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Cotton Defoliation and Harvest Timing Effects on Yields, Quality, and Net Revenues

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INTERPRETIVE SUMMARY

Farmers need to determine the most profitable time to defoliate cotton in a short-season environment such as Tennessee. Research has shown that cotton defoliation and harvest can be scheduled on the basis of heat-unit accumulation after physiological cutout (five nodes above white flower). The COTMAN Expert System computer program uses degree-day accumulation after cutout as a criterion to schedule cotton fields for defoliation. This system can help producers plan crop termination and harvest operations as early as mid-season. The objectives of this study were (i) to evaluate the impact of scheduling defoliation at various degree-days after cutout on lint yields, fiber quality, lint prices adjusted for fiber quality, and net revenues; and (ii) to determine if choice of harvest-aid material altered these responses.

'Stoneville 474' or 'Stoneville 4892 BR' was planted at the West Tennessee Experiment Station in May 1998, 1999, and 2000. Crop progress was monitored using the COTMAN Expert System. The crops reached cutout between 14 and 16 d before the last effective bloom date each year, so crop-oriented COTMAN termination rules were applied. Harvest-aid treatments were (i) a tank mixture of thidiazuron (Dropp 50WP[1]), tribufos (Folex 6EC), and ethephon (Prep 6); and (ii) a prepared mixture of cyclanilide and ethephon (Finish 4 or 6, Aventis CropScience, Research Triangle Park, NC). These two treatments were applied at equivalent ethephon rates at 650, 750, 850, and 950 degree-d (base 60°F) after cutout each year. Cotton from each plot was spindle-picked 14 d after each treatment application, and all plots were picked again 14 to 28 d later to determine total lint yield. Seed cotton was ginned on a 20-saw gin equipped with a stick machine, incline cleaners, and dual lint cleaners. Lint quality was evaluated by high-volume instrument (HVI) and hand-classing procedures. Lint price differences for fiber quality were calculated using fiber quality measured in the experiment and North Delta spot price quotations from 1994/1995 (a relatively high price scenario) and from 2000/2001 (a relatively low price scenario). Average spot base prices in these contrasting marketing years were \$0.88 and \$0.52 lb^{-1} lint, respectively. Net revenues were estimated using lint yields, lint prices adjusted for fiber quality, harvest-aid materials and application expenses, and picking costs.

Results consistently showed the harmful effects of premature crop termination and the beneficial effects of delayed cotton defoliation on fiber quality and lint yields. Incomplete defoliation of cotton at the early (650 degree-d) crop-termination date caused significantly poorer fiber quality and leaf grades than from cotton defoliated at a later date. In addition, both first-harvest and total lint yields at the early defoliation date were significantly lower than lint yields at the later 850 and 950 degree-d defoliation dates. Timing effects did not differ between harvest-aids, although some small response differences between materials were observed. Findings indicate that additional yield occurred by delaying crop termination and harvest. Improved fiber quality and enhanced yields from cotton harvested after

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[1] Harvest-aids are referred to by brand name for clarity in reporting the products applied in this research. Mention of these brand names does not constitute commercial endorsement of the products to the exclusion of others that may be of similar, suitable composition, nor does it guarantee or warrant the standard of the products.

Abbreviations: HVI, high-volume instrument.

defoliation at 950 degree-d produced the largest net revenues among the degree-day criteria evaluated, under either price scenario. Harvest-aid materials applied in this study produced similar net revenues.

Findings also indicate that delaying defoliation to 950 degree-d after cutout can facilitate a single harvest strategy. Single harvest net revenues for cotton defoliated at 950 degree-d produced comparable or larger returns than cotton terminated at an earlier date and harvested twice. This result was similar in either price scenario, although differences in net returns were larger when cotton prices were higher. However, results also indicate that the potential advantages of harvest after defoliation at 950 degree-d need to be weighed against the potential risks of later harvest, especially along the northern edge of the U.S. Cotton Belt. Inclement weather becomes more probable as harvest is delayed, possibly leading to losses of fiber quality and harvest efficiency. In general, these results validate the nominal threshold of 850 degree-d to predict crop maturity using crop-oriented COTMAN rules.

ABSTRACT

Producers need methods to determine the relationship between early defoliation and net revenues for cotton (*Gossypium hirsutum* L.) in a short-season environment. This study evaluated the effects of alternative defoliation timing and harvest-aid strategies on lint yields, prices adjusted for fiber quality, and net revenues. 'Stoneville 474' or 'Stoneville 4892 BR' was planted in May 1998, 1999, and 2000, and the crops were monitored using the COTMAN Expert System. Harvest-aid treatments were (i) a tank mixture of thidiazuron (*N*-phenyl-*N'*-1,2,3-thiadiazol-5-ylurea), tribufos (*S,S,S*-tributyl phosphorotrithioate), and ethephon [(2-chloroethyl)phosphonic acid]; and (ii) a prepared mixture of cyclanilide {1-[[(2,4-dichlorophenyl)amino]carbonyl]cyclopropanecarboxylic acid} plus ethephon. These treatments were applied at 361, 417, 472, and 528 degree-d (base 15.6°C) after cutout each year. Price differences for fiber quality were calculated using fiber quality measured from the experiment and North Delta spot price quotations from contrasting marketing years. Net revenues were estimated using lint yields, price differences, harvest-aid materials and application expenses, and harvesting costs. Results consistently showed the harmful effects of premature crop termination and the beneficial effects of delayed termination beyond the nominal threshold of 472 degree-d. Additional yield occurred with delayed crop termination. Improved fiber quality and enhanced yields from cotton harvested after defoliation at 528 degree-d maximized cotton crop profitability. Findings suggest that delaying defoliation to 528 degree-d can facilitate a single harvest of cotton. However, the potential advantages of delayed defoliation need to be weighed against the potential risks of later harvest when inclement weather is more probable.

Research indicates that cotton (*Gossypium hirsutum* L.) crop termination can be scheduled on the basis of heat-unit accumulation after physiological cutout (five nodes above white flower) or after the last effective bloom date for a given location (Stringer et al., 1989; Bourland et al., 1992; Bourland et al., 1997). Cutout establishes the last boll population to significantly contribute to yield (Bourland et al., 1992). In studies used to develop cotton termination rules, yields began to stabilize at 472 degree-d (base 15.6°C) after cutout (Stringer et al., 1989; Bourland et al., 1992; Bourland et al., 1997).

