EARLY GENERATION TESTING FOR LINT YIELD, FIBER LENGTH, AND BOLL SIZE IN UPLAND COTTON

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ABSTRACT

Considerable literature on early generation testing is available in a number of crops, but relatively little such information is known in cotton (*Gossypium hirsutum* L.). The major objective of this study was to evaluate the reliability of plant selections for lint yield, fiber length, and boll size in upland cotton within previously unselected F_2, F_3, and F_4 generations of three parental combinations for each trait. A second aim of the study was to determine to what extent selection for each of the above traits indirectly affected the unselected characteristics of its nine population-generation combinations. The same selection criteria and intensities were also applied to the cultivars used as parental stocks herein to measure their variability for the traits in question and to determine their potential for further within-cultivar genetic improvement.

Six cultivars and nine crosses among them (ignoring reciprocals) were utilized. Each group of three parental combinations had one parent in common, and each combination was represented by three generations (F_2, F_3, and F_4). Two-way selection was practiced in each group for lint yield, fiber length, or boll size at the 10% level. Each parent was selected for all three characters, and progeny tests were conducted to evaluate the effectiveness of all selections made.

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Selection was effective and significant for lint yield in two of the three parental combinations studied and for fiber length and boll size in all three. Neither generations nor the interaction of generation by selection direction were significant in any of the parental combinations selected for lint yield. The latter observation suggests that selection for lint yield per plant can be applied with statistically equal effectiveness in any generation from the F_2 through the F_4 provided adequate designs and selection methods are used. Picked and pulled lint percents were the only two characters affected by the lint yield selections, and both were higher when lint yield increased.

Fiber length selections in two parental combinations were accompanied by a significant increase in boll size and 50% span length, a decline in uniformity index, and in one case a higher micronaire. In the third combination, a significant generation by selection direction interaction was found; but the same indirect results of selection for fiber length were observed (including also a micronaire increase) except that lint yield and the lint percents significantly decreased and boll size was not influenced.

Significant generation by selection direction interactions were detected in all combinations selected for boll size. Selection was effective in all generations, but the F_4 in general presented significantly larger differences among generations. Selection for boll size resulted in correlated responses with picked and pulled lint percents, 2.5 and 50% span lengths, uniformity index, and fiber strength.

Selections for lint yield, fiber length, and boll size were effective in two cultivars ('Westburn' and 'Paymaster 101-A'). The other four parents exhibited significant responses to only one of the selection criteria apiece, i.e., 'Lankart 3840' to lint yield, 'Del Cerro 526' and 'Stripper Cala-S' to fiber length, and 'Lockett 4789-A' to boll size.

Phenotypic correlations were calculated for all generation-combinations and parents, but the correlated responses actually observed in the selected progenies did not all perform as expected.

Additional index words: Gossypium hirsutum L., Phenotypic correlations, Two-way selection, Correlated responses, Heritability, Lint percent, Micronaire, Uniformity index, Fiber strength.

INTRODUCTION

Methods which permit the rapid, reliable evaluation of a large number of individual plants or lines in segregating generations are of major concern to plant breeders. Evaluations require a considerable investment of time and expense partly because large numbers of lines must be evaluated over several generations. The majority of this material is eventually discarded. If a greater percentage could be eliminated in earlier generations without sacrificing ultimate gains, the efficiency of breeding would increase and its cost decline. Consequently, early generation testing (EGT) has been a subject of considerable study over the past 25 years. The results of this work have shown a great deal of variation and as a whole are inconclusive. However, most workers would agree that simply inherited traits such as maturity and height can be selected efficiently in early generations (4, 9, 12, 22). The matter becomes more complex when breeders select in early generations for yield or other traits which usually exhibit lower heritabilities and substantial genotype by environment interactions. The view that selection for yield in the F_2 is not effective is held by many breeders, but a number of studies have shown that this position is not invariably true (2, 10, 11, 23, 26). McGinnis and Shebeski (11) believe that effectiveness of EGT for yield has been under-rated simply because of inadequate designs.

In contrast to the extensive EGT literature found in soybeans [*Glycine max* (L.) Merr.], barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L. em Thell.), and oats (*Avena sativa* L.), there is relatively little such information in cotton (*Gossypium hirsutum* L.). Meredith and Bridge (12) working with five lines of cotton and their 10

F_2 hybrids found a non-significant correlation between F_2 plants and F_3 mean populations for lint yield. However, good relationships were found for lint percent, seed index, fiber length, fiber strength, and fiber elongation. Because dominance genetic effects were not detected in their F_3's, they suggested that selection in the F_3 or later generations should be more effective than in the F_2. However, selection for lint yield in their F_2 did increase F_3 mean performance by 5.7%.

Selection response is a function of heritability, genetic variability, and selection intensity. Among these three, selection intensity is the primary factor the breeder manipulates. Heritability can most effectively be increased by reducing environmental variation (8). With heritability and genetic variability, the breeder usually tries to estimate their magnitude as accurately as possible to allow predicted response to be fairly close to that realized after selection. Good estimates of those two elements are frequently hindered by the effects of environment and genotype by environment interactions. These topics have been of concern to many workers in cotton, and a considerable amount of such research has been published for the crop.

Lint yield is considered as a trait with generally low heritabilities and that is largely affected by the environment. The results reported on this subject differ to some extent possibly because of differences in genotypes studied; the number and types of locations, years, or both involved; and the size of the area being characterized. The majority of the papers reviewed (1, 5, 14, 15, 19, 27) reported that second-order interactions were generally considerably larger (and highly significant) relative to the first-order interactions and the corresponding genetic components. Two exceptions (1, 19) were noted in which the variety by location interaction was larger or of the same magnitude as the second-order interaction. Richmond and Lewis (21) found a highly significant variety by year interaction but no differences for genetic components. The second-order interaction could not be tested in their study because only one location was utilized. Morrison and Verhalen (17) likewise found a large variety by year interaction for lint yield. Genetic components larger than the interactions ahve occasionally been reported for lint yield (3, 16). In the first report (3), a second-order interaction estimate was not obtained because the work was done within a single year; and in the second (16), only one population was found in which the second-order interaction was significant.

