1247 Defining optimal defoliation timing and harvest timing for compact, normal, and extended fruiting patterns of cotton (*gossypium hirsutum* l.) achieved by cultivar maturity groups

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Abstract

In North Carolina, cotton (*Gossypium hirsutum* L.) defoliation is usually initiated when 60 percent of the total bolls are open. Recent evidence suggests that defoliation could be initiated before 60 percent open bolls (% OB) if fruiting is compact (fruit set over eight to ten nodes), however a crop with extended fruiting may require delayed defoliation to achieve maximum yields. Experiments were conducted in North Carolina during 2004 and 2005 to observe the effects of defoliation and harvest timings on various fruiting patterns of cotton. Compact, normal, and extended fruiting patterns were achieved via planting Deltapine (DP) 444 (early-maturing), DP 451 (medium-maturing) and DP 555 (late-maturing) cultivars, respectively. Targeted defoliation timings were 50, 70, and 90 % OB and the targeted harvest timings included 14 $^{\pm}$ three days after defoliation and 28 $^{\pm}$ three days after defoliation. Data suggest that cultivar characteristics may be largely responsible for variations in fiber quality, however micronaire and strength could be influenced by harvest timing. Defoliation before 60 % OB was proven to be plausible however harvest should be delayed to achieve maximum yields, for this scenario. In contrast, optimal yields were reached when cotton, defoliated beyond 60 % OB, was harvested early. Although, some significant differences were realized, plant mapping data suggest that all three cultivars were somewhat similar in terms of fruiting characteristics, therefore assumptions regarding fruiting compactness can not made based on a particular cultivar maturity group.

Key Words: cultivar, defoliation, harvest.

Introduction

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

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

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

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

The rate of boll opening depends on environmental conditions, cultivar maturity group, and timing and use of plant growth regulators, among other factors. Proper defoliation can improve leaf grades and lead to earlier harvest by accelerating boll opening with the use of ethephon products (Supak, 1996). Lint exposure to weathering, alters fiber characteristics (Barker et al., 1979) and reduce quality grades, therefore cotton should be harvested soon after all harvestable bolls are open. However, boll opening rates may differ between fields or cultivars, and depend upon crop maturity and weather, even if defoliants and boll openers are used. Williford (1992) suggests that harvest should be initiated when harvestable bolls are open, with minimum exposure of open bolls to rainfall. Faircloth (2002) found that seed-cotton losses were correlated to rainfall greater than 0.5 cm and winds greater than 9 m s^{-1}. The benchmark in which rainfall begins to reduce yields and grades, according to the findings of Williford (1992) is approximately 50 mm of rainfall whether rainfall occurs in one event or multiple events. He also noted that grade losses were associated with delayed harvests in two of three years, and both once-over and delayed harvest only in one year. Kelley et al. (2002) found that delayed harvest resulted in several quality penalties, except for micronaire, and also concluded that 7.6 cm of precipitation during the later harvest period, is the threshold where yield and quality reductions begin. Although boll opening rates may vary depending upon genetics, environment, and management, harvest should be conducted soon after all harvestable bolls are open, with minimal exposure to weathering.

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

Materials and Methods

Cultural Methods and Experimental Design

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

Percent open boll and nodes above cracked boll (NACB) measurements were recorded on six adjacent plants chosen randomly in each plot within the designated strip assigned to a specific defoliation timing, and the average was taken across all plots within the strip. All plots within the designated strips were defoliated each year when this average reached the targeted % OB. A standard mixture of tribufos {*S,S,S*-tributyl phosphorotrithioate} (Def®, Bayer Crop Science, Research Triangle Park N.C.) at the 0.6 L ha^{-1} rate, thidiazuron {*N*-phenyl-*N*'-1,2,3-thiadiazol-5-ylurea} (Dropp® 50 WP, Bayer Crop Science, Research Triangle Park N.C.) at the 0.22 kg ha^{-1} rate, and ethephon {2-chloroethyl phosphonic acid} (Prep®, Bayer Crop Science, Research Triangle Park N.C.) at the 2.3 L ha^{-1} rate, was used in each year, across all application timings. Actual defoliation timings were 46, 69, and 83 % OB in 2004, and 50, 66, and 82 % OB in 2005. Defoliation applications were applied using a CO_2-pressurized backpack sprayer, calibrated to deliver 140.3 L ha^{-1} using regular flat-fan nozzles. At each defoliation timing, % OB, total bolls, and NACB (nodes between highest first position cracked boll and highest harvestable boll) were recorded. Plant mapping data were collected for 18 plants per defoliation treatment.