Recent versions of the COTMAN Expert System (Cochran et al., 1998) use degree-day accumulation after cutout to schedule cotton fields for defoliation, which can help producers plan crop termination and harvest operations as early as mid-season. Bourland et al. (1997) suggested that 472 degree-d should be accumulated after the last effective flowering date prior to defoliation. However, field experience with this program indicates that the 472 degree-d criterion may not be optimal for cotton in some parts of the northern U.S. Cotton Belt, where some fields may need to be defoliated as early as possible to advance the overall harvest schedule and avoid inclement weather. It has been suggested that 361 to 417 degree-d may be appropriate for defoliation when plants set fruit in a short period, so that the crop can reach 60 to 70% open bolls by that time (Bourland et al., 1997).

Some of the detrimental effects of premature crop termination on lint yield and fiber quality have been reported. Snipes and Baskin (1994) reported that defoliation before 60% open bolls resulted in yield losses of 7 to 15%. Reductions in lint yield and micronaire were associated with early defoliation. These authors pointed out that in some instances, yield losses may be justified when balanced against the need for a timely harvest. Kerby et al. (1992) also acknowledged the need for an early harvest under some conditions to avoid potential grade losses due to later inclement weather. They suggested that monitoring of nodes above cracked boll could be used as an alternative to classical defoliation timing tools such as cutting of the highest harvestable boll population and estimating the percentage of open bolls. While these classical methods may indicate the current readiness of the crop for defoliation, they do not provide a farm manager with a sufficiently long-range prediction of crop maturity needed to schedule different fields for defoliation and harvest.

The harvest-aid chosen may affect response to defoliation at different dates because of possible differences in temperature regime during or after application (Gwathmey and Hayes, 1997). These investigators showed that the boll opener, ethephon, acts synergistically with defoliants, but their interaction depends on the defoliant used and on the temperature regime. This work suggested that contact-type defoliants such as tribufos may defoliate cotton more rapidly than hormonal-type materials under cool conditions. However, a regional comparison of tribufos and ethephon versus cyclanilide and ethephon showed similar defoliation responses under cool conditions when both were applied at 1.68 kg ethephon ha^{-1} (Hayes et al., 1996).

Timeliness may be the most significant factor contributing to profitability in cotton production and marketing (Brooking, 1997). Shurley and Bednarz (2000, 2001) found that defoliating cotton at approximately 70% open boll produced the largest returns under Georgia production conditions in 1998 and 1999. However, the growing season in South Georgia is much longer than the season in the North Delta of Arkansas, Missouri, and Tennessee. Farmers in northern growing areas such as Tennessee need information about economic tradeoffs that influence cotton defoliation and harvest scheduling decisions. Among the factors influencing the optimal timing of cotton defoliation and harvest include responses of lint yield and fiber quality, changes in price differences for fiber quality, harvest-aid costs, cotton harvesting and handling costs, available field days during the harvest period, and competition for scarce labor resources. The objective of this study was to determine profitable defoliation timing and harvest-aid strategies in short-season environments such as in Tennessee, as measured by timing and harvest-aid effects on lint yields, fiber quality, price differences for fiber quality, and net revenues.

DATA AND METHODS

Cotton Yield Data

Lint yield and fiber-quality data were taken from a defoliation timing study conducted from 1998 through 2000 at the West Tennessee Experiment Station in Jackson, TN. The cotton cultivar Stoneville 474 was planted with no tillage on 15 May 1998 and 3 May 1999 into a Calloway silt loam (fine-silty, mixed, active, thermic Aquic Fragiudalfs) for this study. A closely related cultivar, Stoneville 4892 BR, was planted with no tillage on 11 May 2000 on the same site. Plant populations averaged 84,968 plants ha^{-1} in 1998, 62,491 plants ha^{-1} in 1999, and 92,378 plants ha^{-1} in 2000. Standard no-tillage cotton production and pest control practices were followed (Shelby, 1996). Crop progress was monitored using the COTMAN Expert System 5.0 computer program (Cochran et al., 1998). For the BOLLMAN portion of COTMAN, data on nodes above the highest first-position white flower were collected from 80 flowering plants at eight sites during flowering, 60 to 90 d after planting. On the basis of these data, COTMAN indicated that the crop reached physiological cutout between 23 and 25 July in the 3 yr of this study (Table 1). These cutout dates were 14 to 16 d before the last effective bloom date of 8 August for Jackson, TN (Bourland et al., 1997), so crop-based termination rules were applied to estimate crop maturity with COTMAN each year.

Daily maximum and minimum air temperatures were measured in a standard U.S. Weather Service instrument shelter at the West Tennessee Experiment Station. Cumulative degree-d after treatment were calculated as described by Bourland et al. (1997), using a base temperature of 15.6°C. Four-row plots were established and re-randomized each year for the application of harvest-aid treatments at 361, 417, 472, and 528 degree-d after cutout. The plots were 9.1 m long and had a row spacing of 97 cm. The four stages of defoliation timing were main-plot treatments in a randomized complete block split-plot design. The subplot treatments were (i) a tank

Table 1. Planting, cutout, treatment and harvest dates, and harvest-aids applied each year in the harvest-aid timing study at Jackson, TN.

Item		Year					
		1998		1999		2000	
Planting date:		15 May		3 May		11 May	
Cutout date:		24 July		23 July		25 July	
First harvest:							
Treatment number	**Defoliation timing**	**Tmt. date**	**Hvst. date**	**Tmt. Date**	**Hvst. date**	**Tmt. date**	**Hvst. date**
1	361 DD†	28 Aug	11 Sep	23 Aug	7 Sep	28 Aug	11 Sep
2	417 DD	2 Sep	16 Sep	29 Aug	13 Sep	1 Sep	15 Sep
3	472 DD	8 Sep	22 Sep	3 Sep	17 Sep	5 Sep	19 Sep
4	528 DD	15 Sep	29 Sep	8 Sep	22 Sep	11 Sep	26 Sep
Second harvest (all plots):			9 Oct		30 Sep		5 Oct
Harvest-aid treatment:							
Treatment number	**Harvest-aid**	**Year**					
		1998		1999		2000	
		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
1	Thidiazuron	0.11		0.11		0.11	
	Tribufos‡	0.28-0.43		0.31-0.43		0.43-0.53	
	Ethephon	1.68		1.68		1.68	
2	Cyclanilide plus ethephon	1.68		1.68		1.68	

† DD, degree-days (base 15.6°C) after five nodes above white flower until treatment.
‡ Tribufos rate adjusted for ambient temperature at application (see text).

