MULTIDIRECTIONAL SELECTION IN UPLAND COTTON

FOR THREE FIBER PROPERTIES

By

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INTRODUCTION

The first three chapters of this dissertation are separate and complete manuscripts to be submitted to <u>Crop Science</u> for publication. The format of each manuscript conforms to the style of <u>Crop Science</u>.

Multidirectional Selection

in Upland Cotton.

I. Fiber Length

Multidirectional Selection

in Upland Cotton.

I. Fiber Length[1]

ABSTRACT

A long-term, multidirectional selection study was conducted for
fiber length through five cycles of selection within a genetically
variable population of upland cotton (Gossypium hirsutum L.). The
populations had originally been constructed by mixing equal amounts
of mature seed from 45 F_2 populations. In each cycle, the upper and
lower 10% of the plants in the population were selected and selfed
seed from those selected plants were bulked to form new high and
low populations for subsequent tests and further selections.

Analyses of variance detected significant differences among
populations for all traits in each analysis. Significant population
by year interactions were detected for fiber length, but their
interaction components were very small compared to the population
components. Response to selection for fiber length appeared to be
linear, but more effective for shorter than for longer fiber. Even
after four cycles of selection under enforced selfing, most popu-
lations possessed sufficient variability to show significant selection
responses in the fifth selection cycle. Reverse selection was
effective in most cases, but it also suggested that the first
selection made for fiber length is the most important. Selections
for longer fiber tended to result in lower lint yield, picked and
pulled lint percents, uniformity index, and delayed maturity; tending

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[1]To be submitted for publication in Crop Science.

to increase were another measure of fiber length, fiber fineness, and fiber strength.

Additional index words: Gossypium hirsutum L., Selection response, Correlated response, Realized heritability, Lint yield, Lint percent, Uniformity index, Fiber fineness, Fiber strength, Earliness.

INTRODUCTION

Quantitative genetics studies have included investigations into the effects of long-term selection, two-way selection, and direct vs. correlated selection responses. Examples of such studies in laboratory animals include research reports by Robertson and Reeve (13) with _Drosophila_ and by McLellan and Frahm (7) with mice. The experiment described in this paper was a long-term, multidirectional selection study for fiber length in a genetically variable population of upland cotton (_Gossypium hirsutum_ L.).

Allan and Robertson (1) utilized a computer to develop a theoretical basis for interpreting selection experiments where several generations of reverse selection were followed by renewed forward selection to the limit using constant selection intensities and population sizes. Their model was idealized in that it used a population which guaranteed symmetrical responses for the two-way selections during the early generations. They found that resumption of forward selection in the reverse line would converge on the line continuously selected forward if the initial gene frequency was greater than 0.5 and diverge if the gene frequency were less than 0.5. They also demonstrated that it would be impossible after a certain number of generations (the actual number based primarily upon population size) to return to the original starting point (using the same population size and selection intensity).

A selection study in <u>Tribolium castaneum</u> Herbst. (a small flour beetle) for heavy vs. light pupae weight was conducted by Rumball (14) for 18 generations (three, six-generation periods) with reverse selection practiced at generations 1, 7, and 13. The main lines in the first two six-generation periods showed a steady response to selection while the reverse lines showed an instantaneous and linear "recovery". Response in the upward direction was greater than in the downward. The third six-generation period of selection showed very little response in either the main or reverse lines. Six generations of reverse selection at a given intensity consistently failed to return a population to the same point from which six generations of forward selection had removed it, thereby tending to agree with Allan and Robertson (1).

The Illinois oil and protein selection study in corn (<u>Zea mays</u> L.), begun in 1896 by Hopkins, has set the standard for long-term, two-way selection studies in crop plants. Winter (19), reporting on the first 28 years of selection in that classical study, indicated that the high protein and high oil strains appeared to have no limit to their future progress. The low protein strain had remained fairly constant for the last 20 years and the low oil line was apparently approaching a physiological limit to a further decline. The original 'Burr White' cultivar had a protein content of 10.9% and an oil content of 4.7%. This has increased 50.0 and 109.8% for protein and oil, respectively, in the high selected strains and decreased 23.3 and 67.9% for protein and oil, respectively, in the low strains. After 50 generations of selection, Woodworth et al. (21) reported that oil content was 15.4% in the high strain and 1.0% in the low

strain while protein content in the high line had increased to 19.5%
and decreased to 4.9% in the low line. At that time, progress was
still being made in the high oil and low protein strains while the
high protein and low oil strains had failed to respond for 15
generations. Two generations of reverse selection indicated that
especially the high oil line, but also the high and low protein
lines, still possessed a considerable amount of genetic variability.
After 65 generations of selection, Dudley and Lambert (5) detected a
significant amount of genetic variability in all populations indi-
cating that additional progress should be possible in each, but
again that the low oil line may have reached its physiological
selection limit. Percent oil and protein displayed small, but
positive, correlated responses; the magnitude of which varied with
direction of selection.

Ceccarelli et al. (3) conducted a divergent selection study,
including reverse selection, in an ecotype of perennial ryegrass
(Lolium perenne L.) for dry matter yield (DMY). Selection for high
DMY was more effective than for low. Reverse selection for low DMY
in the high population produced no significant response, while
selection for high DMY in the low population did. Taking cumulative
selection differentials as their reference point, a symmetrical
response pattern was obtained in the two directions of selection
as well as a realized heritability of 0.13 after three selection
cycles. After four cycles, realized heritability was 0.10. The
authors believe that the symmetrical response patterns exhibited
are indirect evidence that inbreeding depression was negligible in
this experiment. A subsequent paper by the same researchers (4)

showed that selection for DMY did not affect leaf size and produced asymmetrical correlated responses on the rates of tiller production and leaf appearance. Selection for high DMY increased the rate of tiller production without changing the rate of leaf appearance while selection for low DMY decreased both.

Altukhov et al. (2) studied the effects of modal vs. directional selection in cotton and concluded that modal selection in general reduces variability within the population. It improved the population over the control and over the two selected populations for a number of economic traits, especially "suitability for mechanized harvest" and "wilt resistance".

Miller and Rawlings (8) performed three cycles of recurrent selection for increased lint yield in cotton with a significant increase of 9.9% detected for each cycle. As lint yield increased, the unselected trait of fiber length decreased and genetic variances in the unselected traits generally decreased with each cycle. They postulated that unselected traits (especially yield components) tend to move toward optimum values for maximum yield. The two-way selection study for fiber length conducted by Quisenberry et al. (12) showed longer fiber to be associated with finer fiber, lower lint yields, and lower lint percent. The association between fiber length and earliness of maturity changed during the selection process.

Miller et al. (9) reported genotypic correlations in three populations between fiber length vs. lint yield (-0.33 to -0.47), lint percent (-0.48 to -0.57), fiber strength (-0.23 to 0.33), and fiber fineness (0.16 to 0.70) with phenotypic correlations of comparable magnitude. Scholl and Miller (15) indicate that selection

for fiber length would be expected to decrease lint percent, lint yield, and fiber fineness and to increase fiber length (both 2.5 and 50% span) and strength (T_1). Woodward and Malm (20) estimated nonsignificant phenotypic correlations for fiber length vs. lint percent, lint yield, fiber fineness, and fiber strength.

Several studies, Verhalen and Murray (17,18) and Verhalen et al. (16), reported genetic information on the original source of germplasm utilized to construct the initial population investigated herein. Those studies indicate a narrow-sense heritability in the F_2 of 0.49 for fiber length with long fiber being on the average partially dominant over short fiber. Fiber fineness had a heritability of 0.19 and displayed overdominance while fiber strength had a heritability of 0.52-0.62 and was partially dominant. Lint yield, lint percent, and earliness in the F_2 were controlled by overdominant gene action and generally had low estimates of heritability (i.e., 0.31, 0.26, and 0.15, respectively).

Once a population is constructed, selection intensity is the only component of selection response under the direct control of the breeder; therefore, the breeder is dependent upon the reliability of the estimates obtained for the other two components (i.e., narrow-sense heritability and phenotypic standard deviation of the population). Relative consistency of performance over environments can be determined through a genotype by environment interaction (GE) study. A GE study of 11 cotton cultivars under Oklahoma conditions (10) detected only a significant cultivar by years interaction mean square for fiber length. The estimated variance component for that interaction was about 1/10 as large as the cultivar variance component.

Other interactions involving fiber length were not significant indicating the relative stability of that trait from environment to environment. A confounded (2 years, one location) GE study of the parental material used in this study was unable to detect significance for the years by parents mean square for fiber length (16).

The objectives of this research were to investigate the direct and indirect effects of a multidirectional selection study for fiber length in a genetically variable population of upland cotton.

MATERIALS AND METHODS

During the winter of 1964-65, crosses were initiated at Iguala,
Mexico, among the entries 'Paymaster 101', 'Gregg', 'Western Storm-
proof', 'Lankart 57', 6-77, 'Deltapine Land 45', 'Coker 100A WR',
'Acala 44', 'Stoneville 7', and 'Auburn M' (16,17,18). Except for
6-77, all entries were commercial cultivars of cotton at the time;
6-77 was a selection for bacterial blight {Xanthomonas malvacearum
(E. F. Sm.) Dows.} resistance in the cultivar 'Stormproof No. 1'.
All 45 possible F_1's (ignoring reciprocals) among the 10 entries were
subsequently selfed to produce F_2's.

In 1968, 100 mature undamaged seed from each F_2 population were
counted, bulked together, thoroughly mixed, planted in a block at
Perkins, Okla., on a Teller loam soil (a fine-loamy, mixed, thermic
Udic Argiustolls), and selfed. All competitive plants (i.e., plants
not bordering alleys or skips within the row) which had one or more
selfed bolls were individually harvested after frost; and their fiber
length was measured on lint from mature, open-pollinated bolls as
2.5% span length on the digital fibrograph in the Oklahoma State Univ.
Cotton Quality Res. Lab. at Stillwater. Ten percent of the harvested
plants were selected at each end of the population distribution
resulting in two populations {high (H) and low (L)}. The selfed seed
from the selected F_2 plants within each population were then bulked,
delinted, and planted in 1969 at Perkins. After frost (and using the

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same criteria as before), approximately 100 F_3 plants were harvested
and those from the upper and lower 10% of the distribution were again
selected for fiber length within each population. This resulted in
four populations (i.e., HH, HL, LH, and LL); and as before, the selfed
seed from the selected plants within each group were bulked. The same
selection and bulking pattern was followed in 1970 (F_4), 1971 (F_5),
and 1979 (F_8) which resulted in 8, 16, and 32 populations, respec-
tively. In 1973, F_6 seed from the fourth selection cycle (16 popu-
lations) were planted, selfed, and harvested without selection to
increase the seed supply. Remnant F_7 seed from that 1973 increase
was again planted, selfed, and harvested without selection in 1976
for the same reason.

All replicated field trials were planted at Tipton, Okla., on a
Tipton silt loam soil (a fine-loamy, mixed, thermic Pachic Argiustolls)
in a randomized, complete-block experimental design with single row
plots 9.1 m in length and 1.0 m apart. The first trial (evaluating
the third selection cycle) was conducted in 1973 with eight entries
(i.e., HHH, HHL,..., LLL) and five replications and repeated in 1974
with four replications. The fourth selection cycle (i.e., HHHH, HHHL,
..., LLLL) was evaluated in 1975 with five replications and again in
1979 with four. The fifth selection cycle (i.e., HHHHH, HHHHL,...,
LLLLL) was evaluated in 1980 with six replications.

Lint weights/plot from the replicated tests were converted into
kg/ha. Fifteen mature bolls, from near the midportion of the plant,
were randomly sampled from each plot. Those samples were ginned on
an eight-saw gin, and the lint taken to the Cotton Quality Res. Lab.
for measurement of its fiber properties. From data collected while

ginning, picked lint percent (the ratio of lint to seedcotton weights, expressed as a percentage) and pulled lint percent (the ratio of lint weight to the combined weights of seedcotton plus bur, expressed as a percentage) were calculated. In the Cotton Quality Res. Lab., the digital fibrograph was employed to measure 2.5% and 50% span lengths (both in inches, converted to mm). Uniformity index was computed as the ratio of 50% to 2.5% span length and expressed as a percentage. Fiber fineness was measured on the micronaire in standard curvilinear micronaire units, i.e., $\mu g/in$. Fiber strength was estimated with the stelometer using 0" gauge (T_0) and also 1/8" (3.175 mm) gauge (T_1) measurements in grams-force/tex (converted into mN/tex). The experiments in 1973 and 1974 were harvested twice (all others were only harvested once); therefore, estimates of earliness measured as percent first harvest {(lint weight from the first harvest/lint weight from both harvests) x 100} were calculated.

Response to selection in a population for fiber length was measured as the difference between the mean performance (estimated from a replicated trial) of the high and low selections from that population. Correlated response to selection was measured in the same manner; but it refers to traits for which selection was not directly practiced. Realized heritability estimates for fiber length were calculated using Falconer's (6) formula: R/S, where R represents the actual response to selection (as estimated from replicated trials) and S represents the selection differential (i.e., the difference between the means of the high and low selection groups obtained from a population at the time selections were made).

Analyses of variance were conducted for all traits in each replicated trial. Selection cycles three and four were each evaluated in 2 years. Those cycles were analyzed pooled over years and within each year separately. Sums of squares attributable to populations were partitioned into a set of orthogonal contrasts which were used to evaluate differences between high vs. low selections within a population (i.e., direct and correlated responses). A nonorthogonal set of contrasts was partitioned from the populations sums of squares in the 2.5% span length analyses to investigate the possible differences among populations with an equal number of high (H) selections in their pedigree (ignoring order) within a selection cycle. All contrasts were appraised for statistical significance using an F-test.

RESULTS AND DISCUSSION

Pooled analyses of variance over years for selection cycle three show significant differences among populations and years for all 10 traits investigated (Table 1). The interaction term can serve as an indicator of genotype by environment interaction between years in this material (although the estimate is confounded because only one location was involved). Significant interactions were detected in fiber length (2.5% span length; the trait for which selection was practiced), lint yield, both measures of fiber strength, and earliness. Such interactions imply that the effects of selection for fiber length on those traits should be evaluated in each year separately. However, comparisons of the interaction variance component for fiber length relative to its corresponding population component showed it was only 1.8% as large. Therefore, though significant, the genotype by environment interaction component is unlikely to be of any practical importance.

The analysis of the cycle four selections is complicated by a difference in generations between the 1975 evaluations and those in 1979. In 1975, F_7 seed were utilized; whereas in 1979, F_8 seed were planted. As in the cycle three analyses, differences among populations were significant for all populations studied, as were year effects for all traits except pulled lint percent and T_1 fiber strength. Again, significant interactions between populations and years were noted for fiber length, lint yield, and T_1 fiber strength, while T_0 fiber

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strength did not exhibit a significant interaction, as it did in cycle three. Traits exhibiting significant interactions in cycle four, but not in cycle three, were pulled lint percent, uniformity index, and fiber fineness. The interaction variance component for fiber length was only 5.9% as large as the population variance component which, as in cycle three, would be unlikely to be of practical importance. Analyses of variance for the cycle five selections (not shown) displayed significant differences among populations for all traits studied.