The center two rows of each experimental unit were harvested using a two-row John Deere spindle picker. The early harvest was conducted on rows two and three in all plots within each defoliation strip. The late harvest was conducted on rows six and seven in all plots within each defoliation strip. Seed-cotton weights for each plot were recorded and sub-samples were collected for high volume instrumentation (HVI) analysis and lint percentage. Data included lint yield, micronaire, length, length uniformity, and strength.

Statistical Analysis

Data were subjected to analysis of variance using the General Linear Model in SAS version 9.1.3 (SAS Inst., Cary, NC). Due to strong interactions with year, and consideration of F-tests, some data were reported separately by year. Where no significant year interactions were expressed, data were reported with years combined. Means of significant main effects and interactions were separated using Fisher's Protected LSD at $p<0.05$.

Results and Discussion

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

The harvest timing by cultivar interaction was significant for lint yield in 2005 (Table 1). Yields of the early harvest for DP 444 were significantly higher than yields for all other harvest timings and cultivars, probably due to earlier maturity and minimum exposure to rainfall events compared to the other two cultivars. Lint yields of the late harvest for DP 444 and both harvest timings for DP 451 and DP 555 were not significantly different from each other, although there was a downward numeric trend in lint yields as harvest was delayed, for all cultivars, possibly due to rainfall events occurring in the latter harvesting period (data not shown).

The defoliation timing by harvest timing interaction was significant for lint yield in 2005 (Table 2). Yields increased significantly as harvest was delayed, when cotton was defoliated at the early defoliation timing, however yields decreased numerically as harvest was delayed when defoliated at the mid defoliation timing, and significantly when defoliated at the late defoliation timing, likely a result of significant rainfall events occurring between defoliation and harvest for the latter two defoliation timings (data not shown). Yields of both harvest timings of the mid defoliation timing were not statistically different from yields of the early harvest defoliated at early defoliation timing, and the yields of the early harvest defoliated at mid defoliation timing were significantly higher than the yields of the late harvest defoliated at late defoliation timing. Yields of the early harvest defoliated at the late defoliation timing were not significantly different from the yields of the late harvest defoliated at early defoliation timing, but the latter scenario was not significantly different from yields of either harvest timing defoliated at mid defoliation timing. These data suggests that delaying harvest, for early-defoliated cotton, may enhance yields by allowing more time for more bolls to open. These data also indicate that an early harvest may be of more importance when defoliation is delayed, due to increased weathering potential.

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

The cultivar main effect was significant for micronaire, fiber length, uniformity, and strength in both years (Table 3). The medium maturing cultivar, DP 451, had significantly higher micronaire values than DP 555 and DP 444, however values of DP 444 were significantly less than that of DP 555. Micronaire values of DP 451 were in the discount range, whereas values of DP 444 and DP 555 were not. Length values of DP 451 were significantly higher than both DP 444 and DP 555, and the values of the latter two cultivars were not significantly different from each other. Uniformity values of DP 451 and DP 444 were not significantly different however, values of both cultivars were significantly higher than values of DP 555. Strength values of DP 451 and DP 444 were not significantly different, however, values of both cultivars were significantly less than values of DP 555. The harvest timing main effect was significant for fiber strength in 2005 (data not shown). Fiber strength decreased by two percent as harvest was delayed in 2005, possibly due to extended field exposure and rain events (data not shown).