mixture of thidiazuron, tribufos, and ethephon; and (ii) a prepared mixture of cyclanilide and ethephon. Equivalent ethephon rates were used for each harvest-aid treatment. Each defoliation timing and harvest-aid treatment combination was replicated four times in the experiment. A commercial 478 g L^{-1} formulation of cyclanilide and ethephon (Finish 4 or 6, Aventis CropScience, Research Triangle Park, NC) was used in 1998 and 1999, but the 718 g L^{-1} formulation was used in 2000 (Rhône-Poulenc Ag, 2000). All treatments were applied on four successive dates at rates shown in Table 1. Rates of thidiazuron, cyclanilide, and ethephon remained the same for all treatment dates in all years. The rate of tribufos was adjusted slightly according to the ambient air temperature at the time of application. Thus in 1998, 0.28 kg ha^{-1} tribufos was applied at 361 and 417 degree-d, and 0.42 kg ha^{-1} was applied at 472 and 528 degree-d after cutout. In 1999, 0.31 kg ha^{-1} tribufos was applied at 361 degree-d, and 0.42 kg ha^{-1} was applied at the three later dates. In 2000, 0.43 kg ha^{-1} tribufos was applied at 361 and 417 degree-d, and 0.53 kg ha^{-1} was applied at 472 and 528 degree-d. All chemicals were applied in 110 L ha^{-1} aqueous solution through a CO_2-pressurized boom attached to a self-propelled high-clearance sprayer, with two spray tips per row operating at 235 kPa. At the time of treatment, boll counts were made in a 1-m segment of row in each plot to calculate percent open bolls. Just before each harvest (14 ± 1 d after each treatment), open boll counts were made and percent defoliation was visually estimated in each plot. The two center rows of each plot were picked with a John Deere 9930 2-row spindle picker (Deere & Company, Moline, IL). Seed cotton harvested from each plot was weighed, and a grab sample was taken from each plot, weighed, and air-dried before ginning. All plots were harvested again after all harvestable bolls opened (Table 1), and the data were used to calculate total yields. Earliness was calculated as the percent of total yield picked at the first harvest. Seed cotton samples were ginned with a Continental 20-saw gin (Continental Gin, Prattville, AL) equipped with a stick machine, dual incline cleaners, and dual lint cleaners at the West Tennessee Experiment Station. Lint was weighed to calculate gin turnout, and a subsample of lint was analyzed by high-volume instrument (HVI) testing and hand-classing procedures at the USDA Agricultural Marketing Service Cotton Classing Office in Memphis, TN (USDA-AMS, 1995b).

Cotton Price Data

To evaluate potential effects on the price received for cotton, fiber quality measured for each defoliation timing and harvest-aid treatment was used to estimate price differences for fiber quality. Quotations collected by the U.S. Department of Agriculture, Agricultural Marketing Service were used to estimate premiums and discounts from a base quality price for each treatment. Relevant quotations for Tennessee are from the North Delta market, which includes northeast Arkansas, Missouri, and Tennessee. The area market reporter determines daily prices by interviewing market participants and collecting sales information (Kuehlers, 1994). The accuracy of spot price quotations for the North Delta is unknown because there has not been an objective evaluation of the price differences reported by the Agricultural Marketing Service for this region (Ethridge and Hudson, 1998). The statistical reliability of spot price quotations is difficult to determine because information about sample characteristics such as number of observations and representativeness are not known (Brown et al., 1995; Hudson et al., 1996). Irrespective of these data limitations, we assume North Delta spot quotes reflect price differences for farmers in Tennessee.

The reported base quotation price is for Strict Low Middling (color 41, leaf 4, staple 34 [fiber length between 26.67 and 27.18 mm], micronaire 35-36 and 43-49, strength 26.5-28.4 g tex^{-1} [259.9-278.5 kN m kg^{-1}], and uniformity 81) cotton. Price differences from the base for the combination of color, leaf, and staple; micronaire; and fiber strength are those reported by the Agricultural Marketing Service. In addition, the Agricultural Marketing Service began reporting price differences for length uniformity for the 2000/2001 marketing year (1 Aug. 2000 through 31 July 2001).

Two price scenarios were applied to the 3-yr fiber-quality data set to evaluate whether supply and demand conditions that influence price differences for fiber quality might affect the defoliation timing decision. Marketing year average spot prices for 1994/1995 (1 Aug. 1994 through 31 July 1995) denote the high price scenario (USDA-AMS, 1995b). For the 1994/1995 marketing year, U.S. cotton system mill consumption was near historic highs not experienced since the early 1940s and exports were at their highest point since the 1926/1927 season (Meyer, 1996). By contrast, spot prices for 2000/2001 represent a relatively low price scenario (USDA-AMS, 2001b). Weak demand for cotton caused by an economic slowdown and strong international competition, coupled with the inelastic production response by farmers to low prices, characterized market conditions in 2000/2001 (Meyer and McDonald, 2001).

The equation used to estimate lint price differences for fiber quality as influenced by defoliation timing and harvest-aid treatment and using North Delta market spot price data is

$$P_d = P_{cls} + P_m + P_{str} + P_u, \quad [1]$$

where P_d is the total price difference for each treatment from the base price of cotton (¢ kg^{-1}); P_{cls} is the price difference for the combination of color grade, leaf grade, and staple (¢ kg^{-1}); P_m is the price difference for micronaire (¢ kg^{-1}); P_{str} is the price difference for strength (¢ kg^{-1}); andP_u is the price difference for length uniformity (¢ kg^{-1}).

Net Revenues

The net impacts of defoliation timing on lint yields and fiber quality were evaluated through the calculation of net revenues for each treatment. The following partial budgeting equation was used to estimate net revenues (NR) for each defoliation timing and harvest-aid treatment:

$$NR = (P_b + P_d) \times Y_1 + (P_b + P_d) \times Y_2 - DC_j - HC_1 - HC_2 \quad [2]$$

where P_b is North Delta base quality lint price (¢ kg^{-1}); P_d is the total price difference for each treatment that was defined previously (¢ kg^{-1}); Y_1 is first-harvest lint yield measured for each treatment (kg ha^{-1}); Y_2 is second-harvest lint yield for each treatment (kg ha^{-1}); DC is the defoliation material and application cost for the harvest-aid treatment j in the experiment (\$ ha^{-1}), and HC_1 and HC_2 are costs of seed cotton picking and handling (\$ ha^{-1}) for the first and second harvests, respectively. Revenues from cottonseed were assumed to equal the cost of ginning and bale handling in the analysis.

Harvest-aid material costs were calculated using prices from the Tennessee Farmers Cooperative 14 Aug. 2000 suggested retail price list (Tennessee Farmers Cooperative, LaVergne, TN). Prices were multiplied by the application rate for each treatment in each year of the experiment. Even though the cost of applying the harvest-aid is the same for both treatments, expenses for a self-propelled boom sprayer to apply the harvest-aid were included in the calculation of treatment costs (Gerloff, 2001).

