam soil) and the Macon Ridge Research Station near Winnsboro, LA (Gigger-Gilbert silt loam soil) during 2003 and 2004. Varieties planted at the Macon Ridge Station were ‘Delta and Pine Land DeltaPearl’ and ‘Stoneville ST 5599 BR’; and at the Dean Lee Station were ‘Delta and Pine Land DP 451 BG/RR’ and ‘Stoneville ST 4892 BR’ in 2003 and 2004, respectively. Cultural practices and integrated pest management strategies recommended by Louisiana Cooperative Extension Service were used to optimize plant development and yield. Supplemental irrigation was applied to the test at Macon Ridge in 2004. The experimental design at each location was a randomized complete block with a factorial treatment arrangement and four replications. Plot size was three rows (centered on 96.5 or 101.6 cm) by 3 m. All data were collected from the center row of each three row plot. The first factor was defoliation method and consisted of insect simulated (manual) or chemical. The second factor was defoliation timing. Mainstem nodes above the uppermost first position white flower (NAWF) and daily heat unit (HU) accumulations were used to characterize the late-season reproductive stages of plant development. Daily HU accumulation was calculated as:  $HU = ([\text{maximum daily temperature} + \text{minimum daily temperature}]/2) - 60$ , using a base of 60°F (15.5°C) (Landivar and Benedict 1996). Defoliation timings consisted of NAWF5 + 450 HU, + 550 HU, + 650 HU, + 750 HU, and + 850 HU.

**Insect Simulated and Chemical Defoliation Treatments.** Insect simulated defoliation levels were based on previous research (Torrey et al. 1999) that established  $\geq$

66% of leaf removal at NAWF5 + 350 HU significantly reduced seedcotton yield. Plant height was used to divide the plant into three equal vertical zones (bottom, middle, and top). The 66% defoliation level corresponded to manual removal of all leaves from the bottom and middle zones of each plant on all three rows of the plot. Chemical defoliation treatments were applied with a CO<sub>2</sub> backpack sprayer calibrated to deliver a carrier volume of 140 liters ha<sup>-1</sup> at 220 kPa and 5.2 km/h through a one row boom equipped with ConeJet<sup>®</sup> (TeeJet Spraying Systems, Wheaton, IL) nozzles. All rows of each plot were treated with a co-application of 56.1 g ai ha<sup>-1</sup> thidiazuron (N-phenyl-N'-1,2,3-thiadiazol-5-ylurea) + 841 g ai ha<sup>-1</sup> tribufos (S,S,S-tributyl phosphorotrithioate) + 1261.6 g ai ha<sup>-1</sup> ethephon (2-chloroethyl phosphonic acid). A standard chemical defoliation treatment with the same harvest-aids mentioned targeted at 80% open bolls was also included.

**Determination of Yield Components.** Cotton plants were monitored twice a week until they reached the NAWF5 reproductive stage of development. At NAWF5, plastic “snap-on-tags” (A.M. Leonard, Inc., Piqua, OH) were placed on the fourth mainstem internode below the plant terminal. This marker was used to bisect the main stem into harvest zones and identify bolls retained below NAWF5 and bolls above that point. Seedcotton yield was determined by harvesting the center row of each plot two weeks after a defoliation treatment was applied. All plots were harvested a second time two weeks after application of the standard chemical defoliation treatment. Each plot was harvested in zones (above or below the NAWF5 tag) to determine the contribution of each section to total yield. Seedcotton subsamples (≈ 200 g) from each plot were ginned with a 12-saw laboratory gin to determine lint percentage and lint weight. Fiber properties were measured using the high volume instrumentation (HVI) method at the

LSU AgCenter Fiber Laboratory, Department of Agronomy, Baton Rouge, LA (Sasser 1981).

**Statistical Analysis.** Seedcotton yields and fiber properties were analyzed using ANOVA (PROC GLM) and Dunnett's *t*-tests comparing means of all treatments to the chemical defoliation standard (SAS Institute 1998).

### **Results and Discussion**

There was no year and location interaction of treatment effects on lint yield; therefore, these data are combined across locations. Flowers that become harvestable bolls after a field average of four nodes above white flower have been shown to contribute less than 2% to overall yield (Bernhardt et al. 1986; Bernhardt and Phillips 1986). The contribution of lint harvested above the NAWF5 tag to total yield was not significant,  $\leq 7.3\%$  (data not shown); therefore yield data are combined across vertical zones on the plant.

The simulated insect defoliation level of 66% leaf removal (all leaves from the bottom two-thirds of the plant) reduced total lint yield 18% at the NAWF5 + 450 HU timing compared to the chemically defoliated standard (Table 3.1). These data show that management of late-season defoliating pests such as cabbage looper and soybean looper can be terminated at NAWF5 + 550 HU, which corresponds to 10% open bolls and seven nodes above cracked boll (NACB) (Figure 3.1). Fiber properties (elongation, fiber strength, micronaire, staple length, and uniformity) were not significantly affected by simulated insect defoliation treatments.

Chemical defoliation at the NAWF5 + 450 HU, + 550 HU, and + 650 HU developmental stages reduced yields by 38%, 36%, and 15%, respectively, compared to that of the

standard chemical defoliation treatment (Table 3.1). Chemical defoliation before NAWF5 + 650 HU at Dean Lee in both years significantly reduced micronaire when compared to the chemically defoliated standard, but did not affect other fiber properties (Table 3.2). Snipes and Baskin (1994) demonstrated that micronaire decreased by prematurely defoliating plants. Early crop termination can be utilized to beneficially reduce micronaire in an effort to avoid discounts on lint quality (Bednarz et al. 2002; Lewis 1993). However, precautions should be exercised in timing harvest-aid application because plant defoliation prior to 60% open bolls may reduce lint yields (Bednarz et al. 2002; Snipes and Baskin 1994; Willford 1992).

Table 3.1. Effect of insect-simulated and chemical defoliation on lint yield, averaged across locations and years.

Defoliation timing <sup>a</sup>	Lint yield	
	Insect-simulated	Chemical
	-----kg ha <sup>-1b</sup> -----	
NAWF5 <sup>c</sup> + 450 HU	877.7* <sup>d</sup>	660.2**
NAWF5 + 550 HU	928.5	681.1**
NAWF5 + 650 HU	927.5	911.6*
NAWF5 + 750 HU	976.0	984.4
NAWF5 + 850 HU	1059.7	985.5
Standard (NAWF5 + 1050 HU )	1072.3	

<sup>a</sup> Manual leaf removal from the bottom two-thirds of cotton plants.

<sup>b</sup> Lint yield averaged across both locations and years.

<sup>c</sup> Abbreviation: NAWF, nodes above white flower.

<sup>d</sup> Lint yield significantly differs from chemically defoliated standard, Dunnett's t-test, P=0.05\* and P=0.01\*\*.

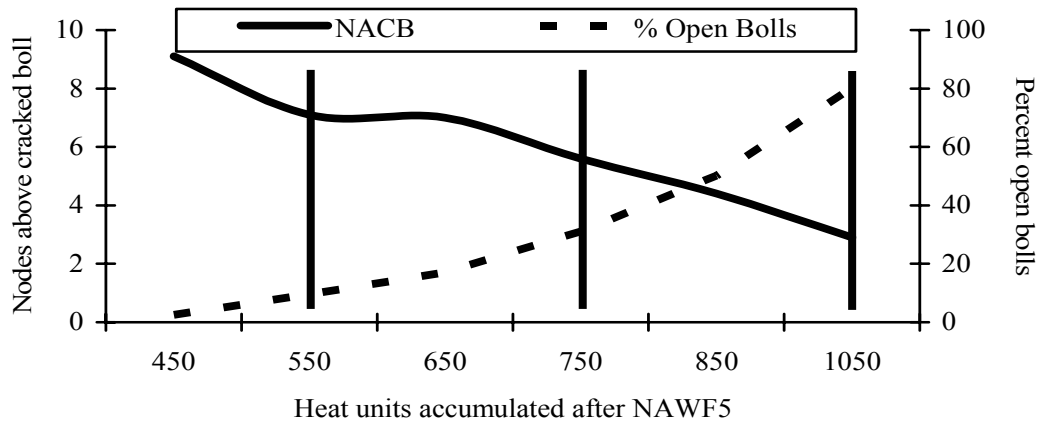


Figure 3.1. Relationship of nodes above cracked boll (NACB) and percent open bolls to heat unit accumulation after cutout. Vertical lines from left to right: Bottom leaf defoliating insect management strategies may be terminated without negatively impacting lint yield; 7 NACB, 10% open bolls; Chemical defoliation may be initiated without significant yield reductions; 5.6 NACB, 40% open bolls; Chemical defoliation timing that maximized lint yield; 2.6 NACB, 80% open bolls.

Table 3.2. Effect of chemical defoliation on micronaire by location and averaged across years.

