

Losses in Yield, Quality, and Profitability of Cotton from Improper Harvest Timing

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ABSTRACT

Excessive weathering may diminish cotton (*Gossypium hirsutum* L.) lint yield and fiber quality to the extent that economic losses occur for the producer. Our objective was to determine the effects of systematic delayed harvest on cotton lint yield, fiber quality, and profitability. Experiments were conducted from 1998 to 2000 at the Coastal Plain Experiment Station, Tifton, GA, on a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiodults). The treatments consisted of a standard harvest-aid combination applied at weekly intervals over a 13-wk period beginning at first open boll. Harvest aids were applied to each plot according to its week after first open boll designation and machine harvested 2 wk thereafter. After ginning, fiber quality was determined on lint samples from each plot. High volume instrument (HVI) fiber length uniformity was greatest in 1999 and 2000 when harvest aids were applied between 58 and 88% open boll, while the advanced fiber information system (AFIS) fiber length by number coefficient of variation and short fiber content by number were lowest when harvest aids were applied from 40.1 to 46.8% open boll. The HVI upper half mean fiber length and the AFIS mean fiber length by number were greatest when harvest aids were applied between 39.1 and 56.7% open boll. In 1999 and 2000 lint yield and adjusted gross income were greatest when harvest aids were applied from 76.5 to 89.0% open boll. Results from this study indicate optimum fiber quality is established earlier during boll opening than lint yield and profitability.

RECENT ADVANCES in yarn spinning and fabric manufacturing technologies have improved the efficiency and competitiveness of the U.S. textile industry (Deussen, 1992). To operate at peak efficiency, however, these newer technologies must process cotton (*Gossypium hirsutum* L.) fibers of exceptionally high quality (Faerber, 1995). To reflect this demand, the U.S. Department of Agriculture (USDA)–Commodity Credit Corporation (CCC) modified the Schedule of Premiums and Discounts for Upland and Extra Long Staple Cotton. The most notable modifications to the schedule were the inclusion of fiber length uniformity (a measure of the degree of length uniformity of the fibers in a sample) and an increase in the fiber strength base (level of fiber strength at which no price premium or discount is received). Beginning with the 2000 crop, price premiums or discounts were applied to cotton fibers that exceed or fail to meet these newly established standards for fiber length uniformity and fiber strength. Some textile manufacturers, however, have already adopted their own standards for fiber length uniformity and have even begun to discriminate against cottons produced in certain regions of the U.S. Cotton Belt, simply because his-

torical records from these regions indicate they generally do not meet the in-house standards. Thus, if cotton produced in the USA is to remain competitive on a global market, fiber quality must meet these new standards.

Cotton fiber quality is determined primarily by genetics, but can also be influenced by environmental factors (Meredith, 1984) such as soil type, insect pressure, weather, growing season length, and harvest and ginning management. While many of the cotton cultivars grown in the USA are genetically similar, the environmental conditions in which they are grown and their impact on crop management are very diverse. For instance, due to poorly drained soils, late season insect pest pressure and inclement weather patterns during the fall months, producers in the Mid-South region of the U.S. Cotton Belt manage their crops such that harvest is completed by late October (Parvin, 1990). In other regions, more favorable fall weather conditions and well-drained soils allow crop maturity and harvest to be delayed if necessary. The Mid-South region, however, historically produces some of the highest quality cotton across the U.S. Cotton Belt. While there may exist several environmentally related explanations for these differences, it may also result from management for early crop maturity and a timely harvest. Thus, the lack of emphasis on a timely harvest in other regions could be a source of significant yield and quality losses.

Many studies have investigated the impact of early and late harvests on cotton lint yield and fiber quality (Barker et al., 1976; Brown and Hyer, 1956; Columbus et al., 1990; Ray and Minton, 1973; Snipes and Baskin, 1994; Williford, 1992; Williford et al., 1995, 1987). Few studies, however, have investigated the effects of systematic delayed harvest on yield and quality (Ray and Minton, 1973; Williford et al., 1995). Also, since fiber length uniformity has not been a determinant of price received by the grower before 2000, current information regarding the relationship between harvest timing and fiber length uniformity is insufficient. Therefore, the objectives of this study were to investigate the effects of systematic delayed harvest on cotton (i) fiber length uniformity and other fiber properties, (ii) lint yield, and (iii) profitability.

MATERIALS AND METHODS

Plot Establishment and Maintenance

Experiments were conducted in 1998, 1999, and 2000 at the Coastal Plain Experiment Station in Tifton, GA, on a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiodults).

Abbreviations: AFIS, advanced fiber information system; AGI, adjusted gross income; CV, coefficient of variation; DAP, days after planting; HVI, high volume instrument; NACB, nodes from the uppermost first sympodial position cracked boll to the uppermost harvestable boll; UHM, upper half mean fiber length.

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dults). In March of each year, 672 kg ha⁻¹ of 3-4-15 (N-P-K) plus micronutrients (8% Ca, 2% Mg, 9% S, 0.13% B, 0.10% Fe, 1% Mn, and 0.35% Zn) was broadcast and harrow incorporated. Trifluralin (α,α,α -trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine; 1.12 kg a.i. ha⁻¹) was then broadcast and harrow incorporated immediately before ripping and bedding. While ripping and bedding, 32 kg a.i. ha⁻¹ of 1,3-dichloropropene was injected under the row for nematode control. All other fertility, weed, and insect-pest control practices were in accordance with the University of Georgia Cooperative Extension Service Guidelines (Brown et al., 1998).

Cotton was planted on 27 Apr. 1998 (cv. SureGrow 501), 10 May 1999 (cv. DeltaPine NuCOTN 33B), and 1 May 2000 (cv. DeltaPine NuCOTN 33B) at a rate of 11 seeds m⁻². The original study area in 1999 was planted to SureGrow 501. As the crop matured, however, severe lodging was observed with this cultivar, which would have hampered harvest-aid application. Thus, the entire study was moved to another test site on the same farm that was planted to DeltaPine NuCOTN 33B. Other than cultivar selection, crop management between the two test sites was identical. At 90 days after planting (DAP) each year, plots were established within the test area by mowing a 7.6-m alley between each block with a tractor mounted, 2.1 m wide Bush Hog (Bush Hog, Inc., Selma, AL) mower. Alleys were not established until this time to avoid the inaccurate measures of plot yield and fiber quality due to the end-of-row effect (Holman and Bednarz, 2001). Each plot was 4 rows (0.9-m centers) wide and 15 m long. Water stress was minimized in all studies with overhead sprinkler irrigation systems. The experimental design was a randomized block design with four replications.

