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Breeding Cottons for Conventional and Late-Planted Production Systems

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) growers in South Carolina are replacing some of their soybean [*Glycine max* (L.) Merr.] hectareage planted after wheat (*Triticum aestivum* L.) with cotton. A breeder must decide whether a small but expanding hectareage of late-planted (LP) cotton will require a breeding scheme separate from one for the conventional (CN) full-season production system. The objective of this study was to assess selection strategies that will result in cottons with improved lint yield and fiber quality for CN and LP production systems. Twenty-five unselected Pee Dee cotton genotypes, along with a full-season and an early maturing cultivar, were evaluated in a 2-yr experiment conducted at Florence, SC, in two production systems: CN, planted approximately the first week of May, and LP, planted 8 June. Lint yield, fiber, and spinning properties were determined. Significant ($P < 0.05$) genotypic variation existed for all traits, but there was no significant genotype × production system interaction. Heritability of each trait plus the genetic correlation between production systems was used to compare predicted and observed direct and correlated response in each production system. Predicted gain in LP yield when selection was conducted in the CN production system was a 2.1% increase in the population mean compared with a 3.1% observed response. Selection for 2.5% span length and yarn strength in the CN system resulted in gains in both production systems. Antagonistic genetic correlations between some of the fiber traits and lint yield will make concurrent improvements in both production systems difficult. Use of a low selection intensity in the CN production system in the initial round of replicated yield testing was found to be an efficient method to improve lint yield or yarn strength.

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Eradication of the boll weevil (*Anthonomus grandis* Boh.) from South Carolina has made it economically feasible for growers to consider cotton as an alternative second crop in the traditional wheat-soybean doublecrop production system. Currently, cotton planted after wheat in South Carolina occupies only a few thousand hectares, though this hectareage may increase because of rising soybean-loss from wildlife predation and recent reduction in monetary return on soybean (USDA, 1993). Cotton cultivars adapted to the Southeast USA have been developed for conventional full-season or early maturity in full-season production systems, but generally not for late planting in a doublecrop system. Knowledge of the genotype × production system interaction, heritabilty of traits, and their genetic associations in each system would allow resources of a cotton breeding program to be allocated accordingly to breed improved cottons for both production systems.

Planting date studies with cotton have reported mixed success in growing cultivars bred for CN production systems in LP systems. Smith and Varvil (1982) evaluated three cultivars and a rapid fruiting genotype in CN monocropped and LP tests after wheat harvest in Arkansas. Across genotypes, LP lint yields ranged from 17 to 77% of the corresponding CN monocropped yield and the authors concluded that double cropping cotton with wheat would likely not be profitable in Arkansas. Hopkins and Culp (1984) compared an early maturing Pee Dee genotype and a southeastern cultivar for lint yield in planting dates ranging from 15 April to 15 June.

Abbreviations: ANOVA, analysis of variance; CN, conventional; LP, late planted.

Although yield declined drastically after 15 May, the authors noted that production of less than a bale per hectare would be profitable when combined with returns from a wheat harvest. Baker (1987) evaluated a cultivar in CN (about 1 May) and LP after wheat harvest (about 1 June) production systems for 3 yr in Georgia. He found that although lint yield in the CN system was greater than the LP system, the 3-yr average for the LP system was more than a bale per hectare. Green and Culp (1990a) evaluated advanced Pee Dee cottons in full-season (1 May) and late-planted (1 June) tests where the cotton lines had originally been selected for lint yield in a full-season system. Although there were large rank changes between tests for several genotypes, they did identify genotypes superior in lint yield to the southeastern cultivar PD-3 in both tests. Other planting date studies across the USA cotton belt have attempted to define the optimum planting time for locally adapted cultivars in full-season production systems (Bilbro and Ray, 1973; Smith, 1985; Verhalen et al., 1992) rather than evaluating genotypes for late planting in a doublecrop system.

A potential problem with late-planted cotton is a reduction of fiber quality associated with fiber development under suboptimal late-season weather conditions. Studies evaluating fiber quality of genotypes grown in a range of planting dates report unfavorable changes in some of the fiber properties such as micronaire and fiber length (Hessler et al., 1959; Gipson and Joham, 1968; Bilbro and Ray, 1973). More recent studies report no effect of late planting on fiber quality (Smith and Varvil, 1982; Baker, 1987) or slight improvements in length and fiber strength (Bauer and Green, 1992).

The objective of this study was to evaluate unselected cotton genotypes in CN and LP production systems to assess selection methods aimed at breeding cottons with improved lint yield and fiber properties for both production systems.

