COMPARATIVE EFFECTIVENESS OF THREE BREEDING METHODS IN MODIFYING COARSENESS OF COTTON FIBER

By

JAMES D. BILBRO, JR.

Bachelor of Science
Panhandle Agricultural and Mechanical College
Goodwell, Oklahoma
1951

Master of Science
Oklahoma Agricultural and Mechanical College
Stillwater, Oklahoma
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Thesis Approved:

John M. Green
Thesis Adviser

Jack R. Harlan

James A. Whatley Jr.

Irmy V. Holt

Ralph S. Matlock

Dean of the Graduate School

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INTRODUCTION

There is ample evidence to indicate that methods of breeding upland cotton (Gossypium hirsutum L.) used in the past have been effective. The frequent appearance of successful new varieties and the disappearance of older varieties reflects the success of breeders in modifying the cotton plant in desirable characteristics. This success should not cause breeders to ignore the possibility that better methods may be available. Instead they should evaluate the various available methods to determine their relative effectiveness in resolving specific breeding problems.

An evaluation of the relative effectiveness of a breeding method can be made in terms of progress effected and also in terms of time and labor required to make this progress.

The primary objective of this study was to make such an evaluation of the relative effectiveness of three breeding methods in modifying fiber coarseness. The breeding methods evaluated were recurrent selection, selection-while-inbreeding, and mass selection.

REVIEW OF LITERATURE

Recurrent Selection

According to Sprague and Brimhall (32), Hayes and Garber in 1919, and East and Jones in 1920, suggested a breeding method similar to what is now termed recurrent selection.

Jenkins (14) was the first to publish a detailed account of the recurrent selection method. It was proposed as a procedure for the production of synthetic varieties of corn for areas where maintenance of inbred lines and the production of hybrid seed would be rather "hazardous." Jenkins based the method on the assumption that heterosis is due to dominant favorable factors. The essential steps are: (a) The isolation of one-generation selfed lines; (b) testing of these lines in top crosses for yield and other characters; (c) intercrossing of the better endowed lines to produce a synthetic variety; (d) repetition of the above process at intervals after each "synthetic variety" had a generation or two of mixing, possibly with the inclusion of lines from unrelated sources.

Hull (12) outlined a procedure which he designated as "recurrent selection for specific combining ability in corn." (He was the first to use the term "recurrent selection.") His breeding plan was based upon the assumption that one or more of three types of interactions occur at numerous loci for yield in maize to the extent that the sum of the heterozygote effects exceeds the sum of the homozygote effects by 20 percent or more. His breeding plan differed from Jenkins' in that Jenkins used a heterozygous tester whereas Hull used an inbred tester.

Comstock et al. (3) designed a breeding system which they called "recurrent reciprocal selection." This system was designed to be effective regardless of the level of dominance and which, by giving attention to specific combining ability from the outset, might be more effective for genes showing complete or partial dominance than were current procedures. A description of the method is as follows:

Foundation material from two sources is used. The hybrid or hybrids to be developed will involve crossing material descended from these two sources, hence the sources should be as genetically divergent as possible. Two varieties, two synthetics, or the F_2 generation plants of the two single crosses involved in a successful double cross can serve as the source material.

S_0 or S_1 plants from source A are self-pollinated and at the same time out-crossed to plants from source B. Selection is based on experimental comparison of test-cross progenies and selected plants are interbred the third year using their selfed seed produced the first year. The cycle is reinitiated the fourth year. Source B plants are tested against source A plants in the same way.