Treatment Establishment and Data Collection

Treatments were begun each year when the first open boll was observed in the test area. Thirteen treatments were randomly assigned to each block in the study. Harvest-aids were applied to each plot according to the week after first open boll designation assigned to it. For example, harvest aids applied to treatments during the fourth week after first open boll were considered Week 4 treatments. Harvest-aids were applied with a John Deere (Moline, IL) model 600 high clearance sprayer equipped with compressed air, TX-8 spray nozzles on 46-cm centers and a 3.6-m boom. The carrier volume for each application was 94 L ha⁻¹. The harvest aids applied were a combination of tribufos (*S,S,S*-tributyl phosphorotrithioate; 0.321 kg a.i. ha⁻¹) plus thidiazuron (*N*-phenyl-*N'*-1,2,3-thiadiazol-5-yl-urea; 0.093 kg a.i. ha⁻¹) plus ethephon ((2-chloroethyl)phos-

phonic acid; 1.103 kg a.i. ha⁻¹). Immediately before each harvest aid application, the numbers of opened and unopened bolls were recorded along a 1-m section of row from one of the two center rows in each plot. Also, immediately before harvest aid application, the number of main stem nodes from the uppermost first sympodial position cracked boll to the uppermost main stem node with a harvestable boll (NACB) were recorded on 10 plants that were randomly selected from the center two rows in each plot. Approximately 2 wk after each harvest aid application, the center two rows of each plot were harvested with a spindle picker (International Harvester model 622; Case Corp., Racine, WI) equipped with a bagging attachment for small plot research. Mechanical difficulties with the plot picker at Week 12 in 1999 resulted in unreliable plot yield data. Therefore, lint yields and economic data are not reported for this week. All defoliation dates, harvest dates, and the mean percent open boll recorded for each week of the study are presented in Table 1.

As each plot was harvested, seed cotton from the entire plot was placed in an open mesh polypropylene bag and hung from the ceiling of an equipment storage facility at the Coastal Plain Experiment Station. After the final plots were harvested, the bags were removed from the storage facility and ginned. In 1998, the seed cotton from each plot was ginned on a 10-saw laboratory gin (Continental Eagle Corp., Prattville, AL) located on the Tifton campus. In 1999 and 2000 the seed cotton was shipped to the USDA-ARS-Cotton Ginning Research Unit in Stoneville, MS, for ginning. The ginning sequence at the Stoneville lab was: cylinder cleaner, drier (52°C), stick machine, cylinder cleaner, extractor feeder, gin stand, and two stages of saw-type lint cleaning. This ginning sequence is consistent with commercial ginning operations for spindle-harvested cotton.

While ginning in 1998, one lint sample per plot was collected and delivered to the USDA-Agricultural Marketing Services (AMS)-Cotton Division, Cotton Classing Office in Macon, GA, for fiber quality analysis. Fiber quality at this office was determined using a Zellweger Uster (Charlotte, NC) model 900-A High Volume Instrument (HVI). In 1999 and 2000, a total of six lint samples were collected per plot. Three lint samples from each plot were again delivered to the Cotton Classing Office in Macon, GA, for fiber quality determination using the HVI line. The other three lint samples were delivered to Cotton Incorporated (Cary, NC) for additional fiber quality analyses using a Zellweger Uster (Charlotte, NC) Advanced Fiber Information System (AFIS) instrument. For each fiber sample, the AFIS instrument analyzed five subsamples of 3000 fibers each.

Table 1. Percent open boll immediately before harvest aid application, defoliation date (Def. date), and harvest date (Hv. date) in number of days after planting (DAP) during each week after first open boll of the harvest timing studies conducted at the University of Georgia Coastal Plain Experiment Station in 1998, 1999, and 2000.

Week	1998			1999			2000		
	Open boll	Def. date	Hv. date	Open boll	Def. date	Hv. date	Open boll	Def. date	Hv. date
	%	DAP		%	DAP		%	DAP	
0	6	106	120	17	108	122	9	113	133
1	42	113	127	31	114	130	30	121	142
2	69	120	134	55	121	135	57	133	147
3	73	127	141	60	130	143	58	137	150
4	92	134	148	64	135	149	76	142	155
5	100	141	155	79	143	157	80	149	163
6	100	148	162	83	149	162	88	155	170
7	100	155	169	97	157	170	94	163	177
8	100	162	176	100	162	178	99	170	185
9	100	169	183	100	170	185	100	177	191
10	100	176	190	100	178	191	100	184	199
11	100	183	197	100	185	198	100	191	204
12	100	190	204	100	191	207	100	198	211

Economic Analysis

Net return was calculated each year for the 13 treatments (weeks after first open boll). Because all production practices, inputs, and costs were the same for each treatment, costs were not considered and it is only necessary to compare income per hectare. The measure of comparison used in this study is the adjusted gross income (AGI), which considers differences in yield and quality. The adjusted gross income was calculated as follows:

$$AGI = Y \times (P + TPD - NGC)$$

where

AGI = adjusted gross income ha⁻¹

Y = the average yield ha⁻¹ for the treatment

P = the average of the 1 November and 1 February Southeast spot market price kg⁻¹ for Strict Low Middling cotton (USDA–AMS–Cotton Program, 1998, 1999, 2000)

TPD = the average total premiums and discounts or spot market differences kg⁻¹ for each treatment for color grade, leaf grade, fiber length, fiber micronaire, fiber strength, and fiber length uniformity on 1 November and 1 February (USDA–AMS–Cotton Program, 1998, 1999, 2000)

NGC = net ginning and warehouse charges kg⁻¹ after cottonseed value

The average 1 November and 1 February cash or spot price was 136¢ kg⁻¹ in 1998, 117¢ kg⁻¹ in 1999, and 129¢ kg⁻¹ in 2000. Net ginning and warehousing charges were 13.2¢ kg⁻¹ in 1998 and 1999 and 11¢ kg⁻¹ in 2000.

