Published November, 1969

Genetic Studies of Earliness, Yield, and Fiber Properties in Cotton (*Gossypium hirsutum* L.)[1]

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ABSTRACT

Earliness, yield, and fiber properties in cotton were studied in a series of experiments conducted in Oklahoma from 1961 through 1966. In these studies a very early selection, OK-86, from an early Yugoslavian strain, PI 235563, and a late commercial variety, 'Acala 44', were used as parents. The P_1, P_2, F_1, F_2, Bc_1, Bc_2, F_3, and Bc_2F_4 generations of this cross were investigated. Single plant analyses of the early generation materials gave inconsistent heritabilities. However, progeny row analyses of the Bc_2F_4 gave predicted genetic advances under selection which corresponded closely with observed selection responses. Selection in this later generation material was highly effective for earliness and fiber length. It probably would have been less effective for yield, fiber coarseness, and fiber strength had selection for those three traits been practiced. The breeding of an early, high-yielding variety with fiber properties more acceptable than those of the early varieties now available appears feasible, although difficult.

Additional index words: **fiber length, fiber coarseness, fiber strength, heritability, genotypic correlation, genotype-environment interaction.**

IN the northern regions of the Cotton Belt, early maturing varieties have several advantages over those which mature later. These advantages include escape from the insect and disease losses usually incurred late in the season; reduction of the damaging effects of an early frost, particularly when coupled with delayed planting; and minimization of the effects of drouth during the summer months. However, the early maturing cotton varieties presently available which are adapted to Oklahoma conditions produce a fiber that is too short and weak to satisfy the demands of the textile industry.

The experiments reported herein were conducted to investigate the possibility of breeding an early, high-yielding variety with fiber properties more acceptable than those of the early varieties now available.

REVIEW OF LITERATURE

In a diallel cross study among eight inbred cotton lines, Miller and Marani (4) calculated highly significant general combining ability (GCA) for lint yield, earliness, fiber length, and fiber strength in the F_1 and F_2 but found significant specific combining ability (SCA) only for yield in the F_2. These results suggest that except for yield a major portion of the genetic variance for these traits in this population was additive or additive by additive or both which implies fairly large narrow-sense heritabilities. The significant SCA for yield indicates sizeable dominance or epistatic genetic variances or both for that trait.

White and Richmond (12) in studies involving five primitive, foreign, and cultivated American upland cottons found significant GCA for lint yield and earliness and significant SCA for yield but not for earliness.

Based on actual selection gains for yield in 'BP52' over six generations of selection, Manning (3) estimated a narrow-sense heritability of .10 to .15 for that trait on a single plant basis. Richmond and Ray (6) studied three "product-quantity" measures of earliness in three crosses of upland cotton and obtained broad-sense heritabilities on a single plant basis ranging from .00 to .41 depending upon the particular cross, measurement, and harvest date being studied. Verhalen and Murray (9) conducted a 10-parent diallel cross study in 1965 and obtained narrow-sense heritabilities in the F_1 on a plot mean basis of .49, .40, .67, and .68 for fiber length, coarseness, T_1 strength, and T_0 strength, respectively. The following year they found F_1 heritabilities in the same material of .61, .25, .58, and .57, respectively, and F_2 heritabilities of .49, .19, .62, and .52, respectively (10).

MATERIALS AND METHODS

The parents used in this study were OK-86 and 'Acala 44'. OK-86 is an extremely early selection of PI 235563, an early strain from Yugoslavia with short fiber and a plant type not well suited for mechanical harvest. Acala 44 is a rather late-maturing commercial variety with long fiber and a plant type adapted to mechanical picking.

Experiment I

This experiment was conducted to obtain narrow- and broad-sense heritability estimates on a single plant basis for the characters studied. Those characters were yield of lint, earliness calculated by dividing the weight of seed cotton from the first harvest by the weight of seed cotton from both harvests, fiber length measured on the digital fibrograph as 2.5% span length in inches, fiber coarseness on the micronaire in micronaire units, and fiber strength on the 0-inch gauge stelometer (T_0) in grams per tex.

Initial crosses were made in 1960. Selfs and backcrosses to both parents were made in the winter of 1960-61. Six populations (P_1, P_2, F_1, F_2, Bc_1, and Bc_2) were grown in 1961 and 1962 under irrigation in a randomized complete block design with three replications at Perkins, Oklahoma. Each plot consisted of two rows 15.2 m long and 1.0 m apart. Plants within rows were spaced 0.6 m apart. Plants were individually harvested when the Acala 44 entry was estimated to have 10% of its bolls open. One subsequent harvest was made after frost when all fully developed bolls were open. After weighing the seed cotton from each harvest, it was bulked by plant and ginned on a saw gin. The lint was then weighed and taken to the fiber laboratory for measurement of the fiber properties.