Fiber length, in contrast to lint yield, presents a quite different situation. Fiber length exhibits stability over environments. Large and statistically significant effects have been detected for the genetic component of this character while nonsignificant (or at least relatively small) effects for the genotype by environment interaction have been reported (3, 5, 14, 15, 16, 18). Verhalen and Murray (24) and Murray and Verhalen (19) found the genetic variance component to be the most important component of all studied, that the first-order interaction was either not significant (24) or was significant but very small compared to the genetic component (19). Second-order interactions could not be tested in the former experiment and were not significant in the latter.

Most work reported on boll size has concerned correlated responses of the trait with yield or fiber characteristics. The majority of breeders would probably agree that as lint yield increases, boll size decreases (6, 13). Ramey and Worley (20) suggest that the determination of lint yield, as affected by boll size, is relatively minor but important compared to other yield components. Culp and Harrell (7) noted that during their first three selection cycles, boll size remained constant while advances in lint yield were significant; the correlated response in their case was 0.196. Somewhat similar results occurred in the study reported by Meredith and Bridge (12) wherein boll size (along with fiber elongation and micronaire) were not significantly affected by lint yield, fiber strength, or random selections.

The major objective of this study was to evaluate the reliability of plant selections for lint yield, fiber length, and boll size in upland cotton within previously unselected F_2, F_3, and F_4 generations of three parental combinations for each trait. A second aim of the study was to determine to what extent selection for each of the above traits indirectly affected the unselected characteristics of its nine population-generation combinations. The same selection criteria and intensities were also applied to the cultivars used as parental stocks herein to measure their variability for the traits in question and to determine their potential for further within-cultivar genetic improvement.

MATERIALS AND METHODS

Six cotton cultivars were utilized herein, i.e., 'Westburn' (A), 'Paymaster 101-A' (B), 'Lockett 4789-A' (C), 'Lankart 3840' (D), 'Del Cerro 526' (E), and 'Stripper Cala-S' (F). Each of the first three cultivars were crossed with each of the last three (reciprocal crosses ignored); and F_2, F_3, and F_4 populations were developed without selection for each of those parental combinations. The 27 population-generation combinations were planted on the Agronomy Research Station at Perkins, Okla., on a Teller loam soil (a fine-loamy, mixed, termic Udic Argiustolls) on 5 June 1975. The plant populations were separated into three groups based on their common parent (A, B, or C), e.g., group A contained the combinations A X D, A X E, and A X F. The A, B, and C cultivars are well adapted to Oklahoma environmental conditions. Combinations within a group were randomly assigned to unreplicated blocks. The three generations (F_2, F_3, and F_4) for each combination were planted in adjacent plots after being randomly allocated within the block. Plots were four rows wide and 15 m long or five rows wide and 12 m long. Rows were 1.0 m apart, and plants within rows were spaced 30 cm apart. Each of the 27 population-generations consisted of approximately 200 plants. All plants were selfed with cloth bags over individual flowers, and all plants which retained one or more selfs at harvest time were harvested individually except for those plants bordering alleys or skips within the row. Lint yield (in grams per plant), fiber length (2.5% span length on a digital fibrograph in inches converted to mm), and boll size (grams of seed cotton per boll) were the selection criteria used for the A, B, and C groups, respectively. Selection was applied to the upper and lower 10% of each population-generation combination. Selfed seed of the selected plants formed two bulks (upper and lower) for each combination. The number of plants forming a bulk ranged from 5 to 15 with a mean of 10. In addition to measuring the character for which selection was practiced in each group, the other two characters studied plus picked lint percent, 50% span length, uniformity index, and fiber strength were also determined. Picked lint percent is the ratio of lint to seed cotton weight expressed as a percentage. The 50% span length, like 2.5% span length, was also measured on a digital fibrograph in inches converted to mm. Uniformity index is the ratio of 50% to 2.5% span length expressed as a percentage. Fiber strength was measured on a stelometer at the 1/8-inch (3.2 mm) gauge setting in grams-force/tex converted to mN/tex. Fiber properties and lint percents were determined on lint from open pollinated bolls. The six parents were also grown in adjacent blocks five rows wide and 12 m long, and they were handled in the same manner as the population-generations except that the selections in each parent were made for all three characters, i.e., lint yield, fiber length, and boll size.

On 5 June 1976, progeny tests were planted at Perkins using a split-plot design with four replications for each selection group. Three whole plot treatments in each test were parental combinations, and six subplot treatments were the high and low selections in each of the F_2, F_3, and F_4 generations. Subplots were 7.6 m long and 1.0 m apart. Selfed seed were insufficient to repeat the test at another location. Lint yield was determined by harvesting the entire plot and converting those weights into kg/ha. Selections from the parents were planted on 8 June 1976 as individual progeny rows on the South Central

Research Station at Chickasha, Okla., on a Reinach silt loam soil (a coarse-silty, mixed, thermic Pachic Haplustolls). Progenies at Chickasha were grouped together by cultivar of origin and randomly assigned to plots within that group. Rows were 6.0 m long and 1.0 m apart with plants at a commercial spacing. The Perkins experiment was harvested on 9 November 1976, and the Chickasha test was harvested on 6 November 1976. Characters measured in 1976 included all those measured the previous year plus pulled lint percent and micronaire (fiber fineness). Pulled lint percent is the ratio of lint to snapped cotton weight expressed as a percentage. Micronaire is measured on the micronaire (an air-flow instrument) and is expressed in μg/inch.

Phenotypic linear correlation coefficients were determined between selected and unselected traits in the 27 population-generations and in the six parents based on 1975 data. Those correlations were then compared to the actual responses observed in 1976 in the unselected traits as a consequence of selection for lint yield, fiber length, or boll size.

Realized (i.e., narrow-sense) heritability was estimated for the nine populations as the ratio of differences between the means of the high and low bulks in the progeny to the differences between the means of the high and low selections in the parental combinations.

RESULTS AND DISCUSSION

Analyses of variance detected highly significant differences among main plot treatments (parental combinations) for the selected trait in each of the three selection groups. Therefore, each combination was studied individually, rather than making inferences about the group as a whole.