The nonorthogonal partition of the population sum of squares for fiber length (not shown) demonstrated that differences existed among all populations in cycle three which had been selected for longer fiber twice (i.e., HHL, HLH, and LHH) and also among those selected for longer fiber only once (i.e., HLL, LHL, and LLH). Similar trends were found in selection cycles four and five. Those differences tend to indicate that the order in which a selection for long or short fiber was made in the development of a population influenced its performance.

The trends exhibited by fiber length through the five selection cycles are displayed in Fig. 1. Single values are shown in selection cycles 3 and 4 of the figure even though multiple estimates were available. The values are shown as such because of the relative lack of importance assigned to the interaction component. Values presented therein have been adjusted, using the method outlined by Patterson (11), to alleviate, as much as possible, the effects of evaluating cycles in different years. The data for cycles three, four, and five were taken directly from replicated trials while those for cycles zero, one, and two were estimated by assuming that high vs. low

selections within a population were equally effective and by averaging all populations in cycles three through five, in each individual experiment, that originated from the point being estimated.

Response to selection for fiber length appears to be linear, but asymmetrical with change being made more rapidly in the low selections than in the high. In fact, the LLL population deviated farther from the calculated starting point than did the HHHH population. The response for reverse selection was relatively rapid in most cases, although the genetic variability in the direction opposite that for which selection was practiced in cycle one was reduced. This is demonstrated by studying the slope of the line connecting the L, LH, ..., LHHH populations and also that connecting the H, HL,..., HLLLL populations. The four cycles of reverse selection practiced in the low population never quite reached the level of one generation of high selection. Four cycles of reverse selection practiced in the H population did not result in a great deal of difference from the level of the initial L selection. The renewal of forward selection in the reverse populations generally produced a response in the desired direction. Apparently, the first fiber length selection practiced by the breeder is the most important one made. Populations LLLL, LLLLH, and LLLLL are not shown in Fig. 1 because of an apparent error made in the composition of LLLL.

Data are presented in Table 2 as suggested by the population by year interaction term in the analyses of variance for each trait (Table 1). Sufficient genetic variability remained in each of the second cycle populations for significant selection response to be detected in at least one of the two years for fiber length. Two

populations, HL and LL, showed significant responses in both years. Five of the seven populations from the third cycle (i.e., HHH, HHL, HLL, LHL, and LLH) displayed significant selection responses in both years with the other two populations exhibiting significance in only one year (Table 3). Data also indicate that selection within the fourth selection cycle was effective in 12 of the 15 populations (Table 4). In each case where a significant difference was detected, the direction of the response was positive. Selections for fiber length were still effective even after four previous generations of selection with rigidly enforced self-pollination.

Realized heritability estimates and their appropriate standard errors (where they could be calculated) are presented in Table 5. Standard errors could not be placed on the estimates for cycles zero and one because selections from those cycles were not evaluated in replicated trials. Falconer (6) indicates that because of inbreeding, these estimates cannot be used as a measure of narrow-sense heritability; however, they are good indicators of selection effectiveness for fiber length under the conditions of this experiment.

Correlated responses (CR) of lint yield to selection for fiber length can be found in Tables 2-4 for the selections made in cycles two, three, and four, respectively. In the selections made in the second cycle, a significant decrease was detected in the HH population in both years and in HL in one year. Selections for longer fiber in LL resulted in a significant increase in lint yield in one year. The third cycle selections detected a significant CR in seven of 14 tests with all but one (HHH in 1979) being negative. The fourth cycle detected only four cases of significant effects on lint yield, three

of which were negative. Most selections for fiber length resulted in significant reductions or neutral effects on lint yield; however, a few instances were noted of significant increases in lint yield. One of the positive lint yield responses (the HHLH population in Table 4) was associated with no significant change in fiber length.

The CR of picked lint percent indicates two significant differences (one positive, one negative) in the selections made in cycle two (Table 2), two differences (again one positive, one negative) in the selections made in cycle three (Table 3), and nine differences (all negative) in the selections made in cycle four (Table 4). Pulled lint percent was significant in all four cases in Table 2, six of 14 in Table 3, and eight of 15 in Table 4. All were negative except in the LL population selections in Table 2.

Fifty percent span length is a measure of fiber length as is 2.5% span length, the trait for which selection was practiced. All significant CR's {i.e., two in cycle two (Table 2), two in cycle three (Table 3), and seven in cycle four (Table 4)} were in the positive direction. Such positive relationships were expected because the two measurements estimate different aspects of the same basic trait and because a highly significant phenotypic correlation (0.44) between 2.5 and 50% span length was found in the unselected base population.

The phenotypic correlation of -0.16 (significant at the 0.05 probability level) between 2.5% span length and uniformity index in the unselected base population indicates that selection only for longer fibers should result in a tendency for decreases to occur in uniformity index. The CR of uniformity index was significant only in selections made in the LL population of cycle two (Table 2). The third

cycle showed five significant changes (Table 3). In the fourth cycle (Table 4), all of the populations which had initially been selected for short fiber showed significant CR's while only two of those initially selected for long fiber detected any significant changes. All significant responses were negative indicating that change in 2.5% span length was greater than in 50% span length.

Fiber fineness and 2.5% span length were negatively related {phenotypic correlation of -0.13 (significant at the 0.10 probability level)} in the base population. Fiber fineness significantly decreased with selection for longer fiber in three of four cycle two populations (Table 2), in five of 14 cases in cycle three (Table 3), and in nine of 15 in cycle four (Table 4).

The CR of T_0 fiber strength significantly increased in one population in the selections made in cycle two, and decreased in three of the other comparisons (Table 2). The three significant changes in the CR of T_0 in cycle three (Table 3) were all positive; the majority of the populations showed no change. Five of the six significant changes found in the fourth cycle (Table 4) were positive.

T_1 fiber strength was related to 2.5% span length in a positive manner in the base population {phenotypic correlation of 0.19 (significant at the 0.05 probability level)}. T_1 fiber strength displayed significant increases in response to selection for fiber length in the HH and HL populations in both years, but showed significant decreases in one year only in each of the LH and LL populations (Table 2). Selection in the third cycle (Table 3) detected significance in only four of the 14 cases, all of which were positive. In the fourth cycle (Table 4), 10 significant increases and one decline occurred in the 15 populations.

Earliness was estimated in the second selection cycle only (Table 2). The HH and HL populations showed significant decreases in both years tested while LL showed a significant decrease only in 1973. Selections based upon fiber length only apparently encourage genotypes requiring longer growing seasons.

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Table 1. Analyses of variance for fiber length selections pooled over years for selection cycles three and four.

Sources	df	2.5% span l.	Lint yield	Lint percent Picked	Lint percent Pulled	50% span l.	Unif. index	Fiber fineness	Fiber strength T₀	Fiber strength T₁	Earliness
Cycle 3 (1973 and 1974)											
Reps (Over years)	7	1.2679*	23,520*	3.29	6.46	0.3703†	1.76	0.22	4.36†	8.67**	107.49
Populations (P)	7	54.8053**	86,147**	13.48**	23.97**	6.5155**	19.43**	1.83**	13.11**	16.23**	576.94**
Years (Y)	1	44.0533**	2,074,414**	59.86**	202.80**	16.8635**	13.87**	1.38**	17.76**	2.80†	6,379.41**
P x Y	7	1.0119†	29,574**	4.28	3.85	0.3169	2.19	0.14	7.26**	1.62*	279.24*
Error	49	0.5318	7,842	4.07	3.95	0.1949	1.54	0.12	2.45	0.72	116.99
Cycle 4 (1975 and 1979)											
Reps (Over years)	7	0.8909*	15,651	22.87**	12.45**	1.2888**	11.25**	0.12	17.45**	4.20**	-‡
Populations (P)	15	27.5968**	85,660**	8.68*	15.67**	3.5970**	22.49**	0.96**	20.84**	17.86**	-
Years (Y)	1	127.3921**	211,519**	30.01**	1.73	66.7819**	116.32**	0.36*	3,292.61**	2.68	-
P x Y	15	1.2021**	37,991**	4.87	7.46*	0.3844	3.16†	0.28**	3.60	2.18*	-
Error	105	0.4186	13,687	4.14	3.50	0.2656	1.95	0.07	2.86	1.10	-

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively. ‡ Trait not estimated in 1975 or 1979.

Table 2. Direct and correlated responses to selection for fiber length within the second selection cycle populations.

Popu-lations	2.5% span l. (mm)		Lint yield (kg/ha)		Lint percent (%)		50% span l. (mm)	Unif. index (%)	Fiber fineness (µg/inch)	Fiber strength (mN/tex)				Earliness (%)	
										T_0		T_1			
	1973	1974	1973	1974	Picked	Pulled				1973	1974	1973	1974	1973	1974
HII	1.02*	-0.23	-158*	-184**	0.4	-2.0*	0.27	0.1	-0.51**	15.7†	-4.9	20.6**	9.8†	-15.4**	-20.9*
HIL	2.24**	2.77**	-4	-157**	-0.8	-2.6**	1.04**	-0.6	-0.33*	0.0	-18.6†	8.8†	-20.6**	-13.5*	-24.3*
LII	0.61	1.12†	-5	63	-1.8*	-1.9*	0.28	-0.4	0.06	-7.8	-15.7	-9.8†	-6.9	-0.4	0.7
LL	2.18**	1.40*	110	112*	2.4*	2.4*	0.43†	-2.0**	-0.53**	-54.9**	-21.6†	-1.0	-11.8*	-11.4*	10.9

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 3. Direct and correlated responses to selection for fiber length within the third selection cycle populations.

Popu- lations	2.5% span l.		Lint yield		Lint percent			50% span l.	Unif. index		Fiber fineness		Fiber strength		
					Picked	Pulled							T₀	T₁	
	1975	1979	1975	1979		1975	1979		1975	1979	1975	1979		1975	1979
	— mm —		— kg/ha —		— % —			mm	— % —		— µg/inch —		— mN/tex —		
IIII	2.18**	1.73**	-86	308**	-0.6	-2.5*	1.5	0.26	-3.1**	-1.2	-0.54**	0.00	18.6*	21.6**	0.0
IIIL	1.55**	1.14*	-262**	-66	2.1*	-0.8	-0.4	0.39	0.2	-1.8	-0.52**	-0.15	3.9	15.7*	-8.8
IIII	0.53	0.97†	-129*	-2	-1.7	-3.1**	-0.5	0.00	-1.3	-1.0	-0.12	0.30	11.8	-2.9	1.0
IILL	2.34**	2.06**	-255**	-128	1.6	-3.8**	0.4	0.64**	-3.0**	0.7	-0.72**	0.00	1.0	8.8	5.9
LIII	1.75**	0.10	-145*	-45	-0.9	-2.6*	1.6	0.38	-0.1	-0.6	0.20	0.15	0.0	11.8†	3.9
LIIL	3.00**	1.75**	-181**	-302**	-2.3*	-3.3**	-3.2*	1.00**	-1.6†	0.6	-0.46**	-0.10	14.7*	8.8	10.8
LIII	1.85**	1.73**	-5	-26	-1.2	-1.9	-1.0	0.37	-1.7*	-2.1†	0.06	-0.70**	20.6*	6.9	15.7*
LLL‡	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively. ‡ An apparent error in the composition of population LLLL nullified this comparison.

Table 4. Direct and correlated responses to selection for fiber length within the fourth selection cycle populations.

Populations	2.5% span l. (mm)	Lint yield (kg/ha)	Lint percent		50% span l. (mm)	Unif. index (%)	Fiber fineness (µg/inch)	Fiber strength (mN/tex)	
			Picked (%)	Pulled (%)				T_0	T_1
IIIII	2.39**	-45	-1.7†	-2.6**	0.76**	-1.3†	-0.82**	27.5**	24.5**
IIIIL	2.13**	-3	-0.5	-0.6	0.91**	-0.3	-0.32	2.0	21.6**
IIIILI	-0.08	76†	-0.7	-0.2	0.05	0.3	-0.10	-13.7	-12.8†
IIIILL	1.91**	-48	-6.6**	-4.6**	0.43	-1.7*	-0.65**	20.6*	18.6*
IIILII	1.02*	8	-2.9**	-2.4**	0.36	-0.4	-0.16	0.0	3.9
IIILIL	1.78**	-35	-0.7	0.4	0.81**	-0.2	0.02	-2.9	1.0
IIILLI	-0.41	58	0.4	-0.3	-0.05	0.4	-0.47*	8.8	-8.8
IIILLL	3.76**	-187**	-4.0**	-5.9**	1.68**	-0.3	0.03	-18.6†	17.7*
LIIII	0.48	-93*	-2.0*	-1.1	-0.43	-2.4**	-0.40†	39.2**	12.8†
LIIIL	2.26**	6	-2.7**	-1.3†	0.36	-2.6**	0.01	74.6**	14.7*
LIILI	2.29**	37	-3.8**	-2.8**	0.71**	-1.4*	-1.21**	-6.9	24.5**
LIILL	4.72**	-78†	-3.6**	-1.7*	1.42**	-3.5**	-0.70**	29.4**	20.6**
LILII	1.12**	-18	0.3	0.3	-0.03	-2.1**	-0.40†	-11.8	-7.8
LILIL	1.25**	0	-1.5†	-1.8*	0.20	-1.5*	-0.58*	2.9	13.7*
LILLI	3.33**	-18	0.7	0.0	0.81**	-3.5**	-1.00**	10.8	12.8†
LLLL‡	..	-	-	-	-	-	-	-	-

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
‡ An apparent error in the composition of population LLLL nullified this comparison.

Table 5. Realized heritability estimates and standard errors for fiber length.

Cycle 0	Cycle 1	Cycle 2 1973	1974	Cycle 3 1975	1979	Cycle 4
						H 0.51±0.08*
		H 0.25±0.09*	-0.06±0.15	H 0.53±0.08*	0.42±0.14*	L 0.44±0.08*
						H -0.03±0.13
	H 0.27			L 0.38±0.08*	0.28±0.14*	L 0.46±0.09*
						H 0.27±0.10*
		L 0.58±0.10*	0.72±0.16*	H 0.15±0.09	0.28±0.16	L 0.51±0.11*
						H -0.56±0.12*
BASE 0.71				L 0.48±0.07*	0.43±0.12*	L 0.88±0.09*
						H 0.12±0.10
		H 0.14±0.09	0.26±0.15	H 0.50±0.09*	0.03±0.16	L 0.51±0.09*
						H 0.56±0.10*
	L 0.55			L 0.68±0.07*	0.40±0.13*	L 0.84±0.07*
						H 0.29±0.10*
		L 0.48±0.08*	0.30±0.13*	H 0.40±0.07*	0.37±0.12*	L 0.29±0.09*
						H 0.69±0.08*
				L -†	-†	L -†

* Significant at the 0.05 probability level, † An apparent error in the composition of population LLLL nullified this comparison.