Picking and handling costs for each harvest were estimated for a harvest equipment complement that included a 4-row, self-propelled cotton picker, a module builder with a tractor, and three trailers with a tractor for overflow when the module builder is full (Cooke et al., 1991). This complement is sized to cover 253 ha for the first harvest in 18 field days suitable for harvesting. Equipment, materials, and labor costs per acre were calculated using machine hours required to cover 253 ha for the first and second harvests. Foregoing the second harvest reduces hours of operation per year and the total costs of picking and handling per acre.

The coefficients for machine hour per hectare for the first and second harvests were from Cooke et al. (1991). Machinery prices, labor costs, and other data used to calculate ownership, repair and maintenance, and labor costs were from Gerloff (2001). Coefficients to estimate machinery remaining value as a function of hours of use and age were from Cross and Perry (1995). Coefficients to estimate machinery repair and maintenance costs for each hour of operation were from the American Society of Agricultural Engineers (1999). Costs for taxes, insurance, housing, and fuel were from Gerloff (2001).

Analysis

Statistical analyses of lint yields and fiber-quality attributes, along with price differences and net revenues, were performed using the mixed model procedure in SAS (SAS Institute, 1997). The mixed procedure in SAS provides Type III *F* statistical values but does not provide mean square values for each element within the analysis or the error terms for mean separation. Therefore, a macro for converting mean separation output to letter groupings with the mixed model procedure was used to evaluate mean separation among treatments through a series of protected pairwise contrasts (Saxton, 1998). A probability level of 0.05 was used for the mean separation comparison. Statistical results were reported for main plot (defoliation timing), subplot (harvest-aid), and interaction (defoliation timings × harvest-aids) effects for yields, fiber quality, and price differences. Because staple and leaf grade are used by the industry for pricing cotton, statistical comparisons were reported for staple and leaf grade, as well as the other standard HVI fiber-quality characteristics (i.e., reflectance, yellowness, trash, fiber length, length uniformity, micronaire, and fiber strength). An additional fixed effect for the number of harvests was specified in SAS to evaluate tradeoffs in net revenue for cotton terminated early and harvested twice and cotton defoliated later but harvested only once. Statistical results for net revenues were reported for main plot (defoliation timing), subplot (harvest-aid), and interaction (defoliation timings × harvest-aids × number of harvests) effects.

RESULTS AND DISCUSSION

Lint Yields

Defoliation scheduling and harvest-aid effects on cotton lint yields are presented in Table 2. The letters after the numbers in the body of the table indicate results for protected pairwise contrasts of defoliation timing and harvest-aid treatments at p = 0.05. Timing of crop termination had a significant impact on first-harvest yields. Lint yields at first harvest increased by 62% (372 kg ha^{-1}) when defoliation was delayed from 361 degree-d after cutout (defoliation timing Treatment 1) to 528 degree-d after cutout (defoliation timing Treatment 4). First-harvest yield response was strongly influenced by crop condition at the time of treatment. Open bolls at treatment ranged from 22% for cotton defoliated at 361 degree-d to 59% for cotton terminated at 528 degree-d. At

Table 2. Main effects and interaction effects of defoliation timing and harvest-aid treatment on cotton lint yields, 1998-2000.

Defoliation timing	Harvest-aid	First-harvest lint yield	Second-harvest lint yield	Total lint yield	First-harvest proportion
Treatment number		----------------------------------kg ha^{-1}	----------------------------	----	%
1		604 d†	222 a	827 c	72.9 c
2		839 c	163 b	1002 b	83.2 b
3		904 b	117 c	1021 b	88.0 a
4		976 a	119 c	1095 a	89.0 a
	1	822 a	159 a	980 a	82.8 a
	2	840 a	152 a	992 a	83.7 a
1	1	589 e	229 a	819 c	71.6 e
1	2	620 e	215 a	835 c	74.2 d
2	1	827 d	161 b	988 b	83.3 c
2	2	850 cd	166 b	1016 b	83.0 c
3	1	897 bc	127 c	1024 b	87.1 b
3	2	912 b	108 d	1019 b	88.8 ab
4	1	975 a	117 cd	1093 a	89.2 a
4	2	977 a	121 cd	1097 a	88.8 ab

† Within each treatment comparison (defoliation timing, harvest-aid, or defoliation timings × harvest-aids interaction), the means followed by the same letters are not significantly different at *p* = 0.05.

time of first harvest, the number of open bolls varied from 76% for cotton defoliated at 361 degree-d to 98% for cotton terminated at 528 degree-d.

Total lint yields were also significantly affected by crop-termination timing. Two harvest lint yields increased by 33% (268 kg ha^{-1}) when defoliation was postponed from 361 degree-d to 528 degree-d. A small but significant increase of 7% (74 kg ha^{-1}) in total lint yields also occurred with the last increment of maturity by delaying defoliation from 472 degree-d to 528 degree-d after cutout. These findings suggest that delaying crop termination allowed for additional yield formation. One possible explanation is that postponing defoliation allows for more carbon assimilation and/or partitioning of photoassimilates to developing cotton bolls.

Choice of harvest-aid material did not significantly affect first-harvest or total lint yield response. There were no significant first-harvest or total yield interaction effects between harvest-aid and the timing of defoliation.

Fiber Quality

Crop-termination timing and harvest-aid treatment effects on cotton lint color and leaf grade are presented in Table 3. The color of cotton fiber is determined by the degree of reflectance and yellowness (USDA-AMS, 1995a). Reflectance indicates how bright or dull the cotton lint is while yellowness indicates the degree of color pigmentation. Timing of defoliation had a significant influence on reflectance and yellowness. Reflectance values tended to decline when defoliation was delayed for a longer period after cutout. Across harvest-aids, reflectance dropped from 74.7% for cotton terminated at 361 degree-d to 72.5% for cotton defoliated at 528 degree-d. Reflectance may have deteriorated because of the longer exposure of open bolls to weathering with the later defoliation date. Yellowness also declined with later defoliation, decreasing from 9.7 for cotton defoliated at 361 degree-d to 9.3 for cotton terminated at 472 and 528 degree-d after cutout. Open bolls on plants defoliated at 528 degree-d might have been exposed to more bleaching than bolls defoliated and harvested earlier (Ray and Minton, 1973).