Defoliation timing	Location	
	Dean Lee <sup>a</sup>	Macon Ridge
	-----Micronaire <sup>b</sup> -----	
NAWF5 <sup>c</sup> + 450 HU	3.9*	4.2
NAWF5 + 550 HU	4.1*	4.0
NAWF5 + 650 HU	4.3	4.2
NAWF5 + 750 HU	4.7	4.1
NAWF5 + 850 HU	4.7	4.2
Standard (NAWF5 + 1050 HU)	4.7	4.6

<sup>a</sup> Micronaire averaged across years.

<sup>b</sup> Within location, micronaire significantly differs from chemically defoliated standard, Dunnett's t-test, P=0.05\*.

<sup>c</sup> Abbreviation: NAWF, nodes above white flower.

Carbon allocation among plant parts in reproductive cotton can explain why removal of the older leaves did not significantly influence yield. Asynchrony between carbon assimilation and utilization occurs in flowering cotton. At anthesis, the subtending leaf is approximately 17 d old (Wullschleger and Oosterhuis 1990a) and peak photosynthesis in that leaf occurs 13 – 16 d after it unfolds. These peak photosynthetic rates are maintained for approximately 12 d. A linear decline occurs beyond that point until the leaf 70 d old and stabilizes at 20% of the maximum (Constable and Rawson 1980). The subtending leaf is not operating at peak photosynthetic capacity during the majority of the boll filling period and carbon must be allocated from other plant parts. Lower position sympodial bolls on the plant (node eight) collectively require > 60% import of carbon to sustain optimum growth rates during the season (Wullschleger and Oosterhuis 1990b). These bolls rely heavily on carbon allocation from leaves higher up on the mainstem, in addition to photosynthate supplied by the bracts and boll walls (Bhatt 1988; Elmore 1973; Ashley 1972; Brown 1968). Furthermore, leaves lower in the canopy exhibit accelerated deterioration of the photosynthetic system, possibly due to mutual shading (Wullschleger and Oosterhuis 1990b). It is likely that the photosynthetic contribution of leaves low in the crop canopy is negligible by the end of the growing season.

Although crop development rules for terminating late-season insect pest management is accepted in several southeastern cotton producing states, the decisions for terminating integrated pest management strategies in Louisiana do not consistently follow the NAWF5 + 350 HU rule. Studies at the Macon Ridge research station in 1994 showed significantly higher seedcotton yields in plots that had termination intervals  $\geq$

NAWF5 + 400 HU. From 1993 to 1995, seedcotton yields generally increased when termination treatments were delayed to NAWF5 + 350 to 400 HU (Torrey et al. 1997). Torrey et al. (1998) reported lower yields in plots receiving  $\geq 66\%$  simulated insect defoliation (removal of all lower leaves from  $\geq$  bottom two-thirds of each plant) at NAWF5 + 350 HU. These findings were similar to those reported by Burris et al. (1997) and are consistent with the results of the present study. Current Louisiana Cooperative Extension Service recommendations call for management of leaf feeding insects until the crop is ready to be chemically terminated (Bagwell et al. 2005). These data can reduce unnecessary insecticide applications for potentially beneficial infestations of late-season bottom defoliators, with respect to reducing the incidence of boll rotting pathogens. Jones et al. (1981) suggested that open canopy architecture of okra-leaf cotton varieties increased air movement and sunlight penetration making the canopy environment less favorable for boll infection by pathogens. A similar change in canopy architecture can be achieved from leaf removal by defoliating insects.

Chemical defoliation can be initiated at 40% open bolls and 5.6 NACB (NAWF5 + 750 HU) without significant yield losses. However, maximum lint yield occurred by chemically defoliating at NAWF5 + 1050 HU, or 80.2% open bolls and 2.6 NACB (Figure 3.1). These results confirm the current defoliation timing recommendations at 65 to 90% open bolls (Brecke et al. 2001) and NACB  $\leq 4$  (Kerby et al. 1992).

Defoliation timing based on HU accumulation after cutout (NAWF5) is an accepted published method based on cotton management with the COTMAN decision aid tool (Tugwell et al. 1998). COTMAN recommends defoliation timing of NAWF5 + 850 HU; however, Benson et al. (2000) reported one situation where timing according to this

method resulted in defoliation one week prior to the grower standard and significantly reduced yield. Timing defoliation using the COTMAN system may not be suited for locations south of Arkansas where longer growing seasons and other cultural practices may require more HU accumulation before harvest-aid application in order to maximize yield.

### **Summary**

Although bolls may be safe to many piercing and sucking insect pests at 350 HU beyond cutout, limited information is available on the effect of premature plant defoliation by insects. This study better defined integrated pest management termination rules for late-season defoliating pests. Significant yield losses did not occur at insect simulated defoliation levels of 66% after the crop accumulated 550 HU beyond cutout. Additional research should evaluate the late-season injury potential for other sporadic leaf feeding pests of cotton, and better define late season management strategies for individual cotton pests.

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## **CHAPTER 4**

### **CARRIER VOLUME AND NOZZLE TYPE AFFECT COTTON HARVEST-AID EFFICACY**

#### **Introduction**

Chemical defoliation is one of the more unpredictable aspects of cotton production. A major limitation to effective defoliation in cotton is the inconsistent response of leaves to chemical treatment for abscission (Oosterhuis et al. 1991). The efficacy of a harvest-aid is directly related to plant condition and weather at the time of application (Cathey 1986). In addition, other factors including spray coverage, canopy penetration, volatilization, photodecomposition, absorption, and translocation can also impact harvest-aid performance (Oosterhuis et al. 1991). Spray coverage and canopy penetration can be manipulated through carrier volume and nozzle selection; however, limited information is available on effects of varying these factors on harvest-aid efficacy.

A carrier serves as a diluent for the harvest-aid chemical and enables a relatively small dosage of chemical to be distributed over a relatively large area. Changes in carrier volume can affect leaf runoff, canopy penetration, drift potential, and chemical concentration per unit leaf area (Monaco et al. 2002). In general, reducing droplet size and increasing carrier volume provides greater weed control, but results vary with weed species, herbicide rate, and mode of action (Buehring et al. 1973). Carrier volume effects on herbicide performance are inconsistent. For herbicides other than glyphosate (Knoche 1994), efficacy generally decreases as carrier volume decreases, but there is no consistent difference on the effect of carrier volume with respect to herbicides with systemic or contact modes of action (Knoche 1994, Edmund and York 1987). However, several

references correlate increased weed control with increased carrier volume (Stougaard 1999; Brewster and Appleby 1990; Lee and Oliver 1982).

Nozzles convert the spray mixture into spray droplets for even distribution to the soil or plant surface (Monaco et al. 2002). Several types of nozzles exist, however, flat fan and cone nozzles are most often used in agricultural applications. Flat fan nozzles, with their small droplet size (volume median droplet diameter 330 - 640 microns), provide excellent coverage, moderate canopy penetration, but are prone to drift (off-target movement) (Anonymous 1996). Cone nozzles increase canopy penetration with equal coverage and greater drift potential than that of flat fan nozzles, because of median droplet diameter of 200 – 280 microns (droplets < 200 microns are considered potential drift contributors) (Anonymous 1996). Increased use of non-selective herbicides on transgenic crops has created the need to reduce off-target movement when applying herbicides near sensitive crops. Primary contributors to drift are wind speed and spray nozzle height above the intended target (Ellis et al. 2002). Air induction or venturi type nozzles introduce air into the nozzle body prior to the nozzle orifice resulting in larger droplets and reduced drift potential (Griffin et al. 2003). Performance of systemic herbicides generally increases as droplet size decreases (Knoche 1994). However, Griffin et al. (2002) reported that weed control with drift reduction (air induction) nozzles was equal to that of standard flat fan nozzles with carrier volumes ranging from 28 – 234 L ha<sup>-1</sup>.

Harvest-aids, much like herbicides, have several modes of action and coverage may be a crucial factor in their performance relative to mode of action. The results from previous studies related to herbicide efficacy suggest that increased coverage can enhance

the activity of contact type harvest-aids due to limited translocation. Complete coverage may not be as important when using a hormonal harvest-aid that is translocated throughout the plant. Herbicidal or contact type harvest-aids physically injure the leaf, stimulating an ethylene response and subsequently causing abscission. Leaf drop with hormonal harvest-aids is mediated by enhanced ethylene evolution (Suttle 1985). Hormonal harvest-aids such as thidiazuron have been shown to disrupt the polar auxin transport system and are excellent inhibitors of regrowth (Suttle 1988); however, this product is not recommended when temperatures drop below 16° C, which limits use in late-fall applications (Snipes and Wells 1994). Herbicidal harvest-aids provide little or no regrowth suppression but are active at lower temperatures. Excessive rates can result in rapid leaf injury and death prior to the formation of the abscission zone (Snipes and Evans 2001; Cothren 1999).

The objective of this research was to determine the optimal combination of carrier volume and nozzle type to maximize efficacy of cotton harvest-aids with herbicidal and hormonal modes of action.