Lint Yield Selections. Response to selection for lint yield was effective and statistically significant in two of the three parental combinations (Table 1). The significant difference in yield between the high vs. low selections in the A X D combination was accompanied by a change in picked and pulled lint percents in the expected direction, i.e., both percents were larger in the higher yielding selections. No other traits were significantly affected when selection for lint yield was practiced in this combination. The significant yield response in the A X E combination was not accompanied by significant correlated effects in any other character. In the A X F combination, selection for lint yield was in the expected direction but not statistically significant (0.05 probability level). The lint percents for A X F followed the same trend as in A X D; however, only picked lint percent was significant at the 0.05 level. Analyses of variance for lint yield showed that neither generations nor the generation by selection direction interaction were significant for any of the three parental combinations. The latter observation suggests that selection for lint yield was equally effective in all three generations (F_2, F_3, and F_4). This result is in opposition to many researchers' current beliefs that selection for lint yield is effective only in later generations.

Another important result in these selections is the fact that in spite of realized (i.e., narrow-sense) heritability estimates for lint yield being very low (0.07, 0.08, and 0.04 for A X D, A X E, and A X F, respectively), significant differences were obtained in the selected progeny which supports the suggestion of McGinnis and Shebeski (11) that EGT has been underestimated because of inadequate designs.

To this could also be added inadequate methods of measurement for selection. Most, if not all, cotton breeders base their plant selections for lint yield on subjective evaluations; whereas, the lint yield of every plant herein was measured to the nearest tenth of a gram. It is undoubtedly impractical to harvest and measure the lint yield of every early-generation plant in a breeder's nursery. Yet, it should be possible for that breeder to eliminate the majority of his plants on a subjective basis to obtain a manageable number, to actually measure the lint weight of those plants which remain, and to make his final decisions based on those lint measurements. Such selections should be more effective than those based on subjective judgment alone.

Precautions were also taken herein to exclude those plants having a competitive advantage, i.e., those bordering alleys or skips in the row . . . precautions which breeders do not always follow in real-life situations. Another factor which probably contributed to the results obtained in this investigation was that selfed seed were used to propagate the selected individuals. Many breeders, especially commercial breeders, do not self except in special situations. Recent unpublished data in Oklahoma suggests that the level of cross pollination in cotton is greater than previously supposed; and the greater the degree of cross pollination, the less effective selection will be due to contamination by foreign pollen.

Phenotypic linear correlation coefficients between lint yield (the selected trait) and the six other characters measured in the nine population-generation combinations in 1975 are shown in Table 2. Significant positive correlations were found for all characters except fiber strength in at least one of the population-generations. Lint percent exhibited significant correlations in the F_3 and F_4 generations of the A X D combination. This was the only case in which predicted significant responses were realized as an indirect result of selection for lint yield. In all other cases where significant correlations were detected in the 1975 data, the characters (after selection for lint yield) followed the predicted directions (although they were not statistically significant) except for uniformity index in A X E and boll size in A X F.

Fiber Length Selections. Response to selection for fiber length was highly significant and in the anticipated direction in all three parental combinations. In two combinations (i.e., B X D and B X F), analyses of variance also showed significant differences among generations at the 0.01 and 0.10 probability levels, respectively. Selection response for fiber length and its correlated effects on other characters in the three combinations are presented in Table 3. In the B X D combination, larger responses were observed in the F_3 generation; but they were significantly higher than only those in the F_4. Picked and pulled lint percents were the only two characters indirectly affected by differences among generations; and both showed higher percents in the F_4 which indicates that as fiber length decreases, lint percent increases. This result is in agreement with the almost uniformly highly significant negative correlations found between fiber length and picked lint percent (Table 4). The significant differences between the high and low fiber length selections in B X D were accompanied by significant (0.05 probability level) changes in three of the unselected characters, i.e., boll size, 50% span length, and uniformity index. All were influenced in the directions predicted by the significant correlation coefficients in Table 4. Predictions based on the phenotypic correlations were accurate in direction (except for fiber strength) even though all responses were not significant at the 0.05 probability level. Perhaps, the higher heritability estimates for fiber length compared to those for lint yield were responsible. This combination exhibited a narrow-sense heritability of 0.58. Heritability estimates for the B X E and B X F combinations were 0.58 and 0.66, respectively.

The F_4 generation of B X F showed the largest response to fiber length selection. However, it was significantly greater than the F_3, but not the F_2. Picked and pulled lint percents were again the only two characters changed between generations when selection for fiber length was applied, and both exhibited the smallest percent where fiber length was greatest. The differences between high and low selection groups had the same effects as in B X D. As fiber length increased, boll size increased, fiber uniformity declined, and 50% span length increased. In this combination, micronaire increased by a significant amount. The only predicted character change not realized as a consequence of selection for fiber length was in fiber strength.

Longer fiber was accompanied by stronger fiber, but the differences in strength were not significant.

Analysis of variance for fiber length in the B X E combinations detected highly significant differences between the high and low selection groups and a significant interaction between generations and selection direction. Significant differences initiated with selection for fiber length were noted for lint yield, picked and pulled lint percents, 50% span length, micronaire, and uniformity index. Fifty percent span length and micronaire were the only two characters that increased as did fiber length; all the others were inversely affected. As mentioned above, differences among generations were not significant; but there was a significant generation by selection direction interaction. Table 3 provides a summary of how the differences between the high and low means were distributed among generations. Greater responses were noted for fiber length in the F_3, for the lint percents in the F_2 and F_3, and for boll size in the F_3 and F_4.

<u>Boll Size Selections</u>. Response to selection for boll size was effective and highly significant in all three parental combinations. Significant interactions for generation by selection direction were detected by analyses of variance in all combinations. Generations were significantly different in only one combination, i.e., C X F, where the F_3 was greater than the F_4 but equal to the F_2. It is shown in Table 5 how large the differences were between the high and low selections in each generation relative to the differences found in the others. The F_4 generation exhibited significantly larger differences for boll size in all three combinations; the F_4 differences were significantly greater than those in either the F_2 or F_3 in the C X D and C X F

combinations and significantly larger than the F_3 difference in the C X E combination. There were no significant differential responses between the F_2 and F_3 generations for any combination. This suggests that although selection for boll size was effective in all generations, more improvement was made in the F_4—the most advanced generation in this experiment.