Choice of harvest-aid also had a significant effect on the reflectance and yellowness values of cotton lint. The thidiazuron-tribufos-ethephon mixture produced a brighter and whiter fiber (larger reflectance and smaller yellowness values) than

Table 3. Main effects and interaction effects of defoliation timing and harvest-aid treatment on cotton color and leaf grade, 1998-2000.

Defoliation timing	Harvest-aid	Color grade			Leaf
		Reflectance	Yellowness	HVI trash	grade
Treatment number		%	units	%	index
1		74.7 ab†	9.75 a	0.79 a	5.1 a
2		74.9 a	9.69 a	0.69 b	4.7 b
3		74.3 b	9.32 b	0.68 b	4.7 b
4		72.5 c	9.32 b	0.70 b	4.5 b
	1	74.3 a	9.41 b	0.72 a	4.7 a
	2	73.9 b	9.63 a	0.70 a	4.8 a
1	1	75.0 a	9.55 cd	0.74 ab	5.0 ab
1	2	74.3 bc	9.95 a	0.83 a	5.3 a
2	1	75.0 a	9.60 c	0.77 ab	4.8 bcd
2	2	74.8 ab	9.78 b	0.62 c	4.7 bcd
3	1	74.4 abc	9.26 ef	0.68 bc	4.5 cd
3	2	74.2 c	9.38 ef	0.68 bc	4.8 bc
4	1	72.7 d	9.24 f	0.71 bc	4.5 cd
4	2	72.4 d	9.40 de	0.68 bc	4.4 d

† Within each treatment comparison (defoliation timing, harvest-aid, or defoliation timings × harvest-aids interaction), the means followed by the same letters are not significantly different at *p* = 0.05.

cyclanilide and ethephon. The harvest-aid and defoliation timing interaction for reflectance was statistically different for the earliest defoliation date (361 degree-d) but was not significant at the three later crop-termination dates (417, 472, and 528 degree-d). Thidiazuron-tribufos-ethephon produced a larger reflectance value for cotton terminated at 361 degree-d. Harvest-aid effects on yellowness were significant for cotton defoliated at 361, 417, and 528 degree-d but not at 472 degree-d. Cyclanilide and ethephon produced higher yellowness values at these termination dates. These findings indicate that thidiazuron-tribufos-ethephon might have been more effective at preserving color by defoliating the crop more completely by 14 d after treatment than cyclanilide and ethephon. Across timing treatments, the defoliation rating at first harvest was 91% for thidiazuron-tribufos-ethephon, compared with 85% for cyclanilide and ethephon.

Both HVI trash and leaf grade were higher for cotton terminated at 361 degree-d compared with defoliation at a later date. Average leaf grade was 5.1 for cotton terminated at 361 degree-d, compared with 4.5 for cotton defoliated at 528 degree-d. Incomplete defoliation may explain the higher trash in lint and leaf grade values for cotton terminated at 361 degree-d. Across harvest-aids, the defoliation rating at first harvest was 76% for cotton terminated at 361 degree-d, compared with 96% defoliation of cotton terminated at 528 degree-d.

Leaf grade and trash in lint were not impacted by choice of harvest-aid. There were no significant HVI trash or leaf grade interaction effects between harvest-aid treatment and the timing of crop termination.

Defoliation scheduling and harvest-aid impacts on fiber length, staple, length uniformity, micronaire, and fiber strength are presented in Table 4. Crop-termination timing had a significant impact on fiber length and staple. The longest fiber length of 27.7 mm occurred for cotton defoliated at 528 degree-d and was significantly smaller than the length values for cotton terminated at 361 and 472 degree-d. Fiber length and staple were not significantly influenced by harvest-aid treatment, and there were no significant fiber length or staple interaction effects between harvest-aid treatment and crop-termination timing.

For length uniformity, the thidiazuron-tribufos-ethephon mixture produced a larger uniformity value than cyclanilide and ethephon when applied at 472 degree-d. Other than for this one interaction, no other defoliation timing and harvest-aid treatment interaction significantly impacted length uniformity.

Micronaire was significantly impacted by crop-termination timing. Micronaire increased from 39.3 for cotton defoliated at 361 degree-d to 42.7 for cotton terminated at 528 degree-d. Increases in micronaire with later harvest-aid application support the hypothesis that delayed defoliation allows for more carbon assimilation and/or partitioning of

Table 4. Main effects and interaction effects of defoliation timing and harvest-aid treatment on cotton fiber length, staple, length uniformity, micronaire, and fiber strength, 1998-2000.

Defoliation timing	Harvest-aid	Fiber length	Staple	Length uniformity	Micronaire	Fiber strength
Treatment number		mm	32s in	%	units	kN m kg^{-1} (g tex^{-1})
1		27.5 b†	34.7 bc	82.3 a	39.3 c	280.8 (28.6) ab
2		27.6 ab	34.9 ab	82.5 a	40.0 c	282.9 (28.9) a
3		27.3 b	34.5 c	82.0 a	41.0 b	276.5(28.2) bc
4		27.7 a	35.1 a	82.5 a	42.7 a	275.1(28.1) c
	1	27.5 a	34.9 a	82.5 a	40.7 a	279.9(28.5) a
	2	27.5 a	34.7 a	82.1 a	40.8 a	277.7(28.3) a
1	1	27.4 ab	34.8 ab	82.4 a	39.4 e	281.7(28.7) a
1	2	27.5 ab	34.7 b	82.3 ab	39.1 e	279.9(28.5) ab
2	1	27.5 ab	34.9 ab	82.5 a	39.8 de	282.9(28.9) a
2	2	27.7 ab	34.9 ab	82.4 a	40.2 de	282.9(28.9) a
3	1	27.4 b	34.5 b	82.3 a	40.6 cd	278.7(28.4) ab
3	2	27.3 b	34.4 b	81.6 b	41.4 bc	274.3(28.0) b
4	1	27.8 a	35.3 a	82.7 a	42.8 a	276.4(28.2) ab
4	2	27.7 ab	34.9 ab	82.3 ab	42.5 ab	273.9 (27.9) b

† Within each treatment comparison (defoliation timing, harvest-aid, or defoliation timings × harvest-aids interaction), the means followed by the same letters are not significantly different at *p* = 0.05.

photoassimilates to developing cotton bolls. Choice of harvest-aid treatment did not significantly influence micronaire and there were no significant harvest-aid and defoliation timing interaction effects.

Fiber strength tended to diminish as crop termination was delayed. The largest fiber strength value of 280.9 kN m kg^{-1} (28.9 g tex^{-1}) was obtained for cotton defoliated at 417 degree-d after cutout. Fiber strength was not affected by choice of harvest-aid and there were no significant harvest-aid and defoliation timing interactions.