### **Materials and Methods**

Experiments were conducted at the Dean Lee Research Station near Alexandria, LA in 2003 (Norwood silt loam soil), near St. Joseph, LA at the Northeast Research Station in 2003 and 2004 (Commerce silt loam soil), and at the West Tennessee Experiment Station near Jackson, TN in 2004 (Grenada silt loam soil). All experimental areas were planted in cotton and maintained according each state's extension service recommendations (Table 4.1). The experimental design was a randomized complete block with four replications and a three factor factorial treatment arrangement. Factors

Table 4.1. Cotton variety, nozzle, spray pressure, and ground speed used for applications at each location.

	Cotton varieties <sup>a</sup>			
	Alexandria, LA	St. Joseph, LA		Jackson, TN
	2003	2003	2004	2004
	Stoneville ‘ST 4892 BR’	Stoneville ‘ST 4892 BR’	Fibermax ‘FM 960 BR’	Delta and Pine Land ‘DP 444 BG/RR’
Nozzle type / spray pressure (kPa) <sup>b</sup>				
Flat fan	TJ XR11001VS / 144	TJ XR11002VS / 207		TJ XR8003VS / 276
Hollow cone	TJ TKVS3 / 243	TJ TKVS12 / 207		TJ TKVS12 / 276
Air induction	GL TDXL11001-V01 / 152	TJ AI11002VS / 207		TJ AI110015VS / 276
Carrier volume	Ground speed (km h <sup>-1</sup> )			
46.7 L ha <sup>-1</sup>	6.4	17.6		12.9
93.5 L ha <sup>-1</sup>	3.2	8.9		6.4
140.2 L ha <sup>-1</sup>	2.1	5.9		4.0

<sup>a</sup> Stoneville, Emergent Genetics, Inc., Memphis, TN 38115; Fibermax, Bayer CropScience Research Triangle Park, NC 27709; Delta and Pine Land Company, Scott, MS 38772.

<sup>b</sup> TJ, TeeJet Spraying Systems Company, Wheaton, IL 60189; GL, Greenleaf Technologies, Covington, LA 70434.

included harvest-aid (hormonal or herbicidal mode of action), carrier volume (46.7, 93.5, or 140.2 L ha<sup>-1</sup>) and nozzle type (flat fan, hollow cone, or air induction). Plot size was four rows 96.5 cm (Alexandria) or 101.6 cm (St. Joseph and Jackson) centers were 12.15 m long.

Treatments were applied to the center two rows of each four row plot when plants reached 70% open boll on September 19 (Alexandria) and October 3, 2003 (St. Joseph) and September 28 (Jackson) and October 20, 2004 (St. Joseph). Treatments were applied using a CO<sub>2</sub> – pressurized sprayer calibrated to deliver 93.5 L ha<sup>-1</sup>. Carrier volumes of 46.7 and 140.2 L ha<sup>-1</sup> were achieved by varying ground speed to maintain a constant spray pressure. Specific nozzles, spray pressure, and ground speeds used at each location are listed in Table 4.1. A four nozzle boom was used to apply hormonal (thidiazuron at 84.1 g ai ha<sup>-1</sup>) (Dropp SC, 0.48 kg ai L<sup>-1</sup>, Bayer CropScience, Research Triangle Park, NC 27709) or herbicidal (tribufos at 841.0 g ai ha<sup>-1</sup>) (DEF 6, 0.72 kg ai L<sup>-1</sup>, Bayer CropScience, Research Triangle Park, NC 27709) harvest-aids alone. No adjuvant was added to the treatments.

Visual estimates of desiccation and defoliation were made 7 to 21 days after treatment (DAT) using a scale of 0 to 100%, where 0 represented no desiccated leaf material present or no defoliation, and 100 equaled complete desiccation of leaf material or no leaves remaining on the plants. Terminal and/or basal regrowth were visually evaluated 21 to 35 DAT. Ratings in Alexandria and Jackson were based on a 0 to 100% scale (percent regrowth), where 0 equaled no new juvenile vegetative growth and 100 represented complete regrowth of all leaf material on plants. Regrowth control was evaluated in St. Joseph using a 0 to 100% scale where 0 represented no regrowth control

(harvest-aid provided no suppression of juvenile growth) and 100 equaled complete regrowth control (no juvenile leaves present).

Data were subjected to analysis of variance and interactions tested for significance. Tables were constructed based upon significant treatment interactions and means were separated using Fisher's protected LSD at the 0.10 significance level (SAS Institute 1998).

### **Results and Discussion**

Significant treatment by location interactions were observed for all variables measured, therefore data are presented by location. Interactions were attributed to the differences in environmental conditions (heat unit accumulation) between locations and cotton varieties planted, both of which may influence harvest-aid activity.

**Alexandria, LA (2003).** A significant harvest-aid by nozzle type interaction was observed for leaf desiccation ratings 7 DAT. Averaged across carrier volumes, thidiazuron applied with flat fan nozzles resulted in significantly more desiccated leaf material (12%) than application with air induction nozzles (6%), but was similar to desiccation observed with hollow cone nozzles (9%) (data not shown). Desiccated leaf material present with tribufos application did not differ among nozzle types (4 – 7%).

There were no interactions for all other variables measured, however differences were attributed to each factor. Averaged across carrier volumes and nozzle types, leaf desiccation 7 DAT was higher with thidiazuron when compared to tribufos (9 vs. 5%) (Table 4.2). Thidiazuron also provided greater defoliation at both 14 (84 vs. 67%) and 21 (80 vs. 55%) DAT and was better at inhibiting both basal (26 vs. 7%) and terminal

Table 4.2. The effect of harvest-aid, carrier volume, and nozzle type on cotton defoliation and regrowth in Alexandria, LA (2003)<sup>a</sup>.

Harvest-aid <sup>b</sup>	Desiccation	Defoliation		Regrowth (21 DAT)	
	7 DAT <sup>c</sup>	14 DAT	21 DAT	Terminal	Basal
	%				
Thidiazuron	9	84	80	7	15
Tribufos	5	67	55	26	32
LSD (0.05)	2	5	7	4	4
Carrier volume (L ha <sup>-1</sup> ) <sup>d</sup>					
46.7	6	75	66	17	24
93.5	6	74	65	17	24
140.2	9	71	72	16	22
LSD (0.05)	3	NS <sup>c</sup>	NS	NS	NS
Nozzle type <sup>e</sup>					
Flat fan	8	77	68	14	20
Hollow cone	8	77	72	15	24
Air induction	5	71	63	20	26
LSD (0.10)	3	6	8	5	NS

<sup>a</sup> Treatments applied at approximately 70% open bolls, September 19, 2003.

<sup>b</sup> Data averaged across carrier volumes and nozzle types.

<sup>c</sup> Abbreviations: DAT, days after treatment; NS, not significant.

<sup>d</sup> Data averaged across harvest-aids and nozzle types.

<sup>e</sup> Data averaged across harvest-aids and carrier volumes. Thidiazuron and tribufos applied at 84.1 and 841.0 g ai ha<sup>-1</sup>, respectively.

(32 vs. 15%) regrowth. Performance differences between these two harvest-aids are well documented in previous research (Valco and Snipes 2001). However, it is important to note that the lack of harvest-aid by nozzle and carrier volume interactions for other variables shows consistent responses to these factors regardless of whether a herbicidal contact type or hormonal harvest-aid is used.

Desiccated leaf material at 7 DAT was equivalent for carrier volumes of 46.7 and 93.5 L ha<sup>-1</sup> (6%), but was significantly less than desiccation associated with applications at 140.2 L ha<sup>-1</sup>, at 9%. Carrier volume did not influence defoliation at 14 and 21 DAT or basal and terminal regrowth, which may have been due to the rapid progression of natural senescence of plants at the time of treatment application that contributed to ease of defoliation and low regrowth potential.

Only subtle differences were recorded for nozzle type and were only significant at  $\alpha = 0.10$ , but were consistent with findings at other locations. Applications with flat fan and hollow cone nozzles resulted in equivalent leaf desiccation 7 DAT (8%) but higher than desiccation with air induction nozzles (5%) (Table 4.2). At 14 DAT, defoliation was 77% for both flat fan and hollow cone nozzles which was slightly greater than defoliation with air induction nozzles at only 71%. At 21 DAT, hollow cone nozzles still provided greater defoliation than did air induction nozzles, 72 and 63% respectively. Terminal regrowth was less than or equal to 15% with hollow cone and flat fan nozzles, and was significantly greater with air induction nozzles (20%). Basal regrowth was not influenced by nozzle type and exceeded 20% with all treatments.

**Jackson, TN (2004).** Due to low temperatures (nighttime low below 15.5°C), treatments containing thidiazuron provided little defoliation activity and were eliminated from statistical analysis. No significant carrier volume by nozzle type interaction was present; however differences were attributed to the main effects.