In the parental combination, C X D, the significant differences found between high and low selections for boll size did not significantly affect the other traits measured. The phenotypic correlations calculated the previous year (Table 6) would have lead one to expect increases in both fiber length and uniformity index, a possible increase in lint yield and decrease in lint percent, and no effects on fiber strength. Only uniformity index exhibited a difference in the expected direction, but that difference was not significant. Only fiber strength, by displaying no response, performed completely as expected.

In the C X E combination, selection for increased boll size was accompanied by highly significant increases in picked lint percent, 50% span length, and uniformity index. With the possible exception of uniformity index (Table 6), none of those effects could have been predicted based on significant phenotypic correlations in the generations before selection. Differential selection effectiveness between generations was found in this parental combination for 2.5% span length ($F_2 > F_3$ and F_4), uniformity index ($F_4 > F_3 > F_2$), and micronaire ($F_4 > F_3 > F_2$).

The highly significant difference found for boll size selection in the C X F combination exhibited correlated responses with picked and pulled lint percent (negatively), 2.5 and 50% span lengths (positively), and fiber strength (positively). A significant interaction for generation by selection direction was detected for pulled lint percent ($F_4 > F_2$ and F_3). The phenotypic correlations for this combination (Table 6) followed very closely the actual results obtained except for lint yield and uniformity index in which no responses were detected after selection for boll size. Heritability estimates for combinations C X D, C X E, and C X F were 0.23, 0.30, and 0.27, respectively.

Selections Within Parents. Two-way selections for lint yield, fiber length, and boll size were also applied to each of the six parents utilized in this study. Individual plants selected for one or more of the three characters were planted at Chickasha as progeny rows in 1976 to determine the variability (if any) remaining in the parents for those traits.

Lint yield selections were significant and effective in three of the six parents (Table 7). In parent A, the significant increase in lint yield was accompanied by a significant increase in boll size and decrease in fiber strength, the only two unselected characters which changed in the parent. Despite a positive response in lint yield, no significant differences were found among the unselected characters in parent B. In parent D, picked and pulled lint percents increased and uniformity index decreased significantly as lint yield increased. The first column in Table 10 presents the phenotypic linear correlation coefficients between lint yield and the unselected characters in each parent. Parent A showed significant correlations for boll size, lint percent, 50% span length, and uniformity index; but of those, significant changes in the progeny were detected only in boll size. Fiber length was not influenced by selection for lint yield in this parent nor was it expected to be (Table 10). The significant correlations found in parents B and D did not agree with the significant responses observed in their progeny nor were the significant responses actually observed after selection in D (picked and pulled lint percents and uniformity index) predicted by significant correlations in the unselected population.

Selection direction for fiber length was effective and significant in parents A, B, E, and F. The response of parent A (Westburn) to selection for fiber length was not surprising since a subsequent, longer-fibered cultivar ('Westburn 70') was developed through plant selections within the original Westburn (25). The response of parent E (Del Cerro 526) was unexpected to some extent because that cultivar already has fiber significantly longer than any other commercial upland cotton in the United States. Apparently, with selection, its fiber can be made still longer. Unselected characters that changed significantly as a consequence of the correlated responses for fiber length were increases in picked and pulled lint percents, 50% span length, and micronaire in parent A, increases in 50% span length in parents B and E, a decrease in uniformity index in parent F, and a decrease in pulled lint percent in parent B. Fifty percent span length and uniformity index were the only ones of the above whose significant responses and directions could have been predicted by examining the significant correlations in column two of Table 10.

Parents A, B, and C exhibited significant and effective responses to selection for boll size (Table 9). Selection in parent E could not be tested because the selections for large bolls in this cultivar were inadvertently omitted from the planting plan in 1976. Significant responses in unselected traits were detected in all three parents. Picked and pulled lint percents increased as boll size increased in parent A. Such changes could not be anticipated based on the boll size—lint percent correlation seen in Table 10. The fiber lengths, fiber strength, and lint yield changed significantly in parent B, and all were in the expected direction. All of those relationships could have been expected based on the 1975 correlations. Increases in boll size in parent C were accompanied by increases in pulled lint percent and micronaire. Selection for boll size should have influenced significant changes in the majority of parents for lint yield, the fiber lengths, and uniformity index. The lack of extensive agreement between the phenotypic linear correlation coefficients based on the 1975 data and the responses observed in the 1976 progenies can be attributed in part to the fact that the correlations were phenotypic rather than genotypic.

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Table 1. Response to two-way selection for lint yield and its indirect effects on other characters in three parental combinations.

Parental combination	Direction of selection	Lint yield	Lint percent		Boll Size	2.5% span length	50% span length	Unif. index	Micro-naire	Fiber strength
			Picked	Pulled						
		kg/ha			g	mm		%	μg/in	mN/tex
A X D	H	777 a*	37.1 a	29.2 a	6.9 a	26.4 a	12.6 a	48.0 a	5.4 a	203.4 a
	L	704 b	36.1 b	28.2 b	6.8 a	25.9 a	12.5 a	48.2 a	5.2 a	204.3 a
A X E	H	738 a	36.1 a	28.1 a	6.8 a	27.8 a	13.1 a	47.3 a	4.9 a	236.2 a
	L	664 b	36.3 a	28.0 a	6.7 a	27.3 a	13.0 a	47.5 a	4.9 a	242.0 a
A X F	H	818 a	37.0 a	29.2 a	6.4 a	25.3 a	12.0 a	47.4 a	5.0 a	201.2 a
	L	768 a	36.2 b	28.7 a	6.6 a	25.4 a	11.8 a	46.6 a	4.8 a	198.1 a

*Means within a column for each parental combination followed by the same letter were not significantly different at the 0.05 level of probability.

Table 2. Phenotypic linear correlation coefficients between lint yield (the selected trait) and other characters measured in nine population-generation combinations.