Price Differences for Fiber Quality

Defoliation timing and harvest-aid impacts on price differences for fiber quality calculated using the high (1994/1995 marketing year) and the relatively low (2000/2001 marketing year) price scenarios are presented in Tables 5 and 6, respectively. Early crop termination at 361 degree-d had a deleterious influence on cotton price differences. Color, leaf, and staple discounts for cotton defoliated at 361 degree-d averaged -12.61 ¢ kg^{-1} for the high price comparison and -5.82 ¢ kg^{-1} for the low price scenario. By comparison, discounts for color, leaf, and staple, calculated using 1994/1995 spot prices, were the smallest for cotton defoliated at 472 degree-d. The discount for cotton defoliated at 472 degree-d was 6.36 ¢ kg^{-1} (51%) smaller than the deduction for cotton terminated at 361 degree-d. For the low price scenario, the smallest discount was received for cotton defoliated at 417 degree-d, which was 3.32 ¢ kg^{-1} (57%) smaller than the deduction for cotton terminated at 361 degree-d. However, discounts for color, leaf, and staple for cotton defoliated at 417, 472, and 528 degree-d were very similar to each other for both price scenarios. Incomplete defoliation of cotton may explain the larger price discounts for color, leaf, and staple at the early 361 degree-d termination date.

Choice of harvest-aid had a modest impact on the price difference for the combination of color, staple, and leaf. For the high and low price scenarios, the thidiazuron-tribufos-ethephon mixture respectively produced 2.47 and 1.79 ¢ kg^{-1} smaller discounts than cyclanilide and ethephon. The thidiazuron-tribufos-ethephon mixture defoliated the crop more completely by 14 d after treatment than cyclanilide and ethephon. More compete defoliation may have improved color grade as indicated by the larger reflectance and smaller yellowness values with the thidiazuron-tribufos-ethephon mixture (Table 3). In addition, thidiazuron-tribufos-ethephon produced leaf grades greater than 4 (i.e., grades subject to discount) in 22 of 48 plots, compared with leaf discounts in 28 of 48 plots for cyclanilide and ethephon. There were no significant differences in the price discount for color, leaf, and staple due to harvest-aid treatment at any of the four defoliation timing dates.

Table 5. Main effects and interaction effects of defoliation timing and harvest-aid treatment on cotton lint price differences using 1994/1995 marketing year average North Delta spot cotton market quotations applied to the 1998-2000 fiber-quality data.

Defoliation timing	Harvest-aid	Price differences from the base price of 194 ¢ kg^{-1} Color, staple, and leaf	Micronaire	Fiber strength	Total price difference
Treatment number		¢ kg^{-1}			
1		-12.61 b†	-3.28 ab	0.20 ab	-15.70 b
2		-7.37 a	-4.91 b	0.28 a	-12.00 ab
3		-6.23 a	-3.60 ab	0.12 b	-9.59 a
4		-8.05 a	-2.73 a	0.11 b	-10.75 a
	1	-7.33 a	-3.88 a	0.20 a	-11.00 a
	2	-9.80 b	-3.39 a	0.15 a	-13.02 a
1	1	-10.80 cd	-3.05 ab	0.24 abc	-13.61 ab
1	2	-14.43 d	-3.52 ab	0.17 abcd	-17.79 b
2	1	-7.73 abc	-5.53 b	0.28 a	-12.98 a
2	2	-7.00 abc	-4.29 ab	0.27 ab	-11.02 a
3	1	-4.86 a	-4.05 ab	0.16 bcd	-8.75 a
3	2	-7.59 abc	-3.15 ab	0.08 d	-10.43 a
4	1	-5.93 ab	-2.87 a	0.14 cd	-8.66 a
4	2	-10.17 bcd	-2.58 a	0.09 d	-12.85 ab

† Within each treatment comparison (defoliation timing, harvest-aid, or defoliation timings × harvest-aids interaction), the means followed by the same letters are not significantly different at *p* = 0.05.

Table 6. Main effects and interactions of defoliation timing and harvest-aid treatment on cotton lint price differences using 2000/2001 marketing year average North Delta spot cotton market quotations applied to the 1998-2000 fiber-quality data.

Defoliation timing	Harvest-aid	Price differences from the base price of 115 ¢ kg^{-1} Color, staple, and leaf	Micronaire	Fiber strength	Length uniformity	Total price difference
Treatment number		¢ kg^{-1}				
1		-5.82 b	-2.73 ab	1.13 ab	0.28 ab	-7.14 a
2		-2.50 a	-4.40 b	1.53 a	0.41 a	-4.95 a
3		-3.03 a	-3.10 ab	0.68 b	0.16 b	-5.30 a
4		-2.91 a	-2.56 a	0.63 b	0.35 ab	-4.57 a
	1	-2.67 a	-3.45 a	1.14 a	0.38 a	-4.59 a
	2	-4.46 b	-2.95 a	0.84 a	0.22 b	-6.39 a
1	1	-4.71 bc	-2.74 ab	1.36 abc	0.39 a	-5.70 ab
1	2	-6.93 c	-2.73 ab	0.91 abcd	0.17 ab	-8.58 b
2	1	-2.60 ab	-5.02 b	1.59 a	0.39 a	-5.64 ab
2	2	-2.40 ab	-3.78 ab	1.47 ab	0.44 a	-4.27 ab
3	1	-1.61 a	-3.33 ab	0.88 bcd	0.31 a	-3.74 a
3	2	-4.45 bc	-2.88 ab	0.48 d	0.00 b	-6.85 ab
4	1	-1.76 ab	-2.70 ab	0.75 cd	0.42 a	-3.29 a
4	2	-4.07 abc	-2.43 a	0.52 d	0.28 ab	-5.85 ab

† Within each treatment comparison (defoliation timing, harvest-aid, or defoliation timings × harvest-aids interaction), the means followed by the same letters are not significantly different at *p* = 0.05.

Even though mean micronaire values were in the base or premium range of the price schedule, price differences for micronaire were negative “on average” for all defoliation timing and harvest-aid choices. A sufficient number of micronaire observations were in the high micronaire discount range (50 and above) in 1999 and the low micronaire discount range (33 and below) in 2000 to cause the price differences to be negative on average. Deductions for micronaire differed by 2 ¢ kg^{-1} or less among the four defoliation scheduling choices. Terminating cotton at 528 degree-d produced the smallest discounts for both price scenarios. However, the smaller micronaire discounts for cotton defoliated at 528 degree-d were not significantly different from the deductions for cotton defoliated at 361 and 472 degree-d. For the high price scenario (Table 5), the micronaire discount of -2.73 ¢ kg^{-1} for cotton defoliated at 528 degree-d was smaller than the -4.19 ¢ kg^{-1} deduction for cotton terminated at 417 degree-d. Under the low price scenario (Table 5), the micronaire discount of -2.56 ¢ kg^{-1} for cotton defoliated at 528 degree-d was smaller than the -4.40 ¢ kg^{-1} deduction for cotton defoliated at 417 degree-d. Findings indicate that the price discounts for micronaire displayed no particular pattern with respect to defoliation schedule and harvest-aid treatment.