Narrow-sense heritabilities were obtained using Warner's (11) method. Broad-sense estimates were made by subtracting an estimate of the environmental variance from the variance of the F_2 and then dividing by the variance of the F_2. The environmental variance was estimated by $(VP_1 + VP_2)/2$ in 1961 and by $(VP_1 + VP_2 + VF_1)/3$ in 1962 where the V's refer to the variances within each designated population. F_1 data were unavailable in 1961 due to extensive seedling disease. The few F_1 plants which did survive in that year were used to obtain additional selfed and backcrossed seed so the experiment could be repeated in 1962.

[1] Contribution from the Oklahoma Agricultural Experiment Station. Published with the approval of the Director as paper No. 1853 of the Journal Series. Received April 19, 1969.

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Experiment II

This experiment was conducted to obtain narrow-sense heritability estimates independent of those calculated in Experiment I. Characters studied were the same as in the previous experiment except that lint yield was measured on a plot rather than a plant basis.

Single F_3 progeny rows from each of the 56 F_2 plants from Experiment I in 1961 were grown under irrigation in 1962 at Perkins and Chickasha, Oklahoma. Rows were 10.6 m long and 1.0 m apart. Plants within rows were spaced approximately .15 m apart.

The F_3 data was scaled, following the suggestion of Frey and Horner (2), to remove the bias caused by contraction or expansion of the phenotypic scale of measurement from environment to environment. Linear regression values of the adjusted performance of the F_3 rows on that of their F_2 parents were then calculated for Perkins and for Chickasha. Confidence intervals about the regressions were obtained following the method of Steel and Torrie (8). The regressions were then multiplied by 2/3, as Smith and Kinman (7) recommended, to convert them into narrow-sense heritabilities.

Experiment III

This experiment was conducted to obtain components of variance, broad-sense heritabilities on a plot basis, comparisons of expected versus actual genetic advances by selection, relative efficiencies of selection on the basis of two compared to one year's data, and genotypic correlations between earliness and the other traits. Characters studied were the same as in Experiment I except that lint yield was measured on a plot rather than a plant basis, that fiber strength was measured by 1/8-inch gauge stelometer (T_1) as well as by T_0, and that earliness was calculated on a lint per harvest rather than on a seed cotton per harvest basis.

Five of the earliest plants which had been backcrossed to Acala 44 were transplanted to the greenhouse in the winter of 1961-62 and backcrossed again to Acala 44. The resulting plants were selfed two generations in bulk without selection. In the third generation 62 random plant selections were made, and selfed seed from those selections were planted in progeny rows at Perkins in 1963. Open-pollinated seed were harvested from each of those rows for future tests. These 62 lines were grown under irrigation in 1964 and 1965 in randomized complete block design experiments with three replications at Chickasha and Altus, Oklahoma. Plots were single rows 10.6 m long and 1.0 m apart. Plants within rows were spaced approximately .15 m apart. The tests were planted each year between May 15 and 20. This planting date was rather late for irrigated cotton at these locations, but it was chosen to evaluate the lines under a relatively short growing season. Plots were harvested the first time when about 35% of Acala 44's bolls were open. This was in contrast to the 10% open bolls in Experiments I and II.

All calculations in this experiment, except those used to obtain the genotypic correlations, followed the procedure of Comstock and Moll (1). The correlations were calculated using the method described by Miller, et al. (5) with one slight difference, i.e., the genotypic covariances were estimated not by components of covariance analyses but by analyses of variance components of summed data. The reasoning for this procedure was based on the well known statistical equation: $V_{(X+\%)} = V_X + V_\% + 2\,Cov_{(X\%)}$ where the V's are variances, Cov is a covariance, % is earliness measured as percent first harvest, and X is the character being correlated with earliness. Each trait was summed with earliness in each plot, and analyses of variance over the two years and two locations were then conducted on those sums using Comstock and Moll's procedure (1). The estimated genotypic covariance, $Cov_{(X\%)}$, was then calculated as follows: $[V_{(X+\%)} - V_X - V_\%]/2 = Cov_{(X\%)}$ where V_X and $V_\%$ were obtained from their respective genotype by environment analyses and $V_{(X+\%)}$ from the summed analysis. This estimate was then used as the numerator in Miller et al.'s formula (5) for genotypic correlation.

