Canopy Photosynthesis and Fiber Properties of Normal- and Late-Planted Cotton

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ABSTRACT

Normal- and late-planted cotton (*Gossypium hirsutum* L.) often differ in fiber properties, especially those properties related to fiber secondary wall characteristics. This field study was conducted to (i) determine the effect of planting date on fiber properties of bolls at two flowering times, and (ii) determine the relationship between fiber properties and canopy photosynthesis during development of those bolls. Cotton ('Stoneville 453') was planted on 3 May and 3 June in 1995 and 3 May and 31 May in 1996. Canopy photosynthesis was measured 10 to 12 times on sunny days from initial flowering through the end of the season. Fiber properties were determined on first sympodial position bolls that bloomed during the first and fourth week of flowering (WOF). Maximum canopy photosynthesis was 21% higher in 1996 than in 1995 and lint yield was 22% greater in 1996 than in 1995. Within each year, average maximum canopy photosynthesis did not differ between planting dates, although yield was approximately 30% lower for the late planting date each year. Bolls from the first WOF generally had lower lint percent, higher short fiber content, lower elongation, and lower whiteness index than bolls from the fourth WOF. Micronaire, immature fiber fraction, and fiber cross-sectional area were linearly related to the amount of canopy photosynthesis that occurred from 15 to 45 d after flowering. Our results are consistent with the hypothesis that assimilate supply influences cotton fiber properties associated with secondary wall characteristics.

The development of cotton fibers in bolls and the developmental times when events within the bolls are sensitive to environmental or competition factors has been summarized by Stewart (1986). Cotton fibers are initiated from single cells on the outer epidermis of cotton seeds around anthesis. Fibers begin elongating about 2 d after anthesis and fiber length is determined during the first 25 d after anthesis. Beginning around 15 d after anthesis, secondary wall formation begins in the fibers; this phase lasts for an additional 30 d or more. The amount of secondary wall deposition determines fiber fineness and maturity. Micronaire, measured as air permeability of a 3-g mass of fibers, is the official USDA-AMS high volume instrumentation (HVI) measure of fiber fineness.

Previous studies have documented the impact of planting date on fiber properties. Bilbro and Ray (1973) found that as planting was delayed, fiber length and micronaire declined while fiber strength increased. In the southeast USA, Porter et al. (1996) reported higher fiber strength, greater elongation, and lower micronaire for late-planted cotton. They found no effect of planting date on fiber length. Cathey and Meredith (1988) found that late planting reduced micronaire but did not affect fiber length, strength, or elongation. Bauer et al. (1998) found that cotton planted in late May had fiber with higher yarn strength, greater elongation, and greater fiber length, but lower micronaire and fiber maturity than fiber produced from cotton planted in late April.

Recent evidence suggests that carbohydrate supply can affect fiber properties of cotton. Pettigrew (1995) evaluated the effects of irradiance on cotton fiber properties. He found that higher irradiance, which would increase carbohydrate supply through higher photosynthetic rates, increased micronaire and fiber strength. Jones et al. (1996) indirectly measured carbohydrate-supply effect on fiber properties by removing flowers, which reduced competition for carbohydrate among the remaining developing bolls. Flower removal resulted in higher boll weight and micronaire of the remaining bolls in that study.

Canopy photosynthesis of cotton increases until 80 to 90 d after planting as plants develop leaf area, then decreases as leaves in the canopy age (Peng and Krieg, 1991). The beginning of flowering of the crop generally does not begin until shortly before this time, although specific dates of initiation are dependent on genotype and environment. Thus, many bolls that contribute to yield and the bulk fiber properties of a crop develop as canopy photosynthesis is declining. With very late planting, such as planting after a winter small grain is harvested, the decline in photosynthetic rates coincides with declining day length and solar irradiation.

Our objective was to determine if fiber properties of normal- and late-planted cotton are related to canopy photosynthesis levels during reproductive growth. Since cotton plants produce reproductive structures over a long period of time and in many canopy positions, differences in fiber properties would be expected as a result of within-plant competition for carbohydrates and differences in environmental conditions during boll development. Therefore, we limited our investigation to first sympodial position bolls that flowered during the first and fourth weeks of reproductive growth.