Fig. 1. Response to five cycles of multidirectional selection
for fiber fineness in cotton.

Multidirectional Selection

in Upland Cotton.

II. Fiber Strength

Multidirectional Selection

in Upland Cotton.

II. Fiber Strength[1]

ABSTRACT

Multidirectional selection for T_1 fiber strength was conducted
through five cycles of selection within a genetically variable popu-
lation of upland cotton (Gossypium hirsutum L.). The population was a
mixture comprised of equal amounts of mature seed from 45 F_2 populations.
The stronger-fibered 10% of the plants, as well as the weaker-fibered
10%, in the population were selected in each cycle. Selfed seed from
selected plants were used to form new populations for testing and
further selection.

Analyses of variance detected significant differences among popu-
lations for all traits in selection cycles three, four, and five except
for fiber fineness in cycle four. No genotype by environment inter-
actions were detected for fiber strength. Response to selection for
fiber strength was effective. After four cycles of selection under
enforced self-pollination, half the populations possessed enough genetic
variability to show significant selection responses in the fifth
selection cycle. One generation of reverse selection for fiber strength
was often followed by dramatic increases in variability and selection
response; however, two or more low selections had a detrimental effect

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on later selections for high fiber strength. Selections for stronger
fiber tended to result in lower picked and pulled lint percents;
increased were 2.5 and 50% span length, uniformity index, and T_0 fiber
strength; variable responses were obtained for lint yield and fiber
fineness.

Additional index words: Gossypium hirsutum L., Selection response,
Correlated response, Realized heritability, Lint yield, Lint percent,
Fiber length, Uniformity index, Fiber fineness, Earliness.

INTRODUCTION

Effective selection results from a detailed knowledge of the crop
in question, the inheritance of the traits under selection, the relative
stability of their performance under various climatic regimes, and the
direction and magnitude of correlated responses among the traits of
interest. In conducting selection studies, researchers can incorporate
most, if not all, of those factors into a single investigation. A
general review of selection studies was presented in the previous paper
of this series.

The experiment reported herein was a multidirectional, long-term
selection study for T_1 fiber strength in a genetically variable popu-
lation of upland cotton (Gossypium hirsutum L.), including correlated
responses with other traits of economic importance in the crop.

Verhalen and Murray (12,13) and Verhalen et al. (11) have reported
genetic analyses for the seed source used to construct the initial
population in this study. Those reports indicate a narrow-sense
heritability estimate for T_1 fiber strength of 0.62 in the F_2 with gene
action in the partial dominance range. Fiber length had a narrow-sense
heritability of 0.49 in the F_2 with long fiber being partially dominant
over short while fiber fineness displayed a narrow-sense heritability
of 0.19 and overdominant gene action. The studies also showed lint
yield, lint percent, and earliness to be governed by overdominance in
the F_2 with no epistasis and estimates of heritability ranging from
0.15 to 0.31.

The relative stability in fiber strength performance over years, locations, or both in Oklahoma has been studied by Murray and Verhalen (7). The only significant genotype by environment (GE) interaction they found was that for cultivars by years; however, it's variance component was only 14% as large as the cultivar component and thus was judged to be of only minimal importance. A confounded GE study (one location, 2 years) of the parental material used in this study was unable to show a significant years by parents mean square for fiber strength (13).

Miller et al. (6) reported genotypic correlations between fiber strength vs. lint yield (-0.01 to -0.34), lint percent (-0.24 to 0.07), fiber length (-0.23 to 0.33), and fiber fineness (-0.31 to 0.06) with similar phenotypic correlations. Woodward and Malm (14) failed to detect significant phenotypic correlations between fiber strength vs. lint yield, lint percent, fiber length, or fiber fineness. Quisenberry et al. (9) showed fiber strength and length to be unrelated in their material; whereas, fiber strength and fineness were closely and positively related. A recurrent selection program (5) for increased lint yield demonstrated a decrease in fiber strength as yield increased and a general decline in the genetic variances for most unselected traits.

Results presented by Scholl and Miller (10) agree with previous determinations that lint yield and fiber strength were negatively correlated. Strength was also negatively correlated with lint percent and fiber fineness, but positively related to fiber length. Miller and Rawlings (4) obtained results suggesting linkage as a contributing factor to that negative association. They found six generations of

intermating in an isolation block with approximately 50% self-fertil-ization changed the genetic correlation between lint yield and fiber strength within their population from -0.69 to -0.35. Similar results by Meredith and Bridge (3) and by Culp et al. (1) corroborate their findings.

This research was conducted to evaluate the direct and indirect responses to five cycles of multidirectional selection for T_1 fiber strength within a genetically variable population of upland cotton.

MATERIALS AND METHODS

This experiment was initiated and conducted simultaneously, though separately, with the fiber length study reported in the previous paper of this series. A multidirectional selection procedure for T_1 fiber strength was conducted through five selection cycles at Perkins, Okla., on a Teller loam soil (a fine-loamy, mixed, thermic Udic Argiustolls). Ten percent of the harvested plants in the first cycle were selected based on their high fiber strength and bulked to form a high (H) population and the 10% with the weakest fiber were selected and bulked to form a low (L) population. The same procedures were followed in each population for five cycles, thereby resulting in 32 populations (i.e., HHHHH, HHHHL,..., LLLLL). Selfed seed were used throughout this study to comprise the subsequent generations.

Replicated field trials were conducted among the populations after selection cycles three, four, and five in 1973 and 1974, 1975 and 1979, and 1980, respectively, at Tipton, Okla., on a Tipton silt loam soil (a fine-loamy, mixed, thermic Pachic Argiustolls). Further details as to the composition of the initial population, selection procedures and resulting populations, and replicated trials can be found in the previous paper.

Agronomic traits investigated were lint yield in kg/ha, picked lint percent {(lint weight/seedcotton weight) x 100}, pulled lint percent {(lint weight/seedcotton plus bur weight) x 100}, and earliness as percent first harvest {(lint weight from the first harvest/total

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lint weight from all harvests) x 100}. Earliness was estimated in the 1973 and 1974 tests only. Fiber properties investigated were 2.5 and 50% span lengths (in inches, converted to mm) as measured on the digital fibrograph; uniformity index, the ratio of 50 to 2.5% span length, expressed as a percentage; fiber fineness measured on the micronaire in standard curvilinear micronaire units (i.e., µg/inch); and fiber strength on the stelometer as 0" gauge (i.e., T_0) and 1/8" (3.175 mm) gauge (i.e., T_1) in grams force/tex converted into mN/tex.

Selection response within a population for fiber strength was calculated as the difference between the mean performance (as estimated from replicated trials) of the high vs. low selections from that population. Correlated responses to selection were measured in the same manner for traits on which selection was not practiced. Realized heritability estimates for fiber strength were calculated using Falconer's (2) formula: R/S, where R is response to selection (as estimated from replicated trials) and S is the selection differential (i.e., the difference between the means of the high and low groups at the time selections were made).

All data from replicated trials were subjected to analyses of variance. Selection cycles three and four were analyzed in separate years as well as pooled over years. The populations sums of squares were partitioned into a set of orthogonal contrasts to evaluate differences between high vs. low selections within a population (i.e., direct and correlated responses). The populations sums of squares for T_1 fiber strength were partitioned into another set of contrasts (not orthogonal) to investigate differences among populations with an equal number of high (H) selections in their pedigree (ignoring the order in

which they occur) within a selection cycle. The contrasts were compared to the experimental-error term (an F-test) to evaluate their level of significance.

RESULTS AND DISCUSSION

Analyses of variance pooled over years for selection cycle three
(Table 1) showed significant differences among populations for T_1 fiber
strength, and all other traits investigated. The source of variation
attributable to years was likewise significant for all traits. The
populations by years interaction was used as an indicator of genotype
by environment interaction, though the term is confounded with a
location effect. Viewing the interaction as such, the relative perfor-
mance of T_1 fiber strength, the trait for which selection was practiced,
was stable over the 2 years of testing. Of the other traits investi-
gated, only lint yield and pulled lint percent exhibited significant
interaction terms in selection cycle three.

Table 1 also contains the analyses for selection cycle four popu-
lations performed over years. Highly significant differences were
detected among populations for all traits except fiber fineness, while
the effects due to years were significant for all but pulled lint
percent and fiber fineness. The significant interactions in the cycle
four analyses included lint yield and all of the fiber properties. The
interaction of pulled lint percent was not significant, as it had been
in cycle three. Analyses of variance for the cycle five selections
(not shown) exhibited significant differences among populations for all
traits studied.

The data used to construct Fig. 1 were adjusted for year effects
in the manner described by Patterson (8). Data in cycles zero through

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two were estimated by assuming that high-low selections within a
population were equally effective and by averaging all succeeding
populations that originated from that point within each cycle (three
through five), then averaging over cycles. The data in cycles three
through five are adjusted means from replicated field trials, with
cycles three and four being averaged over two environments each.
Single values are shown in the figure because the interaction term
involving populations and years was not significant.

Previous work in this material has indicated that some dominant
alleles increase strength while others decrease it (13). Continuous
forward selection would be expected to decrease genetic variability by
increasing the frequency of genes favorable to the direction of
selection. Conversely, the variability gained through practicing
reverse selection and shifting gene frequency toward the opposite
direction should allow these populations to approach or exceed the
magnitude of the continuously forward selected populations. This
situation appears to have occurred in the third cycle with the LHL and
LLL populations. The continuously high selected population was
apparently not affected in this manner until the fourth cycle when the
HHLH, HLHH, HLHL, and HHHL populations were near, or greater than,
HHHH. Reverse selection practiced in HH and HHH were followed by
dramatic increases in variability and selection response. This
phenomenon can also be observed in several initially low-selected
populations as well, e.g., LH, LHHL, and LLHL. One explanation for
this observation may be that effective selection was being practiced
in a variable population which contained numerous genes governing
large dominant effects for both strong and weak fiber; and homozygosity

was being approached in many of the loci involved. A reverse selection probably shifted the gene frequency back toward the point of optimum selection effectiveness; thereby, allowing large gains to be made in the following selection cycle. It could be that a single generation of reverse selection increases genetic variability in the same manner as does relaxation of selection pressure for several generations in Drosophila and mice (2).

The slope of the line formed by the continuously high selected populations is approximated by that connecting the L population to the LHHH. This suggests that variability for high strength was not drastically decreased by one generation of low selection. The line connecting the LL and LLHHH populations exhibits a flatter slope while that connecting the LLL and LLLHH is flatter still. These trends imply that the frequency of genes for high strength declined as two or more selections for weaker fiber were practiced. Similar trends were not detected in the populations selected initially for strong fiber.

The non-orthogonal partition of the populations sum of squares for fiber strength (not shown) indicated that the order in which the high and low selections were made in constructing the populations of selection cycle three had an effect on a population's performance in 1973 but not in 1974. Both evaluations of cycle four, and the single evaluation of cycle five, indicated that the order in which high and low selections occurred in a pedigree affected the performance of a population.

Phenotypic correlations with T_1 fiber strength in the original, unselected population were calculated for all traits upon which data were available. Positive correlations were found for T_1 vs. 2.5 and

50% span length, and uniformity index (0.32, 0.51, and 0.30, respec-
tively), while a value of -0.17 was found for T_1 vs. fiber fineness.
The first three correlations were significant at the 0.01 probability
level while the latter was significant at the 0.05 level.

Values in Table 2 are presented in accordance with the method of
presentation as suggested by the analyses of variance in Table 1. The
data indicate that effective selections for T_1 fiber strength were made
in the HH and LH populations but not in HL or LL. The 1973 data of
cycle three show that selections for higher strength positively
influenced the direction of yield response in two populations, but had
a negative effect in the other two. The trend was the same for HH in
1974, but reversed for LH. Picked lint percent declined with high
strength selections in three of four populations as did pulled lint
percent in 1973. No significant differences were detected for pulled
lint percent in the 1974 data. A tendency to increase with selection
for stronger fiber was exhibited by 2.5% span length in two populations
and by 50% span length in three of four populations. Uniformity index
increased in the HH, LH, and LL populations while fiber fineness was
significantly affected in only one population. T_0 fiber strength
changed significantly only in the LL population, and it was in the
negative direction! This negative response in T_0 was unexpected since
T_0 and T_1 are both measures of fiber strength. Selection for stronger
fiber favored earliness in three of four populations.

Selections practiced for T_1 fiber strength in the third cycle
populations (Table 3) were effective only in the HHL population.
Correlated responses for lint yield were largely nonsignificant,
although three significant increases were detected over the 2 years.

Both picked and pulled lint percents showed significant decreases in two populations. A positive correlated response was detected in HLL for both lint percents, while only picked lint percent displayed that response in LLH. The 2.5% span length showed five increases with stronger fiber selection in 1975, but one increase and two declines in 1979. The 50% span length exhibited two positive, significant responses in 1975 and one in 1979. Three positive responses in 1975, but none in 1979, were found for uniformity index. Fiber fineness was relatively unaffected although one significant, positive response was found in 1975. T_0 fiber strength significantly increased in three populations in 1975 and in five of eight in 1979.

Data from T_1 fiber strength selections made in the fourth selection cycle populations (Table 4) indicate that considerable genetic variability remained in the populations at that time. Significant increases were found in eight populations, while a significant decline was noted in one! Eight of the sixteen populations showed significant changes in lint yield due to selection for fiber strength; five were negative, three positive. Six of seven populations showing significant differences in picked lint percent were negative, while all six significant changes in pulled lint percent were negative. Seven of the nine significant changes in 2.5% span length were increases in fiber length with selection for stronger fiber while six of seven significant deviates in 50% span length were increases. Uniformity index significantly increased in five populations and decreased in another. Only two significant responses were detected for fiber fineness; one positive, the other negative. Where significant differences were found for T_0 fiber strength, all six were in the positive direction.

Falconer (2) indicates that the validity of the heritability estimates presented in Table 5 is based upon the assumptions that observed selection response is not confounded with systematic changes in generation means due to environment or the effects of inbreeding and that maternal effects are absent. However, he does indicate that regardless of the validity of the estimate as narrow-sense heritability, the values obtained provide excellent descriptions of selection effectiveness. This argument indicates that the best use of the realized heritabilities presented is to evaluate selection effectiveness since severe inbreeding in the form of self-pollination was imposed throughout the study.

The estimates in Table 5 follow the trends exhibited in Fig. 1. In cycle two, the LH estimate is the only one differing from zero at the 0.05 probability level, and it is the population exhibiting the most response to selection. The same can be said of the HHL population in cycle three and the HHHH, HHHL, LLHL, LHHL, HLHL, and HHLH populations in cycle four.