Premiums for fiber strength are small under the high price scenario (Table 5), averaging less than 0.30 ¢ kg^{-1} among the defoliation timing and harvest-aid treatments. Strength premiums are larger for the low price scenario, ranging from 0.48 to 1.5 ¢ kg^{-1}. The largest strength premiums were for cotton defoliated at 417 degree-d and the smallest strength premiums were for cotton defoliated at 472 degree-d; the largest and smallest premiums were statistically different from each other under both price scenarios. Choice of harvest-aid did not have a significant impact on strength premiums. There were no significant strength premium interactions among defoliation timing and harvest-aid strategies.

Premiums for length uniformity calculated using 2000/2001 spot prices in Table 6 were small, averaging less than 0.5 ¢ kg^{-1} among the defoliation timing and harvest-aid alternatives. The largest uniformity premium was for cotton defoliated at 417 degree-d and the smallest uniformity premium was for cotton terminated at 472 degree-d after cutout. The premiums for cotton defoliated at 417 degree-d and 472 degree-d differed from each other but not from the premiums for cotton terminated at 361 and 528 degree-d. Findings indicate price differences for uniformity followed no particular pattern with respect to scheduling of crop termination.

Choice of harvest-aid did have a small but significant influence on the premium for length uniformity. The thidiazuron-tribufos-ethephon mixture produced a larger uniformity premium than did the cyclanilide and ethephon treatment. In addition, the uniformity premium for the thidiazuron-tribufos-ethephon mixture for cotton defoliated at 472 degree-d was higher than the premium for cyclanilide and ethephon. No other length uniformity defoliation timing and harvest-aid interaction were significant.

Estimated total price differences as influenced by crop-termination timing and harvest-aid treatment are presented in the last column of Tables 5 and 6. Under the high price scenario (Table 5), cotton defoliated at 472 and 528 degree-d after cutout produced significantly smaller discounts than cotton terminated at 361 degree-d. The lowest price discount of -9.59 ¢ kg^{-1} for cotton terminated at 472 degree-d was 6.11 ¢ kg^{-1} smaller than the deduction for cotton defoliated at 361 degree-d. Total discounts were smaller under the low price scenario (Table 6), differing by 2.57 ¢ kg^{-1} or less among the four defoliation dates. Consequently, the defoliation schedule did not have a significant impact on the total price discount for the low price comparison. Findings indicate that price discounts for fiber quality in a tight supply-and-demand situation may be smaller at the later 472 and 528 degree-d defoliation dates than for prematurely defoliated cotton. On the other hand, price discounts for fiber quality were not influenced by defoliation timing in the low price scenario. Total price differences due to fiber quality were not affected by harvest-aid material under either price scenario.

Net Revenues

Crop-termination timing and harvest-aid treatment effects on cotton net revenues are presented in Table 7 for one or two harvests. Premature crop defoliation had a significant and detrimental impact on cotton net revenues. Averaged across harvest-aid materials, net revenues for cotton terminated at 361 degree-d averaged 37% less ($617 ha^{-1}) under the high price scenario (1994/1995 spot prices) than the revenues for cotton defoliated at 528 degree-d. In percentage terms, revenue lost from premature defoliation was even greater under the low price scenario (2000/2001 spot prices), averaging 41% less ($369 ha^{-1}) than for cotton defoliated at 528 degree-d. These findings indicate that early defoliation at 361 degree-d results in considerable

Table 7. Main effects and interactions of defoliation timing, harvest-aid treatment, and number of harvest operations on cotton net revenues.

Defoliation timing	Harvest-aid	Number of harvests	Net revenues: 1994/1995 marketing year average spot prices: base = 194 ¢ kg^{-1}	Net revenues: 2000/2001 marketing year average spot prices: base = 115 ¢ kg^{-1}
Treatment number			----------$ ha^{-1} ----------	
1			1014 d†	511 c
2			1413 c	753 b
3			1515 b	793 b
4			1631 a	880 a
	1		1378 a	725 a
	2		1409 a	744 a
		1	1273 b	670 b
		2	1514 a	798 a
1	1	1	812 i	395 h
1	1	2	1188 h	606 g
1	2	1	859 i	427 h
1	2	2	1198 h	616 g
2	1	1	1245 gh	657 fg
2	1	2	1494 cde	790 bcd
2	2	1	1325 fg	712 ef
2	2	2	1587 c	854 ab
3	1	1	1404 ef	743 de
3	1	2	1598 bc	843 b
3	2	1	1454 de	756 cde
3	2	2	1606 bc	829 b
4	1	1	1552 cd	837 b
4	1	2	1727 a	926 a
4	2	1	1533 cd	832 bc
4	2	2	1711 ab	923 a

† Within each treatment comparison (defoliation timing, harvest-aid, or defoliation timings × harvest-aids × number of harvests interaction), the means followed by the same letters are not significantly different at *p* = 0.05.

foregone income when compared with defoliation and harvest at a later date, with either low or high cotton prices.

The largest net revenues were obtained for cotton defoliated at 528 degree-d under both price scenarios. The bulk of the revenue gain from delaying defoliation and harvest came from additional yield formulation. Less important was the positive impact on lint prices from improved fiber quality by delaying defoliation. These findings suggest that delaying defoliation beyond the recommended 472 degree-d date can increase net revenues in some years for cotton growers in short-season environment such as Tennessee. Defoliating at 528 degree-d is roughly consistent with the classical defoliation criterion of applying harvest-aids at 60% open boll (Snipes and Baskin, 1994). In this research, the number of open bolls averaged 59% for cotton terminated at 528 degree-d.

Choice of harvest-aid had a minimal impact on net revenues in this study. Cotton treated with cyclanilide and ethephon produced similar lint yields, price discounts, and net revenues relative to thidiazuron-tribufos-ethephon.