MATERIALS AND METHODS

The experiment was conducted in 1995 and 1996 on a Goldsboro loamy sand soil (fine-loamy, siliceous, subactive, thermic

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Abbreviations: DAP, days after planting; HVI, high volume instrumentation; IFF, immature fiber fraction; TDR, time-domain reflectrometry; WOF, week of flowering.

Table 1. Morphological description and environmental conditions during development of the bolls studied.

Year	Planting date	Week of flowering	Flowering date	Mainstem node	Days from flower to harvest	Heat units†	Mean daily solar irradiation
						°C	MJ m^{-2}
1995	3 May	1st	13 July	5	52	681	21.0
		4th	7 Aug.	13	51	527	16.9
	31 May	1st	9 Aug.	6	50	516	16.9
		4th	30 Aug.	12	75	363	14.1
1996	3 May	1st	4 July	6	57	652	20.3
		4th	26 July	14	56	577	19.4
	3 June	1st	29 July	7	67	624	18.2
		4th	19 Aug.	14	74	449	16.5

† Heat units were calculated from maximum and minimum temperatures as Σ(maximum temperature + minimum temperature/2) − 15.

Aquic Paleudult) at Clemson University's Pee Dee Research and Education Center near Florence, SC. The site of the experiment in 1996 was within 500 m of the 1995 experiment site. Normal soil fertility and pest management techniques were used. Cotton (cv. Stoneville 453) was planted into rows spaced 1 m apart at a seeding rate of approximately 10 seeds m^{-1} of row each year. Plots were eight 15-m-long rows in 1995 and 24 23-m-long rows in 1996. Water deficit stress was minimized by applying irrigation water (approximately 25 mm at each irrigation event) via a traveling-gun irrigation system at the first visual sign of this stress. Soil water was monitored throughout both years with time-domain reflectrometry (TDR). Two TDR probes were inserted vertically into the soil of each plot. One measured soil water between 0 and 30 cm and the other measured soil water between 30 and 60 cm. Probes were attached to a cable tester (Model 1502B, Tektronix,[1] Beaverton, OR) and traces were converted to volumetric soil water content (Baker and Allmaras, 1990). Unfortunately, the soil water data collected after 7 August in 1996 was lost because of damage to the laptop computer before the data could be downloaded and analyzed. Soil water data collected in 1995 and until August of 1996 indicated no severe stress occurred either year. Over both planting dates in 1995, the lowest soil water content was 0.09 and 0.27 m^3 m^{-3} for the 0- to 30- and 30- to 60-cm depths, respectively. In 1996, the lowest soil water content was 0.08 and 0.23 m^3 m^{-3} for the 0- to 30- and 30- to 60-cm depths, respectively.

Experimental design was a randomized complete block with four replicates. Treatments were planting dates (normal and late) and WOF (first and fourth). The normal planting date was 3 May in both years. The late planting date was 3 June in 1995 and 31 May in 1996. Within each planting date, a dated tag was placed on the peduncle of all first sympodial position white flowers (flowers at anthesis) during the first and fourth WOF. The tagging dates and the mainstem node number of sympodial branches occupied by tagged flowers are shown in Table 1. Also in Table 1 are the heat units accumulated during boll development and the sum of the daily total solar irradiation for the two sets of bolls at each planting date in each year. Heat units were calculated as $\Sigma\{[(\text{maximum daily temperature} + \text{minimum daily temperature})/2] - 15\}$. Solar irradiation was measured with a pyranometer (Model 8-48, Eppley Laboratory, Newport, RI).

When nearly all of the tagged bolls from a given planting date and WOF were open, four (1995) or eight (1996) bolls were collected and the number of motes and normal seeds in each boll were counted. Seeds and motes were identified by compressing each unginned locule from each boll between the thumb and forefinger. Nonfiber masses smaller and less resistant to digital compression than normal seeds (abnormally developed seeds) were counted as motes. The mainstem node of the sympodial branch that held each boll was determined when it was harvested. After these samples were collected, the rest of the tagged bolls within each plot and WOF were bulk-harvested and saw-ginned. Lint percent and fiber physical properties of the bulk-harvested samples were determined. Days from flower until harvest for the two sets of bolls within each planting date are given in Table 1.