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Table 1. Analyses of variance for fiber strength selections pooled over years for selection cycles three and four.

Source	df	T_1 fiber strength	Lint yield	Lint percent Picked	Lint percent Pulled	Span length 2.5%	Span length 50%	Unif. index	Fiber fineness	T_0 fiber strength	Earliness
Cycle 3 (1973 and 1974)											
Reps (Over years)	7	5.79**	6,222	4.67	12.03†	0.4091	0.4158†	4.04**	0.31**	6.09†	304.49**
Populations (P)	7	24.80**	30,460**	21.93**	17.75**	7.4919**	2.6660**	7.68**	0.20*	29.12**	769.21**
Years (Y)	1	15.90**	2,423,829**	112.17**	276.50**	75.4490**	29.8921**	28.93**	1.41**	19.60*	8,671.06**
P x Y	7	1.31	47,816**	5.16	16.36*	0.6396	0.1760	1.52	0.12	1.47	106.90
Error	49	1.75	6,031	4.36	5.86	0.6286	0.2102	1.04	0.09	3.27	83.93
Cycle 4 (1975 and 1979)											
Reps (Over years)	7	6.36**	10,736	3.81	0.92	1.0076**	0.7389**	7.59**	0.10†	15.85**	-‡
Populations (P)	15	41.16**	35,662**	23.20**	16.30**	15.8089**	5.4032**	10.83**	0.04	37.97**	-
Years (Y)	1	15.55**	293,508**	10.78†	0.83	189.4365**	55.0572**	18.45**	0.09	3,127.08**	-
P x Y	15	2.12	17,424*	3.59	1.95	1.1481**	0.4284**	2.31†	0.16**	5.83**	-
Error	105	1.48	8,710	3.11	2.13	0.3235	0.1894	1.47	0.06	2.23	-

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively. † Trait not estimated in 1975 or 1979.

Table 2. Direct and correlated responses to selection for fiber strength within the second
selection cycle populations.

Populations	T1 fiber strength mN/tex	Lint yield 1973	1974	Lint percent Picked	Pulled 1973	1974	Span length 2.5%	50%	Unif. index	Fiber fineness	T0 fiber strength	Earliness
		—— kg/ha ——		———————— % ————————			—— mm ——		%	µg/inch	mN/tex	%
IHI	10.8†	160**	117*	-1.9†	-2.2*	-1.5	-0.26	0.45*	2.1**	-0.05	9.8	8.5*
IIL	6.9	164**	1	0.2	0.3	0.8	0.78*	0.36	-0.1	-0.19	5.9	-5.8
III	24.5**	-114*	219**	-1.6†	-3.2**	-3.3	0.62†	0.73**	1.7**	0.28*	-2.0	18.1**
IL	6.9	-200**	61	-3.0**	-3.2**	-1.9	-0.04	0.33†	1.5**	-0.02	-17.7†	10.8*

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 3. Direct and correlated responses to selection for fiber strength within the third selection cycle populations.

Populations	T₁ fiber strength mN/tex	Lint yield 1975 kg/ha	Lint yield 1979 kg/ha	Lint percent Picked %	Lint percent Pulled %	Span length 2.5% 1975 mm	Span length 2.5% 1979 mm	Span length 50% 1975 mm	Span length 50% 1979 mm	Unif. index 1975 %	Unif. index 1979 %	Fiber fineness 1975 µg/inch	Fiber fineness 1979 µg/inch	T₀ fiber strength 1975 mN/tex	T₀ fiber strength 1979 mN/tex
HHH	3.9	-77	-15	-0.9	-0.9	0.58†	0.38	0.03	0.15	-1.0	-0.1	0.14	0.00	12.8	27.5*
HHL	65.7**	24	-46	-4.1**	-3.4**	3.53**	4.55**	2.21**	2.36**	2.2**	0.9	0.18	-0.02	60.8**	73.6**
HLH	2.0	-40	161*	0.1	0.5	0.61*	-0.10	0.25	-0.05	-0.1	0.0	-0.08	0.13	11.8	21.6†
HLL	3.9	77	-37	1.8*	1.8**	-0.13	-1.12*	0.05	-0.25	0.4	1.0	0.24†	0.00	7.8	32.4**
LHH	4.9	-28	-80	-0.5	-0.3	-0.41	-0.20	0.18	-0.28	1.4†	-0.7	0.08	-0.08	9.8	-14.7
LHL	-8.8	92†	-89	-4.3	-2.0**	0.86**	0.51	0.31	0.41	-0.3	0.6	0.06	0.22	27.5**	-8.8
LLH	1.0	26	104	1.5†	0.5	0.08	0.25	0.41	0.31	1.7*	0.7	-0.10	-0.05	-13.7	-6.9
LLL	6.9	123*	25	0.4	-0.3	0.97**	-0.91†	0.61*	-0.13	0.6	1.1	-0.06	0.02	20.6*	23.5*

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 4. Direct and correlated responses to selection for fiber strength within the fourth selection cycle populations.

Populations	T₁ fiber strength mN/tex	Lint yield kg/ha	Lint percent Picked	Lint percent Pulled	Span length 2.5%	Span length 50%	Unif. index %	Fiber fineness µg/inch	T₀ fiber strength mN/tex
IHHHI	44.1**	-130**	-2.8**	-4.1**	0.71†	1.55**	4.5**	0.25	-10.8
IHHH	52.0**	-75*	-1.8†	-2.9**	0.69	0.89**	2.2**	-0.12	25.5*
IHHJI	21.6**	-57†	-1.8†	-2.7**	0.33	0.33	0.6	-0.10	18.6†
IHLJ	-7.8	-6	0.7	0.2	0.38	0.33	0.8	-0.23	11.8
IHJHI	11.8†	-75*	-1.4	-1.8†	-0.03	0.36	1.3	0.03	77.5**
IHJH	22.6**	61†	1.9*	0.8	1.04*	1.25**	2.8**	0.22	-6.9
IHLJI	6.9	70*	-0.3	0.1	0.51	0.13	-0.4	0.08	-3.9
HLIL	-12.8†	29	0.2	0.3	-1.70**	-0.53†	1.2	0.05	23.5*
IJHHI	8.8	-45	-0.5	0.2	0.46	0.13	-0.4	0.07	20.6*
IJHH	20.6**	-110**	-2.0*	-1.6	0.74†	0.25	-0.4	-0.01	-5.9
IHJI	8.8	-9	-0.4	1.4	0.46	0.69*	1.8*	0.45*	-3.9
IJHLJ	5.9	64†	-4.3**	-2.2*	1.32**	0.79**	0.7	0.03	37.3**
IJJHI	8.8	3	1.3	0.4	-0.74†	-0.08	1.1	0.10	16.7
IJJH	35.3**	26	-0.7	0.3	1.30**	0.97**	1.5†	-0.20	10.8
IJJI	11.8†	14	-0.5	-1.9*	0.94*	0.10	-1.4†	-1.04**	-7.8
IJJL	8.8	7	-2.5**	-1.4	0.99*	0.46	0.1	0.10	7.8

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 5. Realized heritability estimates and standard errors for fiber strength.

Cycle 0	Cycle 1	Cycle 2		Cycle 3		Cycle 4
		1973	1974	1975	1979	
		H 0.11±0.10	0.23±0.16	H -0.13±0.17	0.35±0.13*	H 0.74±0.11*
						L 0.87±0.11*
	H 0.00			L 0.70±0.10*	0.80±0.08*	H 0.30±0.09*
						L -0.22±0.18
		L 0.12±0.09	0.07±0.16	H 0.11±0.15	-0.04±0.12	H 0.22±0.13
						L 0.43±0.13*
BASE 0.89				L 0.10±0.20	0.07±0.17	H 0.13±0.12
						L -0.30±0.16
	L 0.41	H 0.45±0.15*	0.75±0.26*	H 0.24±0.16	-0.05±0.13	H 0.18±0.14
						L 0.43±0.14
				L -0.37±0.21	-0.02±0.17	H 0.26±0.20
						L 0.13±0.15
		L 0.05±0.12	0.22±0.20	H 0.00±0.18	0.06±0.15	H 0.19±0.15
						L 0.77±0.15*
				L 0.23±0.17	0.02±0.13	H 0.28±0.16
						L 0.20±0.16

* Significant at the 0.05 probability level.
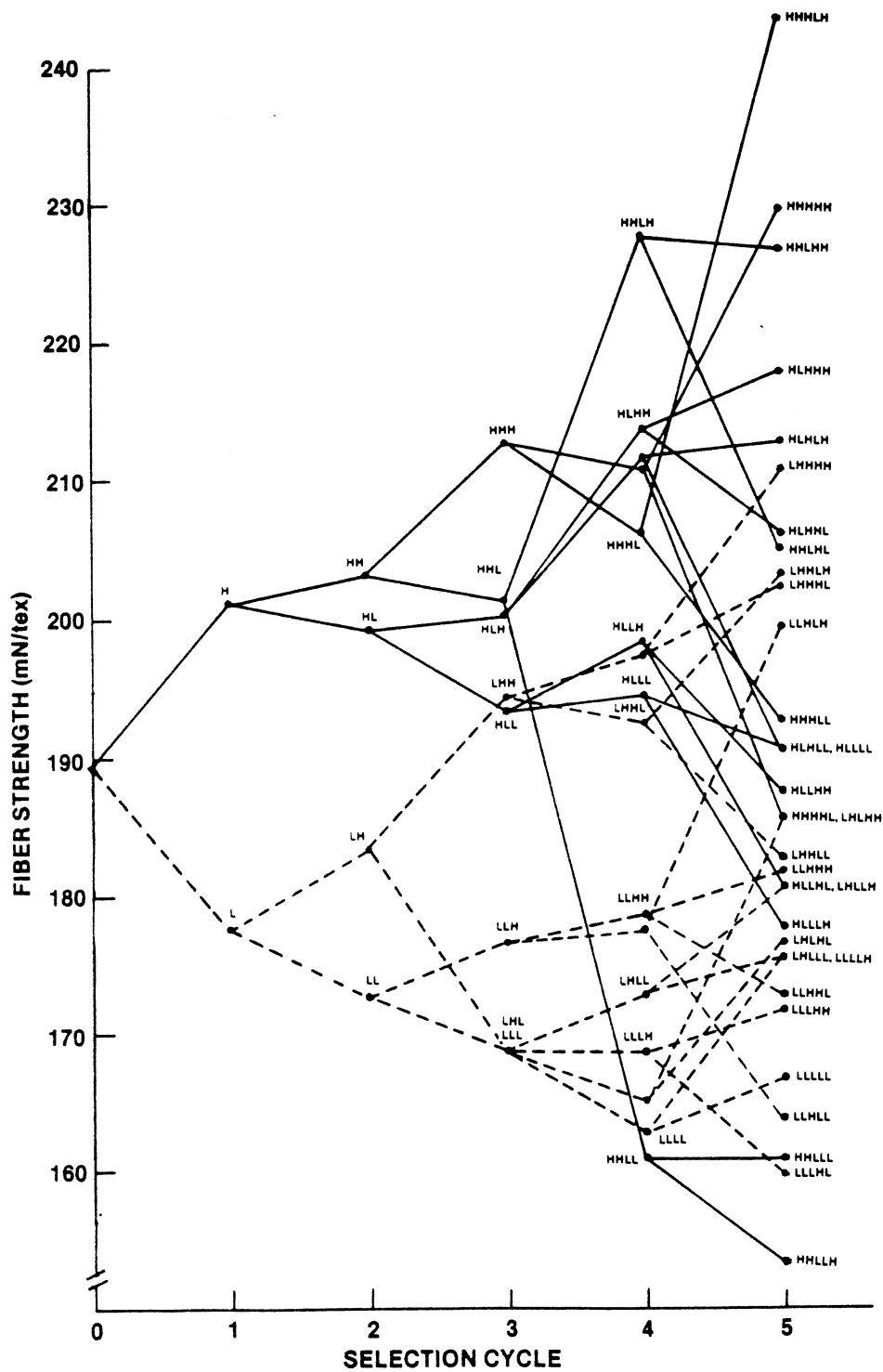
Fig. 1. Response to five cycles of multidirectional selection
for fiber strength in cotton.

Multidirectional Selection

in Upland Cotton.

III. Fiber Fineness

Multidirectional Selection

in Upland Cotton.

III. Fiber Fineness[1]

ABSTRACT

Multidirectional selection for fiber fineness was practiced through
five selection cycles within a genetically variable population of upland
cotton (Gossypium hirsutum L.). The initial population was composed of
equal amounts of mature seed from 45 F_2 populations. The extreme 10%
of the plants at each end of the population distribution were selected
based upon their fiber fineness. Selfed seed from those selected plants
were bulked to form new high and low populations for further selections
and replicated trials.

Analyses of variance showed significant differences among popu-
lations for all traits in selection cycles three, four, and five except
for pulled lint percent and T_1 fiber strength in cycle three. Signif-
icant populations by years interactions were detected for fiber fineness
in cycle four, but not in cycle three; however, the interaction variance
component was only 24% as large as the populations variance component in
cycle four. Selections toward higher micronaire (i.e., coarser fiber)
were generally effective through five cycles; whereas, those toward
lower micronaire (finer fiber) apparently reached a limit after only

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two selections. One reverse selection for fiber fineness apparently greatly reduced the genetic variability of the trait. Selections for coarser fiber tended to result in shorter 2.5% span length and in higher uniformity index. All other traits except earliness displayed significant correlated responses, but no general trends in direction were evident among those correlations.

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Additional index words: Gossypium hirsutum L., Selection response, Correlated response, Realized heritability, Lint yield, Lint percent, Fiber length, Uniformity index, Fiber strength, Earliness.

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INTRODUCTION

Fiber fineness of upland cotton (Gossypium hirsutum L.) is a trait
of economic importance to producers; however, it is an unusual charac-
teristic in that it has a range of acceptable values, and producers are
penalized when the lint fineness of their cotton falls outside those
boundaries. Generally, unidirectional selection for higher or lower
fineness values are not made by breeders; rather, stabilizing selection
is practiced to retain fiber fineness within the prescribed range.
With that point in view, a long-term, multidirectional selection study
for fiber fineness was conducted through five cycles of selection in a
genetically variable population of upland cotton with attention given
also to its relationships with other traits of importance.

A general overview of two-way selection studies has been presented
in the first paper of this series; therefore, those sources will not be
duplicated herein. Only those studies pertaining directly to fiber
fineness are summarized below.

Verhalen et al. (10) and Verhalen and Murray (11, 12) have
reported genetic studies on the seed source used to comprise the
initial population of this experiment. They report a narrow-sense
heritability estimate in the F_2 of 0.19 for fiber fineness and over-
dominant gene action (with some dominant genes increasing fineness
values and yet others decreasing them). The instability of fiber
fineness estimates under Oklahoma environmental conditions has been
reported by Murray and Verhalen (6). Indicated by their work was the

need to test the trait in multiple environments to obtain reliable performance estimates.