Correlated character	A X D			A X E			A X F		
	F_2	F_3	F_4	F_2	F_3	F_4	F_2	F_3	F_4
2.5% span length, mm	0.28**	0.23**	0.18	0.10	0.09	0.22*	0.15	0.03	0.12
Boll size, g	0.29**	0.11	0.33**	0.14	0.22**	0.19*	0.14	0.22**	0.48**
Lint percent (picked)	0.10	0.29**	0.24**	0.17	0.14	-0.00	0.10	0.16	0.02
50% span length, mm	0.37**	0.10	0.21*	0.29**	0.15	0.24*	0.20*	0.00	0.33**
Uniformity index, %	0.16	-0.10	0.08	0.30**	0.10	0.08	0.10	-0.04	0.25*
Fiber strength, mN/tex	0.13	-0.11	0.01	0.04	-0.10	-0.02	-0.10	-0.09	-0.04

*,**Significant at the 0.05 and 0.01 probability levels, respectively. n = 130, 152, and 112 for the F_2, F_3, and F_4, respectively, in A X D; 96, 150, and 103 in A X E; and 105, 133, and 86 in A X F.

Table 3. Response to two-way selection for fiber length and its indirect effects on other characters in three parental combinations.

Parental combination	Generation	Direction of selection	2.5% span length	Lint yield	Lint percent Picked	Lint percent Pulled	Boll size	50% span length	Unif. index	Micro-naire	Fiber strength
			mm	kg/ha			g	mm	%	µg/in	mN/tex
B X D	F_2	-	24.8 ab*	685 a	35.2 b	27.8 ab	7.2 a	12.5 a	50.6 a	5.4 a	208.3 a
	F_3	-	25.8 a	687 a	34.9 b	27.3 b	6.9 a	12.6 a	48.8 a	5.5 a	214.6 a
	F_4	-	24.0 b	683 a	37.3 a	29.0 a	7.0 a	12.2 a	50.9 a	5.6 a	212.5 a
	-	H	26.3 a	688 a	35.4 a	27.8 a	7.3 a	13.0 a	49.3 b	5.5 a	210.2 a
	-	L	23.4 b	681 a	36.2 a	28.2 a	6.7 b	11.9 b	50.9 a	5.6 a	213.4 a
B X E	F_2	H	28.7 b†	722 a	34.6 a	25.8 a	6.7 b	13.6 a	47.6 a	4.9 a	257.8 a
		L	25.6	856	38.0	28.8	6.6	12.8	49.9	5.1	247.4
	F_3	H	29.6 a	597 a	35.1 a	26.2 a	7.1 a	14.0 a	47.4 a	4.6 a	266.6 a
		L	24.9	708	38.8	30.3	6.4	12.1	48.5	5.4	243.8
	F_4	H	28.0 b	572 a	35.5 b	26.6 b	6.8 c	13.7 a	48.3 a	5.0 a	259.5 a
		L	25.9	697	36.5	28.0	7.3	12.5	48.5	5.2	248.4
B X F	F_2	-	25.0 ab‡	734 a*	35.6 ab	28.0 ab	6.7 a	12.3 a	49.3 a	5.0 a	224.2 a
	F_3	-	24.3 b	733 a	37.5 a	29.7 a	6.5 a	12.0 a	49.3 a	5.4 a	215.0 a
	F_4	-	25.3 a	694 a	35.0 b	27.2 b	6.7 a	12.2 a	48.4 a	5.1 a	229.1 a
	-	H	26.5 a*	732 a	35.9 a	27.9 a	6.9 a	12.7 a	47.8 b	5.0 b	228.2 a
	-	L	23.2 b	713 a	36.4 a	28.9 a	6.4 b	11.7 b	50.2 a	5.4 a	216.5 a

*Means within a column for generations or direction of selection in B X D and B X F followed by the same letter were not significantly different at the 0.05 level of probability. †Differences between high and low means among generations within a column in B X E followed by the same letter were not significantly different at the 0.05 level of probability. ‡Means in this column only for generations in B X F followed by the same letter were not significantly different at the 0.10 level of probability.

Table 4. Phenotypic linear correlation coefficients between fiber length (the selected trait) and other characters measured in nine population-generation combinations.

Correlated character	B X D			B X E			B X F		
	F_2	F_3	F_4	F_2	F_3	F_4	F_2	F_3	F_4
Lint yield, kg/ha	0.28**	0.15	0.12	-0.07	-0.05	0.20	0.12	0.07	0.09
Boll size, g	0.49**	0.24**	0.01	0.18	0.16	0.14	0.35**	0.28**	0.16
Lint percent (picked)	-0.14	-0.25**	-0.51**	-0.46**	-0.54**	-0.25	-0.15	-0.26**	-0.34**
50% span length, mm	0.83**	0.75**	0.65**	0.74**	0.72**	0.85**	0.71**	0.77**	0.78**
Uniformity index, %	-0.16	-0.34**	-0.39**	-0.44**	-0.38**	-0.36*	-0.23*	-0.48**	-0.69**
Fiber strength, mN/tex	0.50**	0.41**	0.20	0.61**	0.52**	0.29*	0.50**	0.47**	0.33**

*,**Significant at the 0.05 and 0.01 probability levels, respectively. n = 105, 132, and 93 for the F_2, F_3, and F_4, respectively, in B X D; 68, 114, and 48 in B X E; and 95, 147, and 80 in B X F.

Table 5. Response to two-way selection for boll size and its indirect effects on other characters in three parental combinations.