Canopy photosynthesis was measured on sunny days 10 to 12 times for each planting date each year. Measurements began at 78 and 75 days after planting (DAP) for the normal and late planting dates, respectively, in 1995. In 1996, the first measurement was at 61 DAP for the normal planting date and 56 DAP for the late planting date. A 1-m-long by 1-m-wide by 1.2-m-high chamber was used to measure canopy

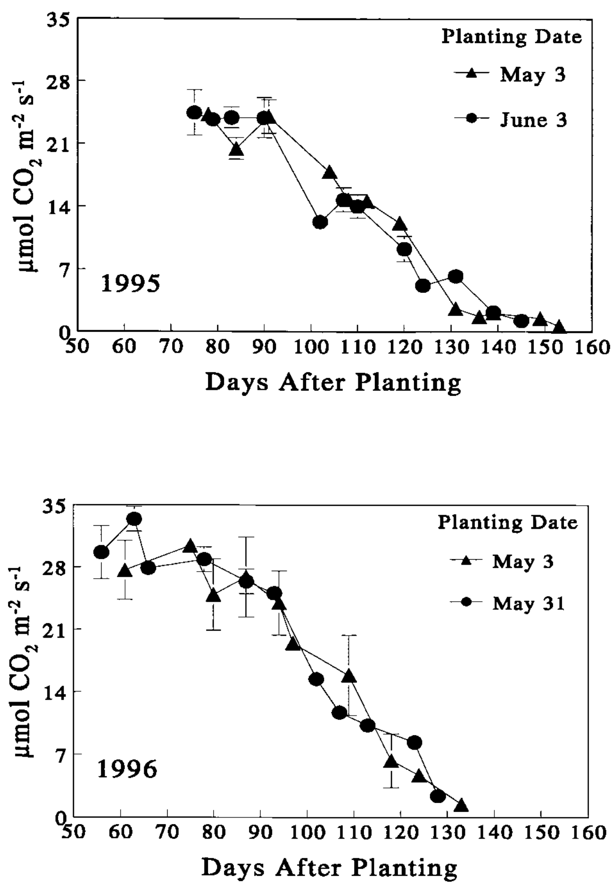

Fig. 1. Mean canopy photosynthesis of cotton planted on two dates in 1995 and 1996 at Florence, SC.

[1]Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA or Clemson University.

Table 2. Effect of planting date and week of flowering on boll characteristics of cotton grown in 1995 and 1996 at Florence, SC.

Year	Week of flowering	Lint Percentage			Seeds			Motes		
		Normal	Late	Mean	Normal	Late	Mean	Normal	Late	Mean
		%			no. boll^{-1}					
1995	1st	41.8	40.6	41.2**	29.2	24.9	27.1	2.1	3.1	2.6
	4th	44.4	44.8	44.6	25.3	31.4	28.3	4.3	2.3	3.3
	Mean	43.1	42.9		27.2	28.2		3.2	2.7	
	LSD†	NS			5.9			2.1		
1996	1st	37.6	36.3	36.9**	33.1	29.5	31.3**	3.3	4.2	3.8
	4th	42.4	42.9	42.7	34.3	34.2	34.3	3.8	2.9	3.3
	Mean	40.0	39.6		33.7*	31.9		3.5	3.5	
	LSD	NS			1.9			NS		

*, ** Significant at the $P \leq 0.05$ and 0.01 levels, respectively.
† LSD compares week of flowering means within a planting date. NS indicates the planting date × week of flowering interaction was not significant.