Desiccated leaf material at 7 DAT increased as carrier volume increased from 46.7 to 140.2 L ha<sup>-1</sup>, but was not greater than 3% (data not shown). Defoliation was at least 10% higher 7 DAT with carrier volumes greater than or equal to 93.5 L ha<sup>-1</sup>. At 14

DAT, differences were marginal but there was still an increase in defoliation with each increase in carrier volume. Terminal regrowth was similar for tribufos applied at 46.7 and 93.5 L ha<sup>-1</sup> (19%) and was reduced 5% with applications at 140.2 L ha<sup>-1</sup> (Table 4.3).

Table 4.3. The effect of carrier volume and nozzle type on cotton defoliation and regrowth in Jackson, TN (2004)<sup>a</sup>.

Carrier volume <sup>b</sup>	Defoliation		Regrowth (26 DAT)
	7 DAT	14 DAT	Terminal
L ha <sup>-1</sup>	————— % —————		
46.7	71	87	19
93.5	81	82	19
140.2	83	90	14
LSD (0.05)	6	3	4
Nozzle type <sup>d</sup>			
Flat fan	78	85	22
Hollow cone	82	89	17
Air induction	75	84	14
LSD (0.05)	6	3	4

<sup>a</sup> Tribufos at 841 g ai ha<sup>-1</sup> applied at approximately 70% open bolls, September 28, 2004.

<sup>b</sup> Data averaged across nozzle types.

<sup>c</sup> Abbreviations: DAT, days after treatment; NS, not significant.

<sup>d</sup> Data averaged across carrier volumes.

Nozzle type did not influence leaf desiccation 7 DAT (Table 4.3). Hollow cone nozzles resulted in 82% defoliation 7 DAT, which was significantly greater than that for air induction nozzles (75%). At 14 DAT, defoliation with hollow cone nozzles was 89% and was greater than both flat fan and air induction nozzles (85 and 84%, respectively)

(Table 4.3). Terminal regrowth was at least 5 to 8% greater for applications made with flat fan nozzles when compared to hollow cone and air induction nozzles.

**St. Joseph, LA (2003 and 2004).** There were no interactions for all variables during 2003 and 2004; however, differences were detected for each factor. Averaged across carrier volumes and nozzle types, defoliation with tribufos was at least 22% greater than thidiazuron at 7 and 19 DAT in 2003 (Table 4.4). In 2004, tribufos provided 79% defoliation 12 DAT compared to 77% obtained with thidiazuron. By 21 DAT defoliation increased to 91% with thidiazuron and was better than tribufos at 88%. Regrowth control was much greater with thidiazuron in both years when compared to tribufos, which never exceeded 30% (Table 4.4). The difference in activity of defoliants between years is due to temperature and heat unit accumulation following application. In 2003, the daily low temperature was below 10° C for two days following application, and a total of only nine heat units were accumulated during that period. These conditions favor herbicidal type defoliants such as tribufos (Anonymous 2004). However, in 2004 night temperatures were above the 18.3° C threshold for adequate activity (Snipes and Wells 1994) for an entire week after defoliation and averaged 18.1 heat units per day, increasing performance of thidiazuron. Similar to Alexandria during 2003, the lack of increased harvest-aid efficacy by carrier volume or nozzle type interaction supports the finding that harvest-aid mode of action is not an important factor when selecting carrier volumes or nozzle types.

In 2003 and 2004, defoliation generally increased as carrier volume increased. In 2003, 140.2 L ha<sup>-1</sup> provided significantly greater defoliation levels than 46.7 L ha<sup>-1</sup> at 7 and 19 DAT (Table 4.4). This trend was also evident in 2004 with defoliation levels

decreasing with each decrease in carrier volume from 140.2 to 46.7 L ha<sup>-1</sup> (81%, 78%, and 76%, respectively) at 12, but not 21 DAT. Terminal regrowth control was not influenced by carrier volume or nozzle type in either year (Table 4.4).

Table 4.4. The effect of harvest-aid, carrier volume, and nozzle type on cotton defoliation and terminal regrowth in 2003 and 2004 at St. Joseph, LA<sup>a</sup>.

Harvest-aid <sup>b</sup>	Defoliation				Terminal regrowth	
	2003		2004		2003	2004
	7 DAT <sup>c</sup>	19 DAT	12 DAT	21 DAT	21 DAT	35 DAT
	%				% Control	
Thidiazuron	19	44	77	91	83	51
Tribufos	56	66	79	88	30	25
LSD (0.05)	2	4	2	2	6	7
Carrier volume (L ha <sup>-1</sup> ) <sup>d</sup>						
46.7	34	50	76	89	57	38
93.5	37	55	78	90	55	38
140.2	40	60	81	91	56	38
LSD (0.05)	4	5	2	NS <sup>c</sup>	NS	NS
Nozzle type <sup>e</sup>						
Flat fan	43	62	81	91	55	36
Hollow cone	42	60	82	91	55	39
Air induction	26	43	72	87	59	39
LSD (0.05)	4	5	2	2	NS	NS

<sup>a</sup> Treatments applied at approximately 70% open bolls, Oct. 3, 2003 and Oct. 20, 2004.

<sup>b</sup> Data averaged across carrier volumes and nozzle types.

<sup>c</sup> Abbreviations: DAT, days after treatment; NS, not significant.

<sup>d</sup> Data averaged across harvest-aids and nozzle types. Thidiazuron and tribufos applied at 84.1 and 841.0 g ai ha<sup>-1</sup>, respectively.

<sup>e</sup> Data averaged across harvest-aids and carrier volumes.

Defoliation with flat fan and hollow cone nozzles was not different at any rating date in either year (Table 4.4). In 2003, flat fan and hollow cone nozzles provided 42 and 43% defoliation 7 DAT, and 62 and 60% defoliation 19 DAT and were always at least 16% greater than air induction nozzles. Differences in defoliation were not as great in 2004; however, flat fan and hollow cone nozzles resulted in at least 9% and 4% greater defoliation than air induction nozzles at 12 and 21 DAT, respectively (Table 4.4).

### **Summary**

Across a wide range of environmental conditions similar results were observed. Defoliation and regrowth inhibition, when using either hormonal or herbicidal harvest-aids, is generally enhanced with applications at higher carrier volumes applied using flat fan and hollow cone nozzles. This may be due to increased canopy coverage. Womac et al. (1992) documented a 4.8% increase in the coverage of water sensitive paper when carrier volume was increased from 47 to 94 L ha<sup>-1</sup> using flat fan nozzles. In the same study defoliation ratings increased from 58.8 to 74.1% with an increase in carrier volume from 47 to 187 L ha<sup>-1</sup>, respectively.

Cooperative Extension Service guidelines in Louisiana and Tennessee as well as the product labels of many registered cotton harvest-aids recommend application with hollow cone nozzles at carrier volumes of at least 93.5 L ha<sup>-1</sup>. Even though hollow cone nozzles are preferred, these data indicate performance of flat fan nozzles to be similar. Air induction nozzles should not be recommended for cotton harvest-aid application due to inconsistent and generally inferior performance. However, it is important to recognize that air induction nozzles are excellent at accomplishing the function for which they were designed, reducing off-target movement of pesticides. Air induction nozzles should be

considered for applications in or around sensitive urban areas, and these applications should be made with the highest practical and economical carrier volume possible to maximize harvest-aid efficacy. These recommendations are even more important for producers attempting to achieve adequate defoliation for a once over cotton harvest with a single harvest-aid application.

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## **CHAPTER 5**

### **USING A RANGE OF MATURE FRUITING BRANCHES TO TIME COTTON DEFOLIATION AND CORRELATING PERCENT OPEN BOLLS, NODES ABOVE CRACKED BOLL, AND HEAT UNIT ACCUMULATION TO LINT YIELD**

#### **Introduction**

Chemical defoliation is a cultural practice which induces abscission of cotton foliage earlier than normal (Cathey 1986). The ultimate goal of harvest-aid use is to facilitate mechanical harvest and protect fiber and seed quality by allowing earlier harvest. Thus, reducing field weathering losses, minimize trash content, and staining of the lint. Numerous factors must be taken into consideration when determining which harvest-aids to use and when to apply them. These management decisions play a large role in determining the final economic value of a cotton crop.

Proper defoliation timing involves balancing the value of potential yield increases and losses with possible alterations in fiber quality and possible discounts (Faircloth et al. 2004b). Premature defoliation (prior to 60% open bolls) can result in yield losses of 7 to 15% (Snipes and Baskin 1994), but may be beneficial in reducing micronaire in an effort to avoid discounts on lint quality (Bednarz et al. 2002; Lewis 1993). Delaying defoliation allows immature bolls to develop, potentially enhancing yield (Snipes and Baskin 1994) and can increase staple length (UHM) and length uniformity (Laferney et al. 1963). Along with the potential benefits of later defoliation are the risks of adverse weather conditions that may delay or prevent harvest.