High volume instrument leaf grades were not considered reliable in 1998 as the seed cotton was not ginned with lint cleaning. Therefore, leaf grades in 1998 were assumed to be the same as the color grade (i.e., 41 color grade = 4 leaf grade; 51 color grade = 5 leaf grade, etc). Leaf grades in 1999 and 2000 ranged from 3.0 to 3.4 and 2.0 to 2.2, respectively. Uniformity was not considered an official USDA–AMS quality factor for price premiums or discounts before 2000.

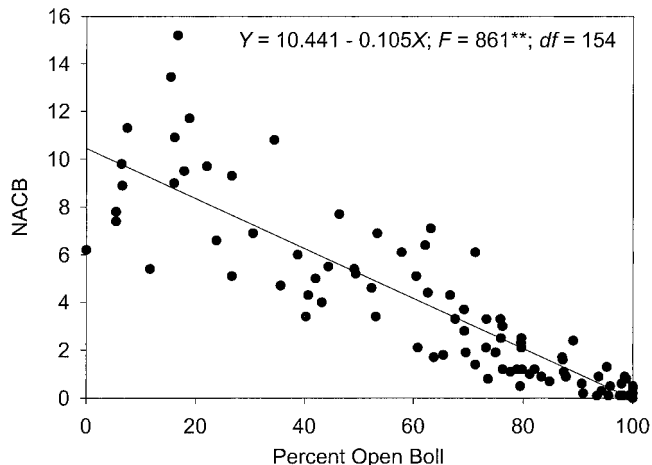


Fig. 1. Nodes from the uppermost first sympodial position cracked boll to the uppermost harvestable boll (NACB) vs. percent open boll in harvest timing studies conducted at the University of Georgia Coastal Plain Experiment Station in 1998, 1999, and 2000. **Denotes significance at the P = 0.01 level.

Statistical Analyses

The data for fiber quality in 1999 and 2000 were analyzed using PROC MIXED (SAS Inst., 2000) as a split-plot in space (stripped split-plot; Steel and Torrie, 1960, p. 242–250) where treatment (weeks after first open boll) was the main plot and lint sample was the subplot. While ginning in 1999 and 2000, the first lint sample was taken from the beginning of the gin run, the second sample from the middle of the same run, and the third sample from near the end of the same run. Thus, these three samples are considered stripped across the main plots (samples were ordered).

The data for fiber quality in 1998 and lint yield in 1998, 1999, and 2000 were analyzed as a randomized complete block design using PROC MIXED. The data were not combined across years because (i) cultivar and ginning technique differed between the first and last 2 yr of the study and (ii) the amount and distribution of rainfall during the harvest period differed in all years of the study.

The data for Fig. 1 were, however, combined across years

Table 2. High volume instrument (HVI) fiber length uniformity, advanced fiber information system (AFIS) fiber length by number coefficient of variation [L(n)CV], and HVI fiber strength during each week after first open boll of the harvest timing studies conducted at the University of Georgia Coastal Plain Experiment Station in 1998, 1999, and 2000.†

Week	HVI—length uniformity		AFIS—L(n)CV		HVI—strength		
	1999	2000	1999	2000	1998	1999	2000
	%				kN m kg ⁻¹		
0	81.58	80.75	59.83	46.13	345.9	270.8	260.5
1	81.58	81.14	60.05	45.09	333.4	274.6	260.0
2	81.92	81.33	59.62	45.30	322.2	274.4	252.2
3	81.92	81.90	60.08	45.03	324.1	269.4	250.9
4	82.17	81.54	60.09	45.67	318.2	268.8	250.7
5	82.33	81.68	60.38	45.83	314.3	266.9	245.7
6	81.67	81.64	61.17	46.58	314.3	265.9	245.3
7	80.92	80.79	61.23	46.31	302.1	254.1	241.9
8	81.75	80.73	63.05	46.50	315.0	265.5	246.6
9	81.58	80.97	62.45	47.01	304.3	254.7	241.0
10	81.75	81.39	63.30	47.28	305.7	259.6	240.7
11	81.58	81.16	62.47	46.82	296.7	252.3	240.3
12	81.33	80.91	63.43	47.36	307.9	255.8	238.5
F	3.21**	5.58**	4.17**	6.19**	14.24**	7.59**	13.91**
LSD (0.05)	0.571	0.472	2.011	0.919	10.28	8.17	5.58

* Significant at the 0.05 level.

** Significant at the 0.01 level.

† Least square means are presented. df = 36.

and were analyzed as a randomized complete block design using PROC MIXED. A regression analysis was done to examine the impact of cultivar and year. The *F* test did not change whether cultivar or year were or were not included in the model. Therefore, we concluded that the slope presented is representative of all cultivars and years and no loss of information occurred through combining the data.

Two regression models were used each for lint yield, fiber quality, and adjusted gross income. The first regression model (PROC MIXED) was fitted against percent open boll. One hundred percent open boll occurred at 5, 8, and 9 wk after first open boll in 1998, 1999, and 2000, respectively. A second regression model (PROC MIXED) was fitted against weeks after 100% open boll with the remainder of the lint yield, fiber quality, and adjusted gross income data.

RESULTS AND DISCUSSION

Figure 1 illustrates the relationship between percent open boll and NACB. In a regional study, Kerby et al. (1992) studied the relationship between NACB and lint yield and fiber quality. Their results indicated the optimum timing for harvest aid application was NACB = 4. Snipes and Baskin (1994) also reported there was no evidence to indicate harvest aid applications made at 60% open boll or greater resulted in yield loss or lower quality fiber. Our data (Fig. 1) indicate NACB = 4 and 60% open boll occur simultaneously.