Parental combination	Generation	Direction of selection	Boll size	Lint yield	Lint percent Picked	Lint percent Pulled	2.5% span length	50% span length	Unif. index	Micro-naire	Fiber strength
			g	kg/ha			mm	mm	%	µg/in	mN/tex
C X D	F_2	H	7.6 b*	761 a	37,0 a	28,7 a	26,2 a	12.6 a	48.0 a	5.5 a	208.2 a
		L	7.0	860	36.9	28.7	27.3	13.0	47.7	5.2	201.6
	F_3	H	7.1 b	736 a	36,2 a	28.2 a	27,2 a	13.0 a	47.8 a	5.0 a	204.4 a
		L	6.8	773	35.4	27.7	27,7	13.0	46.9	5.3	200.4
	F_4	H	7.9 a	637 a	35,8 a	27.8 a	26,1 a	12.9 a	49.7 a	5.3 a	213.1 a
		L	6.6	741	35.6	28.2	28.0	13.5	48.4	5.0	220.4
C X E	F_2	H	7.4 ab	696 a	36.9 a	28.2 a	29.5 a	14.0 a	47.4 c	4.9 c	242.3 a
		L	6.5	683	37.1	28,2	26.6	13.0	48.8	5.3	229.5
	F_3	H	7.2 b	685 a	35.8 a	27.3 a	28,5 b	13.4 a	47.0 b	4.9 b	246.0 a
		L	6.6	675	34.0	25.8	29.2	13.2	45.3	4.8	249.4
	F_4	H	7.5 a	777 a	37.3 a	28.5 a	27.9 b	13.6 a	48.6 a	5.2 a	237.4 a
		L	6.3	706	35.5	27.4	28.7	13.0	45.2	4.7	229.3
C X F	F_2	H	7.0 b	818 a	35.5 a	27.9 b	26.2 a	12.5 a	47.6 b	5.1 a	211.2 a
		L	6.3	829	37.4	29.6	25.6	12.4	48.6	5.5	205.3
	F_3	H	7.0 b	754 a	34.8 a	27.4 b	28,1 a	12.9 a	46.0 b	5.0 a	216.8 a
		L	6.3	744	36,6	28,8	25.5	12.1	47.5	4.8	199.6
	F_4	H	7.0 a	825 a	35,5 a	28.2 a	26.6 a	12.9 a	48.4 a	5.2 a	211.9 a
		L	6.0	838	35.5	27.8	26.0	12.2	46.9	5.0	196.9

*Differences between high and low means among generations within a column for each parental combination followed by the same letter were not significantly different at the 0.05 level of probability.

Table 6. Phenotypic linear correlation coefficients between boll size (the selected trait) and other characters measured in nine population-generation combinations.

Correlated character	C X D			C X E			C X F		
	F_2	F_3	F_4	F_2	F_3	F_4	F_2	F_3	F_4
Lint yield, kg/ha	0.32**	0.18	0.18	0.24	0.01	0.01	0.23*	0.25**	0.42**
2.5% span length, mm	0.36**	0.33**	0.22*	0.08	0.05	-0.06	0.18	0.36**	0.36**
Lint percent (picked)	-0.08	-0.26**	0.03	-0.05	0.01	0.01	-0.20*	-0.25**	0.11
50% span length, mm	0.44**	0.39**	0.31**	0.16	0.15	0.12	0.48**	0.42*	0.62**
Uniformity index, %	0.24*	0.16	0.23*	0.03	0.14	0.23*	0.40**	0.21*	0.39**
Fiber strength, mN/tex	0.10	0.06	0.16	-0.12	-0.01	0.00	0.04	0.24**	0.16

*,**Significant at the 0.05 and 0.01 probability levels, respectively. n = 89, 132, and 99 for the F_2, F_3, and F_4, respectively, in C X D; 59, 121, and 91 in C X E; and 111, 133, and 118 in C X F.

Table 7. Response of the parental cultivars to two-way selection for lint yield and its indirect effects on other characters.

Parent	Direction of selection	Lint yield	2.5% span length	Boll size	Lint percent Picked	Lint percent Pulled	50% span length	Unif. index	Micronaire	Fiber strength
		kg/ha	mm	g			mm	%	μg/in	mN/tex
A	H	335 a*	23.6 a	5.8 a	37.6 a	29.5 a	10.8 a	46.0 a	4.6 a	179.0 a[†]
	L	245 b	23.1 a	5.3 b	37.3 a	29.2 a	10.7 a	46.1 a	4.4 a	192.0 a
B	H	255 a	22.0 a	6.3 a	38.7 a	29.8 a	10.9 a	49.6 a	5.2 a	190.1 a
	L	185 b	21.8 a	5.9 a	39.2 a	19.4 a	10.8 a	49.5 a	5.1 a	185.7 a
C	H	241 a	23.9 a	5.3 a	36.6 a	28.1 a	11.3 a	47.4 a[†]	4.4 a	170.0 a
	L	187 a	23.9 a	5.1 a	36.0 a	27.6 a	11.6 a	48.5 a	4.5 a	186.3 b
D	H	397 a	25.7 a	6.3 a	39.7 a	30.6 a[†]	12.1 a	47.1 b	6.0 a	196.8 a
	L	290 b	25.7 a	6.4 a	38.4 b	29.9 a	12.4 a	48.3 a	6.0 a	202.1 a
E	H	208 a	30.6 a	5.8 a	37.4 a	27.3 a	14.2 a	46.4 a	4.5 a	292.1 a
	L	167 a	31.0 a	5.7 a	36.7 a	26.4 a	14.6 a	47.2 a	4.4 a	301.5 a
F	H	279 a	24.4 a	5.7 a	37.7 a	29.5 a	11.2 a	45.9 a	5.0 a	196.5 a
	L	280 a	24.3 a	5.2 a	37.0 a	28.6 a	10.7 a	44.2 a	4.5 b	186.7 a

*Means within a column for each parent followed by the same letter were not significantly different at the 0.05 level of probability.

[†]Direction of selection was significant at the 0.10 level of probability.

Table 8. Response of the parental cultivars to two-way selection for fiber length and its indirect effects on other characters.