Currently, there are several accepted techniques for timing cotton defoliation; however, no single technique is foolproof and more than one should be used to help verify or confirm another. The percent open boll technique specifies that harvest-aid

application should occur when 65 to 90% of harvestable bolls on the plant are open. However, this technique does not allow for gaps in the fruiting pattern or differences in boll maturity (Brecke et al. 2001). The “cut boll” technique refers to timing defoliation when the uppermost harvestable boll is mature enough to be opened either naturally or chemically. In this technique a boll is referred to as “mature” when a cross section reveals seeds with well defined cotyledons and black seed coats (Cothren 1999).

Nodes above cracked boll (NACB) is a technique that is based on the principles of plant monitoring and average HU accumulation to determine when a plant is ready for chemical termination. NACB refers to the number of mainstem nodes between the uppermost first position cracked boll and the last harvestable boll on the plant. Data generated by Kerby et al. (1992) from field tests conducted in California, Oklahoma, Texas, and Mississippi surmised that defoliation of cotton at a NACB of equal to or less than four resulted in a yield loss of less than one percent with no reduction in fiber quality. However, for the NACB method to be accurately used, the number of fruiting branches and contribution of each position must be noted.

Another method of timing cotton defoliation is based on the COTMAN (Tugwell et al. 1998) decision aid and is based on accumulated HU after NAWF5. Recently, several studies have indicated that a first position white flower five nodes below the terminal (NAWF5) indicates the last effective boll of the boll population and flowers that mature above this position contributed little towards total yield (Bourland et al. 1992; Jenkins et al. 1990a; and Benson et al. 1999). This method states that fields monitored with COTMAN recommend defoliation at 850 HU beyond NAWF5 (Bourland et al. 1992). Benson et al. (2000) showed that in one of three fields tested using Arkansas

defoliation timing recommendations according to COTMAN occurred seven days earlier than the producer standard and resulted in significantly lower yields. Timing defoliation using the COTMAN system may not be suited for locations outside Arkansas where environmental variations and different cultural practices may require more HU accumulation before harvest-aid application in order to maximize yield.

The objective of this research was to examine defoliation timing effects on cotton lint yield, fiber quality, and gross revenue using three accepted defoliation timing methods (HU accumulation after NAWF5, NACB, and open boll percentage at defoliation (OBPD)); and to determine which of these methods is the most consistent for maximizing revenue in Louisiana and if any correlations exist between them.

## **Materials and Methods**

**Study Site and Management Practices.** Field experiments were initiated at the Dean Lee Research Station near Alexandria, LA on a Norwood silt loam soil during 2003 and 2004. The experiment was conducted twice in each year, once in an area planted in ‘Stoneville ST 4892 BR’ and again in an area planted in ‘Delta and Pine Land DP 555 BG/RR’. Cotton was planted on May 22, 2003 and May 24, 2004. Cultural practices and integrated pest management strategies recommended by the Louisiana Cooperative Extension Service were used to optimize plant development and yield. No supplemental irrigation was applied in either year. The experimental design for all trials was a randomized complete block with four replications. Plot size was four rows (96.5 cm wide) and 12.15 m long. All data were collected from the center two rows of the four row plot.

**Application of Harvest-aids.** Defoliation treatments were applied when a physiologically mature first position boll (cut boll technique, Cothren 1999) occurred 6, 8, 10, 12, or 14 mainstem nodes above the first sympodial branch. Sympodial branches with a mature first position boll are referred to as mature fruiting branches (MFB). Treatments were applied with a tractor mounted CO<sub>2</sub> sprayer calibrated to deliver a carrier volume of 140 liters ha<sup>-1</sup> at 330 kPa and 5.81 km h<sup>-1</sup> through a four row boom equipped with ConeJet<sup>®</sup> (TeeJet Spraying Systems, Wheaton, IL) nozzles. All rows of each plot were treated with a co-application of 56.1 g ai ha<sup>-1</sup> thidiazuron (N-phenyl-N<sup>2</sup>-1,2,3-thiadiazol-5-ylurea) (Dropp SC, Bayer CropScience, Research Triangle Park, NC 27709) + 841 g ai ha<sup>-1</sup> tribufos (S,S,S-tributyl phosphorotrithioate) (DEF 6, Bayer CropScience, Research Triangle Park, NC 27709).

**Data Collection.** Cotton plants were monitored twice a week until they reached the NAWF5 reproductive stage of development. At NAWF5 HU accumulation was calculated as:  $HU = ([\text{maximum daily temperature} + \text{minimum daily temperature}]/2) - 60$ , using a base of 60°F (15.5°C) (Landivar and Benedict 1996). At each application timing HU accumulation beyond NAWF5 was documented as well as the OBPD and NACB. Seedcotton yield was determined by harvesting the center two rows of each plot with a commercial two – row spindle picker fitted with a weigh cell capable of being tared between plots two weeks after a defoliation treatment was applied. All plots were harvested a second time two weeks after application of the last defoliation treatment. An approximate 0.9 kg sub-sample of seedcotton was retained from each plot and ginned on a 12-saw research gin to determine lint percentage. Fiber properties were measured using the high volume instrumentation (HVI) method at the LSU AgCenter Fiber Laboratory,

Department of Agronomy, Baton Rouge, LA (Sasser 1981). Revenue was calculated by multiplying total lint yield by the local base loan rate for Rapides Parish, Louisiana (114¢ kg lint, color grade 41 SLM (strict low middling, leaf content 3) with premiums and discounts applied based on physical fiber properties according to the United States Department of Agriculture Commodity Credit Corporation (USDA CCC) cotton loan schedule (Anonymous 2005).

**Statistical Analysis.** Yield, physical fiber property, loan premiums/discounts, and revenue data were subjected to analysis of variance where interactions were tested for significance. Tables were constructed according to interactions observed and mean separated using Fisher's protected LSD at the 0.05 significance level (SAS Institute 1998). Significant (0.05) correlations between defoliation timing methods and total lint yield were determined using PROC CORR (SAS Institute 1998) and are ranked using Pearson's correlation coefficients.

## **Results**

Data were combined across years when significant interactions did not exist. All other data are presented by year. Interactions, where present, were attributed to a 25 cm increase in rainfall from 15 May to 31 Aug. in 2004 in comparison to 2003 which resulted in delayed fruiting. In all studies harvestable bolls were retained over a 14 to 16 node range on the plant with the absence of significant fruiting gaps.

**Correlation of Total Yield and Defoliation Timing Methods.** The only defoliation timing method that significantly correlated to total yield in all four studies was accumulated HU after NAWF5 (Table 5.1). Previous research has shown the close relationship between temperature and boll development (Hesketh et al. 1968; Gipson and

Ray 1970) which supports that HU accumulation is probably the best method of determining crop maturity. However, this method is not practical in commercial production due to the intensive monitoring required to determine when the majority of plants reach NAWF5. NACB and OBPD measurements are more feasible methods of determining crop maturity. OBPD was significantly correlated to total lint yield in three of four studies, and actually had greater correlation coefficients than did HU accumulation in all three cases. OBPD was also highly correlated ( $\geq 0.935$ ) to HU accumulation in all four studies (Table 5.1). NACB was only significantly correlated to total lint yield in studies conducted with ‘DP 555 BG/RR’ and in most cases did not correlate to HU accumulation as well as OBPD, suggesting that OBPD is a better tool for determining crop maturity than NACB.

Table 5.1. Pearson correlation coefficients for defoliation timing methods and total lint yield, DP 555 BG/RR and ST 4892 BR, 2003 and 2004.

	DP 555 BG/RR – 2003					ST 4892 BR – 2003			
	OBPD <sup>b</sup>	NACB <sup>b</sup>	HU <sup>a</sup>	Yield		OBPD	NACB	HU	Yield
OBPD	1.000	-0.929*	0.935*	0.610*	OBPDs	1.000	-0.896*	0.986*	0.533*
NACB	-0.929* <sup>c</sup>	1.000	-0.935*	-0.587*	NACB	-0.896*	1.000	-0.900*	-0.463
HU	0.935*	-0.935*	1.000	0.528*	HU	0.986*	-0.900*	1.000	0.505*
	DP 555 BG/RR – 2004					ST 4892 BR – 2004			
	OBPD	NACB	HU	Yield		OBPD	NACB	HU	Yield
OBPD	1.000	-0.971*	0.948*	0.741*	OBPD	1.000	-0.954*	0.958*	0.391
NACB	-0.971*	1.000	-0.962*	-0.685*	NACB	-0.954*	1.000	-0.911*	-0.380
HU	0.948*	-0.962*	1.000	0.734*	HU	0.958*	-0.910*	1.000	0.469*

<sup>a</sup> Cumulative heat unit, base 60F, from NAWF = 5 until treatment.

<sup>b</sup> Abbreviation: NACB, nodes above cracked boll; OBPD, open boll percentage at defoliation.

<sup>c</sup> Pearson’s correlation coefficients are significant at P=0.05.