Interactions with year were significant for most parameters, so analyses for plant mapping parameters were reported separately over 2004 and 2005 (Tables 4, 5). In 2004 (Table 4), total bolls on nodes four to seven were highest for DP 444, followed by DP 451 and lastly DP 555, while DP 555 yielded more bolls on nodes 11 to 19 than both DP 451 and DP 444. DP 555 yielded significantly more sympodial bolls that DP 444, while values of DP 451 were not significantly different from either of the other cultivars. Values of DP 555 were significantly greater than both DP 451 and DP 444, with respect to total nodes and node of first sympodial branch.

In 2005 (Table 5), DP 444 yielded significantly less values than both DP 451 and DP 555, with respect to total bolls, sympodial bolls, and total bolls on nodes 11 to 19. With respect to total nodes and sympodial nodes, DP 555 was higher than DP 451 or DP 444. Also, values of DP 451 exceeded that of DP 444. With respect to final plant height, DP 555 had higher values than DP 451 and DP 444, however, DP 444 yielded significantly higher values for height node^{-1} ratio values.

Conclusions

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

In North Carolina, discounts for high micronaire are likely, therefore management practices that can potentially decrease micronaire without sacrificing yields, should be considered. These data suggest that delaying harvest may help reduce micronaire values to an optimal (no-discount) range, regardless of defoliation timing or cultivar planted. However, as seen in previous studies, micronaire may be strongly influenced by cultivar, along with environmental conditions. Differences in fiber length, length uniformity, and fiber strength may also be due to varietal tendencies, however, fiber strength may also be influenced by environmental conditions following boll opening. Similar to findings of Kelley et al. (2002) and Williford (1992) significant rainfall as seen in 2005 can result in yield loss and quality penalties (data not shown).

Similar to varietal differences found in previous studies by Pustejovsky and Albers (2003), plant mapping data suggest that fruiting characteristics may differ for various maturity groups. Although variation in plant fruiting were evident, differences between the cultivars were subtle. Regardless of cultivar maturity, early or delayed defoliation may be plausible, however other factors such as harvest scheduling, and prevailing environmental conditions should be considered foremost before making a defoliation decision. Also, proper defoliation and harvest timing may be used to avoid discounts in fiber quality. Perhaps, similar studies conducted in environments, where fruiting patterns are drastically different, may yield more conclusive results, as to the optimal defoliation and harvest timing for cultivar maturity groups.

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Table 1. Harvest timing by cultivar interaction effects on lint yield in 2005.[z]

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

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

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

Table 2. Defoliation timing by harvest timing interaction effects on lint yield in 2005.[z]

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

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

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

Table 3. Cultivar main effect for micronaire, length, uniformity, and strength for both years combined.[z]

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

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

Table 4. Cultivar main effect on nodes and fruit numbers in 2004.[z]

Cultivar	Node of 1st Sympodial branch	Total nodes	Sympodial bolls	Total bolls on nodes 4 to 7	Total bolls on nodes 11 to 19
	——————— no. ———————				
Deltapine 555	8a	16a	11a	0.8c	5.2a
Deltapine 451	6b	14b	8b	2.8b	2.1b
Deltapine 444	6b	14b	9ab	4.0a	1.6b

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

Table 5. Cultivar main effect on plant height, nodes, and fruit numbers and position in 2005.[z]

Cultivar	Total bolls	Sympodial bolls	Total bolls on nodes 11-19	Total nodes	Sympodial nodes	Height node^{-1} ratio	Plant height
	——no.——						——cm——
Deltapine 555	7a	7a	3a	18a	10a	4.7b	84a
Deltapine 451	7a	7a	3a	16b	9b	4.8b	76b
Deltapine 444	6b	5b	1b	14c	8c	5.4a	78b

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