Parent	Direction of selection	2.5% span length	Lint yield	Boll size	Lint percent		50% span length	Unif. index	Micro-naire	Fiber strength
					Picked	Pulled				
		mm	kg/ha	g			mm	%	µg/in	mN/tex
A	H	23.8 a*	305 a	5.6 a	38.1 a	29.9 a†	10.8 a†	45.1 a	4.6 a	180.4 a
	L	22.6 b	308 a	5.4 a	36.4 b	28.7 a	10.3 a	45.8 a	4.2 b	191.0 a
B	H	22.7 a	240 a	6.1 a	38.1 a	28.9 b	11.2 a	49.4 a	4.9 a	192.6 a
	L	21.4 b	267 a	6.0 a	38.3 a	30.0 a	10.7 b	50.0 a	5.2 a	185.9 a
C	H	23.5 a	199 a	5.0 a	36.2 a	27.7 a	11.2 a	47.6 a	4.4 a	176.2 a
	L	22.7 a	168 a	5.1 a	36.7 a	28.1 a	11.0 a	48.4 a	4.5 a	173.6 a
D	H	25.8 a	336 a	6.6 a	39.3 a	30.6 a	12.2 a	47.5 a	6.1 a	190.1 a
	L	24.9 a	299 a	6.2 a	38.6 a	29.8 a	12.1 a	48.8 a	6.2 a	187.4 a
E	H	31.1 a	177 a	5.7 a	36.7 a	26.2 a	14.5 a	46.7 a	4.4 a	300.9 a
	L	30.4 b	161 a	5.7 a	37.2 a	26.7 a	13.9 b	45.7 a	4.4 a	301.2 a
F	H	24.7 a†	275 a	5.5 a	37.8 a	29.6 a	11.0 a	44.4 b	4.9 a	197.2 a
	L	22.2 a	286 a	5.5 a	38.1 a	29.2 a	11.1 a	49.9 a	5.1 a	183.0 a

*Means within a column for each parent followed by the same letter were not significantly different at the 0.05 level of probability.

†Direction of selection was significant at the 0.10 level of probability.

Table 9. Response of the parental cultivars to two-way selection for boll size and its indirect effects on other characters.

Parent	Direction of selection	Boll size	Lint yield	2.5% span length	Lint percent Picked	Lint percent Pulled	50% span length	Unif. index	Micro-naire	Fiber strength
		g	kg/ha	mm			mm	%	µg/in	mN/tex
A	H	5.8 a*	329 a	23.3 a	37.9 a	29.8 a	10.6 a	45.7 a	4.6 a	186.8 a
	L	5.3 b	295 a	23.2 a	36.3 b	28.6 b	10.7 a	46.3 a	4.3 a	186.2 a
B	H	6.3 a	267 a[†]	22.3 a	39.3 a	30.4 a	11.2 a[†]	50.0 a	5.2 a	200.3 a
	L	5.6 b	205 a	21.5 b	39.4 a	30.1 a	10.8 a	50.1 a	5.0 a	183.7 b
C	H	5.3 a	218 a	23.3 a	37.0 a	28.5 a[†]	11.2 a	48.1 a	4.6 a[†]	179.8 a
	L	4.6 b	166 a	22.9 a	36.0 a	27.2 a	11.1 a	48.4 a	4.2 a	176.1 a
D	H	6.5 a	345 a	25.2 a[†]	39.7 a	30.9 a	11.9 a	47.4 a	6.0 a	184.1 a
	L	6.5 a	322 a	25.6 a	38.7 b	30.1 a	12.3 b	47.8 a	6.1 a	189.2 a
E	H[‡]	-	-	-	-	-	-	-	-	-
	L	5.8	199	30.8	37.0	26.8	14.2	45.9	4.4	293.7
F	H	5.9 a	273 a	25.0 a	37.7 a	29.7 a	11.6 a	46.3 a	4.9 a	204.4 a
	L	5.9 a	354 a	24.2 a	36.1 a	28.4 a	10.8 a	44.9 a	4.5 a	182.5 a

*Means within a column for each parent followed by the same letter were not significantly different at the 0.05 level of probability.

[†]Direction of selection was significant at the 0.10 level of probability. [‡]The selections for larger boll size in this parent were inadvertently omitted from the planting plans in 1976.

Table 10. Phenotypic linear correlation coefficients between the selected traits and other characters measured in six parental cultivars.

Correlated character	Lint yield	2.5% span length	Boll size
	kg/ha	mm	g
2.5% span length, mm	0.05†	-	-
	0.29**	-	-
	0.11	-	-
	0.32*	-	-
	0.08	-	-
	0.44*	-	-
Boll size, g	0.30**	0.17	-
	0.32**	0.19*	-
	0.41**	-0.02	-
	0.26*	0.40**	-
	0.35**	0.14	-
	0.54*	0.59**	-
Lint percent (picked)	0.23*	-0.35**	-0.02
	0.15	-0.15	-0.18
	0.11	-0.56**	0.06
	0.08	-0.53**	-0.17
	0.12	-0.30**	0.02
	-0.01	-0.49*	-0.27
50% span length, mm	0.24*	0.73**	0.42**
	0.24*	0.81**	0.37**
	0.01	0.27**	0.12
	0.31*	0.85**	0.41**
	0.17	0.71**	0.34**
	0.43*	0.61**	0.41*
Uniformity index, %	0.27**	-0.22*	0.40**
	-0.06	-0.23*	0.31**
	0.06	-0.25**	0.35**
	0.08	0.08	0.16
	0.14	0.03	0.33**
	-0.11	-0.46*	-0.28
Fiber strength, mN/tex	0.04	0.33**	-0.04
	0.09	0.50**	0.19*
	-0.17	0.23*	-0.16
	0.21	0.56**	0.11
	-0.22*	0.38**	-0.13
	0.14	0.07	0.03

*,**Significant at the 0.05 and 0.01 probability levels, respectively.

†In each column of data for each character combination, the order of the parents is A, B, C, D, E, and F; and n for each parent is 122, 124, 112, 65, 98, and 26, respectively.

APPENDIX

(Tables 11 to 13)

Table 11. Analyses of variance related to data presented in Table 1.