**Delta and Pine Land DP 555 BG/RR.** In 2003, maximum lint yields were obtained with harvest-aid application at 12 MFB (1,575.4 kg ha<sup>-1</sup>), which corresponded to NAWF5 + 906 HU, 62 OBPD, and NACB = 5 (Table 5.2). Significant reductions in total lint yield occurred with harvest-aid applications both prior to and after this point. It is important to note that in order to realize the total yield at the 12 MFB defoliation timing a second harvest was necessary. First harvest lint yields did not differ between harvest-aid applications at 12 or 14 MFB, 1250.3 and 1273.7 kg ha<sup>-1</sup>, respectively (Table 5.2). However, the first harvest proportion increased from 79.3 to 91.7% when defoliation was delayed from 12 to 14 MFB. In 2004, the greatest total lint yields were achieved by defoliation at  $\geq 10$  MFB (NAWF5 +  $\geq 790$  HU,  $\geq 64\%$  OBPD, and NACB  $\leq 4$ ) (Table 5.2). By delaying harvest-aid application to 12 or 14 MFB, the first harvest accounted for at least 94.3% of the total yield and was greater than 86.6% first harvest proportion of the 10 MFB timing (Table 5.2).

Defoliation timing did not influence micronaire or staple length (UHM) of DP 555 BG/RR in either year, nor was uniformity affected in 2003 (Table 5.3). In 2003, a significant reduction in fiber strength was observed when defoliation was delayed to 14 MFB. In 2004 defoliation timings required to maximize yield ( $\geq 10$  MFB) resulted in significant reductions in both fiber strength and uniformity when compared to earlier treatments (Table 5.3). Although differences in fiber properties did exist, none were detrimental with respect to adjusted loan value (Table 5.4). In 2003, defoliation at 6 and 8 MFB brought a 0.41¢ fiber strength premium, while defoliation at 14 MFB brought none. Higher uniformity with defoliation treatments at 6 or 8 MFB brought greater

Table 5.2. Heat unit (HU) accumulation, open boll percentage at defoliation (OBPD), nodes above cracked boll (NACB), and lint yield for defoliation timing treatments, DP 555 BG/RR, 2003 - 2004.

Treatment	Defoliation timing methods						Lint yield					
	HU <sup>a</sup>		OBPD		NACB		Total		1 <sup>st</sup> harvest		1 <sup>st</sup> harvest proportion	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
MFB <sup>b</sup>			—— % ——				———— kg ha <sup>-1</sup> ————				—— % ——	
6	694	580	11	20	10	9	1189.1	1179.8	681.4	802.8	57.6	68.0
8	776	680	31	39	9	7	1231.5	1529.0	801.2	1210.8	65.2	79.3
10	814	790	42	64	7	4	1400.5	1721.0	944.2	1486.4	67.5	86.6
12	906	1011	62	86	5	2	1575.4	1780.0	1250.3	1726.1	79.3	96.9
14	1060	1089	74	91	2	1	1389.6	1759.3	1273.7	1659.8	91.7	94.3
LSD (0.05)	-	-	-	-	-	-	160.9	217.7	148.7	211.6	6.5	6.1

<sup>a</sup> Cumulative heat units, base 60°F (15.5°C), from NAWF = 5 until treatment.

<sup>b</sup> Number of mainstem nodes above the first sympodial branch on which a physiologically mature first position boll occurred at harvest-aid application or the number of mature fruiting branches present on the plant (MFB).

Table 5.3. Effect of defoliation timing on DP 555 BG/RR cotton fiber micronaire, strength, UHM, and uniformity, 2003 - 2004.

Treatment	Micronaire <sup>a</sup>	Strength		UHM <sup>c</sup>	Uniformity	
		2003	2004		2003	2004
MFB <sup>b</sup>	— units —	— grams tex <sup>-1</sup> —	— cm —	— % —		
6	4.6	29.7	30.3	2.95	82.4	83.6
8	4.6	29.8	32.3	2.92	82.6	83.5
10	4.6	29.2	29.9	2.90	82.9	82.2
12	4.6	29.4	28.5	2.90	82.1	82.4
14	4.6	28.1	29.6	2.90	82.5	82.3
LSD (0.05)	NS <sup>c</sup>	1.1	1.6	NS	NS	0.8

<sup>a</sup> Data averaged across experiments conducted in 2003 and 2004.

<sup>b</sup> Number of mainstem nodes above the first sympodial branch on which a physiologically mature first position boll occurred at harvest-aid application or the number of mature fruiting branches present on the plant (MFB).

<sup>c</sup> Abbreviation: NS, not significant; UHM, upper half mean.

Table 5.4. Effect of defoliation timing on DP 555 BG/RR cotton lint price differences using 2005 USDA CCC<sup>Y</sup> cotton loan information applied to 2003 and 2004 fiber data.

Treatment	Price difference from the base price of 114¢ kg <sup>-1</sup>										Gross revenue	
	Micronaire		Strength		UHM <sup>b</sup>		Uniformity		Total difference		2003	2004
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
MFB <sup>a</sup>	¢ kg <sup>-1</sup>										\$ ha <sup>-1</sup>	
6	0.00	0.00	0.41	0.74	4.29	4.29	0.33	0.66	5.03	5.69	1417	1415
8	0.00	0.00	0.41	1.05	3.99	4.29	0.33	0.72	4.73	6.05	1464	1838
10	0.00	0.00	0.14	0.63	4.29	4.29	0.47	0.28	4.90	5.20	1667	2054
12	0.00	0.14	0.28	0.14	3.99	3.99	0.14	0.14	4.40	4.40	1868	2110
14	0.00	0.00	0.00	0.39	3.99	4.29	0.41	0.14	4.40	4.81	1646	2092
LSD (0.05)	NS <sup>b</sup>	NS	0.30	NS	NS	NS	NS	0.35	NS	NS	183	265

<sup>a</sup> Number of mainstem nodes above the first sympodial branch on which a physiologically mature first position boll occurred at harvest-aid application or the number of mature fruiting branches present on the plant (MFB).

<sup>b</sup> Abbreviation: USDA CCC, United States Department of Agriculture Commodity Credit Corporation; NS, not significant; UHM, upper half mean.

premiums than all other timings. There was no difference between defoliation timing treatments with respect to total difference from the base price in either year (Table 5.4).

The highest gross revenue was achieved by defoliating at 12 MFB in both 2003 and 2004, \$1868 and \$2110 ha<sup>-1</sup> respectively (Table 5.4). In 2003, significant reductions in revenue occurred with all defoliation treatments other than 12 MFB. Revenue from defoliation at 10 or more MFB were not different (Table 5.4) in 2004.

**Stoneville ST 4892 BR.** In 2003, the greatest total lint yields were obtained with defoliation at 10 and 12 MFB (1444.7 and 1603.9 kg ha<sup>-1</sup>, respectively) which occurred at NAWF5 + 814 to 906 HU, 40 – 60 OBPD, and NACB 6 to 4 (Table 5.5). Although the greatest first harvest lint proportion occurred with defoliation at 14 MFB (88.3%), first harvest lint yields were not different for defoliation timings  $\geq$  10 MFB (Table 5.5). Total lint yield was similar for all defoliation timings in 2004. This is reflected in first harvest proportion which was at least 80% for all defoliation timing treatments except 10 MFB (75.3%), which received 10.2 cm of rain three d before harvest and suffered severe weathering losses. The lack of a defoliation timing effect on total lint yield is attributed to environmental conditions during 2004 which were conducive for a short bloom period. Excessive rainfall early in June delayed fruiting and five consecutive days with nighttime temperatures below 15.5°C (61.5 HU, 12 Aug to 16 Aug 2004) lead to premature arrival of the last effective bloom date (Anonymous 2004).

Micronaire, fiber strength, and UHM were not influenced by defoliation timing in 2003. In 2004, micronaire progressively increased with later defoliation timings and a decline in fiber strength occurred with defoliation timings after 8 MFB (Table 5.6).

Table 5.5. Heat unit (HU) accumulation, open boll percentage at defoliation (OBPD), nodes above cracked boll (NACB), and lint yield for defoliation timing treatments, ST 4892 BR, 2003 - 2004.

Treatment	Defoliation timing methods						Lint yield					
	HU <sup>a</sup>		OBPD		NACB		Total		1 <sup>st</sup> harvest		1 <sup>st</sup> harvest proportion	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
MFB <sup>b</sup>			—— % ——				———— kg ha <sup>-1</sup> ————				—— % ——	
6	694	586	21	11	7	7	1246.8	1070.6	859.9	859.2	68.8	80.2
8	776	701	36	17	7	7	1395.6	1260.8	924.1	1102.9	70.3	87.4
10	814	808	40	50	6	5	1444.7	1145.5	1097.0	860.7	76.0	75.3
12	906	908	60	78	4	2	1603.9	1105.3	1237.8	971.7	80.6	88.1
14	1023	1020	78	92	2	1	1418.9	1263.6	1186.8	1154.1	88.3	91.4
LSD (0.05)	-	-	-	-	-	-	184.7	NS <sup>c</sup>	197.8	185.7	6.8	8.7

<sup>a</sup> Cumulative heat units, base 60°F (15.5°C), from NAWF = 5 until treatment.