To compare predictions of expected with actual genetic progress by selection for earliness and fiber length in this material, the upper and lower 10% of the progenies were selected for each of those traits. These selections, four control populations (bulked seed of all 62 progenies), and three Acala 44 check entries were grown in experiments at Chickasha and Altus under irrigation in 1966 in randomized complete block designs with two replications. Plots were single rows 15.3 m long. The experiment (except for plot length and number of replications) and characters analyzed were the same as in the 1964 and 1965 experiments.

RESULTS AND DISCUSSION

Experiment I

The mean yield, earliness, and fiber properties for the P_1, P_2, F_2, Bc_1 and Bc_2 populations in 1961 and for the same populations plus the F_1 in 1962 are given in Table 1 primarily to give the reader some idea how these populations, especially the parents, compared with one another. These means reflect the lower yield, earlier maturity, and shorter fiber of OK-86 in comparison with Acala 44. OK-86 also appeared to have a slightly coarser fiber than the Acala parent. Fiber strength differences, if any, were negligible. The means of the F_1 and F_2 progenies in comparison with the midparent averages suggested partial dominance for higher yield and longer fiber. The F_1 and F_2 means for earliness were very similar to the midparent. These data suggested that the genetic system for earliness was primarily additive. Fiber coarseness almost exactly fit the additive scheme in 1962, but results were inconclusive in 1961. Micronaire is greatly influenced by environment, and in 1962 the fiber may have matured more fully and the genetic differences expressed more clearly than in 1961.

The heritabilities for these traits (Table 2) were too inconsistent for one to have appreciable confidence in their accuracy. The large number of negative estimates (at least one for each trait) indicate that in many cases supposedly non-segregating populations (F_1's and parents) and backcross populations with less genetic variability than F_2's were phenotypically more variable than F_2 populations. This leads one to suspect a non-uniform test environment in these tests.

Experiment II

Regression coefficients of the adjusted F_3 progeny rows at Perkins and at Chickasha in 1962 on their

Table 1. Mean yield, earliness, and fiber properties of parental and segregating populations in Experiment I.

	Lint yield, g/plant		Earliness		2.5% span length		Micronaire		T_0 fiber strength	
Populations	1961	1962	1961	1962	1961	1962	1961	1962	1961	1962
OK-86	17.9	32.7	76.9	54.1	.920	.893	3.8	4.9	32.4	37.2
Acala 44	26.9	89.4	11.2	11.4	1.148	1.168	3.6	4.1	32.4	38.0
Midparent	22.4	61.1	44.1	32.8	1.034	1.031	3.7	4.5	32.4	37.6
F_1*	--	67.3	--	33.0	--	1.072	---	4.4	--	37.1
F_2	35.6	75.4	46.5	24.5	1.063	1.068	3.8	4.5	33.1	38.0
Bc_1 to OK-86	20.7	54.7	48.3	43.3	.990	.993	3.8	4.7	32.9	38.0
Bc_1 to Acala 44	26.9	81.7	27.2	17.9	1.087	1.114	3.8	4.3	32.7	37.9

* F_1 data not available in 1961.

Table 2. Narrow- and broad-sense heritabilities (h^2) estimated from early generation materials in Experiment I.

	Narrow-sense h^2		Broad-sense h^2	
Characters	1961	1962	1961	1962
Lint yield	.75	.00*	.82	.20
Earliness	.55	.00*	.57	.00*
2.5% span length	.00*	.20	.17	.27
Micronaire	.46	.00*	.00	.02
T_0 fiber strength	.00*	.19	.10	.24

* Negative estimate for which the most reasonable value is zero.

respective F_2 parents' performance at Perkins in 1961 are listed in Table 3. Standard deviations of the coefficients and narrow-sense heritabilities derived from the coefficients are also included. The standard errors for all coefficients were relatively large. In fact, only one estimate was significantly different from zero at the 0.05 probability level. All heritabilities were small except the estimate from Chickasha for fiber length. However, the estimate from Perkins for that trait was a negative number. Since heritabilities theoretically cannot be negative, the most reasonable value for such an estimate is zero. The low, inconsistent heritabilities obtained suggest that little progress for any of these characters could be made in this population by selecting among single F_2 plants for the performance of their F_3 progeny rows.