In 1998, HVI fiber length uniformity, the ratio between the mean fiber length and the average length of the longest one-half of the fibers in a sample, ranged from 83.85 to 85.10% and did not differ (data not presented). In 1999 and 2000, however, differences were observed (Table 2). In 1999, length uniformity was greatest when harvest aids were applied at 64 and 79% open boll (Weeks 4 and 5), while in 2000 length uniformity was greatest when harvest aids were applied from 58 to 88% open boll (Weeks 3–6). Regression analyses indicated HVI fiber length uniformity and percent open bolls when harvest aids were applied were not related in 1998 and 1999 (Table 3). In 2000, however, HVI fiber length uniformity was greatest when harvest aids were applied at 61.2% open boll (Table 3). In addition, once the crop reached 100% open boll, HVI fiber length uniformity decreased 0.387 and 0.427% wk⁻¹ in 1999 and 2000, respectively (Table 4).

The fiber length uniformity base, or range at which no price premium or discount is offered, is from 80 to 82%. While the USDA-AMS schedule (1999) did not include price premiums or discounts for fiber length uniformity in 1999, application of harvest aids from 64 to 79% open boll with a timely harvest did result in >82% uniformity.

The fiber lengths in a sample are highly variable and can range from <0.5 to >5 cm. High volume instrument fiber length uniformity and the AFIS average fiber length by number coefficient of variation [*L(n)CV*] are both indicators of this variability. As indicated earlier, the AFIS instrument analyzed five subsamples of 3000 fibers each and computed a coefficient of variation (CV) for each sample. These CVs were statistically analyzed and the results are presented in Table 2. The AFIS

Table 3. Regression coefficients for the relationship between high volume instrument (HVI) fiber length uniformity, advanced fiber information system (AFIS) length by number coefficient of variation [*L(n)CV*], HVI fiber strength, HVI upper half mean fiber length (UHM), AFIS mean fiber length by number [*L(n)*], AFIS short fiber content by number [*SFC(n)*], HVI fiber micronaire, AFIS fiber fineness, AFIS fiber maturity ratio, lint yield and adjusted gross income (AGI) vs. percent open boll at the time of harvest aid application in harvest timing studies conducted at the University of Georgia Coastal Plain Experiment Station in 1998, 1999, and 2000.†

Variable	Equation	1998	1999	2000
HVI—length uniformity, %	Intercept	84.3**	82.0**	80.4**
	Linear	4.66e ⁻³	3.80e ⁻³	3.61e ^{-2*}
	Quadratic	n.s.	n.s.	-2.95e ^{-4*}
	Max/min	—	—	61.2%
AFIS— <i>L(n)CV</i> , %	Intercept	—	60.7**	46.4**
	Linear	—	-5.42e ⁻²	-4.95e ^{-2**}
	Quadratic	—	6.75e ^{-4‡}	5.29e ^{-4*}
	Max/min	—	40.1%	46.8%
HVI—strength, kN m kg ⁻¹	Intercept	347**	278**	263**
	Linear	-0.32**	-0.15**	-0.20**
	Quadratic	n.s.	n.s.	n.s.
	Max/min	—	—	—
HVI—UHM, cm	Intercept	2.92**	2.68**	2.69**
	Linear	2.56e ⁻³	2.65e ^{-3*}	7.72e ⁻⁴
	Quadratic	-2.67e ^{-5‡}	-2.34e ^{-5*}	-9.88e ^{-6*}
	Max/min	47.9%	56.7%	39.1%
AFIS— <i>L(n)</i> , cm	Intercept	—	1.77**	1.92**
	Linear	—	2.66e ^{-3*}	1.42e ^{-3*}
	Quadratic	—	-2.77e ^{-5**}	-1.67e ^{-5*}
	Max/min	—	48.1%	42.4%
AFIS— <i>SFC(n)</i> , %	Intercept	—	33.7**	25.65**
	Linear	—	-7.44e ⁻²	-6.65e ^{-2**}
	Quadratic	—	8.24e ^{-4*}	7.28e ^{-4**}
	Max/min	—	45.1%	45.7%
HVI—micronaire	Intercept	4.24**	3.87**	3.44**
	Linear	4.85e ^{-3**}	8.61e ^{-3**}	1.69e ^{-2*}
	Quadratic	n.s.	n.s.	-8.50e ^{-5‡}
	Max/min	—	—	99.3%
AFIS—fineness, mg kg ⁻¹	Intercept	—	172**	160**
	Linear	—	0.11*	9.59e ^{-2**}
	Quadratic	—	n.s.	n.s.
	Max/min	—	—	—
AFIS—maturity ratio	Intercept	—	0.89**	0.82**
	Linear	—	7.94e ^{-4**}	3.70e ^{-4**}
	Quadratic	—	n.s.	n.s.
	Max/min	—	—	—
Lint yield, kg ha ⁻¹	Intercept	1310**	535*	613*
	Linear	2.62**	25.3**	14.52**
	Quadratic	n.s.	-0.17**	-8.16e ^{-2*}
	Max/min	—	76.5%	89.0%
AGI, \$ ha ⁻¹	Intercept	1586.34**	387.79**	638.15**
	Linear	7.02	30.60**	18.86*
	Quadratic	-5.80e ⁻²	-0.197*	-0.111*
	Max/min	60.6%	77.8%	84.7%

* Significant at the 0.05 level.

** Significant at the 0.01 level.

† *n* = 24, 35, and 39 in 1998, 1999, and 2000, respectively. n.s. denotes no significance.

‡ Significant at the 0.10 level.

L(n)CV was greatest in 1999 and 2000 when harvest aid applications were delayed until >90% open boll. Regression analyses indicated the AFIS *L(n)CV* was lowest when harvest aids were applied at 40.1 and 46.8% open boll in 1999 and 2000, respectively (Table 3).