MATERIALS AND METHODS

Lint yield, fiber, and spinning properties were obtained from 25 unselected Pee Dee cotton genotypes evaluated in CN and LP production systems for 2 yr at the Clemson University Pee Dee Research and Education Center at Florence, SC. The soil type was a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudult). The unselected cotton genotypes represent a random sample from a large F_4 population described by May and Green (1994). The 25 genotypes descend from single crosses made in 1987 among Pee Dee germplasm lines and were evaluated in the F_5 generation in 1992 and the F_6 in 1993. Planting dates were 12 and 6 May, respectively, in 1992 and 1993 for the CN production system and 8 June for the LP system. Each production system consisted of the 25 Pee Dee cotton genotypes, a full-season cultivar, PD-3, and an early maturing cultivar, Delta Pine 51 (DP 51), in randomized complete block designs with four replicates. Plots were two rows, 10.6 m long with 96-cm spacing between rows. Plots were thinned to two plants per 0.3 m at the two-leaf stage. Standard cultural practices and production recommendations of the Clemson University Cooperative Extension Service were followed for all experiments.

Preceding mechanical harvest, a sample of 25 bolls in each plot was picked from the middle of the plant's fruiting zone for fiber testing. Boll samples from Replicates 1 and 2, and Replicates 3 and 4 were composited prior to ginning to give two 50-boll samples for fiber and spinning analysis. Fiber and spinning properties were measured by Starlab, Knoxville, TN, as follows: (i) 50% span length = length (millimeters) at which 50% of the fibers are ≥ this length; (ii) 2.5% span length = length (millimeters) at which 2.5% of the fibers are ≥ this length; (iii) fiber strength as force (kiloNewton meter per kilogram) necessary to break the fiber bundle with the jaws of the testing instrument (Stelometer) set 3.2 mm apart; (iv) fiber elongation = the percent elongation at the break of the center 3.2 mm of the fiber bundle measured for fiber strength on the Stelometer; (v) micronaire reading = fineness of the fiber measured by the Micronaire and expressed in standard micronaire units; (vi) yarn strength as force (kiloNewton meter per kilogram) necessary to break 27 tex yarn derived from a micro-spinning test (Landstreet et al., 1959, 1962).

A combined ANOVA over production systems and years as well as each production system within and over years was run for each response. Years and genotypes were considered random effects in the ANOVA. For the estimation of heritability, genetic correlations, and predicted response to selection, variance components were estimated from an ANOVA that inlcuded only the random cotton genotypes.

Heritability for each trait on an entry mean basis in the two production systems was estimated from variance components derived from an ANOVA over years from the following formula:

$$H^2 = \sigma^2_{\text{genotype}} / (\text{genotype mean square}/r \cdot y)$$

where r and y refer to number of replicates and years, respectively. Genetic correlations between lint yield and the fiber properties along with yarn strength were estimated for each production system within and over years after Falconer (1989, p. 311–335). Genetic correlations between lint yield and fiber traits were considered statistically significant if the genetic covariance exceeded twice its standard error. Genetic correlations between production systems for each trait from combined ANOVAs within and over years were estimated after Robertson (1959).

Predicted direct response to selection for each trait in the CN and LP production systems was calculated as:

$$\Delta\text{gain} = i \cdot H^2 \cdot \sigma_p,$$

where i = standardized selection differential (i = 0.743 for about 50% selection intensity in population size of 25; Becker, 1992), H^2 = heritability, and σ_p = phenotypic standard deviation. Predicted indirect response of each trait in one production system based on selection conducted in the other system was estimated as

$$\Delta\text{gain} = i \cdot r_{g(\text{CN,LP})} \cdot H_{\text{CN}} \cdot H_{\text{LP}} \cdot \sigma_p,$$

where i is as defined above, $r_{g(\text{CN,LP})}$ is the genetic correlation between production systems, H_{CN} and H_{LP} are square roots of heritability in each production system, and σ_p as previously defined. Observed direct response to selection in each production system was determined by selecting the top 13/25 (about 50% selection intensity) genotypes in 1992 and evaluating their response in the same production system in 1993. A 50% selection intensity was chosen to reflect a situation where many entries are evaluated in the initial round of replicated yield testing and approximately one-half are advanced to the next level of inbreeding for further testing and selection. Observed indirect response to selection in one production system based on selection in the alternate system was similarly evaluated by selecting top 13/25 in 1992 and determining the response of the same genotypes in 1993. Observed direct and indirect

Table 1. Mean squares from the ANOVA of 25 random Pee Dee cotton genotypes tested in 1992 and 1993 at Florence, SC, in conventional full-season and late-planted production systems (PS).