Miller et al. (5) reported genotypic, and similar phenotypic, correlations for fiber fineness vs. lint yield (-0.25 to -0.71), lint percent (-0.09 to -0.43), fiber length (0.16 to 0.70), and fiber strength (-0.31 to 0.06). Woodward and Malm (13) detected no significant phenotypic correlations for fiber fineness vs. lint percent, lint yield, 2.5% span length, or fiber strength. Quisenberry et al. (8) found a positive relationship in their selected lines between fiber fineness vs. fiber strength. Their work detected no relationship between fiber fineness vs. lint yield or lint percent. The relationship for fiber fineness vs. earliness changed from -0.21 to 0.33 during their selection process.

Meredith and Bridge (2) found that two generations of random intermating in a population after the F_3 affected the relationships of several traits with fiber fineness when comparing the original to the intermated population. They found the genotypic correlations to become larger for fiber fineness vs. lint yield (0.42 to 0.65), lint percent (0.37 to 0.48), 2.5% span length (-0.42 to -0.52), and T_1 fiber strength (-0.21 to -0.26) while the correlation with 50% span length declined (0.09 to -0.05). Miller and Rawlings (3) have reported similar results for fiber fineness with lint yield, fiber length, and fiber strength.

Miller and Rawlings (4) reported that as lint yield increased in a recurrent selection program, fiber fineness showed a slight tendency to decrease. With successive cycles of selection, the genetic variance for fineness, as well as for most other traits, showed a general decline in magnitude. Scholl and Miller (9) predicted that selection for fiber

fineness in their material would increase lint yield and lint percent, decrease 2.5% span length and fiber strength, and have no effect on 50% span length.

This experiment was conducted to evaluate the direct and indirect responses to five cycles of multidirectional selection for fiber fineness within a segregating population of upland cotton.

MATERIALS AND METHODS

In 1968, three separate populations were constructed in the same manner from selfed seed of 45 F_2's originally developed for a 10-parent diallel study (10, 11, 12). One population was selected within only for fiber length (those results are reported in the first paper of this series), another for only fiber strength (the second paper in this series), and the last for fiber fineness (the topic of this paper). The five multidirectional selection cycles and replicated field trials for all three trait-selection populations were conducted simultaneously.

Selection was practiced for the extreme 10% of the population distribution for both coarse and fine fiber in the original population at Perkins, Okla., on a Teller loam soil (a fine-loamy, mixed, thermic Udic Argiustolls). Selfed seed from the selected plants were bulked to form two populations, H (composed of the coarse-fiber selections) and L (composed of the fine-fiber selections). This procedure of selecting 10% at both extremes of the population distribution and bulking the selfed seed of selected plants to form the next generation populations was followed in each population for five cycles.

Replicated field trials were conducted on the populations derived from selection cycle two populations in 1973 and 1974, those developed from selection cycle three populations in 1975 and 1979, and those selected from selection cycle four materials in 1980 at Tipton, Okla., on a Tipton silt loam soil (a fine-loamy, mixed, thermic Pachic

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Argiustolls). Further details of the procedures followed can be found in the first paper of this series.

Data were gathered from the replicated trials for several agronomic and fiber traits. The agronomic traits investigated in all trials were lint yield in kg/ha, picked lint percent {(lint weight/ seedcotton weight) x 100}, and pulled lint percent {(lint weight/ seedcotton plus bur weight) x 100}. Earliness as percent first harvest {(first harvest lint weight/total harvested lint weight) x 100} was estimated only in the 1973 and 1974 evaluations. The fiber traits measured were 2.5 and 50% span lengths on the digital fibrograph (in inches, converted to mm); uniformity index, the ratio of 50 to 2.5% span length, expressed as a percentage; fiber fineness on the micronaire in standard curvilinear micronaire units (i.e., μg/inch); and fiber strength as 0" gauge (i.e., T_0) and 1/8" (3.175 mm) gauge (i.e., T_1) stelometer in grams-force/tex converted into mN/tex.

Selection response, both direct and correlated, was calculated as the difference in the mean performance (from replicated trials) of the high and low populations developed from that population. Realized heritability was calculated using Falconer's (1) formula: R/S, where R is the response to selection (as obtained from replicated trials) and S is the selection differential (i.e., the difference between the mean of high and low selections from a population at the time those selections were made).

Analyses of variance were performed on all traits from the replicated trials. Analyses were performed for selection cycle three and four in separate years and pooled over years. The populations sums of squares were partitioned into a set of orthogonal contrasts that

evaluated the statistical significance of the difference between high vs. low selections within a population (i.e., direct and correlated responses). The populations sums of squares for fiber fineness were also partitioned into a set of nonorthogonal contrasts to determine if differences existed among populations containing an equal number of high (H) selections in their pedigree (ignoring order) within a selection cycle. An F-test was employed to evaluate the statistical significance of the contrasts.

In the 1974 field trial among the selections made in the cycle two populations, HHH, LLH, and LLL were not planted due to a lack of seed. Therefore, direct and correlated responses to selection in the HH and LL populations could not be evaluated in that year.

RESULTS AND DISCUSSION

Analyses of variance for selection cycle three pooled over years
(Table 1) indicate significant differences among populations for all
traits except pulled lint percent and T_1 fiber strength. Differences
among years were noted for all traits except the two measures of fiber
strength. The source of variation attributable to the populations by
years interaction provides a confounded (2 years, one location)
estimate of genotype by environment interaction. None of those inter-
actions were found to be significant.

Significant differences were detected among populations for all
traits in the cycle four analyses pooled over years (Table 1). All
traits except picked lint percent showed   significant differences
among years. Significant populations by years interactions were shown
by all fiber traits, including fiber fineness, but not for lint yield
or either lint percent. Analyses of variance for selection cycle five
populations (not shown) displayed significant differences among popu-
lations for all traits studied.

Fig. 1 presents the fiber fineness data for all selection cycles
adjusted by Patterson's (7) technique. Utilizing a single data point
for each population in cycle three was permissible because the inter-
action between populations and years was not significant. Following
this procedure in cycle four was more questionable because a signif-
icant interaction term was detected between populations and years;
however, the interaction variance component was only 24% of the

magnitude of the populations component. Therefore, any bias introduced into the figure by presenting the data in this fashion was probably not major. The values for cycles three through five represent data collected from replicated field trials, while the values for cycles zero through two were estimated by calculating the means of all data points in cycles three, four, and five independently which originated from the point being estimated and then averaging over cycles. This process assumes that the high and low selections within a population were equally effective.

A study of Fig. 1 reveals that the populations selected continuously in the high direction showed a fairly steady increase in micronaire readings (i.e., toward coarser fiber); whereas, those selected continuously in the low direction appeared to have reached a limit (or plateaued) after only two selections. Tracing selections from the LH population through the LHHHH compared to HH through HHHHH leads one to believe that the initial low selection greatly reduced the frequency of genes concerned with higher micronaire readings because the rapidity of progress decreased dramatically after the third cycle of selection. The reversal of selection in the LH population to produce LHL appears to have increased variability. This is suggested by the relative distance between the LHLHH and LHLLL populations. Selections within the HHLH population produced populations which also appeared considerably different. Selections within the HHHH population were considerably greater than all other populations in cycle five.

The nonorthogonal partition of the populations sums of squares for fiber fineness (not shown) indicated that in selection cycle three significant differences occurred among all populations receiving two

high selections (regardless of order) and also among those populations receiving only one high selection in 1973. The 1974 data indicated that no differences occurred among those populations receiving two high selections; no comparisons among those populations receiving only one high selection could be made because LLH was not grown. The evaluation of the cycle four means detected significant differences among populations receiving three high selections and among those receiving two high selections in 1975. Differences were detected only among those populations receiving one high selection in 1979. Evaluation of the 1980 trial of cycle five populations detected differences among populations receiving three high selections, among those receiving two high selections, and also among those receiving one high selection. A general trend over all selection cycles suggests that the order in which the high selections occurred affects the performance of a population.

Phenotypic correlations with fiber fineness were calculated in the unselected base population for 2.5% span length and T_1 fiber strength. Data were not available for the other traits investigated in this paper. Selection for coarser fiber should result in only minimal changes in 2.5% span length {r = -0.15 (significant at the 0.10 probability level)} and T_1 fiber strength (r = -0.13).

Estimates of direct and correlated response to selection for fiber fineness in the cycle two populations are presented in Table 2 for each year separately. Responses in the HH and LL populations could not be calculated in 1974 because HHH, LLH, and LLL were not planted due to a lack of seed. Response to selection for fiber fineness was significant in three of six comparisons. Significant correlated responses were

detected for lint yield in one comparison (negative), for picked and pulled lint percent in three comparisons each (both had two positive, one negative), for 2.5% span length in four (one positive, three negative), for 50% span length in four (two positive, two negative), for uniformity index in three (all positive), for T_0 fiber strength in one (positive), for T_1 fiber strength in two (one positive, one negative) and for earliness in none.

An evaluation of selections made within the third cycle populations is presented in Table 3. Response to selection for fiber fineness was significant in five of 16 comparisons (all positive). Among the agronomic traits, significant correlated selection responses were observed for lint yield in 50% of the populations (two positive, two negative), for picked lint percent in 50% (two positive, two positive), and for pulled lint percent in 50% (one positive, three negative). Significant correlated selection responses among the fiber traits were found for 2.5% span length in nine of 16 populations (four positive, five negative), for 50% span length in eight (four positive, three negative), for uniformity index in seven (five positive, two negative), for T_0 fiber strength in eight (five positive, three negative), and for T_1 fiber strength in five (two positive, three negative).

Significant, but negative, responses were detected for fiber fineness selection made in the HHHH and HLLH populations of cycle four (Table 4). Positive responses for fiber fineness selection were detected in four populations. Significant correlated responses among the agronomic traits were noted for lint yield in five of 16 populations (three positive, two negative), for picked lint percent in seven (five positive, two negative), and for pulled lint percent in nine (six

positive, three negative). Among the fiber traits, significant corre-
lated responses were detected for 2.5% span length in seven (two
positive, five negative), for 50% span length in six (three positive,
three negative), for uniformity index in eight (seven positive, one
negative), for T_0 fiber strength in four (two positive, two negative),
and for T_1 fiber strength in five (two positive, three negative).

The estimates of realized heritability {Falconer (1)} presented
in Table 5 serve to reinforce earlier conclusions as to the relative
ineffectiveness of selection for fiber fineness in this material. Of
the estimates presented for selections made in cycles two through four,
only 11 of 38 estimates were significantly different from zero.

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LIST OF TABLES AND FIGURE

Table 1. Analyses of variance for fiber fineness selections pooled over years for selection cycles three and four.

				Mean squares							
		Fiber	Lint	Lint percent		Span length		Unif.	Fiber strength		
Source	df	fineness	yield	Picked	Pulled	2.5%	50%	index	T_0	T_1	Earliness
Cycle 3 (1973 and 1974)											
Reps (Over years)	7	0.16	9,547	1.32	5.01	0.2496	0.1024	0.75	7.51*	3.38**	117.63
Populations (P)	4	0.83**	32,591*	9.55†	10.96	8.0875**	0.8745**	13.97**	9.05*	1.03	207.15*
Years (Y)	1	1.56**	1,335,621**	37.58**	153.18**	14.6454**	7.7477**	14.16**	1.60	0.03	6,820.01**
P x Y	4	0.34	12,843	3.08	3.87	0.9145	0.1344	2.84	2.67	1.53	109.22
Error	28	0.18	9,205	3.78	9.88	0.5746	0.1285	1.40	2.39	0.79	64.11
Cycle 4 (1975 and 1979)											
Reps (Over years)	7	0.13	22,942†	36.60**	24.65**	1.5385**	1.5032**	9.64**	19.44**	5.33**	-‡
Populations (P)	15	1.69**	123,669**	26.72**	18.83**	18.4718**	2.0301**	19.69**	22.58**	8.29**	-
Years (Y)	1	2.36**	257,721**	9.34	11.59†	222.5460**	87.0964**	85.28**	2,891.81**	4.10†	-
P x Y	15	0.28**	12,869	2.97	4.42	3.7844**	0.6709**	2.72*	4.06†	3.58**	-
Error	105	0.11	11,430	3.95	3.59	0.4291	0.1825	1.29	2.43	1.22	-

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively. ‡ Trait not estimated in 1975 and 1979.

Table 2. Direct and correlated responses to selection for fiber fineness within the second selection cycle populations.

Popu-lations	Fiber fineness 1973	1974	Lint yield 1973	1974	Lint percent Picked 1973	1974	Pulled 1973	1974	Span Length 2.5% 1973	1974	50% 1973	1974	Unif. index 1973	1974	Fiber strength T₀ 1973	1974	T₁ 1973	1974	Earliness 1973	1974
	— µg/inch —		— kg/ha —		———— % ————				———— mm ————				—— % ——		———— mN/tex ————				— % —	
III	0.80**	-‡	71	-‡	-0.4	-‡	-0.8	-‡	-1.37**	-‡	0.13	-‡	2.6**	-‡	-10.8	-‡	-4.9	-‡	5.0	-‡
IIL	0.02	0.70*	-133*	-72	-1.6**	-0.5	-1.2†	-2.5	-0.76†	-0.28	-0.46†	0.18	-0.3	1.2†	-11.8	-8.8	-13.7*	2.9	5.2	8.5
LII	0.64*	0.18	56	28	1.8**	-0.3	1.3†	-0.8	0.71†	0.01	0.76**	0.48*	1.5*	0.8	-3.9	2.9	3.9	4.9	-8.3	-1.1
LL	0.06	-‡	41	-‡	4.4**	-‡	3.6**	-‡	-1.30**	-‡	-0.48†	-‡	0.4	-‡	15.7†	-‡	10.8†	-‡	3.8	-‡

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively. ‡ One or both populations required to estimate this value were not grown in 1974 because of insufficient seed.

Table 3. Direct and correlated responses to selection for fiber fineness within the third selection cycle populations.