Fiber elongation occurs for the first 16 to 19 d postanthesis (Berlin, 1986). As an indeterminate crop, cotton will produce fruit that vary in age by several weeks. Thus, application of harvest aids too early (i.e., before ≈60% open boll) probably resulted in reduced fiber

Table 4. Regression coefficients for the relationship between high volume instrument (HVI) fiber length uniformity, lint yield, and adjusted gross income (AGI) vs. weeks after 100% open boll in harvest timing studies conducted at the University of Georgia Coastal Plain Experiment Station in 1998, 1999, and 2000.†

Variable	Equation	1998	1999	2000
HVI—length unif., %	Intercept	83.7**	81.3**	80.9**
	Linear	-8.30e ⁻²	-0.387‡	-0.427‡
Lint yield, kg ha ⁻¹	Intercept	1409**	1513**	1076**
	Linear	-20.3*	-15.5	-64.0**
AGI, \$ ha ⁻¹	Intercept	1501.99**	1562.30**	1140.62**
	Linear	-35.82*	-16.65	-69.94*

* Significant at the 0.05 level.

** Significant at the 0.01 level.

† $n = 22, 13,$ and 10 in 1998, 1999, and 2000, respectively. $X = x - 13$.

‡ Significance at the 0.10 level.

length uniformity because the process of fiber elongation was not fully complete in many fruit at this time.

Fiber length uniformity also began to decrease when harvest aids were applied after 90% open boll in 1999 and 2000. In both years, fiber length uniformity was lowest when harvest aid applications were delayed until >90% open boll. While the physiological stages of boll maturity may aid in the understanding of decreased fiber length uniformity before 60% open boll, they do not provide an explanation for decreased uniformity when harvest aid applications were delayed until >90% open boll. Examination of the fiber strength data, however, may provide some insight.

Fiber strength differed with timing of harvest aid application in all years (Table 2). In all years fiber strength was greatest during the initial harvest aid application timings and decreased thereafter (Table 3). Regression analysis revealed a relationship between fiber strength and fiber length uniformity after ginning in 1999 and 2000. The slopes of the relationships were found to be different between years and the data were not combined. Fiber strength and fiber length uniformity after ginning were positively related in 1999 [slope = 0.037, $F(1,154) = 35.71, P < 0.01$] and 2000 [slope = 0.013, $F(1,154) = 5.27, P < 0.03$]. These data indicate fiber strength and fiber length uniformity decreased concurrently in 1999 and 2000.

Several researchers have shown that the ginning setup will influence fiber properties (Anthony, 1990, 1992, 1996; Barker et al., 1976; Columbus et al., 1990; Mangialardi, 1993; Williford et al., 1987). In these studies, reductions in fiber length uniformity were documented when additional lint cleaners were included in the ginning sequence. Reduced fiber length uniformity has also been reported after ginning cotton cultivars of lower fiber strength (Anthony, 1990, 1996). Thus, the relationship between fiber strength and length uniformity in 1999 and 2000 could be the result of lint cleaning fibers of lower strength. This observation is further supported by the nonsignificant relationship between fiber strength and length uniformity in 1998, as lint cleaning was not included in the ginning setup during this year.

The USDA-AMS base for HVI fiber strength (1998, 1999, 2000) ranged from 230 to 250 kN m kg⁻¹ in 1998 and 1999 and from 250 to 288 kN m kg⁻¹ in 2000. In

Table 5. High volume instrument (HVI) upper half mean fiber length (UHM) and advanced fiber information system (AFIS) fiber length by number [length (n)] and short fiber content by number [$SFC(n)$] during each week after first open boll of the harvest timing studies conducted at the University of Georgia Coastal Plain Experiment Station in 1998, 1999, and 2000.†

Week	HVI—UHM			AFIS—Length (n)		AFIS—SFC (n)	
	1998	1999	2000	1999	2000	1999	2000
	cm				%		
0	2.92	2.69	2.70	1.80	1.92	32.53	25.25
1	3.02	2.74	2.69	1.82	1.95	32.68	24.18
2	2.93	2.71	2.70	1.82	1.94	32.05	24.31
3	2.96	2.74	2.71	1.82	1.96	32.42	23.83
4	2.92	2.76	2.69	1.84	1.93	32.34	24.82
5	2.92	2.72	2.69	1.83	1.92	32.68	25.00
6	2.96	2.75	2.68	1.79	1.90	33.50	25.98
7	2.92	2.69	2.66	1.77	1.90	33.83	25.70
8	2.95	2.71	2.67	1.75	1.91	35.33	26.03
9	2.93	2.70	2.65	1.75	1.88	34.87	26.96
10	2.88	2.71	2.68	1.74	1.86	35.73	27.42
11	2.90	2.68	2.66	1.75	1.88	35.00	26.75
12	2.97	2.71	2.65	1.73	1.85	35.83	27.48
<i>F</i>	NS	NS	3.94**	3.98**	8.70**	4.09**	9.24**
LSD (0.05)	0.084	0.053	0.029	0.055	0.013	2.011	1.163

* Significant at the 0.05 level.

** Significant at the 0.01 level.

† Least square means are presented. $df = 36$. NS denotes no significance.

1998 and 1999 price premiums were received throughout the study period for fiber strength. In 2000, however, price discounts were received from Week 5 to 12 for low fiber strength (Table 2). These discounts were primarily due to changes in the USDA-AMS schedule for 2000.

The HVI upper half mean fiber length (UHM), defined as the mean fiber length of the longest one half of the fibers in a sample, did not differ in 1998 and 1999 (Table 5). In 2000, the HVI-UHM was greatest when harvest aids were applied before 80% open boll (Table 5). Regression analyses (Table 3) indicated the HVI-UHM was greatest when harvest aids were applied at 47.9, 56.7, and 39.1% open bolls in 1998, 1999, and 2000, respectively. The USDA-AMS base for HVI-UHM (1998, 1999, 2000) is 2.70 cm. Thus, in 2000 price discounts were received for low UHM at several harvest timings (Table 5).

In 1999, the AFIS fiber length [$L(n)$], defined as the mean length of fibers in a sample, was reduced when harvest aid applications were delayed until >83% open boll (Table 5). The AFIS short fiber content [$SFC(n)$], defined as the percentage of fibers in a sample <1.27 cm in length, also significantly increased in 1999 when harvest aid applications were delayed until >83% open boll (Table 5). In 2000, the AFIS fiber length was greatest and AFIS short fiber content was lowest when harvest aids were applied from 30 to 58% open boll (1–3 wk after first open boll; Table 5). Regression analyses indicated the AFIS fiber length was greatest when harvest aids were applied at 48.1 and 42.4% open boll in 1999 and 2000, respectively, while the AFIS short fiber content was lowest when harvest aids were applied at 45.1 and 45.7% open boll in 1999 and 2000, respectively (Table 3).