Source	df	Lint yield	Micronaire	50% Span length	2.5% Span length	Elongation	Fiber strength	Yarn strength
Yr	1	5 176 592**	0.15	0.0882**	0.0761**	37.20**	9.4**	361.8**
PS	1	245 894	9.37	0.0102	0.0182	33.01	0.9	1699.4
Yr × PS	1	6 897 179**	1.67	0.0086	0.0981**	6.39**	0.4	406.1
Rep (Yr × PS)	12†	128 986**	0.28**	0.0012*	0.0039**	0.06	0.6	70.3**
Genotype	24	29 531**	0.20**	0.0007*	0.0029**	0.51**	1.6*	87.7**
Genotype × Yr	24	9 084	0.03	0.0003	0.0002	0.12	0.7	12.8
Genotype × PS	24	15 893	0.04	0.0003	0.0005	0.19	0.5	22.9
Genotype × Yr × PS	24	11 079	0.04	0.0002	0.0004	0.18*	1.0	16.3
Error	288†	13 011	0.04	0.0003	0.0004	0.11	0.6	11.8

*, ** Significant at $P < 0.05$ and 0.01, respectively.
† For fiber traits and yarn strength, Rep(Yr × PS) df = 4 and error df = 96.

responses to selection were expressed as percent change in the population mean.

RESULTS AND DISCUSSION

Significant genotypic variation existed for lint yield and all of the fiber traits and YS in the combined ANOVA over years and production systems (Table 1). Significant genotypic variation combined with reasonably high heritability estimates (Table 2) for most traits suggested that selection in either production system should be effective in this population. The necessity of separate cotton breeding programs for the CN and LP production systems would be suggested by a genotype × production system interaction characterized by rank changes. Interactions of genotypes with production system were nonsignificant (Table 1), suggesting that the performance of genotypes in one production system were predictable from their performance in the alternate system. The lack of significant genotype × production system interaction was also reflected by high genetic correlations between production systems for all traits except elongation (Table 3).

In evaluating response of lint yield to selection in a test conducted at one location and 1 yr, interactions of genotypes with years/locations could bias our findings. We justified evaluating response to selection in this manner for two reasons. One is that most cotton breeding programs do not initiate multi-location/year yield testing until the number of lines is reduced and seed supplies are greater. Two, cooperative yield trials of advanced Pee Dee germplasm lines grown at locations in Florida, Georgia, and two locations in South Carolina indicated nonsignificant interactions with year/locations despite significant genetic variance for lint yield (O.L. May and C.C. Green; 1987-1990, 1992-1993; unpublished data). For the fiber and spinning properties, literature reports indicate that genotype × environment interactions are small relative to genetic variance (Miller et al., 1958; Bridge et al., 1969; Green and Culp, 1990b; Meredith et al., 1970).

Predicted direct response to selection for lint yield in the CN system was a 4% increase in the population mean, which compared favorably with a 3.5% observed response (Table 4). Selection for LP lint yield also resulted in an increase in the population mean. The genetic correlation between the two production systems for lint yield was 0.64, suggesting that selection in one production system would result in a correlated response in the alternate production system (Table 3). Considering the expense and effort involved in yield testing, the ideal situation would be for an initial round of evaluation and selection only in the CN system to lead to progress in both systems. The predicted correlated response of lint yield in the LP system based on selection in the CN system was a 2.1% increase in the population mean compared with a 3.1% observed response (Table 4). Selection for lint yield in the LP system also resulted in progress in the CN system, though this correlated response was not as large as that for selection in the CN system. Heritability of lint yield was almost twice as large in the CN system as it was in the LP system (Table 3), explaining the greater direct and correlated response of lint yield to selection in the CN system.

Heritability estimates for 2.5% span length and yarn strength were similar between cropping systems while for the remaining fiber traits, heritability was generally dissimilar (Table 2). Positive direct responses to selection

Table 2. Heritability (H^2) estimates for traits measured on 25 random Pee Dee cotton genotypes grown in 1992 and 1993 at Florence, SC, in conventional (CN) and late-planted (LP) production systems.

Production system	Trait: Lint yield	Micronaire	50% Span length	2.5% Span length	Elongation	Fiber strength	Yarn strength
	H^2						
CN	0.73**	0.59**	0.63**	0.80**	0.78**	0.12	0.74**
LP	0.40	0.77**	0.22	0.83**	0.00	0.26	0.73**

*, ** Significant at $P < 0.05$ and 0.01, respectively.