Sources within parental combination	df	Lint yield	Lint percent: Picked	Lint percent: Pulled	Boll size	2.5% span length	50% span length	Unif. index	Micro-naire	Fiber strength
		Mean squares								
		kg/ha			g	mm	mm	%	μg/in	mN/tex
A X D										
Replications	3	863	1.15	1.03	0.46	0.0046*	0.0014*	5.13	0.12	9.11**
Generations (G)	2	4765	1.19	1.03	0.60	0.0011	0.0002	0.06	0.01	1.40
Selection direction (SD)	1	31387*	5.65**	6.15**	0.16	0.0018	0.0002	0.22	0.09	0.05
G X SD	2	5450	0.80	0.32	0.40	0.0007	0.0001	0.38	0.01	0.63
Error	15	97803	0.41	0.49	0.17	0.0012	0.0003	2.18	0.06	1.30
A X E										
Replications	3	4890	0.90	0.55	0.27**	0.0046	0.0026**	5.94**	0.12	17.89**
Generations (G)	2	7119	2.33	1.03	0.49**	0.0054	0.0005*	1.42	0.36*	8.96*
Selection direction (SD)	1	32222*	0.27	0.03	0.04	0.0026	0.0003	0.43	0.03	2.10
G X SD	2	22438	1.56	2.43	0.33**	0.0013	0.0000	2.42	0.06	6.88
Error	15	7108	1.56	1.14	0.05	0.0010	0.0001	1.02	0.07	2.42
A X F										
Replications	3	10774	2.80	3.40	0.26	0.0062*	0.0016	0.52	0.21*	5.39
Generations (G)	2	8250	1.62	1.31	0.57	0.0084**	0.0040**	6.48	0.02	8.80*
Selection direction (SD)	1	15021	4.15*	1.57	0.23	0.0001	0.0003	4.42	0.17	0.60
G X SD	2	6923	3.49*	4.78	0.04	0.0004	0.0014	9.75	0.02	0.04
Error	15	9217	0.87	1.47	0.17	0.0012	0.0006	4.31	0.07	2.24

*,**Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 12. Analyses of variance related to data presented in Table 3.

Sources within parental combination	df	Mean squares								
		2.5% span length	Lint yield	Lint percent		Boll size	50% span length	Unif. index	Micro-naire	Fiber strength
				Picked	Pulled					
		mm	kg/ha			g	mm	%	μg/in	mN/tex
B X D										
Replications	3	0.0009	11970	0.34	1.17	0.22	0.0003	3.06	0.15	8.32**
Generations (G)	2	0.0099**	24	13.53**	6.69*	0.15	0.0005	10.85*	0.08	0.84
Selection direction (SD)	1	0.0817**	239	3.54	1.02	2.05*	0.0109**	16.01*	0.11	0.67
G X SD	2	0.0010	24382	4.73*	2.35	0.02	0.0006	1.15	0.01	1.31
Error	15	0.0012	4225*	0.92	0.79	0.27	0.0004	2.67	0.06	1.33
B X E										
Replications	3	0.0022	2440	2.71	4.01*	0.30	0.0006	6.66*	0.33*	6.14
Generations (G)	2	0.0004	57455**	1.84	2.39	0.33	0.0000	1.33	0.05	0.14
Selection direction (SD)	1	0.0995**	91211**	44.33**	47.63**	0.06	0.0166**	8.64*	0.92**	13.50*
G X SD	2	0.0051*	276	4.69*	3.85*	0.79	0.0009	2.12	0.22	1.02
Error	15	0.0011	5376	1.17	0.86	0.11	0.0004	1.54	0.07	3.35
B X F										
Replications	3	0.0005	4686	0.82	1.41	0.39	0.0002	2.83	0.12	7.69
Generations (G)	2	0.0029	2426	9.29*	8.68*	0.08	0.0005	0.87	0.28	2.98
Selection direction (SD)	1	0.0874**	2697	1.57	3.85	1.17**	0.0085**	28.00**	0.92**	6.46
G X SD	2	0.0005	130	0.26	0.07	0.06	0.0001	2.08	0.23	2.24
Error	15	0.0008	4807	1.62	1.43	0.12	0.0003	0.85	0.08	2.23

*,**Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 13. Analyses of variance related to data presented in Table 5.

Sources within parental combination	df	Mean squares								
		Boll size	Lint yield	Lint percent		2.5% span length	50% span length	Unif. index	Micro-naire	Fiber strength
				Picked	Pulled					
		g	kg/ha			mm		%	µg/in	mN/tex
C X D										
Replications	3	0.22*	1252	1.75**	1.69*	0.0064	0.0014	3.10	0.25*	5.83
Generations (G)	2	0.23*	28546	2.89**	1.01	0.0001	0.0004	5.21	0.07	4.32
Selection direction (SD)	1	2.60**	29708	0.48	0.00	0.0081	0.0005	4.02	0.02	0.02
G X SD	2	0.39**	1900	0.35	0.32	0.0004	0.0001	0.62	0.16	1.88
Error	12[†]	0.06	10240	0.27	0.30	0.0033	0.0004	3.56	0.05	3.79
C X E										
Replications	3	0.17*	1134	0.53	0.59	0.0006	0.0016*	10.34**	0.11	1.46
Generations (G)	2	0.00	8690	9.40**	6.11**	0.0020	0.0002	8.23**	0.13	4.86
Selection direction (SD)	1	4.41**	6032	7.34*	4.13	0.0022	0.0034**	9.25**	0.04	2.10
G X SD	2	0.18*	2330	2.64	4.76	0.0142**	0.0006	11.87**	0.41**	1.44
Error	15	0.05	5720	1.01	0.96	0.0015	0.0004	0.42	0.06	1.52
C X F										
Replications	3	0.49**	14712	1.99	1.81	0.0013	0.0002	4.27*	0.18*	6.32*
Generations (G)	2	0.07*	16528	2.10	1.41	0.0024	0.0000	3.49	0.34**	0.40
Selection direction (SD)	1	3.78**	139	9.53**	3.02*	0.0150**	0.0025*	0.67	0.00	10.01*
G X SD	2	0.12**	334	2.51	2.59*	0.0044	0.0006	5.02*	0.18	0.74
Error	15	0.02	6047	0.75	0.72	0.0017	0.0004	1.25	0.05	1.54

*,**Significant at the 0.05 and 0.01 levels or probability, respectively. [†]Error degrees of freedom were 12 instead of 15 due to missing data.

VITA

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Doctor of Philosophy

Thesis: EARLY GENERATION TESTING FOR LINT YIELD, FIBER LENGTH, AND BOLL SIZE IN UPLAND COTTON

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