In all years of this study, HVI micronaire and AFIS fineness, both measures of fiber fineness, and as AFIS maturity were lowest when harvest aids were applied

Table 6. High volume instrument (HVI) fiber micronaire and advanced fiber information system (AFIS) fiber fineness and fiber maturity ratio during each week after first open boll of the harvest timing studies conducted at the University of Georgia Coastal Plain Experiment Station in 1998, 1999, and 2000.†

Week	HVI—micronaire			AFIS—fineness		AFIS—maturity ratio	
	1998	1999	2000	1999	2000	1999	2000
	— mg kg ⁻¹ —						
0	4.27	3.98	3.48	173.4	157.8	0.907	0.824
1	4.50	4.01	3.72	172.0	163.1	0.905	0.835
2	4.39	4.35	4.17	180.4	167.3	0.924	0.848
3	4.66	4.51	4.24	180.9	167.1	0.929	0.853
4	4.78	4.44	4.21	180.3	167.3	0.928	0.853
5	4.71	4.60	4.27	180.2	167.0	0.927	0.853
6	4.72	4.60	4.28	182.1	168.4	0.925	0.855
7	4.75	4.79	4.43	184.5	171.8	0.932	0.871
8	4.74	4.60	4.18	179.5	166.4	0.921	0.848
9	4.73	4.65	4.28	181.3	167.8	0.922	0.854
10	4.73	4.61	4.26	181.2	168.9	0.921	0.859
11	4.69	4.68	4.33	182.7	170.4	0.925	0.862
12	4.78	4.74	4.33	183.2	168.5	0.925	0.852
<i>F</i>	3.69**	9.69**	59.40**	7.53**	19.65**	5.97**	10.87**
LSD (0.05)	0.238	0.235	0.099	3.74	2.25	0.009	0.010

* Significant at the 0.05 level.

** Significant at the 0.01 level.

† Least square means are presented. *df* = 36.

from 0 to 2 wk after first open boll and increased thereafter (Table 6). Percent open boll at the time of harvest aid application was related to HVI micronaire and AFIS fineness and maturity (Table 3). In 1998 and 1999 HVI micronaire increased from first open boll to 100% open boll and in 2000 increased from first open boll to 99.3% open boll. The AFIS fineness and maturity increased from first open boll to 100% open boll in 1999 and 2000. After the fiber elongation phase, fiber filling occurs for the next 3 to 6 wk postanthesis (Berlin, 1986). Thus, the initial harvest-aid applications resulted in lower fiber micronaire and maturity because fiber filling was not complete during these timings.

Early crop termination has been suggested as a means of controlling fiber micronaire (Lewis, 1993). In 1999 and 2000 price premiums for HVI micronaire (within the range of 3.7–4.2) were received when harvest aids were applied from 17 to 57% open boll (Table 6). Regression analyses (Table 3) indicated an HVI micronaire of 4.0 occurred at <0, 15, and 42% open boll in 1998, 1999, and 2000, respectively. Regression analysis also indicated that crop termination at 15% open boll in 1999 and at 42% open boll in 2000 would have resulted in AFIS maturity ratios of 0.902 and 0.836, respectively. The AFIS maturity ratios ranging from 0.85 to 0.95 are classified as mature, while those ranging from 0.80 to 0.85 are classified as below average. Thus, our data suggest the timing of crop termination for optimum HVI micronaire is year dependant and could also result in below average fiber maturity.

A total of 20 rainfall events occurred during the 13 wk that cotton was harvested in this study in both 1998 and 1999 (Table 7). In 1998, however, the total amount of rainfall received was more than three times greater than in 1999. In 1998, most of the rainfall occurred from Week 3 to 7 and very little rainfall occurred thereafter. In 2000, a total of 24 rainfall events were recorded dur-

Table 7. Number of rainfall events and total rainfall during each week after first open boll of the harvest timing studies conducted at the University of Georgia Coastal Plain Experiment Station in 1998, 1999, and 2000.

Week	1998		1999		2000	
	Events	Total	Events	Total	Events	Total
mm						
0	5	89	2	4	0	0
1	1	8	2	7	4	106
2	1	4	2	20	3	67
3	2	221	2	8	3	56
4	0	0	3	33	5	54
5	3	106	1	22	0	0
6	3	18	4	32	1	38
7	3	96	0	0	0	0
8	0	0	0	0	0	0
9	0	0	1	26	0	0
10	0	0	0	0	0	0
11	0	0	0	0	4	27
12	2	4	3	18	4	76
Total	20	546	20	170	24	424

ing the harvest period, which mostly occurred from Weeks 1 to 4 (Table 7).

In all years of this study, HVI reflectance and yellowness decreased with weeks after first open boll, which resulted in progressively poor color grades (Table 8). In 1998, light spotted color grades (i.e., color grade 52) were observed during the period when most of the rainfall occurred. Also in 1998, color grades returned to white (i.e., 51 and 61) during the last several weeks of the study, a period in which very little rainfall was received. In 2000, light spotted color grades were recorded during the initial harvests, again corresponding to a period of significant rainfall. In 1999, color grades were all white because little rainfall was received during the study period. Price discounts (USDA–AMS–Cotton Program, 1998, 1999, 2000) were received for below base color grades (below Grade 41) in 1998 and 2000, which

Table 8. High volume instrument (HVI) Rd, +b, and color grade during each week after first open boll of the harvest timing studies conducted at the University of Georgia Coastal Plain Experiment Station in 1998, 1999, and 2000.