Table 3. Genetic correlation (r_g) between production systems and between lint yield and fiber properties derived from 25 random Pee Dee cotton genotypes grown in 1992 and 1993 at Florence, SC, in conventional (CN) and late-planted (LP) production systems.

Trait	r_g between prod. system	r_g between lint yield and each fiber property: CN	LP
Lint yield	0.64	–	–
Micronaire	1.02	0.47†	0.63†
50% Span length	0.94	0.45†	0.08
2.5% Span length	0.95	0.50†	0.01
Elongation	0.00	−0.22†	0.00
Fiber strength	1.03	1.21†	−0.93†
Yarn strength	0.86	−0.02	−0.41

† This genetic covariance is twice as large as its standard error.

Table 4. Predicted and observed response to selection of lint yield and several key fiber traits derived from 25 random Pee Dee cotton genotypes grown in conventional (CN) and late-planted (LP) cotton production systems in 1992 and 1993 at Florence, SC.

Trait	Production system	Predicted		Observed	
		direct†	correlated‡	direct§	correlated¶
		% of population mean			
Lint yield	CN	4.0	1.9	3.5	1.1
	LP	2.4	2.1	1.9	3.1
2.5% Span length	CN	1.2	1.2	0.7	0.8
	LP	0.9	0.8	0.8	0.5
Fiber strength	CN	0.2	0.3	−0.05	1.1
	LP	0.4	0.3	−0.1	0.9
Yarn strength	CN	1.6	1.3	0.9	1.0
	LP	1.2	1.0	0.7	0.5

† Predicted direct, selection response based on selection in the given production system, using the heritability values shown in Table 2.
‡ Predicted correlated, selection response in the given production system based on selection in the alternate production system, using the heritability values of Table 2 and genetic correlations of Table 3.
§ Observed direct, 1993 selection response in the given production system based on selection in the same production system in 1992.
¶ Observed correlated, 1993 selection response in the given production system based on selection in the alternate production system in 1992.

for 2.5% span length and yarn strength in each cropping system were observed and were similar to predicted responses (Table 4). However, selection for fiber strength resulted in negative direct responses in each production system. Because of similar heritability and high genetic correlations between production systems for 2.5% span length and yarn strength, predicted and observed correlated responses in one production system to selection in the other system were similar (Table 4). Thus, as opposed to lint yield, there was no advantage to selection in a particular production system to maximize direct and correlated response.

Lint yield and fiber quality must both be improved to meet grower needs for higher yield and textile industry needs for longer, stronger fiber. In choosing a selection scheme one must consider the magnitude and direction of genetic correlations between lint yield and key fiber traits such as 2.5% span length, fiber strength, and yarn strength, and whether or not these associations differ between production systems. In a previous study, Culp et al. (1979) reported a negative genetic correlation between fiber strength and lint yield in the Pee Dee germplasm. In the present study, the calculated genetic correlation between fiber strength and lint yield was greater than 1.0 in the CN system and highly negative in the LP system (Table 3). Since genetic variance for fiber strength was not significant in either production system in the combined ANOVA over years (Table 2), one explanation for the discrepancy in genetic correlations is that we have an estimate of a zero genetic correlation between fiber strength and lint yield in both production systems. If so, then one would not expect to make progress in concurrently improving both traits in this population. We did however, observe a 0.5% correlated response of fiber strength to selection for lint yield in the CN system. A positive correlated response of fiber strength to selection for lint yield is evidence for a positive genetic correlation. In the LP system, we found a −0.5% response of fiber strength to selection for lint yield consistent with the negative genetic correlation between yield and fiber strength (Table 3).

As noted earlier, selection for lint yield in the CN system resulted in the largest yield increase in both systems (Table 4). This finding was considered optimal with respect to allocation of a fixed amount of resources for yield testing. Unfortunately, selection for lint yield in the CN system did not necessarily result in favorable correlated changes in fiber traits. Selection for CN yield resulted in higher 2.5% span length in the CN system (0.7%) but there was an unfavorable reduction in yarn strength (−0.2%). Similarly, selection for lint yield in the LP system resulted in reductions in 2.5% span length (−0.5%) and yarn strength (−0.7%). To improve yarn strength and lint yield in either system some type of index selection will be necessary.

Selection for lint yield in one production system was associated with changes in fiber traits in the other production system. For example, selection for CN yield resulted in lower yarn strength in the LP system (−0.1%), but increases in fiber strength (0.7%) and 2.5% span length (0.9%). Selection for LP yield uniformly led to low (<2%), but consistent reductions in fiber strength, 2.5% span length, and yarn strength in the CN system (data not shown).