A farmer who is interested in maximizing net revenues may wish to forego a second harvest when harvest costs exceed the gross receipts of that harvest. However, the results of this study indicate that harvesting twice produced net revenues significantly larger than the net revenues from a single harvest (Table 7). Averaged over harvest-aid and defoliation timing treatments, the increase in net revenues with a twice-over harvest ranged from $241 ha^{-1} (19%) more for the high price scenario to $128 ha^{-1} (19%) more for the low price comparison.

Even though second-harvest net revenues were positive for all four defoliation dates, various tradeoffs may influence a farmer's decision of when to harvest and how many times to harvest. Because of competition for scarce resources at harvest time, farmers may be interested in options that minimize foregone income from cotton production. Factors that might influence the harvest decision include available field days and competition for labor and other resources with additional fall harvest and planting operations (e.g., harvesting corn [*Zea mays* L.] or soybean [*Glycine max* (L.) Merr.] or planting winter wheat [*Triticum aestivum* L.]). Given that choice of harvest-aid was not significant in the crop-termination decision, net revenues averaged across harvest-aid materials for alternative defoliation and harvest strategies are presented in Figs. 1 and 2 to facilitate evaluation of potential tradeoffs. The letters below the numbers in the figures indicate results of protected pairwise contrasts of defoliation timing and harvest strategies at *p* = 0.05. Several important findings can be obtained from the two figures.

First, revenues from cotton prematurely defoliated and harvested twice are significantly smaller than revenues gained from terminating cotton later and harvesting only once. Forgone revenues for defoliating at 361 degree-d and harvesting twice are quite large, averaging 23% less ($350 ha^{-1}) under the

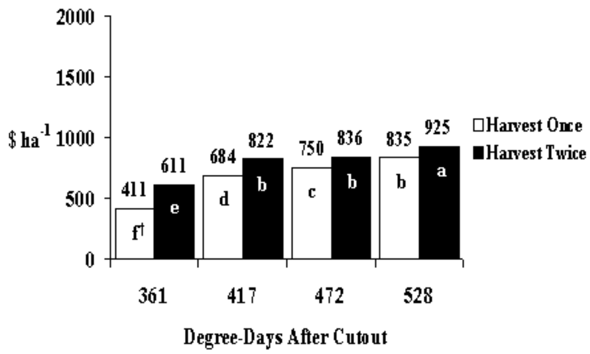

Fig. 1. Defoliation timing effects on net revenues for cotton harvested once or twice, calculated using 2000/2001 marketing year average North Delta spot cotton market quotations. † , Net revenue means with the same letters are not significantly different at *p* = 0.05.

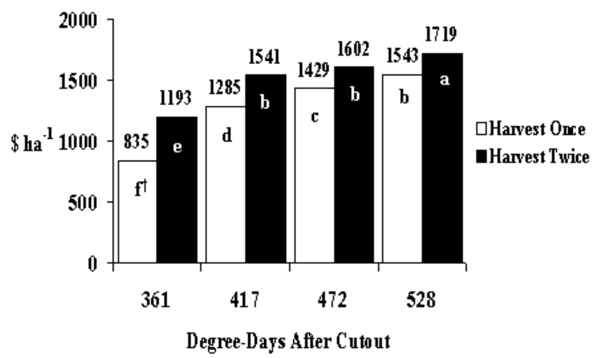

Fig. 2. Defoliation timing effects on net revenues for cotton harvested once or twice, calculated using 1994/1995 marketing year average North Delta spot cotton market quotations. † , Net revenue means with the same letters are not significantly different at *p* = 0.05.

high price scenario and 29% less ($224 ha^{-1}) under the low price scenario than revenues for cotton terminated at 528 degree-d and harvested once.

Second, defoliating cotton at 528 degree-d and harvesting once produced net revenues similar to cotton terminated at 417 or 472 degree-d and harvested twice. Under the low price scenario, net revenues for cotton defoliated at 528 degree-d and harvested once averaged $835 ha^{-1} compared with twice-over harvest net revenues of $822 and $836 ha^{-1} for cotton terminated at 417 and 472 degree-d, respectively. The difference in revenues for cotton defoliated at 528 degree-d and harvested once compared with a twice-over harvest after defoliating at 417 or 472 degree-d are numerically greater under the high price scenario but those differences are still not statistically significant.

Finally, besides having the largest first-harvest net revenues, defoliating cotton at 528 degree-d minimizes revenue foregone if a farmer is unable to conduct a second harvest. Under the low price scenario, revenue foregone from not harvesting twice is $90 ha^{-1} for cotton defoliated at 528 degree-d compared with $200 ha^{-1} for cotton terminated at 361 degree-d.

For the high price scenario, revenue lost from not harvesting twice is $176 ha^{-1} for cotton terminated at 528 degree-d compared with $350 ha^{-1} for cotton defoliated at 361 degree-d.

CONCLUSIONS

Information about net-revenue tradeoffs for different defoliation timing schemes is useful for cotton farmers in scheduling defoliation and harvest activities and allocating scarce resources. The 3 yr of this study consistently showed the harmful effects of premature crop termination and the beneficial effects of delaying cotton defoliation beyond the nominal threshold of 472 degree-d after cutout. Findings indicated that incomplete defoliation of cotton at the early 361 degree-d crop-termination date caused higher leaf grades than for cotton terminated at a later date. In addition, both first-harvest and total-harvest lint yields at the early 361 degree-d defoliation date were lower than yields at the later defoliation dates. Choice of harvest-aid did not alter timing effects significantly, although some small response differences between materials were observed. Yield findings support the hypothesis that additional yield is gained as crop termination is delayed. Improved fiber quality and enhanced yields from cotton harvested after defoliation at 528 degree-d after cutout provide the largest cotton net revenues, regardless of whether cotton prices are relatively high or low. Findings also indicate that scheduling defoliation at 528 degree-d can facilitate a once-over harvest strategy because it produces net revenues similar to cotton terminated at 417 or 472 degree-d and harvested twice. In addition, defoliating cotton at 528 degree-d minimizes potential net revenue forgone if a second-harvest operation cannot be conducted.

The potential advantages of harvest after defoliation at 528 degree-d needs to be weighed against the potential risks of later harvest, especially along the northern edge of the U.S. Cotton Belt. Inclement weather becomes more probable as harvest is delayed, possibly leading to losses of fiber quality and harvest efficiency. In general, these results validate the nominal threshold of 472 degree-d to predict crop maturity using crop-oriented COTMAN rules. The procedure is less suited for determining the precise timing for harvest-aids than classical defoliation timing tools. Additional study is needed to compare these results with other cotton-growing regions, and to evaluate the economic tradeoffs involved in the scheduling of cotton defoliation, harvest techniques, and competition for labor and other resources with additional fall harvest and planting operations.

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