photosynthesis. Chamber walls and top were constructed of clear Lexan (GE Structured Products, Mt. Vernon, IN) polycarbonate sheets. Two electric fans that were mounted on the chamber walls mixed the air within the chamber during the measurements. Wind speed 30 cm from each fan outlet was approximately 12 m s^{-1}. A portable generator was used to supply the electricity to the fans in the field. Carbon dioxide depletion within the chamber was measured by connecting the chamber to a Li-Cor 6200 Photosynthesis System (Li-Cor, Lincoln, NE). The effect of soil respiration on the canopy photosynthesis measurements was minimized by placing a base of two sheets of clear polycarbonate tightly against the stems of the plants. The sides of the polycarbonate sheets were fitted with foam rubber on the ends to avoid damaging the stems and to provide a seal. The sheets were held approximately 8 cm from the soil surface by wooden frames. The chamber was then placed on top of the polycarbonate sheets. Foam rubber on the bottom of the chamber was used to ensure an airtight seal between the chamber and the base. One canopy photosynthesis measurement was collected in each plot between 1100 and 1400 EDT on clear days. All measurements were collected when PAR levels were greater than 1800 μmol m^{-2} s^{-1}. On occasions when clouds reduced PAR below this level, no measurements were taken until about 5 min after the clouds had passed. After the photosynthesis measurement, the height of the plants in the chamber was measured.

Lint yield was determined by hand-harvesting 3 m of row in 1995 and by machine-harvesting 40 m of row in 1996. Lint yields were calculated after saw-ginning approximately 300-g samples of the harvested seed cotton.

Fiber length, bundle strength, micronaire, elongation, whiteness (Rd), and yellowness (Hunter's +b) were determined by HVI at Star-Lab, Knoxville, TN. A production model Advanced Fiber Information System (AFIS-A2, Zellweger-Uster, Knoxville, TN) with modules for length, diameter, and fineness and maturity was used to determine short fiber content (percentage of fibers less than 12.7 mm long), fiber cross-sectional area, and immature fiber fraction [IFF, derived from a dimensionless value of fiber circularity and calculated as 4π(cross-sectional area)/(fiber perimeter)^2; IFF is the percentage of fibers with fiber circularity values less than 0.25] (Bradow et al., 1997).

The plant height and yield data were subjected to analysis of variance with sources of variation including year, replicate, and planting date. For analysis of the plant height data, only measurements collected on 18 Aug. 1995 and 20 Aug. 1996 were used. Means and standard errors were calculated for the canopy photosynthesis measurements. All of the photosynthesis data for each of the planting dates each year was fitted with a cubic polynomial regression, with days after planting being the independent variable. The areas under the photosynthetic rate curves were calculated for the following time periods for the bolls at the first and fourth WOF in each planting date in each year: (i) 0 to 15 d after flowering; (ii) 0 to 5 d from boll opening; (iii) 15 to 5 d from boll opening; (iv) 0 to 45 d after flowering; and (v) 15 to 45 d after flowering.

For unknown reasons, there were exceedingly poor secondary wall characteristics for the bolls from the first WOF from the late planting date in 1996. Thus, separate analyses of variance for each year were conducted for all of the fiber property and boll characteristics data. When interaction (planting date × WOF) sources of variation were significant ($P \leq 0.05$), means were separated with a LSD. Mean values of fiber strength and the fiber properties related to secondary wall characteristics (micronaire, fiber cross-sectional area, and immature fiber fraction) were regressed against the integrated areas from the photosynthetic rate curves of each year, planting date, and WOF combination. Because of the suspicion that the bolls from the first WOF in the late planting date from 1996 were not representative, data from those bolls were not used in the canopy photosynthesis regression analysis.

RESULTS AND DISCUSSION

Canopy Photosynthesis and Crop Yield

Early-season plant development rates were greater in 1996 than in 1995 for both planting dates. For both

Table 3. Effect of planting date and week of flowering on fiber length of cotton grown in 1995 and 1996 at Florence, SC.

Year	Week of flowering	Fiber length			Short fiber content		
		Normal	Late	Mean	Normal	Late	Mean
		mm			%		
1995	1st	28.5	29.0	28.8**	9.6	8.6	9.1**
	4th	27.7	27.0	27.3	8.1	7.7	7.9
	Mean	28.1	28.0		8.9	8.1	
	LSD†		NS			NS	
1996	1st	29.1	28.3	28.7	10.7	12.8	11.8**
	4th	28.8	28.5	28.6	9.2	8.0	8.6
	Mean	28.9	28.4		10.0	10.4	
	LSD		NS			2.0	

*, ** Significant at the $P \leq 0.05$ and 0.01 levels, respectively.
† LSD compares week of flowering means within a planting date. NS indicates the planting date × week of flowering interaction was not significant.