<sup>b</sup> Number of mainstem nodes above the first sympodial branch on which a physiologically mature first position boll occurred at harvest-aid application or the number of mature fruiting branches present on the plant (MFB).

<sup>c</sup> Abbreviation: NS, not significant.

Table 5.6. Effect of defoliation timing on ST 4892 BR cotton fiber micronaire, strength, UHM, and uniformity, 2003 - 2004.

Treatment	Micronaire		Strength		UHM <sup>c</sup>		Uniformity <sup>a</sup>
	2003	2004	2003	2004	2003	2004	
MFB <sup>b</sup>	— units —		— grams tex <sup>-1</sup> —		— cm —		— % —
6	5.0	4.0	30.4	32.6	2.82	2.95	83.8
8	5.2	4.4	31.0	32.1	2.84	2.90	83.4
10	5.0	4.5	30.6	29.5	2.87	2.87	83.5
12	5.1	4.6	29.9	29.5	2.82	2.84	82.7
14	5.1	4.7	29.9	29.6	2.82	2.87	82.4
LSD (0.05)	NS <sup>c</sup>	0.3	NS	1.1	NS	0.05	0.5

<sup>a</sup> Data averaged across experiments conducted in 2003 and 2004.

<sup>b</sup> Number of mainstem nodes above the first sympodial branch on which a physiologically mature first position boll occurred at harvest-aid application or the number of mature fruiting branches present on the plant (MFB).

<sup>c</sup> Abbreviation: NS, not significant; UHM, upper half mean.

UHM also declined with later defoliation timings in 2004 and in both years uniformity was significantly lower when defoliation was delayed until 12 or 14 MFB, demonstrating an obvious deterioration in fiber quality over time (Table 5.6). Although no differences in micronaire existed with respect to defoliation timing, all values in 2003 were high enough to reduce the base loan price at least 1.68¢ kg<sup>-1</sup> (Table 5.7). Fiber strength premiums associated with defoliation at 6 to 10 or 6 and 8 MFB increased cotton base loan price at least 0.66 and 1.02¢ kg<sup>-1</sup> in 2003 and 2004, respectively. Uniformity premiums were lower than all other treatments when defoliation was delayed until 14 MFB in 2003, and premiums were at least 0.20¢ kg<sup>-1</sup> lower when defoliation occurred at 12 and 14 MFB in 2004 (Table 5.7). Due to high micronaire values, all defoliation timings except 6 and 10 MFB had negative total differences from the cotton loan base price in 2003; and in 2004 total premiums above the loan base price were significantly

greater for the earliest defoliation timings (6 and 8 MFB) with at least a 5.94¢ kg<sup>-1</sup> increase. Defoliation timing did not influence gross revenue in 2004. In 2003 the greatest gross revenue (\$1787 ha<sup>-1</sup>) was obtained by defoliating at 12 MFB, which did not differ than defoliation at 10 or 14 MFB, but was at least \$88 ha<sup>-1</sup> greater than all other treatments (Table 5.7).

### **Discussion**

Our findings support the use of timing defoliation based on accumulated HU after NAWF5. In large operations where time is a critical factor in determining crop maturity, the percentage of open bolls should be used rather than NACB. This contradicts Faircloth et al. (2004b) who stated NACB was more effective than OBPD for timing defoliation. However, these differences may be due to the variability between environmental conditions in Louisiana and North Carolina.

These studies demonstrate that defoliation should be initiated at 60 OBPD in order to maintain fiber quality and maximize harvester efficiency by removing the majority of seedcotton in one trip through the field. This supports current recommendations in both Louisiana (Stewart et al. 2003) and Mississippi (Snipes and Baskin 1994). However, under some circumstances, such as when the majority of harvestable fruit are retained over a relatively short range on the plant, defoliation may occur as early as 40 OBPD (NAWF5 + 700 HU, NACB = 7) without sacrificing yield or gross revenue. Faircloth et al. (2004a) supported this by stating that yield data from North Carolina suggest the possibility for defoliating before the recommended 60% open bolls without negatively impacting yield. However, a second harvest may be necessary

Table 5.7. Effect of defoliation timing on ST 4892 BR cotton lint price differences using 2005 USDA CCC<sup>Y</sup> cotton loan information applied to 2003 and 2004 fiber data.

Treatment	Price difference from the base price of 114¢ kg <sup>-1</sup>										Gross revenue	
	Micronaire		Strength		UHM <sup>b</sup>		Uniformity		Total difference		2003	2004
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
MFB <sup>a</sup>	¢ kg <sup>-1</sup>										\$ ha <sup>-1</sup>	
6	-3.36	0.28	0.66	1.02	2.61	4.29	0.66	0.88	0.58	6.46	1433	1291
8	-7.18	0.14	0.88	1.05	3.38	3.99	0.61	0.77	-2.31	5.94	1554	1513
10	-1.68	0.00	0.88	0.41	3.69	3.69	0.66	0.72	3.55	4.81	1699	1363
12	-6.71	0.00	0.55	0.28	3.08	3.38	0.41	0.41	-2.50	4.07	1787	1308
14	-5.50	0.00	0.55	0.39	2.31	3.69	0.14	0.28	-2.67	4.35	1596	1497
LSD (0.05)	NS <sup>b</sup>	NS	0.26	0.41	NS	NS	0.28	0.35	4.47	1.30	228	NS

<sup>a</sup> Number of mainstem nodes above the first sympodial branch on which a physiologically mature first position boll occurred at harvest-aid application or the number of mature fruiting branches present on the plant (MFB).

<sup>b</sup> Abbreviation: USDA CCC, United States Department of Agriculture Commodity Credit Corporation; NS, not significant; UHM, upper half mean.

to realize maximum yield with early defoliation timings. Defoliant combinations including ethephon (Snipes and Cathey 1992) or ethephon plus a synergist (Stewart et al. 2000) could also be used to increase boll dehiscence which may help alleviate this problem. Yield losses with premature harvest-aid application were consistent with findings of Snipes and Baskin (2004); and degradation of fiber properties with delayed crop termination similar to those documented by Bednarz et al. (2002).

These data suggest that defoliation timing based on a range of MFB present on the plant should be further investigated. Gross revenue was not significantly reduced when defoliation occurred at 10 MFB in both years with two drastically different varieties (with respect to maturity). Defoliation timing methods presently used (NACB, OBPD, and the cut boll technique) all present the same challenge of identifying the uppermost harvestable boll on the plant. Delaying crop termination to wait on “phantom” bolls (bolls that will never mature and contribute to overall yield) can have negative effects on lint yield and fiber quality. Defoliation timing based on MFB removes the factor of identifying the uppermost harvestable boll and focuses on fruit retained on lower branches. Jenkins et al. (1990a) reported, in studies conducted with eight cultivars, nodes 9 to 14 (which correspond to the third to eight sympodial branches) were the largest contributors to yield. Harvestable bolls retained on 16 to 18 sympodial branches in those studies. Greater than 80% of the total harvestable lint was occurred on the lower 10 sympodial branches, and up to 93% of harvestable lint on the lower 14 sympodial branches. Jenkins et al. (1990b) showed that first position bolls increase in size from sympodial branches 3 to 9 and then began decreasing above that point. It is also documented that boll size generally decreases as the season progresses (Meredith and

Bridge 1973). Bolls retained above the 14<sup>th</sup> sympodial branch and on monopodial branches contributed less than 2 and 10% of total lint, respectively (Jenkins et al. 1990a). Bernhardt et al. (1986) and Bernhardt and Phillips (1986) found that flowers that mature to harvestable bolls after a field average growth stage of four nodes above white flower have been shown to contribute less than 2% to overall yield. Yield gained by delaying defoliation to harvest the uppermost bolls (bolls retained at or above the 16<sup>th</sup> sympodial branch) will not offset discounts received due to fiber deterioration and supports the practice of timing defoliation to protect fiber quality on the greatest proportion of harvestable lint.

Defoliation timing is best determined for individual fields. These recommendations should be used as a guideline with appropriate considerations made for cultivar (Kerby et al. 1990), environmental conditions throughout the season, and 10 to 14 day weather forecast.

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## CHAPTER 6

### SUMMARY AND CONCLUSIONS

Field studies were conducted at multiple locations throughout the cotton, *Gossypium hirsutum* L., production regions of Louisiana to evaluate the effect of reduced plant population and seeding configuration, late-season insect pest management termination, and harvest-aid application and timing strategies on cotton.

The first series of studies conducted near Alexandria, LA focused on the cotton growth, development, and yield response to plant population and seeding configuration (drill- and hill-drop seeding). Seeding configuration did not influence the plant growth and development parameters measured (plant height, mainstem nodes, number of white flowers, days after planting to peak bloom, nodes above white flower, and boll distribution). Therefore, whether seeds are placed in a single row with equal spacing between each seed (drilled) or dropped in “hills” of three or four seed with uniform spacing between hills (hill-drop), plants within a given population develop similarly. However, plants grown at varying plant populations differ in development.