Experiment III

In the previous experiments, the inefficiency of selection for these traits in early generation materials was inferred from the low, often inconsistent, heritabilities obtained. The low estimates were due either to relatively large amounts of environmental variation in comparison with genetic variability or to little genetic variability *per se.* A comparison of parental means especially for yield, earliness, fiber length, and fiber coarseness (see Table 1) as well as visual observation of parental performance incline one to reject the conclusion of little genetic variability for those traits. Large environmental variation was suspected in Experiment I because in several cases genetically more variable populations showed less phenotypic variability than did genetically less variable populations. These large effects from environment certainly could have been operative in Experiment II where two years and two locations were involved as well as two different plant spacings. This was in addition to the usual lack of correspondence between F_2 and F_3 generations because of segregation. Conceivably, lowering the heterozygosity within lines by taking them to more advanced generations, using the same plant spacing from test to test, and taking observations on rows rather than on individual plants might partially eliminate the confusing effects of segregation and environment. The results of such an attempt are given in the remainder of this section.

Components of variance estimates and their standard errors obtained from analyses of variance among 62 Bc_2F_4 lines in experiments conducted two years at two locations are listed in Table 4. The error variance for each trait was larger than the components, individually or combined, of that trait. With the exception of micronaire, the genetic component of variance for each trait was larger than any of its corresponding interaction components. The combined interaction components were larger than the genetic component for yield as well as micronaire. This suggests the necessity of multiple years or locations or both to accurately differentiate relative performance among lines for those traits. Based on the relative magnitude of their interaction components, testing at several locations appeared more informative than over years for yield and T_0 fiber strength. The reverse appeared to be the case for earliness, fiber coarseness, and T_1. However, the relatively large genotype by location by

Table 3. Regression coefficients (b), standard errors of the coefficients (s_b), and narrow-sense heritabilities (h^2) estimated by the regression of adjusted F_3 progeny rows at two locations on their F_2 parents.

Characters	Perkins b	Perkins s_b	Perkins h^2	Chickasha b	Chickasha s_b	Chickasha h^2
Lint yield, kg/plot	.182	.190	.121	.002	.126	.001
Earliness	.126	.173	.084	.095	.110	.063
2.5% span length	-.036	.873	.000*	.616	.200	.411
Micronaire	.228	.126	.152	.111	.167	.074
T_0 fiber strength	.057	.228	.038	.105	.219	.070

* Negative estimate for which the most reasonable value is zero.

Table 4. Components of variance and their respective standard errors obtained from the analyses of variance of an experiment conducted two years at two locations.

Components*	Lint yield	Earliness	2.5% span length	Micronaire	T_0 fiber strength	T_1 fiber strength
			$\times 10^{-3}$	$\times 10^{-2}$		
V_F	902.4 ± 487.3	36.82 ± 9.84	.58 ± .13	.547 ± .369	.315 ± .183	.214 ± .084
V_{FL}	785.0 ± 506.5	1.95 ± 5.76	.02 ± .04	.000† ± .381	.329 ± .178	.000† ± .073
V_{FY}	141.5 ± 414.4	3.75 ± 6.01	.04 ± .04	.374 ± .432	.159 ± .153	.056 ± .080
V_{FLY}	286.0 ± 588.0	11.14 ± 8.05	.00† ± .06	1.105 ± .552	.000† ± .196	.006 ± .109
V_E	8,419.0	95.61	.88	5.619	3.069	1.683

* V_F is the component of variance due to genetic differences among families, V_{FL} the family × location component, V_{FY} the family × year component, V_{FLY} the family × location × year component, and V_E the error variance. † Negative estimate for which the most reasonable value is zero.

Table 5. Heritability, expected genetic advance by selection, and relative efficiency of two years versus one year's testing before making selections for each trait.

Characters	Heritability	Genetic advance: In actual units	Genetic advance: In percent of the mean	Relative efficiency of 2 vs. 1 year's testing
Lint yield	.45	40.	6.2	.66
Earliness	.73	9.1	18.2	.44
2.5% span length	.85	.039	3.5	.58
Micronaire	.37	.1	2.7	.61
T_0 fiber strength	.39	.06	1.4	.58
T_1 fiber strength	.56	.06	2.6	.54

year component for earliness and micronaire compared to each of their other interaction components indicated substantial interaction effects not attributable to locations or years. Interaction components for fiber length were very small implying that fairly accurate estimates of relative performance for that trait could be obtained from a single test. Each of the fiber traits had a negative estimate among its interaction components which intimates some error of estimation since variances theoretically cannot be less than zero. The standard errors in Table 4 are informative in this respect.