Table 4. Effect of planting date and week of flowering on fiber strength, elongation, and color of cotton grown in 1995 and 1996 at Florence, SC.

Year	Week of flowering	Fiber strength			Elongation			Whiteness (Rd)			Yellowness (Hunter's +b)		
		Normal	Late	Mean	Normal	Late	Mean	Normal	Late	Mean	Normal	Late	Mean
		kN m kg^{-1}			%								
1995	1st	257	241	249	9.4	9.0	9.2**	76	72	74**	9.5	10.1	9.8
	4th	250	243	246	9.2	10.0	9.6	76	78	77	9.3	9.9	9.6
	Mean	254*	242		9.3	9.5		76	75		9.4*	10.0	
	LSD†	NS			0.4			4			NS		
1996	1st	227	209	218**	8.7	8.8	8.8**	73	72	73**	9.7	10.3	10.0**
	4th	247	247	247	9.3	10.0	9.7	78	79	79	9.2	8.7	8.9
	Mean	237	228		9.0	9.4		75	76		9.4	9.5	
	LSD	NS			NS			NS			NS		

*, ** Significant at the $P \leq 0.05$ and 0.01 levels, respectively.
† LSD compares week of flowering means within a planting date. NS indicates the planting date × week of flowering interaction was not significant.

planting dates, it took more than 1 wk (8 or 9 d) longer for the flowers from the first WOF to appear in 1995 than in 1996, even though the bolls from the first WOF in 1995 were on average one node lower on the main-stem than the bolls from the first WOF in 1996 (Table 1). Besides faster early-season development rates, plants in 1996 were taller than plants in 1995. Average plant height on 18 Aug. 1995 was 54 cm, while height was 90 cm on 20 Aug. 1996 ($P = 0.0003$).

Maximum canopy photosynthetic rates in 1996 were higher than rates in 1995 ($P = 0.0041$). Averaged over both planting dates, photosynthetic rates between the first measurement date and 90 d after planting were 22% higher in 1996 (average of 28.5 μmol CO_2 m^{-2} s^{-1}) than in 1995 (average of 23.5 μmol CO_2 m^{-2} s^{-1}). Wells et al. (1988) compared F_1 cotton hybrids to their parents and found that the hybrids had higher yield because they had greater seedling growth that corresponded to greater per-plant CO_2 assimilatory capacity. The greater seedling growth in our study in 1996 compared with 1995 resulted in 22% higher canopy photosynthetic rates, and 1996 had 21% greater yield than 1995. Averaged over both planting dates, cotton lint yield was 940 kg lint ha^{-1} in 1996 and 775 kg lint ha^{-1} in 1995 ($P = 0.106$). This supports the speculation of Wells et al. (1988) that early-season management of factors that affect seedling growth rates are critical for ultimate crop photosynthesis and that early-season stresses can ultimately affect the productivity of the crop.

Canopy photosynthesis was similar among planting dates both years (Fig. 1). Beginning about 90 d after planting for each planting date each year, canopy photosynthesis declined to near 0 μmol CO_2 m^{-2} s^{-1} at 130 d after planting. The rate of decline between 90 and 130 DAP was about 0.50 μmol CO_2 m^{-2} s^{-1} per day in 1995 and 0.57 μmol CO_2 m^{-2} s^{-1} per day in 1996. Our data are supported by the previous findings of Peng and Krieg (1991) who showed that canopy photosynthesis began declining about 90 d after planting.