In 2003, a plant population of 152,883 plants ha<sup>-1</sup> resulted in taller plants than did 50,958 and 33,975 plants ha<sup>-1</sup>; however, 152,883 plants ha<sup>-1</sup> produced fewer total mainstem nodes than all other populations. The lower height to node ratio associated with reduced plant density can make cotton plants easier to manage for height and may have implications in reducing plant growth regulator applications. Plants in reduced population also have a less dense canopy which increases air movement and sunlight penetration (which may reduce the incidence of boll rotting pathogens), as well as allowing greater penetration of droplets from agricultural pesticide applications.

The potential benefits of less intensive plant growth regulator management and increased pesticide efficacy with lower plant densities do not come without drawbacks. White flower counts were used to assess crop maturity, which showed 4- and 5-day (2003) and 13- and 14-day (2004) delay in peak bloom associated with 50,958 and 33,975 plants ha<sup>-1</sup>, respectively, when compared to 152,883 plants ha<sup>-1</sup>. This delay in maturity was explained by the difference in boll distribution when mapping plants. Plant mapping data, averaged across years, showed a negative linear relationship between total number of bolls per plant, number of second and third position sympodial bolls per plant, and monopodial bolls per plant and plant population. The increased boll retention on plants grown at low populations, which was mostly composed of an increased number of outer position sympodial and monopodial bolls, requires additional time and heat unit accumulation for development. This delay in maturity can be problematic if temperatures decline rapidly in the fall preventing accumulation of the required heat units to mature all bolls.

The increased boll load demonstrated the ability of cotton to compensate when given ample space, light, water, and nutrients. Lint yield, averaged across years, was highest for the plant population of 152,883 plants ha<sup>-1</sup> (1465 kg ha<sup>-1</sup>) planted in a hill-drop configuration with three plants per 20 cm hill spacing. Lint yield was not negatively affected until plant populations were lowered to 33,975 (drill seeded with 30.5 cm plant spacing, 1263 kg ha<sup>-1</sup>) or 50,958 (three plants per hill, 60 cm hill spacing, 1177 kg ha<sup>-1</sup>) plants ha<sup>-1</sup>. Analysis of fiber properties revealed no differences in micronaire, staple length, strength, or uniformity regardless of plant population or seeding configuration.

A second set of studies conducted for two years at both the Macon Ridge Research Station near Winnsboro and the Dean Lee Research Station near Alexandria investigated the influence of management termination timing for late-season bottom defoliating insects on cotton yield and physical fiber properties and compared late-season insect simulated defoliation to harvest-aid application. Insect simulated defoliation was accomplished by manually removing all leaves with scissors from the lower two-thirds of the plant canopy (based on plant height), while all harvest-aids were applied with a CO<sub>2</sub> backpack sprayer. Defoliation timings at selected plant growth stages were based on heat unit (HU) accumulation beyond the last effective boll population that contributes to yield (physiological cutout; NAWF5). Lint yield, averaged across experiments, was 82% of the standard control (chemical defoliation at 80% open, NAWF5 + 1050 HU) when insect simulated defoliation occurred at the NAWF5 + 450 HU stage of development. Once plants reached the NAWF5 + 550 HU stage of development lint yield was no longer negatively impacted by 66% insect simulated leaf removal. However, caution must be exercised when dealing with infestations of defoliating insects and management strategies applied to prevent defoliation levels from exceeding the 66% threshold. Insect simulated defoliation did not impact fiber properties. Chemical defoliation at NAWF5 + 450 HU, + 550 HU, and + 650 HU development stages reduced lint yield 38, 37, and 15%, respectively, below that of the standard control. Harvest-aid application to plants at growth stages  $\leq$  NAWF5 + 550 HU lowered fiber micronaire at one location in both years. Chemical defoliation did not influence fiber strength, length, elongation, or uniformity. Due to potential yield reductions chemical crop termination should not be initiated until the crop reaches the NAWF5 + 750 HU stage of development; however,

harvest-aid application prior to this point may be a beneficial tool for controlling high micronaire.

Proper harvest-aid application timing plays a crucial role in maximizing yield, revenue, and protecting fiber quality. Studies in Louisiana using both early maturing (Stoneville ‘ST 4892 BR’) and full season (Delta and Pine Land ‘DP 555 BG/RR’) varieties evaluated three defoliation timing methods; heat unit (HU) accumulation after node above white flower five (NAWF5), open boll percentage at defoliation (OBPD), and nodes above cracked boll (NACB) to determine which was the most consistent for maximizing yield, fiber quality, and revenue; and if any correlations exist between these methods. Harvest-aids were applied when a physiologically mature first position boll was present 6, 8, 10, 12, or 14 mainstem nodes (MFB) above the lowest sympodial branch with a harvestable boll and accumulated HU, OBPD, and NACB recorded. In all studies, HU accumulation was significantly correlated to total lint yield, and was the best method of determining crop maturity. However, due to the practical limitations of using this method, OBPD which was significantly correlated to lint yield in three of four studies and was highly correlated to HU accumulation in all studies (correlation coefficient of at least 0.935) is recommended rather than NACB. Studies indicate that maximum lint yield can be obtained by defoliating ‘DP 555 BG/RR’ at 10 MFB (42 - 64 OBPD, NAWF5 + 790 – 906 HU, NACB = 4 – 5), while it may be possible to defoliate ‘ST 4892 BR’ at 8 MFB (17 - 40 OBPD, NAWF5 + 701 – 814 DD60’s, NACB = 6 – 7) without significantly reducing yield. However, to maximize lint yield with early defoliation a second harvest may be necessary. Delaying crop termination until after 75 OBPD may have detrimental effects on fiber quality leading to quality based discounts

and reducing gross revenue. Using MFB to time crop termination eliminates determination of the uppermost harvestable boll, a critical flaw of the OBPD and NACB defoliation timing methods. Using MFB as defoliation timing criterion is feasible and further studies should investigate this method across different environmental conditions and varieties.

Once the decision has been made to chemically terminate a cotton crop several decisions including harvest-aid combination can improve efficacy and increase the chance of an adequate defoliation for a once over harvest. The optimum combination of carrier volume and nozzle type for maximizing efficacy of cotton harvest-aids having both hormonal and herbicidal modes of action was evaluated in field studies for two years at three locations. In Alexandria, LA, more desiccated leaf material was present 7 days after treatment (DAT) with carrier volumes of 140.2 L ha<sup>-1</sup> when compared to 93.5 or 46.7 L ha<sup>-1</sup>, regardless of the type of harvest-aid or nozzle. At 14 DAT, flat fan and hollow cone nozzles provided greater defoliation than did air induction nozzles, regardless of harvest-aid and/or carrier volume. Defoliation with hollow cone nozzles was still greater than air induction nozzles 21 DAT. In Jackson, TN, leaf defoliation and desiccation was greater with applications at 93.5 and 140.2 L ha<sup>-1</sup> (7 DAT) compared to 46.7 L ha<sup>-1</sup> across all nozzle types. Hollow cone nozzles provided greater defoliation than air induction nozzles 7 DAT and were superior to both flat fan and air induction nozzles at 14 DAT, averaged across carrier volumes. Results from studies in both 2003 and 2004 at St. Joseph, LA were similar. Regardless of harvest-aid and nozzle type, defoliation generally increased as carrier volume increased. Averaged across harvest-aids and carrier volumes, flat fan and hollow cone nozzles increased defoliation at least

16% at both 7 and 19 DAT, compared to air induction nozzles (2003). Similar trends were observed in 2004. These data support current harvest-aid application recommendations in LA and TN that advise using flat fan or hollow cone nozzles at carrier volumes no less than 93.5 L ha<sup>-1</sup>. Air induction nozzles should not be recommended for cotton defoliation due to inconsistent and generally inferior performance.

Results and conclusions derived from these studies demonstrate the importance of continuously investigating production practices with respect to their relationship with advances in technology to improve crop productivity, management efficiency, and ensure the sustainability of production agriculture in the United States.

## VITA

Jonathan Daniel Siebert, son of Paul and Debra Siebert, was born September 3, 1978, in Eunice, Louisiana. He remained in Eunice where he attended and graduated from Eunice High School in 1996. In 2000, Jonathan earned a Bachelor of Science degree in agronomy at Louisiana State University Agricultural and Mechanical College. After completing his Bachelor of Science degree, Jonathan enrolled in the weed science graduate program in the Department of Plant Pathology and Crop Physiology at Louisiana State University under the direction of Dr. James L. Griffin. He completed requirements for the Master of Science degree in 2003 and immediately began pursuing a Doctor of Philosophy degree in agronomy under the supervision of Drs. Alexander M. Stewart and Gerald O. Myers with a minor in entomology under Dr. B. Rogers Leonard. Jonathan is currently a doctoral candidate in the Department of Agronomy and Environmental Management at Louisiana State University and anticipates graduation at the December 2005 commencement.