Broad-sense heritabilities calculated from the components in Table 4 are presented in Table 5. All of these estimates were fairly large although the earliness and fiber length estimates were substantially larger than the others. The unexpectedly high estimates for T_1 and T_0 insinuates that all of these heritabilities may be inflated to some degree since OK-86 and Acala 44 apparently differed very little for fiber strength. The calculated heritabilities were then used to estimate expected genetic advance based on the assumption that the upper 10% of the population is selected. This genetic advance is expressed in the original units of measurement as well as in a percent of the mean.

Table 5 also includes the relative efficiencies per unit of time of two versus one year's testing before making selections in this material for each trait. The importance of this parameter should be readily apparent. The breeder usually assumes that he will be able to make more accurate selections if those selections are based on more than a single year's data. In striving for this accuracy, he sacrifices an additional selection for each year's data he accumulates before making his selections. Assuming this increase in accuracy is invariably true (which it probably is not), the breeder may actually be sacrificing progress per unit of time for the accuracy of an individual selection merely because he makes fewer selections in the same period of time. The estimates in Table 5 indicate that the breeder of this material should not wait for a second year's data before making selections for any of these traits. Whether this statement for these traits applies to other cotton breeding materials remains to be seen.

Genotypic correlations of earliness with yield, fiber length, fiber coarseness, T_0, and T_1 were (—.38), (—.55), .37, .28, and (—.28), respectively. The correlations with yield, fiber length, and coarseness were significantly different from zero at the 0.01 probability level. The others were significant at the 0.05 level. Based on the signs of these correlations, selection for earliness in this material would tend to result in progeny with lower yield, shorter fiber, coarser fiber, higher T_0 and lower T_1 than the original population. The negative correlations for yield, fiber length, and T_1 imply that their improvement along with increased earliness will be obtained only with some difficulty. However, since none of these correlations approached unity, the desired combinations of those traits is deemed just that – a difficulty, but not an impossibility.

A two-way selection experiment for earliness and fiber length was conducted to verify the genetic advances and genotypic correlations predicted for those two traits. Earliness was chosen because it was the character of primary importance in this research. Fiber length was selected because of its high heritability and economic importance. The results of this experiment are given in Table 6.

Actual progress by selection in any one direction was computed by dividing the difference between the means of the high and low selection groups by two. This, of course, ignores any bias in the form of a limit which natural selection may place in the path of artificial selection in one direction but not in the other. Actual selection progress for earliness using this method was (64.3% — 54.8%)/2 or 4.8% compared to the 9.1% predicted. Actual progress for fiber length was .034 compared to the .039 predicted. The correspondence between expected and achieved progress was remarkably close for fiber length while earliness was less satisfactory. Based upon the facts that actual and predicted genetic advance corresponded more closely for fiber length than for earliness and that broad-sense rather than narrow-sense heritabilities were used to make the predictions, one can assume that earliness has relatively more dominance or epistatic variance or both in its genetic makeup than does fiber length.

As expected, the average performance of the progeny selected for increased earliness was toward shorter,

Table 6. Mean performance of Acala 44, control populations, and lines selected for early and late maturity and for short and long fiber.

Selection groups	Lint yield, kg/plot	Earliness	2.5% span length	Micronaire	T_0 fiber strength	T_1 fiber strength
Acala 44	771	37.1	1.153	2.7	37.5	22.1
Control populations	979	58.1	1.134	3.0	37.6	21.0
Early selections	1,114	64.3	1.143	3.1	38.2	20.8
Late selections	1,036	54.8	1.147	2.9	37.6	21.3
Short selections	1,051	62.3	1.107	3.0	37.1	21.1
Long selections	976	52.0	1.174	2.9	38.4	21.8

coarser fiber with higher T_0 and lower T_1 than in those lines selected for lateness. In the selections for long versus short fiber, long fiber was again associated with lateness and short fiber with earliness reinforcing the previous observations on the interrelationship between the two characters. The only discrepancy between expected and observed correlations involved yield. Lower yield should have been associated with earliness; whereas, the opposite results were observed. All of the micronaires in 1966 were below 3.5, the lower limit of the range desired by fiber mills. Strict attention will have to be given to that trait in this material in future testing to determine whether this apparent fineness was inherent or due to the rather peculiar environmental conditions of that year.

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