Even though canopy photosynthesis was similar among planting dates, lint yield of the normal planting date was 39% higher in 1995 and 30% higher in 1996 than lint yield of the late planting date ($P = 0.002$). As the season progressed, maximum and minimum temperatures declined. The lower temperature regime resulted in a prolonged developmental period for the bolls from the fourth WOF (Table 1) of the late planting date each year. Since there were numerous flower buds on the plants at the time the fourth WOF treatment flowers were blooming each year, it is likely that the reason for the higher yields in the normal planting date was because more of the bolls from these flower buds matured in the normal planting date than in the late planting date.

Boll Characteristics

Percentage of lint in seed cotton was lower for the bolls from the first WOF than for the bolls from the fourth WOF at both planting dates in both years (Table 2). Lint percentage did not differ between the two planting dates in either year. In the normal planting date, there was no difference in boll seed number at the two flowering times. For the late planting date, the bolls from the first WOF had fewer seeds than the bolls from the fourth WOF in both years. Motes are seeds that do not become fully developed; the fiber on motes gener-

Table 5. Effect of planting date and week of flowering on fiber micronaire and secondary wall characteristics of cotton grown in 1995 and 1996 at Florence, SC.

Year	Week of flowering	Micronaire			Immature fiber fraction			Cross-section area		
		Normal	Late	Mean	Normal	Late	Mean	Normal	Late	Mean
		reading			%			μm^2		
1995	1st	4.5	4.4	4.5**	11.7	11.1	11.4**	125	124	124**
	4th	3.6	4.0	3.8	17.3	12.8	15.0	104	116	110
	Mean	4.0	4.2		14.5*	11.9		115	120	
	LSD†	NS			NS			8		
1996	1st	4.8	3.4	4.1	11.1	21.1	16.1	131	114	122**
	4th	4.4	4.0	4.2	13.9	15.9	14.9	118	115	117
	Mean	4.6**	3.7		12.5**	18.5		125**	114	
	LSD	0.5			3.4			5		

*, ** Significant at the $P \leq 0.05$ and 0.01 levels, respectively.
† LSD compares week of flowering means within a planting date. NS indicates the planting date × week of flowering interaction was not significant.

Table 6. Regression equations for canopy photosynthesis data in Fig. 1.†

Year	Planting date	Equation	R^2
1995	Normal	$P_c = -200 + 6.57\ d - 0.0615\ d^2 + 0.000177\ d^3$	0.99
	Late	$P_c = -59.4 + 2.90\ d - 0.0308\ d^2 + 0.000094\ d^3$	0.98
1996	Normal	$P_c = -102 + 4.42\ d - 0.0461\ d^2 + 0.000141\ d^3$	0.99
	Late	$P_c = -86.5 + 4.23\ d - 0.0472\ d^2 + 0.000154\ d^3$	0.98

† P_c, canopy photosynthesis; *d*, days after planting.

ally has little secondary wall development. They are a source of immature fiber in cotton. There were no clear trends among the treatments for the number of motes per boll (Table 2).