Week	HVI—reflectance			HVI—yellowness			HVI—color grade		
	1998	1999	2000	1998	1999	2000	1998	1999	2000
	Rd			+b					
0	71.2	76.1	67.8	8.1	8.7	9.4	41	31	42
1	69.9	78.3	70.9	8.1	8.6	9.0	41	31	41
2	69.7	77.7	70.2	8.2	8.6	9.1	41	31	42
3	69.6	74.5	71.5	7.7	9.2	8.8	51	31	41
4	66.4	75.4	72.5	8.4	8.5	8.3	51	31	41
5	64.3	73.5	71.8	8.2	8.7	7.7	52	41	41
6	64.3	76.1	72.8	8.4	7.9	7.6	52	31	41
7	64.6	75.8	72.6	7.8	7.7	7.2	51	41	41
8	65.1	76.4	71.6	7.6	7.4	7.4	51	41	41
9	66.4	75.8	71.3	7.7	7.2	7.5	51	41	51
10	65.6	75.7	69.7	8.2	7.4	7.4	51	41	51
11	63.3	71.3	68.8	8.2	7.9	7.6	61	41	51
12	63.5	74.7	68.6	7.8	7.2	7.2	61	41	51
<i>F</i>	15.89**	9.43**	12.92**	NS	32.75**	22.10**			
LSD (0.05)	1.96	1.66	1.30	0.58	0.34	0.49			

* Significant at the 0.05 level.

** Significant at the 0.01 level.

† Least square means are presented. *df* = 36 on all but +b in 2000 (*df* = 24 due to significant week × sample interaction).

Table 9. Lint yield, adjusted gross income, and sum of premiums and discounts during each week after first open boll of the harvest timing studies conducted at the University of Georgia Coastal Plain Experiment Station in 1998, 1999, and 2000.†

Week	Lint yield			Adjusted gross income			Premium/discount		
	1998	1999	2000	1998	1999	2000	1998	1999	2000
	kg ha ⁻¹			\$ ha ⁻¹			\$ 100 kg ⁻¹		
0	1296	890	711	1610.47	932.25	807.75	+1.10	+1.05	-4.68
1	1475	987	925	1832.37	1054.84	1101.72	+1.10	+3.25	+0.83
2	1466	1180	1007	1821.21	1233.35	1146.35	+1.10	+0.83	-4.40
3	1504	1504	1281	1703.29	1604.71	1518.80	-9.90	+3.03	+0.28
4	1533	1581	1241	1733.82	1687.16	1471.01	-9.90	+3.03	+0.28
5	1583	1631	1249	1740.12	1690.27	1435.55	-13.20	0	-3.30
6	1529	1453	1295	1680.84	1549.73	1488.34	-13.20	+3.03	-3.30
7	1476	1385	1179	1670.21	1436.03	1355.72	-9.90	0	-3.30
8	1524	1428	1370	1723.64	1480.15	1517.96	-9.90	0	-7.43
9	1376	1472	1285	1556.99	1525.42	1317.39	-9.90	0	-15.68
10	1533	1486	1208	1733.82	1540.51	1329.23	-9.90	0	-8.25
11	1378	—	1101	1420.33	—	1212.20	-20.02	0	-8.25
12	1445	1499	1095	1492.92	1553.28	1123.28	-19.80	0	-15.68
<i>F</i>	1.88*	9.39**	16.97**						
LSD (0.05)	167	195	113						

* Significant at the 0.05 level.

** Significant at the 0.01 level.

† Least square means are presented. *df* = 36 on all but lint yield 1999 (*df* = 33 due to missing data).

were most likely the result of rainfall subsequent to boll opening.

The harvest aid application made before 42% open boll in 1998 (i.e., Week 0) resulted in a lower lint yield than applications made from Weeks 1 through 8 (Table 9). In 1999 and 2000, harvest aid applications made from 9 to 57% open boll (Weeks 0, 1, and 2) resulted in lower lint yields than latter applications. These results are in agreement with Snipes and Baskin (1994) and Williford (1992), who also showed reduced lint yields when harvest aids were applied before 60% open boll.

Regression analysis indicated lint yield in 1998 increased from first open boll to 100% open boll (Table 3). After the crop achieved 100% open boll in 1998, lint yield decreased by 20.3 kg ha⁻¹ wk⁻¹ (Table 4). In 1999 lint yield was greatest when harvest aids were applied at 76.5% open boll, whereas in 2000, the maximum lint yield occurred when harvest aids were applied at 89.0% open boll (Table 3). In 2000 lint yield decreased by 64.0 kg ha⁻¹ wk⁻¹ once the crop reached 100% open boll (Table 4).

The maximum adjusted gross income in 1998 occurred when harvest aids were applied at 60.6% open boll (Table 3). Price discounts received for unacceptable HVI fiber color in 1998 were primarily responsible for the lower adjusted gross incomes at later dates when lint yields were greater (Table 9). Addition of lint cleaning to the ginning sequence has been shown to improve fiber color grades (Anthony, 1994). Recall, in 1998 lint cleaning was unavailable with the ginning equipment used for this study. Thus, price discounts received for reduced HVI fiber color may have been somewhat less or entirely omitted if the ginning setup had been consistent with commercial ginning operations for spindle-harvested cotton. In 1998 the adjusted gross income decreased by \$35.82 ha⁻¹ wk⁻¹ once the crop reached 100% open boll (Table 4).

The maximum adjusted gross income in 1999 occurred when harvest aids were applied at 77.8% open boll (Table 3). Price discounts were not received for reduced

fiber quality in 1999 (Table 9). Thus, the maximum adjusted gross income and lint yield occurred concurrently (Table 3). In 2000, the maximum adjusted gross income occurred when harvest aids were applied at 84.7% open boll. In 2000 the adjusted gross income decreased by \$69.94 ha⁻¹ wk⁻¹ once the crop reached 100% open boll (Table 4).

CONCLUSIONS

In 1999 and 2000, maximum lint yields occurred when harvest aids were applied at 76.5 and 89.0% open boll, respectively (Table 3). Regression analysis indicated most of the HVI and AFIS fiber length variables were optimized when harvest aids were applied from 40 to 60% open boll (Table 3). Thus, our study indicates maximum lint yield and optimum fiber lengths occur at different stages of crop maturity. Given that fiber elongation occurs before fiber filling (Berlin, 1986), this observation seems reasonable.