Popu-lations	Fiber fineness 1975	1979	Lint yield	Lint percent Picked	Pulled	Span length 2.5% 1975	1979	50% 1975	1979	Unif. index 1975	1979	Fiber strength T0 1975	1979	T1 1975	1979
	— µg/inch —		kg/ha	——— % ———		————— mm —————				——— % ———		————— mN/tex —————			
IHHI	1.26**	0.05	-198**	-0.2	-1.5†	-6.66**	-2.34**	1.80**	-0.33	5.8**	3.0**	2.0	2.9	-30.4**	2.0
IHIL	0.06	0.50*	7	1.7†	-0.2	2.06**	0.38	1.17**	0.15	1.0	-0.1	-2.0	-5.9	21.6**	5.9
IHJI	0.20	0.02	99*	3.0**	3.2**	-0.81†	-1.04*	0.20	-0.25	2.2**	0.9	-33.4**	-58.9**	-2.9	-13.7*
HIL	0.62**	-0.05	-329**	-3.3**	-2.2*	-2.03**	-0.36	-1.07**	-0.66*	-0.5	-1.8*	18.6†	6.9	-24.5**	-7.8
IIHI	0.16	0.13	-53	-0.8	-1.1	-0.23	-0.08	-0.20	-0.05	1.3†	0.0	26.5*	18.6†	3.9	2.9
IIHL	0.76**	0.45†	174**	0.7	0.8	1.45**	1.30**	0.79**	0.91**	0.6	1.2	-14.7	18.6†	10.8	4.9
LIJI	0.22	0.33	-49	0.8	-0.2	0.48	-0.46	0.28	0.23	0.2	1.6†	8.8	14.7	4.9	6.9
LLL	0.24	-0.05	-39	-2.5**	-3.0**	-0.58	1.70**	-0.69*	0.61*	-1.5*	-0.5	18.6†	-19.6†	3.9	12.8†

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 4. Direct and correlated responses to selection for fiber fineness within the fourth selection cycle populations.

Populations	Fiber fineness µg/inch	Lint yield kg/ha	Lint percent Picked (%)	Lint percent Pulled (%)	Span length 2.5% (mm)	Span length 50% (mm)	Unif. index (%)	Fiber strength T₀ (mN/tex)	Fiber strength T₁ (mN/tex)
IHHHI	-0.37†	2	0.3	-0.4	-3.15**	-0.97**	3.1**	-10.8	-37.3**
IHHIL	0.21	-20	1.2	0.5	-0.53	-0.05	0.7	-19.6†	-10.8
IHIJI	0.84**	63†	1.9*	3.0**	0.28	0.51†	1.3†	-1.0	-2.0
IHILL	-0.19	-9	-1.1	-1.6*	-0.94*	-0.89**	-1.9**	6.9	-5.9
IHLHI	-0.19	-26	-0.8	-0.5	-0.51	-0.31	-0.2	-5.9	6.9
IHLIL	-0.23	5	-0.2	0.2	0.38	0.36	0.6	-15.7	-5.9
IHLLI	-0.66**	-96**	-2.5**	-1.9*	-2.62**	-0.74**	2.1**	-6.9	-10.8†
IILLL	0.00	15	1.1	0.5	-0.13	-0.15	-0.3	1.0	10.8
LIHHI	0.05	-41	-1.7†	-2.3**	-0.43	0.03	0.9	15.7	2.9
LIHIL	0.40*	57†	1.7†	2.7**	-0.23	0.28	1.4*	-14.7	-2.9
LIIJI	0.03	83*	-0.1	0.2	1.45**	1.17**	2.0**	17.7†	16.7*
LIILL	0.35†	41	1.2	0.9	-0.18	-0.08	0.1	-10.8	-6.9
LLHHI	-0.30	-40	4.2**	3.2**	-0.71†	0.48†	3.2**	-22.6†	6.9
LLHIL	0.54**	-83*	6.5**	4.1**	-1.50**	-0.13	2.2**	-11.8	-3.9
LLIJI	-0.02	45	1.6†	1.6*	0.64†	0.20	-0.2	-2.0	14.7*
LLLL	-0.17	7	1.3	1.4†	-0.28	-0.33	-0.7	17.7†	-12.8†

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 5. Realized heritability estimates and standard errors for fiber fineness.

Cycle 0	Cycle 1	Cycle 2		Cycle 3		Cycle 4
		1973	1974	1975	1979	
				H 0.92±0.15*	0.04±0.17	H -0.17±0.09
		H 0.37±0.12*	-†			L 0.15±0.13
	H 0.20			L 0.04±0.15	0.35±0.16*	H 0.74±0.17*
						L -0.18±0.18
				H 0.11±0.12	0.01±0.13	H -0.14±0.13
		L 0.01±0.10	0.27±0.10*			L -0.19±0.15
				L 0.48±0.16*	-0.04±0.18	H -0.41±0.12*
BASE 0.13						L 0.00±0.16
				H 0.11±0.15	0.09±0.16	H 0.04±0.12
		H 0.27±0.11*	0.08±0.11			L 0.24±0.12*
	L 0.57			L 0.48±0.13*	0.28±0.15	H 0.03±0.14
						L 0.28±0.15
				H 0.13±0.13	0.20±0.14	H -0.44±0.29
		L 0.03±0.14	-†			L 0.81±0.29*
				L 0.19±0.17	-0.04±0.19	H -0.03±0.26
						L -0.30±0.31

* Significant at the 0.05 probability level. † One or both populations required to estimate this value were not grown in 1974 because of insufficient seed.

Fig. 1. Response to five cycles of multidirectional selection for fiber length in cotton (Populations LLLL, LLLLH, and LLLLL not shown because of an apparent error in the composition of LLLL).

Multidirectional Selection

in Upland Cotton.

IV. APPENDIX

(Tables 1 through 21)

Table 1. Analyses of variance for fiber length selections in 1973 and 1974 or pooled over years for selection cycle three.

	df‡		2.5% span l.		Lint yield		Lint percent		50% span l.	Unif. index	Fiber fineness
Source	1973	1974	1973	1974	1973	1974	Picked	Pulled			
Reps	4	3	0.0033**	0.0003	40,962*	264	3.29	6.46	0.3703†	1.76	0.22
Populations	7	7	0.0544**	0.0322**	82,637**	33,084**	13.48**	23.97**	6.5155**	19.43**	1.83**
HHI-HHL	1	1	0.0040*	0.0002	61,994*	67,271**	1.02	19.88*	0.1830	0.00	1.23**
HHI-HLL	1	1	0.0195**	0.0238**	36	49,172**	2.88	31.74**	4.6430**	2.15	0.54*
HHI-LHL	1	1	0.0014	0.0039†	60	8,009	16.51*	19.83*	0.4000	0.60	0.03
LLI-LLL	1	1	0.0182**	0.0059*	30,118	25,088*	23.87*	26.14*	0.7799†	16.99**	1.11**
Error	28	21	0.0005	0.0012	10,746	3,970	4.07	3.95	0.1949	1.54	0.12

(Mean squares)

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
‡ 7, 7, 1, 1, 1, 1, and 49 df, respectively, for the traits pooled over years (1973 and 1974).

Table 1. (Continued)

	df‡		Mean squares					
			Fiber strength				Earliness	
			T₀		T₁			
Source	1973	1974	1973	1974	1973	1974	1973	1974
Reps	4	3	1.03	8.81*	10.44**	6.33**	165.93†	29.58
Populations	7	7	12.90**	7.48*	7.58**	10.28**	490.96**	365.22†
HHH-HHL	1	1	6.56†	0.55	11.45**	2.10†	592.90**	875.71*
HLH-HLL	1	1	0.02	7.03†	2.40†	8.41**	455.63*	1,180.98*
LHH-LHL	1	1	1.68	4.96	2.50†	0.78	0.48	1.05
LLH-LLL	1	1	78.96**	9.25†	0.00	3.00*	329.48*	236.53
Error	28	21	2.20	2.30	0.81	0.59	72.53	176.27

Table 2. Analyses of variance for fiber length selections in 1975 and 1979 or pooled over years for selection cycle four.

Source	df‡ 1975	df‡ 1979	2.5% span l. 1975	2.5% span l. 1979	Lint yield 1975	Lint yield 1979	Lint percent Picked	Pulled 1975	Pulled 1979	50% span l.	Unif. index 1975	Unif. index 1979
Reps	4	3	0.0008	0.0022†	7,312	26,769	22.87**	1.94	26.48**	1.2888**	10.20**	12.66**
Populations	15	15	0.0284**	0.0163**	87,761**	35,892†	8.68*	15.90**	7.24†	3.5970**	16.39**	9.27**
IHHHI-IHHIL	1	1	0.0185**	0.0093**	18,209	189,728**	0.90	15.13*	4.50	0.3371	24.03**	3.00
IHHJI-IHH.L	1	1	0.0092**	0.0041*	172,008**	8,733	20.02*	1.76	0.28	0.5460	0.05	6.48
IHJHI-IHJHL	1	1	0.0011	0.0028†	41,907*	10	10.03	24.34**	0.61	0.0019	4.36	2.10
IHJJI-IHLLL	1	1	0.0212**	0.0132**	161,595**	32,604	2.69	37.64**	0.41	2.1089**	23.10**	0.91
IJHHI-IJHHL	1	1	0.0118**	0.0001	52,510*	4,115	2.47	16.38*	4.81	0.4858	0.03	0.55
LJHJI-IJHLL	1	1	0.0345**	0.0096**	82,505**	182,553**	22.35*	26.24**	20.48*	4.4855**	6.40†	0.72
LJJHI-LJJHL	1	1	0.0134**	0.0092**	72	1,415	7.69	8.45	2.10	0.5933	7.92*	8.82†
LJJJI-LLLL	1	1	0.0643**	0.0134**	17,829	583	1.52	0.12	3.13	0.0280	100.49**	43.25**
Error	60	45	0.0004	0.0431	8,424	20,704	4.14	3.06	4.08	0.2656	1.66	2.35

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
‡ 7, 15, 1, 1, 1, 1, 1, 1, 1, 1, and 105 df, respectively, for the traits pooled over years.

Table 2. (Continued)

	df‡		Fiber fineness		Fiber strength		
						T_1	
Source	1975	1979	1975	1979	T_0	1975	1979
Reps	4	3	0.03	0.25†	4.20**	4.98**	3.16†
Populations	15	15	0.87**	0.37**	17.86**	12.53**	7.52**
IHHHI-IHHIL	1	1	0.73**	0.00	5.50*	12.10**	0.00
IHHJI-IHHL	1	1	0.68**	0.05	0.63*	6.40*	1.45
IIIJHI-IHJHL	1	1	0.04	0.18	0.08	0.26	0.01
IHLJI-IHLL	1	1	1.30**	0.00	2.53	1.85	0.85
LIHHI-LIHIL	1	1	0.10	0.05	2.64	3.25†	0.32
IJHJI-IJILI	1	1	0.53	0.02	4.40*	2.21	2.21
LIJHI-LIHL	1	1	0.01	0.98**	5.88*	1.23	5.12*
LIJII-LILL	1	1	2.12**	0.02	12.54**	8.65**	4.50†
Error	60	45	0.06	0.09	1.10	0.97	1.26

Table 3. Analyses of variance for fiber length selections in 1980 for selection cycle five.

				Mean squares						
		2.5%	Lint	Lint percent		50%	Unif.	Fiber	Fiber strength	
Source	df	span l.	yield	Picked	Pulled	span l.	index	fineness	T0	T1
Reps	5	0.0040**	62,659**	5.06†	4.91*	0.0020**	6.00**	0.38*	6.47†	8.21**
Populations	31	0.0341**	28,301**	31.80**	33.58**	0.0055**	12.86**	1.31**	28.31**	18.80**
IHHHHI-IHHHIL.	1	0.0263**	5,971	9.01†	21.07**	0.0026**	4.81†	2.00**	24.94**	19.00**
IHHIIJI-IHHILJ.	1	0.0211**	34	0.70	0.96	0.0040**	0.33	0.30	0.08	15.41**
IHIIJHI-HHIIJIL.	1	0.0000	17,486†	1.54	0.14	0.0000	0.16	0.03	8.60	5.07†
IHILIJI-IHILLI.	1	0.0173**	6,958	129.36**	64.40**	0.0009	8.50*	1.27**	13.87*	9.36*
IHIJHHI-HIJHIL.	1	0.0048*	221	24.37**	16.80**	0.0005	0.61	0.08	0.00	0.44
IHIJHIJI-IHIJILL.	1	0.0147**	3,578	1.47	0.65	0.0032**	0.10	0.00	0.27	0.05
IHIJIHI-HILIJIL.	1	0.0007	10,241	0.52	0.24	0.0000	0.61	0.65*	2.00	2.71
IHLIJII-IHLLL.	1	0.0653**	104,116**	47.20**	103.84**	0.0131**	0.30	0.00	10.83†	9.72*
IJHHHI-IJHHIL.	1	0.0010	26,133*	11.80*	3.41	0.0009	17.28**	0.48†	48.40**	4.81†
IJHIIJI-IJHHLL.	1	0.0239**	135	20.80**	5.47†	0.0006	19.76**	0.00	173.28**	6.60*
IJHIJHI-IJHIJIL.	1	0.0243**	4,140	43.70**	22.69**	0.0024**	5.88*	4.44**	1.54	19.51**
IJHLIJI-IJHLLL.	1	0.1045**	18,003†	39.24**	9.36*	0.0092**	37.45**	1.47**	26.70**	12.81**
IJJHHI-IJJHIL.	1	0.0057**	943	0.37	0.30	0.0000	13.65**	0.48†	4.08	2.52
LIJHIJI-LIJIILL.	1	0.0073**	0	6.90†	9.90*	0.0002	7.21*	1.02*	0.37	6.16*
LIJIJHI-LIJIJIL.	1	0.0521**	924	1.61	0.00	0.0031**	36.40**	3.00**	3.63	5.60†
LLIJIJI-LLLLL.	1	0.0021†	4,968	15.87*	8.67*	0.0003	0.04	0.21	18.01*	18.50**
Error	155	0.0007	5,086	2.46	1.91	0.0003	1.45	0.17	3.17	1.51

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 4. Mean performance for three fiber traits by year for fiber length selections for selection cycle three.

Populations	2.5% span 1.		Fiber fineness		T_1 fiber strength	
	1973	1974	1973	1974	1973	1974
	— mm —		— µg/inch —		— mN/tex —	
HHH	29.85	27.43	3.74	3.43	219.7	209.0
HHL	28.83	27.66	4.14	4.08	199.1	199.1
HLH	28.88	26.95	4.66	4.28	202.1	213.9
HLL	26.65	24.18	4.88	4.75	193.3	193.3
LHH	27.43	26.29	4.48	4.18	194.2	191.3
LHL	26.82	25.17	4.58	3.90	204.0	198.2
LLH	24.11	22.81	4.50	4.63	182.5	165.8
LLL	21.92	21.41	5.30	4.83	183.4	177.6
$LSD_{0.05}$	0.76	1.30	0.46	0.51	11.5	10.8

Table 5. Mean performance for three fiber traits by year for fiber
length selections for selection cycle four.