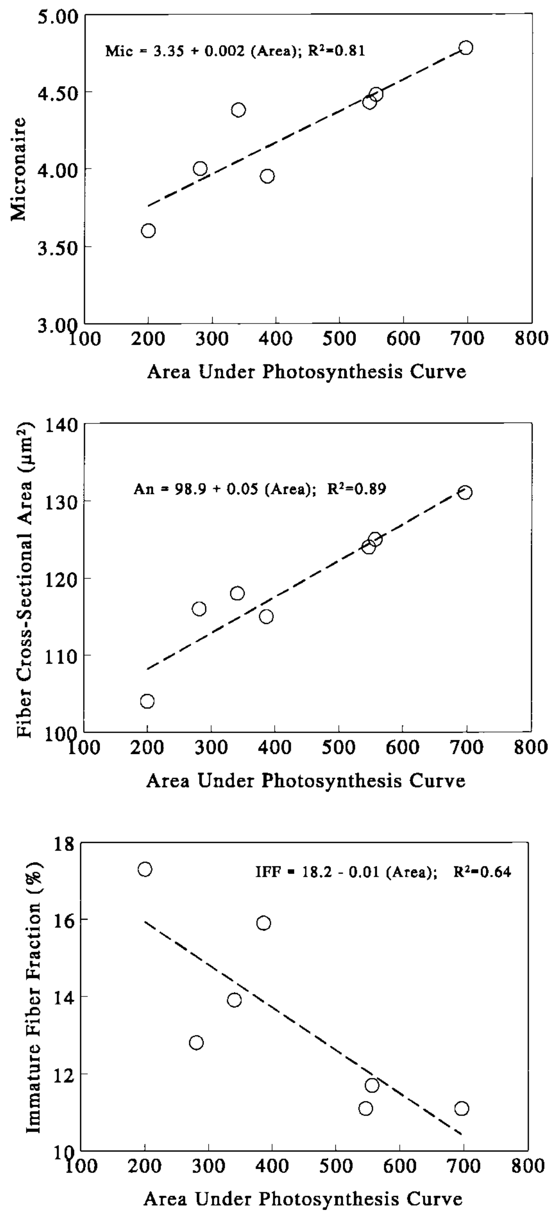

Fig. 2. Relationship between cotton fiber secondary wall characteristics and the integrated area under the photosynthetic curves determined during the period of secondary wall development (from 15–45 d after flowering). Each symbol represents mean values of each year, planting date, and week of flowering (WOF) combination (n = 4). Data from the first WOF in 1996 was omitted due to abnormal development.

Fiber Properties

In 1995, fiber from bolls from the first WOF was 1.5 mm longer but had 1.2% more short fiber content than bolls from the fourth WOF (averaged over both planting dates) (Table 3). No differences occurred among planting dates and flowering times for fiber length in 1996. Bolls from the first WOF in the late planting date in 1996 had higher short fiber content than the bolls from the fourth WOF in that planting date.

There was no clear impact of planting date or flowering time on fiber bundle strength, fiber elongation, or color (Table 4). In 1995, bolls from the normal planting date had higher strength but were more yellow regardless of flowering time. Also in that year at the normal planting date, canopy positions did not differ for elongation or whiteness, but in the late planting date, bolls from the fourth WOF had higher elongation and whiter fibers than bolls from the first WOF. In 1996, the bolls from the first WOF had lower strength and elongation and were less white and more yellow than bolls from the fourth WOF. Planting date did not affect these fiber properties.

Bauer et al. (1998) conducted a study with similar planting dates to those used in this experiment and found that micronaire and fiber maturity were lower for late-planted cotton in two of three years. In the year where differences were small in that study, cool spring temperatures slowed growth and development of the cotton in the normal planting date, and flowering occurred at about the same time for the two planting dates. In this study, micronaire did not differ between planting dates in 1995 (Table 5), even though there was a wide spread in flowering dates (Table 1). Fiber maturity was greater in the late-planted cotton, as immature fiber fraction was lower for the late-planted cotton. Even though the planting date × WOF interaction was not significant for immature fiber fraction, the bolls from the fourth WOF in the normal planting date (which had the lowest micronaire that year) had higher immature fiber fraction and lowest cross-sectional area (Table 5). In 1995, the bolls from the first WOF had higher micronaire, lower immature fiber fraction, and higher cross-sectional area than the bolls from the fourth WOF.

The bolls from the first WOF in the late planting date in 1996 had very low micronaire and high immature fiber fraction compared with the rest of the bolls evaluated (Table 5). Interestingly, fiber cross-sectional area for the bolls from the first WOF in the late planting date in 1996 was similar to values for the bolls from the fourth WOF at both planting dates, even though micronaire was lower and immature fiber fraction was higher.

Previous research suggests that the amount of canopy photosynthesis influences the secondary wall characteristics of cotton fibers. Single-leaf photosynthesis was correlated with both micronaire and fiber maturity in 1 of 2 yr in a comparison of cotton genotypes (Pettigrew and Meredith, 1994). Also, Pettigrew (1995) reported cotton from shaded plots had lower micronaire and fiber strength than an open canopy treatment in which neighboring rows were bent away from the row of cotton plants studied. Therefore, regression equations were derived from the canopy photosynthesis data in this study and the integrated areas under the canopy photosynthesis curves for different periods during boll development were used as independent variables for regressions with secondary wall characteristics and with fiber strength. The regression equations derived from the mean photosynthetic rates for the two planting dates each year are given in Table 6.