Under the current cotton marketing system, the penalty for reduced lint yield is much greater than the penalty for unacceptable fiber quality. Therefore, it may become less profitable for growers to manage for maximum fiber quality if lint yield is sacrificed in the process. Within the textile industry, however, profitability is highly dependant on fiber quality. Thus, a consensus over the value of raw cotton fiber would likely benefit both groups.

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REFERENCES

Anthony, W.S. 1990. Performance characteristics of cotton ginning machinery. *Trans. ASAE* 33:1089–1098.

- Anthony, W.S. 1992. Cotton length uniformity and short fiber content. *Trans. ASAE* 35:443-449.
- Anthony, W.S. 1994. The effect of gin machinery on measurement of high volume instrument color and trash of cotton. *Trans. ASAE* 37:373-380.
- Anthony, W.S. 1996. Impact of cotton gin machinery sequences on fiber value and quality. *Appl. Eng. Agric.* 12:351-363.
- Barker, G.L., C.S. Shaw, K.E. Luckett, and F.T. Cooke, Jr. 1976. Effects of defoliation, plant maturity, and ginning setup on cotton quality and value in the midsouth. *Bull. ARS-S-120*. USDA, Washington, DC.
- Berlin, J.D. 1986. The outer epidermis of the cottonseed. p. 375-414. *In* J.R. Mauney and J.M. Stewart (ed.) *Cotton physiology: Number one*. The Cotton Foundation, Memphis, TN.
- Brown, L.C., and A.H. Hyer. 1956. Chemical defoliation of cotton: V. Effects of premature defoliant and desiccant treatments on boll components, fiber properties, germination, and yield of cotton. *Agron. J.* 48:50-55.
- Brown, S.M., M. Bader, R.E. Baird, G. Harris, P.M. Roberts, and W.D. Shurley. 1998. 1998 Cotton Production Guide. *Bull. CSS 97-01*. Univ. of Georgia Coop. Ext. Serv., Tifton, GA.
- Columbus, E.P., P.D. Bel, and K.O. Robert. 1990. Maintaining cotton quality. *Trans. ASAE* 33:1057-1065.
- Deussen, H. 1992. Improved cotton fiber properties: The textile industry's key to success in global competition. p. 43-63. *In* C.R. Benedict and G.M. Jividen (ed.) *Cotton fiber cellulose: Structure, function and utilization conference*. Nat. Cotton Council of Am., Memphis, TN.
- Faerber, C. 1995. Future demands on cotton fiber quality in the textile industry, technology-quality-cost. p. 1449-1454. *In* D.A. Richter and J. Armour (ed.) *Proc. Beltwide Cotton Conf.*, San Antonio, TX. 4-7 Jan. 1995. Nat. Cotton Council of Am., Memphis, TN.
- Holman, E.M., and C.W. Bednarz. 2001. Alley effect on several cotton cultivars in small plot research. *Commun. Soil Sci. Plant Anal.* 32: 119-126.
- Kerby, T.A., J. Supak, J.C. Banks, and C. Snipes. 1992. Timing defoliations using nodes above cracked boll. p. 155-156. *In* D.J. Herber and D.A. Richter (ed.) *Proc. Beltwide Cotton Conf.*, Nashville, TN. 6-10 Jan. 1992. Nat. Cotton Council of Am., Memphis, TN.
- Lewis, H. 1993. Fiber monitoring: Regulation of cotton fiber maturity with harvest aids. p. 39-46. *In* D.M. Oosterhuis (ed.) *Proc. 1993 Cotton Res. Mtg. Spec. Rep. 162*. Arkansas Agric. Exp. Stn., Fayetteville, AR.
- Mangialardi, G.J. 1993. Effect of lint cleaning at gins on market value and quality. *Appl. Eng. Agric.* 9:365-371.
- Meredith, W.R., Jr. 1984. Quantitative genetics. p. 132-147. *In* R.J. Kohel and C.F. Lewis (ed.) *Cotton*. ASA, CSSA, and SSSA, Madison, WI.
- Parvin, D.W. 1990. The importance of harvest initiation date. p. 471-474. *In* J.M. Brown and D.A. Richter (ed.) *Proc. Beltwide Cotton Conf.*, Las Vegas, NV. 9-14 Jan. 1990. Nat. Cotton Council of Am., Memphis, TN.
- Ray, L.L., and E.B. Minton. 1973. Effects of field weathering on cotton. *Bull. MP-1118*. Texas Agric. Exp. Stn., College Station, TX.
- SAS Institute. 2000. SAS/C OnlineDoc, Release 7.00. SAS Inst., Cary, NC.
- Snipes, C.E., and C.C. Baskin. 1994. Influence of early defoliation on cotton yield, seed quality, and fiber properties. *Field Crops Res.* 37:137-143.
- Steel, R.G.D., and J.H. Torrie. 1960. Principles and procedures of statistics. p. 242-250. McGraw-Hill, New York.
- U.S. Department of Agriculture-Agricultural Marketing Service-Cotton Program. 1998. Southeast differences. *Bull. MP-CN003*. USDA-AMS-CP, Macon, GA.
- U.S. Department of Agriculture-Agricultural Marketing Service-Cotton Program. 1999. Southeast differences. *Bull. MP-CN003*. USDA-AMS-CP, Macon, GA.
- U.S. Department of Agriculture-Agricultural Marketing Service-Cotton Program. 2000. Southeast differences. *Bull. MP-CN003*. USDA-AMS-CP, Macon, GA.
- Williford, J.R. 1992. Influence of harvest factors on cotton yield and quality. *Trans. ASAE* 35:1103-1107.
- Williford, J.R., F.T. Cooke, Jr., D.F. Caillouet, and S. Anthony. 1995. Effect of harvest timing on cotton yield and quality. p. 633-638. *In* D.A. Richter and J. Armour (ed.) *Proc. Beltwide Cotton Conf.*, San Antonio, TX. 4-7 Jan. 1995. Nat. Cotton Council of Am., Memphis, TN.
- Williford, J.R., W.R. Meredith, Jr., and W.S. Anthony. 1987. Factors influencing yield and quality of Mississippi Delta cotton. *Trans. ASAE* 30:311-316.