Populations	2.5% span 1.		Fiber fineness		T_1 fiber strength	
	1975	1979	1975	1979	1975	1979
	—— mm ——		— µg/inch —		— mN/tex —	
HHHH	29.01	30.76	2.98	3.45	220.7	206.0
HHHL	26.82	29.03	3.52	3.45	199.1	206.0
HHLH	27.36	29.16	3.40	3.25	188.4	181.5
HHLL	25.81	28.02	3.92	3.40	172.7	190.3
HLHH	27.41	28.75	3.66	3.85	196.2	193.3
HLHL	26.87	27.79	3.78	3.55	199.1	192.3
HLLH	27.20	28.47	3.34	3.45	185.4	203.1
HLLL	24.87	26.42	4.06	3.45	176.6	197.2
LHHH	26.62	28.32	3.82	3.78	189.3	188.4
LHHL	24.87	28.22	3.62	3.63	177.6	184.4
LHLH	26.16	27.61	3.66	4.00	186.4	183.4
LHLL	23.17	25.86	4.12	4.10	177.6	172.7
LLHH	24.79	26.21	4.04	3.48	169.7	176.6
LLHL	22.94	24.49	3.98	4.18	162.8	160.9
LLLH	21.69	25.25	4.86	4.10	176.6	180.5
LLLL+	-	-	-	-	-	-
LSD$_{0.05}$	0.66	1.12	0.30	0.43	11.8	15.7

+ An apparent error was made in the composition of LLLL.

Table 6. Mean performance for three fiber traits in 1980 for fiber
          length selections for selection cycle five.

Populations	2.5% span 1.	Fiber fineness	T$_1$ fiber strength
	mm	µg/inch	mN/tex
HHHHH	30.10	3.23	244.3
HHHHL	27.71	4.05	219.7
HHHLH	29.03	3.48	238.4
HHHLL	26.90	3.80	216.8
HHLHH	28.12	3.28	203.1
HHLHL	28.19	3.38	215.8
HHLLH	27.18	3.28	202.1
HHLLL	25.27	3.93	183.4
HLHHH	29.41	3.87	221.7
HLHHL	28.40	4.03	217.8
HLHLH	28.12	4.30	221.7
HLHLL	26.34	4.28	220.7
HLLHH	28.07	4.08	209.9
HLLHL	28.47	4.55	218.8
HLLLH	28.55	4.20	209.0
HLLLL	24.79	4.17	191.3
LHHHH	27.33	3.43	207.0
LHHHL	26.85	3.83	194.2
LHHLH	27.74	3.58	205.0
LHHLL	25.48	3.57	190.3
LHLHH	27.38	3.52	218.8
LHLHL	25.10	4.73	194.2
LHLLH	27.15	4.00	209.0

Table 6.(Continued)

Populations	2.5% span 1. mm	Fiber fineness µg/inch	T_1 fiber strength mN/tex
LHLLL	22.43	4.70	188.4
LLHHH	26.19	4.03	190.3
LLHHL	25.07	4.43	198.2
LLHLH	24.82	4.20	182.5
LLHLL	23.57	4.78	168.7
LLLHH	25.40	3.92	197.2
LLLHL	22.07	4.92	184.4
LLLLH†	-	-	-
LLLLL†	-	-	-
$LSD_{0.05}$	0.76	0.46	13.7

†Deleted from analyses because of an apparent error in the composition of LLLL.

Table 7. Analyses of variance for fiber strength selections in 1973 and 1974 or pooled over years for selection cycle three.

Source	df‡ 1973	df‡ 1974	T₁ fiber strength	Lint yield 1973	Lint yield 1974	Lint percent Picked	Lint percent Pulled 1973	Lint percent Pulled 1974	Span length 2.5%	Span length 50%	Unif. index	Fiber fineness	T₀ fiber strength	Earliness
Reps	4	3	5.79**	5,638	7,000	4.67	5.33†	20.98	0.4091	0.4158†	4.04**	0.31**	6.09†	304.49**
Populations	7	7	24.80**	45,000**	33,277**	21.93**	25.83**	8.29	7.4919**	2.6060**	7.68**	0.20*	29.12**	769.21**
IHHI-IHIL	1	1	6.06†	63,949**	27,135*	17.07†	11.66*	4.35	0.1667	0.9936*	19.46**	0.01	3.48	363.21*
IIHI-IHL	1	1	2.10	67,030**	1	0.31	0.32	1.36	2.6152*	0.5449	0.03	0.20	0.89	173.47
IJHI-IJIL	1	1	29.36**	32,499*	95,397**	12.84†	26.57**	21.78	1.8645†	2.4466**	13.11**	0.37*	0.12	1,460.07**
LJII-LJL	1	1	2.55	100,705**	7,248	41.34**	25.92**	6.85	0.0035	0.6158†	11.27**	0.00	12.25†	559.75*
Error	28	21	1.75	6,589	5,288	4.36	2.12	10.85	0.6287	0.2102	1.04	0.09	3.27	83.93

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
‡ 7, 7, 1, 1, 1, 1, and 49 df, respectively, for the traits pooled over years.

Table 8. Analyses of variance for fiber strength selections in 1975 and 1979 or pooled over years for selection cycle four.

	df‡		T₁ fiber	Lint yield		Lint percent		Span length 2.5%		Span length 50%		Unif. index		Fiber fineness		T₀ fiber strength	
Source	1975	1979	strength	1975	1979	Picked	Pulled	1975	1979	1975	1979	1975	1979	1975	1979	1975	1979
Reps	4	3	6.36**	2,816	21,296	3.81	0.92	0.0017**	0.0014	0.0018**	0.0004	11.88**	1.89	0.15*	0.04	13.10**	19.53**
Populations	15	15	41.16**	37,886**	15,199	23.20**	16.30**	0.0129**	0.0135**	0.0049**	0.0042**	9.43**	3.72**	0.12*	0.09	22.43**	21.38**
HHHH-HHHL	1	1	1.42	14,844	457	2.24	3.34	0.0013†	0.0004	0.0000	0.0001	2.30	0.02	0.05	0.00	4.22	15.13*
HHHH-HHLL	1	1	204.15**	1,409	4,269	75.99**	53.98**	0.0482**	0.0643**	0.0188**	0.0172**	12.54**	1.53	0.08	0.00	94.86**	113.25**
HHHH-HHHL	1	1	0.09	4,110	51,842*	0.09	1.46	0.0013*	0.0000	0.0002	0.0000	0.04	0.01	0.02	0.03	3.48	10.13†
HHLL-HHLL	1	1	0.55	14,844	2,732	14.04*	15.42**	0.0001	0.0039*	0.0000	0.0002	0.40	2.10	0.14†	0.00	1.52	21.13**
LLHH-LLHH	1	1	1.12	1,929	12,826	1.88	0.60	0.0007	0.0002	0.0001	0.0003	5.18†	0.98	0.02	0.01	2.21	4.65
LLHH-LLHL	1	1	2.86	21,293†	15,956	88.31**	20.54**	0.0030**	0.0008	0.0004	0.0005	0.26	0.78	0.01	0.10	20.45**	1.45
LLHH-LLHH	1	1	0.08	1,717	21,815	10.47†	1.57	0.0000	0.0002	0.0007	0.0003	6.89*	0.91	0.03	0.05	4.76	1.13
LLLL-LLLL	1	1	1.98	37,396*	1,298	1.14	0.13	0.0036**	0.0026†	0.0014*	0.0001	0.96	2.53	0.01	0.00	11.66*	11.52*
Error	60	45	1.48	5,984	12,358	3.11	2.13	0.0003	0.0007	0.0003	0.0003	1.49	1.44	0.05	0.06	1.78	2.84

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively. ‡ 7, 15, 1, 1, 1, 1, 1, 1, 1, 1, and 105 df, respectively, for the traits pooled over years.

Table 9. Analyses of variance for fiber strength selections in 1980 for selection cycle five.

Source	df	T_1 fiber strength	Lint yield	Lint percent Picked	Lint percent Pulled	Span length 2.5%	Span length 50%	Unif. index	Fiber fineness	T_0 fiber strength
Reps	5	6.57**	11,530**	4.83	5.50†	0.0043**	0.0018**	9.12**	0.07	5.17
Populations	31	29.12**	29,598**	16.81**	15.99**	0.0119**	0.0051**	15.16**	0.85**	22.90**
IIIIIII-IIIIIIIIL	1	61.20**	50,347**	23.80**	50.43**	0.0023†	0.0113**	60.30**	0.19	3.52
IIIIIIJI-IIIIILL	1	81.12**	16,977*	10.08†	26.11**	0.0021	0.0038**	14.08**	0.04	20.54*
IIIIJIII-IIIIJIL	1	14.30**	9,788†	9.54†	20.80**	0.0005	0.0006	1.27	0.03	11.02†
IIIIIJJI-IIIIILL	1	2.00	143	1.27	0.21	0.0007	0.0006	1.61	0.16	4.32
IIIJIIII-IIIIIIIL	1	3.85†	16,977*	5.88	10.15†	0.0000	0.0006	4.94	0.00	24.65**
IIIJIIJI-IIIJILL	1	15.41**	11,178†	11.60*	1.69	0.0050*	0.0070**	22.96**	0.14	1.40
IIIJIIII-IIIJIL	1	1.69	14,779*	0.30	0.03	0.0012	0.0001	0.56	0.02	0.48
IIIJIJI-IIIJLL	1	5.07†	2,577	0.10	0.21	0.0135**	0.0013†	3.97	0.01	17.76*
IJIIIII-IJIIIIIL	1	2.43	6,071	0.70	0.05	0.0010	0.0001	0.40	0.01	13.87*
IJIIIJI-IJIIILL	1	13.02**	36,759**	11.41†	7.05	0.0024†	0.0003	0.44	0.00	1.14
IJIIJII-IJIIJIL	1	2.34	251	0.44	5.88	0.0010	0.0023*	10.45*	0.61*	0.30
IJILJII-IJILLL	1	1.08	12,013†	56.33**	12.81*	0.0081**	0.0029**	1.47	0.00	43.70**
LJIIIII-LJJIIIL	1	2.34	34	5.20	0.40	0.0024†	0.0000	3.52	0.03	9.19
IJJIIJI-LJIIILL	1	39.24**	2,049	1.40	0.37	0.0077**	0.0044**	6.31†	0.12	3.74
LJJIIII-LLJJIL	1	4.32†	604	0.70	11.60*	0.0042*	0.0000	6.02†	3.20**	1.76
LLLJJI-LJJLL	1	2.08	159	38.52**	6.02	0.0046*	0.0010	0.01	0.03	1.69
Error	155	1.40	3,352	2.94	2.91	0.0008	0.0004	1.91	0.12	3.54

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 10. Mean performance for three fiber traits by year for fiber strength selections for selection cycle three.

Populations	T_1 fiber strength 1973	T_1 fiber strength 1974	2.5% span 1. 1973	2.5% span 1. 1974	Fiber fineness 1973	Fiber fineness 1974
	— mN/tex —		— mm —		— μg/inch —	
HHH	215.8	209.9	27.86	26.06	4.06	4.00
HHL	208.0	194.2	28.68	25.63	4.20	3.93
HLH	209.0	190.3	27.89	25.68	4.40	4.00
HLL	200.1	185.4	27.03	25.02	4.40	4.43
LHH	192.3	196.2	26.77	25.58	4.32	4.03
LHL	173.6	163.8	26.42	24.64	4.14	3.63
LLH	176.6	175.6	25.91	23.77	4.10	4.00
LLL	174.6	162.8	26.04	23.72	4.36	3.73
$LSD_{0.05}$	13.4	23.5	0.91	1.32	N.S.	0.44

Table 11. Mean performance for three fiber traits by year for fiber strength selections for selection cycle four.

Populations	T_1 fiber strength 1975	T_1 fiber strength 1979	2.5% span 1. 1975	2.5% span 1. 1979	Fiber fineness 1975	Fiber fineness 1979
	— mN/tex —		— mm —		— µg/inch —	
HHHH	195.2	206.0	26.14	28.22	3.70	3.73
HHHL	202.1	188.4	25.55	27.84	3.56	3.73
HHLH	212.9	220.7	25.68	28.19	3.86	3.53
HHLL	153.0	147.2	22.15	23.65	3.68	3.55
HLHH	200.1	206.0	26.98	29.16	3.66	3.53
HLHL	194.2	208.0	26.37	29.26	3.74	3.40
HLLH	184.4	190.3	24.38	26.16	3.82	3.58
HLLL	180.5	187.4	24.51	27.28	3.58	3.58
LHHH	188.4	177.6	25.02	27.23	3.88	3.30
LHHL	175.6	187.4	25.43	27.43	3.80	3.38
LHLH	140.3	167.8	24.08	27.48	3.44	3.75
LHLL	155.0	168.7	23.22	26.98	3.38	3.53
LLHH	165.8	170.7	24.08	25.78	3.46	3.65
LLHL	165.8	167.8	24.00	25.53	3.56	3.70
LLLH	157.0	159.9	24.18	25.40	3.56	3.80
LLLL	145.2	158.9	23.22	26.31	3.62	3.78
$LSD_{0.05}$	16.6	13.7	0.58	0.99	0.28	N.S.

Table 12. Mean performance for three fiber traits in 1980 for fiber strength selections for selection cycle five.