The regression equations for micronaire and fiber cross-sectional area with canopy photosynthesis were significant ($P \leq 0.05$) for all of the periods. However, the regression equation with the highest level of significance (lowest P value) and highest R^2 value for fiber cross-sectional area was for the period of 15 to 45 d after flowering. For micronaire, there were two regression equations that had the highest level of significance ($P = 0.006$) and R^2 (0.81) values. These two equations were those that included the periods of 15 to 45 d after flowering and 0 to 45 d after flowering. For immature fiber fraction, only the regression equation that included 15 to 45 d after flowering as the independent variable was significant ($P = 0.03$). Fiber strength was not related to canopy photosynthesis, as none of the regression equations for that variable were significant for any of the periods.

The relationship between fiber secondary wall characteristics and canopy photosynthesis during 15 to 45 d after flowering is shown in Fig. 2. There was a positive relationship between canopy photosynthesis and micronaire and fiber cross-sectional area, and a negative relationship between canopy photosynthesis and IFF. These relationships between canopy photosynthesis during the phase when fiber secondary wall is forming (Schubert et al., 1973) and secondary wall properties supports the hypothesis that carbohydrate supply influences fiber secondary wall characteristics.

In summary, late planting resulted in lower yield in this study compared with planting at a normal planting date, but planting date did not have a large impact on the fiber properties of the bolls at the two WOF times that were measured. Secondary wall characteristics of these first sympodial position bolls were associated with the amount of canopy photosynthesis that was occurring during fiber development. These results may help in devising strategies for reducing the amount of immature fibers and improving fiber uniformity in harvested cotton.

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REFERENCES

Baker, J.M., and R.R. Allmaras. 1990. System for automating and multiplexing soil moisture measurement by time-domain reflectometry. Soil Sci. Soc. Am. J. 54:1–6.

Bauer, P.J., O.L. May, and J.J. Camberato. 1998. Planting date and potassium fertility effects on cotton yield and fiber properties. J. Prod. Agric. 11:415–420.

Bilbro, J.D., and L.L. Ray. 1973. Effect of planting date on the yield and fiber properties of three cotton cultivars. Agron. J. 65:606–609.

Bradow, J.M., L.H. Wartelle, P.J. Bauer, and G.F. Sassenrath-Cole. 1997. Small sample cotton fiber quality quantitation. J. Cotton Sci. 1:48–60.

Cathey, G.W., and W.R. Meredith, Jr. 1988. Cotton response to planting date and mepiquat chloride. Agron. J. 80:463–466.

Jones, M.A., R. Wells, and D.S. Guthrie. 1996. Cotton response to seasonal patterns of flower removal: I. Yield and fiber quality. Crop Sci. 36:633–638.

Peng, S., and D.R. Krieg. 1991. Single leaf and canopy photosynthesis response to plant age in cotton. Agron. J. 83:704–708.

Pettigrew, W.T. 1995. Source-to-sink manipulation effects on cotton fiber quality. Agron. J. 87:947–952.

Pettigrew, W.T., and W.R. Meredith, Jr. 1994. Leaf gas exchange parameters vary among cotton genotypes. Crop Sci. 34:700–705.

Porter, P.M., M.J. Sullivan, and L.H. Harvey. 1996. Cotton cultivar response to planting date on the southeastern Coastal Plain. J. Prod. Agric. 9:223–227.

Schubert, A.M., C.R. Benedict, J.D. Berlin, and R.J. Kohel. 1973. Cotton fiber development: Kinetics of cell elongation and secondary wall thickening. Crop Sci. 13:704–709.

Stewart, J.M. 1986. Integrated events in the flower and fruit. p. 261–300 *In* J.R. Mauney and J. McD. Stewart (ed.) Cotton physiology. The Cotton Foundation, Memphis, TN.

Wells, R., W.R. Meredith, Jr., and J.R. Williford. 1988. Heterosis in upland cotton: II. Relationship of leaf area to plant photosynthesis. Crop Sci. 28:522–525.