These data indicate that improvement of lint yield, 2.5% span length, and yarn strength individually could be accomplished in either production system. There was a small advantage to selection for lint yield in the CN system as this resulted in more direct and correlated gain in yield than did selection for LP lint yield. These data also suggest that an initial round of selection in the CN system for either lint yield, 2.5% span length, or yarn strength would lead to progress in both production systems and eliminate for at least one generation the need to test genotypes in the LP system. In this Pee Dee cotton population, concurrent improvement of lint yield and either 2.5% span length and fiber strength appears feasible in the CN system but not in the LP system. Improvement of lint yield and fiber quality in the LP system will require some type of index selection.

An additional concern with cotton planted in June is a potential reduction in fiber quality due to the fact that fiber development occurs later in the season when daylength and temperature are declining. Since yarn strength is the expression of individual fiber properties such as 2.5% span length and fiber strength (Meredith et al., 1991), comparing CN and LP yarn strength means for the same genotype should give some indication of whether or not fiber quality was adversely affected by late planting. Overall, the lack of a significant production system main effect and nonsignificant interactions among genotypes, years, and systems (Table 1) suggests that fiber quality was not reduced with late planting. Though not significant, there was a consistent slight improvement of yarn strength from the CN to the LP system (Table 5) for all but one of the 25 random genotypes (data not shown). This finding indicates that fiber quality was not adversely affected by late planting in agreement with

Table 5. Mean lint yield, yarn strength (YS), and rank for 13 random cotton genotypes and two cultivars grown in 1992 and 1993 at Florence, SC, in conventional (CN) and late-planted (LP) cotton production systems.

	Lint Yield			Yarn strength	
Genotype	CN	LP	Genotype	CN	LP
	—— kg ha^{-1} ——			—— kN m Kg^{-1} ——	
2505	912 (1)	839 (2)	2111	1505 (1)	1533 (4)
2408	894 (2)	813 (4)	3109	1475 (2)	1503 (7)
3212	894 (2)	656 (23)	3212	1475 (2)	1495 (9)
1216	870 (3)	751 (13)	3315	1473 (3)	1483 (14)
2111	855 (4)	708 (17)	3403	1473 (3)	1523 (5)
2402	837 (5)	652 (25)	1406	1473 (3)	1545 (1)
2206	836 (6)	755 (12)	4201	1468 (4)	1535 (3)
1406	833 (7)	769 (10)	2402	1465 (5)	1498 (8)
3207	824 (8)	842 (1)	3509	1465 (5)	1543 (2)
3210	820 (9)	806 (5)	2309	1463 (6)	1498 (8)
3507	815 (10)	800 (6)	2408	1455 (7)	1488 (12)
1414	810 (11)	772 (9)	2210	1450 (8)	1518 (6)
2411	795 (12)	776 (8)	1216	1445 (9)	1483 (14)
DP 51	840	801	DP 51	1275	1280
PD-3	776	762	PD-3	1438	1515
LSD 0.10	82	124		59	54

several studies (Smith and Varvil, 1982; Baker, 1987; Bauer and Green, 1992). The improvement in yarn strength between production systems was not the same for all genotypes accounting for the different ranking between production systems. These changes in rank were not of a magnitude to be significant in the combined ANOVA over years and production systems (Table 1).

The remaining decision is what yield and fiber testing scheme will result in improved genotypes for both production systems. In the Pee Dee cotton breeding program, replicated yield trials commence in the F_5 generation. Results of this study suggest that it would not be necessary to conduct both CN and LP tests at this level of inbreeding to make progress for lint yield in both production systems. Although several rank changes for yield were observed (Table 5) in spite of a nonsignificant genotype × production system interaction (Table 1), a moderate selection intensity (about 40%) in the CN system would have identified four of the top five genotypes for lint yield in the LP test. The same methodology would similarly have selected the top five lines for yarn strength in both systems. After the initial round of replicated yield testing when fewer genotypes are evaluated, it would be worthwhile to obtain yield and fiber performance in both systems. Similar findings were reported by Pfeiffer (1987) in a study of the need for separate breeding programs for soybean genotypes adapted to CN and LP production systems. By not testing all F_5 lines in both production systems, this would allow more F_4 genotypes to be advanced to F_5 which should lead to more progress. Simultaneous improvement of both lint yield and fiber traits, however, will be difficult in this population because of some antagonistic genetic correlations. We recommend additional research on a selection index that will result in lint yield and fiber quality improvements.

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