Populations	T_1 fiber strength mN/tex	2.5% span l. mm	Fiber fineness μg/inch
HHHH	248.2	27.33	4.13
HHHHL	204.0	26.62	3.88
HHHLH	262.9	26.92	3.98
HHHLL	210.9	26.24	4.10
HHLHH	245.3	24.41	3.95
HHLHL	223.7	27.08	4.05
HHLLH	171.7	23.65	3.85
HHLLL	179.5	23.27	4.08
HLHHH	236.4	27.61	4.20
HLHHL	224.6	27.64	4.17
HLHLH	231.5	26.98	4.35
HLHLL	209.0	25.93	4.13
HLLHH	206.0	25.40	4.60
HLLHL	199.1	24.89	4.52
HLLLH	196.2	24.03	4.45
HLLLL	209.0	25.73	4.40
LHHHH	229.6	26.47	4.30
LHHHL	220.7	26.01	4.23
LHHLH	221.7	26.75	4.12
LHHLL	201.1	26.01	4.13
LHLHH	204.0	26.62	3.53
LHLHL	195.2	26.16	3.08
LHLLH	200.1	27.43	4.03

Table 12.(Continued)

Populations	T_1 fiber strength	2.5% span 1.	Fiber fineness
	mN/tex	mm	µg/inch
LHLLL	194.2	26.11	4.00
LLHHH	200.1	24.97	4.03
LLHHL	191.3	25.71	3.93
LLHLH	217.8	26.52	3.85
LLHLL	182.5	25.22	4.05
LLLHH	190.3	25.38	3.23
LLLHL	178.5	24.44	4.27
LLLLH	194.2	26.59	3.28
LLLLL	185.4	25.60	3.18
$LSD_{0.05}$	13.7	0.84	0.40

Table 13. Analyses of variance for fiber fineness selections in 1973 and 1974 or pooled over years for selection cycle three.

	df		Fiber fineness		Lint yield		Lint percent Picked		Lint percent Pulled		Span length 2.5%		Span length 50%	
Source	1973	1974	1973	1974	1973	1974	1973	1974	1973	1974	1973	1974	1973	1974
Reps	4	3	0.38†	0.52*	21,551†	8,340	0.41	7.04	0.25	31.49	0.0002	0.0007	0.0002	0.0001
Populations	7	7	1.51**	0.42*	40,490**	16,470**	19.84**	4.07	14.67**	8.53	0.0015**	0.0042**	0.0009**	0.0006**
IHHI-IHII	1	1	1.60**	0.21	12,526	725	0.48	0.18	1.44	5.95	0.0071**	0.0005	0.0001	0.0006*
IHJI-IHJ	1	1	0.00	0.98*	44,260*	10,196	6.72**	0.61	3.84†	13.01	0.0023†	0.0002	0.0008†	0.0001
IJHI-IJIL	1	1	1.02*	0.06	7,715	1,506	7.74**	0.18	4.36†	1.53	0.0021†	0.0012	0.0022**	0.0007*
LIJI-LLL	1	1	0.01	1.45**	4,247	83	47.96**	0.50	32.04**	8.00	0.0066**	0.0008	0.0009†	0.0010*
Error	28	21	0.17	0.15	8,957	6,364	0.87	8.94	1.17	18.98	0.0007	0.0006	0.0002	0.0001

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 13. (Continued)

| Source | df 1973 | df 1974 | Mean squares | | | | | | | |
			Unif. index 1973	1974	T_0 1973	1974	T_1 1973	1974	Earliness 1973	1974
Reps	4	3	1.18	1.73	5.45*	18.92**	8.43**	2.85**	105.34	303.35*
Populations	7	7	14.00**	3.17*	6.46**	1.82	1.71†	1.00†	158.04*	228.16*
HHH-HHL	1	1	17.69**	2.10	2.92	0.06	0.68	0.15	61.50	45.13
HHH-HLL	1	1	0.23	2.88†	3.72	1.53	4.62*	0.15	66.56	142.81
HHH-HHL	1	1	5.33*	1.20	0.36	0.15	0.36	0.66	170.57	2.31
HHH-LLL	1	1	0.32	2.88†	6.40†	0.21	3.03†	0.08	35.34	933.12**
Error	28	21	1.24	0.92	1.89	2.57	0.76	0.47	60.59	71.55

Table 14. Analyses of variance for fiber fineness selections in 1975 and 1979 or pooled over years for selection cycle four.

	df‡		Fiber fineness		Lint yield	Lint percent		Span length 2.5%		50%		Unif. index	
Source	1975	1979	1975	1979		Picked	Pulled	1975	1979	1975	1979	1975	1979
Reps	4	3	0.06	0.23	22,942†	36.60**	24.65**	0.0027**	0.0021*	0.0011*	0.0040**	2.08	19.73**
Populations	15	15	1.44**	0.54**	123,669**	26.72**	18.83**	0.0270**	0.0075**	0.0032**	0.0010**	14.51**	7.91**
IHHHI-IHHIL	1	1	3.97**	0.01	170,689**	0.22	10.40†	0.1713**	0.0168**	0.0127**	0.0003	84.68**	17.11**
IHHJI-IHILL	1	1	0.01	0.50*	522	13.77†	0.12	0.0164**	0.0005	0.0055**	0.0001	2.50	0.03
IHJHI-IHJIL	1	1	0.10	0.00	45,965*	42.37**	44.03**	0.0026†	0.0033*	0.0002	0.0002	13.00**	1.62
IHJJI-IHJLL	1	1	0.96**	0.01	494,262**	47.09**	20.12*	0.0161**	0.0004	0.0043**	0.0014*	0.63	6.30*
IJHHI-IJHIL	1	1	0.06	0.03	17,111	2.67	5.63	0.0002	0.0000	0.0002	0.0000	3.72†	0.00
IJHJI-IJHLL	1	1	1.44**	0.41†	133,381**	1.10	1.38	0.0081**	0.0052**	0.0024**	0.0027**	0.68	3.00
IJJHI-IJJIL	1	1	0.12	0.21	12,513	3.31	0.02	0.0009	0.0007	0.0003	0.0002	0.17	4.96†
IJJJI-IJJLL	1	1	0.14	0.01	8,909	31.57**	47.16**	0.0014	0.0090**	0.0018	0.0011*	6.24*	0.50
Error	60	45	0.11	0.11	11,430	3.95	3.59	0.0006	0.0007	0.0003	0.0003	1.14	1.49

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively. ‡ 7, 15, 1, 1, 1, 1, 1, 1, 1, and 105 df, respectively, for the traits pooled over years.

Table 14. (Continued)

| | df† | | Mean squares Fiber strength | | | |
| | | | T_0 | | T_1 | |
Source	1975	1979	1975	1979	1975	1979
Reps	4	3	31.87**	2.86	8.52**	1.07
Populations	15	15	11.66**	14.98**	8.21**	3.67**
IHHHI-IHHIL	1	1	0.06	0.21	24.65**	0.08
IHIJI-IHILL	1	1	0.05	0.72	11.88**	0.66
IHJHI-IHJHL	1	1	28.90**	71.40**	0.20	4.35*
IHJJI-IHLLL	1	1	8.46†	1.05	16.38**	1.28
IJHHI-LJHIL	1	1	17.42*	7.41†	0.53	0.21
IJHJI-IJHLL	1	1	5.78	7.41†	2.81	0.55
LJJHI-LJJIL	1	1	1.94	4.96	0.58	1.20
LLJJI-LLLL	1	1	9.03†	7.41†	1.30	3.51†
Error	60	45	2.66	2.14	1.35	1.04

Table 15. Analyses of variance for fiber fineness selections in 1980 for selection cycle five.

Source	df	Fiber fineness	Lint yield	Lint percent		Span length		Unif. index	Fiber strength	
				Picked	Pulled	2.5%	50%		T_0	T_1
Reps	5	0.24†	64,496**	4.54	8.22**	0.0017*	0.0013**	4.69*	9.74**	5.20**
Populations	31	2.34**	12,927**	35.04	19.99**	0.0352**	0.0061**	10.45**	30.47**	18.00**
IØIIØI-IØIØIL	1	0.40†	27	0.19	0.56	0.0460**	0.0042**	28.83**	3.85	41.07**
IIIØIIJI-IIIØILL	1	0.14	1,311	4.20	0.80	0.0013	0.0000	1.47	11.60†	3.63
IIIIJØI-IIIIJIL	1	2.08**	12,155†	11.41*	26.70**	0.0004	0.0012†	5.60†	0.10	0.12
IØILIJI-IØILLL	1	0.10	221	4.20	6.90*	0.0040*	0.0038**	10.45**	1.69	0.96
IILIØØI-IILIØIL	1	0.10	2,078	2.00	0.75	0.0012	0.0004	0.14	1.02	1.33
IILIIIJI-IILIILL	1	0.16	88	0.03	0.05	0.0007	0.0006	1.27	7.21	1.33
IIL.IIIØI-IIL.IJIL	1	1.33**	27,833**	20.02**	11.41*	0.0319**	0.0025**	13.02**	1.47	4.20†
IILLIJI-IILLLL	1	0.00	669	4.08	0.65	0.0001	0.0001	0.30	0.01	3.20
IJIØØI-IJIØIL	1	0.01	5,014	8.67†	16.57**	0.0008	0.0000	2.17	7.36	0.56
IJIIIJI-IJIØLL	1	0.48*	9,788†	8.84†	21.60**	0.0003	0.0003	6.31*	6.60	0.30
IJIIJØI-IJIIJIL	1	0.00	20,887*	0.02	0.19	0.0097**	0.0064**	11.60**	9.19†	8.50*
IJILIJI-IJILLL	1	0.37†	5,198	4.32	2.43	0.0001	0.0000	0.01	3.31	1.27
LIJIØØI-LIJIØIL	1	0.27	4,787	52.08**	31.69**	0.0024†	0.0011†	29.45**	16.80*	1.54
LIJIIJI-LIJIILL	1	0.85**	20,793*	128.05**	48.80**	0.0109**	0.0001	14.96**	4.32	0.52
LIJIJØI-LIJIJIL	1	0.00	6,021	7.68†	7.68*	0.0019†	0.0002	0.19	0.10	6.60*
LILIJI-LLLLL	1	0.08	128	4.56	5.74†	0.0004	0.0005	1.47	9.90†	5.20†
Error	155	0.11	3,567	2.79	1.76	0.0007	0.0004	1.52	3.10	1.46

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 16. Mean performance for three fiber traits by year for fiber fineness selections for selection cycle three.

Populations	Fiber fineness		2.5% span l.		T_1 fiber strength	
	1973	1974	1973	1974	1973	1974
	— µg/inch —		—— mm ——		— mN/tex —	
HHH†	5.10	-	27.05	-	190.3	-
HHL	4.30	4.15	28.42	26.44	195.2	189.3
HLH	4.66	4.80	25.55	24.46	184.4	190.3
HLL	4.64	4.10	26.31	24.74	198.2	187.4
LHH	5.42	4.53	26.72	26.14	193.3	200.1
LHL	4.78	4.35	26.01	25.53	189.3	195.2
LLH†	3.90	-	27.76	-	203.1	-
LLL†	3.84	-	29.06	-	192.3	-
$LSD_{0.05}$	0.53	0.72	0.86	1.15	N.S.	1.2

†Not planted in 1974 due to limited supply of seed.

Table 17. Mean performance for three fiber traits by year for fiber
fineness selections for selection cycle four.

Populations	Fiber fineness		2.5% span 1.		T_1 fiber strength	
	1975	1979	1975	1979	1975	1979
	$-$ µg/inch $-$		$-$ mm $-$		$-$ mN/tex $-$	
HHHH	5.10	3.93	18.87	25.17	142.2	179.5
HHHL	3.84	3.88	25.53	27.51	172.7	177.6
HHLH	.3.98	4.20	29.96	26.95	192.3	177.6
HHLL	3.92	3.70	23.90	26.57	170.7	171.7
HLHH	4.16	3.85	24.51	26.29	173.6	166.8
HLHL	3.96	3.83	25.32	27.33	176.6	180.5
HLLH	4.24	3.58	22.86	27.08	168.7	187.4
HLLL	3.62	3.63	24.89	27.43	193.3	195.2
LHHH	4.60	4.08	25.48	27.81	189.3	197.2
LHHL	4.44	3.95	25.71	27.89	185.4	194.2
LHLH	4.26	3.95	25.58	27.13	180.5	174.6
LHLL	3.50	3.50	24.13	25.83	169.7	169.7
LLHH	3.34	3.48	26.01	27.92	185.4	188.4
LLHL	3.12	3.15	25.53	28.37	180.5	181.5
LLLH	3.48	2.98	26.21	29.90	181.5	187.4
LLLL	3.24	3.03	26.80	28.19	188.4	174.6
$LSD_{0.05}$	0.42	0.47	0.81	0.94	14.7	14.7

Table 18. Mean performance for three fiber traits in 1980 for fiber
fineness selections for selection cycle five.

Populations	Fiber fineness µg/inch	2.5% span 1. mm	T$_1$ fiber strength mN/tex
HHHH	5.55	18.42	127.5
HHHL	5.92	21.57	163.8
HHHLH	4.13	27.20	188.4
HHHLL	3.92	27.74	199.1
HHLHH	4.67	27.03	202.1
HHLHL	3.83	26.75	204.0
HHLLH	3.63	24.11	183.4
HHLLL	3.82	25.04	189.3
HLHHH	4.73	25.55	187.4
HLHHL	4.92	26.06	180.5
HLHLH	4.37	26.42	183.4
HLHLL	4.60	26.04	190.3
HLLHH	3.92	23.01	185.4
HLLHL	4.58	25.63	196.2
HLLLH	3.52	26.16	216.8
HLLLL	3.52	26.29	206.0
LHHHH	4.58	26.98	198.2
LHHHL	4.53	27.41	194.2
LHHLH	4.55	26.70	210.9
LHHLL	4.15	26.92	213.9
LHLHH	4.63	26.65	192.3
LHLHL	4.60	25.20	175.6
LHLLH	3.95	25.25	182.5

Table 18.(Continued)

Populations	Fiber fineness	2.5% span 1.	T_1 fiber strength
	µg/inch	mm	mN/tex
LHLLL	3.60	25.43	189.3
LLHHH	3.82	26.19	198.2
LLHHL	4.12	26.90	191.3
LLHLH	3.67	25.86	195.2
LLHLL	3.13	27.38	199.1
LLLHH	3.68	27.79	215.8
LLLHL	3.70	27.15	201.1
LLLLH	3.40	27.69	202.1
LLLLL	3.57	27.97	214.8
$LSD_{0.05}$	0.38	0.74	13.7

Table 19. Analyses of variance and nonorthogonal contrasts for three fiber traits in selection cycle three.

	df		Mean squares 2.5% span l.		T_1 fiber strength		Fiber fineness	
Source	1973	1974	1973	1974	1973	1974	1973	1974
Reps	4	3	0.0033**	0.0003	7.20**	3.91	0.38+	0.52*
Populations	7	7	0.0544**	0.0322**	14.93**	11.18**	1.51**	0.41*
2H	2	2	0.0052**	0.0030	4.66*	0.38	1.63**	0.43+
1H	2	2	0.0180**	0.0088**	10.75**	4.96	1.12**	0.08
Error	28	21	0.0005	0.0012	1.12	2.57	0.17	0.15

+, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 20. Analyses of variance and nonorthogonal contrasts for three fiber traits in selection cycle four.

Source	df 1975	df 1979	2.5% span 1. 1975	2.5% span 1. 1979	T_1 fiber strength 1975	T_1 fiber strength 1979	Fiber fineness 1975	Fiber fineness 1979
Reps	4	3	0.0008	0.0022†	6.75**	5.85**	0.06	0.23
Populations	15	15	0.0284**	0.0163**	25.48**	17.80**	1.44**	0.54**
3H	3	3	0.0012*	0.0008	5.11*	11.52**	0.55**	0.11
2H	5	5	0.0078**	0.0040**	20.83**	18.93**	0.76**	0.16
1H	3	3	0.0131**	0.0043**	6.92*	5.65**	0.23	0.36*
Error	60	45	0.0004	0.0431	1.85	0.98	0.11	0.11

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 21. Analyses of variance and nonorthogonal contrasts for three fiber traits in selection cycle five.

Source	df	Mean squares		
		2.5% span l.	T_1 fiber strength	Fiber fineness
Reps	5	0.0040**	6.75**	0.24†
Populations	31	0.0341**	29.12**	2.34**
4H	4	0.0072**	28.45**	2.64**
3H	9	0.0048**	18.78**	1.15**
2H	9	0.0185**	6.76**	1.02**
1H	4	0.0458**	8.89**	0.29*
Error	155	0.0007	1.40	0.11

†, *, ** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

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Thesis: MULTIDIRECTIONAL SELECTION IN UPLAND COTTON FOR THREE FIBER
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