Sprague and Brimhall (32) in 1950, and Sprague et al. (33) in 1952, published the results of studies of the relative effectiveness of selection within selfed lines as compared to recurrent selection for increasing oil content of the corn kernel. The general procedures followed in the studies may be outlined briefly: (a) One-hundred shoots of a chosen variety were self-pollinated; (b) the ears were analyzed for oil content and the 10 ears having the highest oil percentage were used as parents; (c) these 10 ears were grown in ear-row progenies and all possible intercrosses were made by hand; (d) equal quantities of seed of each combination were bulked and planted; (e) plants were selfed within this bulk increase population; (f) approximately 100 selfed ears were individually analyzed for oil content and the 10 having the highest oil percentage were grown in ear-row progenies and intercrossed as before. The selfing series was derived from the same 10 ears that were used to initiate the recurrent selection study. The general procedure used was as follows:

(a) Seed from the 10 ears were planted in 25-plant progeny rows and approximately one half of the resulting plants were self-pollinated; (b) at harvest time five of these were saved for analyses. The two ears from each family having the highest oil content were again planted in progeny rows for further selection and inbreeding. (c) After the oil analyses were available the sibling progeny within each pair having the lowest mean oil content was discarded; (d) in the sibling progeny having the highest mean oil percentage the two selfed ears having the highest mean oil percentage were saved to propagate the strain. This process was continued through five generations of selfing.

The authors concluded from their studies that recurrent selection was much the better of the two methods. The most outstanding features of the experimental results were (a) the maintenance of near maximum amounts of variability, as measured by standard deviations, in the recurrent selection cycles; (b) the high heritabilities which were maintained through one and two cycles of recurrent selection; and (c) recurrent selection was from 1.3 to 3.0 times as effective as selection during inbreeding, depending on the method of comparison used.

Lonnquist (21) concluded from his study of "recurrent selection as a means of modifying combining ability in corn," that the method appeared to provide a greater efficiency in the selection of superior genotypes as well as a higher level of combining ability in the lines obtained.

Jenkins _et al_. (15) used recurrent selection as a method for concentrating genes for resistance to _Helminthosporium turcicum_ (leaf blight in corn). Three cycles of recurrent selection were made within each of nine groups of material. In 24 of the 27 possible comparisons the differences were positive indicating increases in resistance and in 3 comparisons the differences were negative indicating reductions in resistance. Sixteen of the positive differences were highly significant, 3 were significant and 5 were non-significant. Two of the negative differences were highly significant and not explained. The remaining one was non-significant.

From these results they concluded that 2 cycles of recurrent selection were sufficiently effective to be warranted in most of the groups studied. The need for a third cycle of selection depended upon the amount of improvement accomplished in the first two cycles.

In a study of combining ability in an open-pollinated variety of corn, McGill and Lonnquist (24) compared two cycles of recurrent selection with a system of continuous self-pollination and selection based upon test-cross performance. From this study the authors concluded that two cycles of recurrent selection had been effective in modifying combining ability in the materials used. They also concluded that recurrent selection was equal to and possibly superior to the continuous selfing method.

In a subsequent paper dealing with the performance of synthetic varieties of corn, Lonnquist and McGill (22) reported the results of two cycles of recurrent selection. From this study the authors concluded: "...there can be little doubt that an improvement in yield and general agronomic worth has been achieved through use of the recurrent selection for general combining ability method."

Horner *et al.* (11) completed three cycles of recurrent selection for combinability with a single cross, F44 x F6. In each cycle about 500 test crosses were tested for one season at 2 or more locations. From these, 20 crosses were selected on the basis of yield and other desirable agronomic characters. A standard hybrid, Dixie 18, was used as a check in the tests.

A general summary of the results may be illustrated in the following table.

Yield in percent of Dixie 18

Cycle	Mean of all crosses	Mean of selected crosses
1	91	106
2	95	109
3	107	122

The apparent proportion of genetic variance to total phenotypic variance was as large in the third cycle as in the second, indicating that a "leveling-off" point had not been reached.

Johnson (16), from studies of the "effectiveness of recurrent selection for general combining ability in sweetclover, Melilotus officinalis," concluded: "The large positive gains in a single cycle of recurrent selection indicate that this breeding procedure may be an effective method of breeding in forage crops."

Johnson and Goforth (18) compared the results from the above mentioned recurrent selection cycle with those from the fourth generation of controlled (undesirable plants removed prior to flowering) mass selection. They stated, with reference to combining ability: "From these results it may be inferred that four generations of visual selection for desirable plants in the second year was not as effective as a single cycle of recurrent selection based upon progeny performance."

Johnson (17) subsequently reported the results from the second cycle of the previously mentioned study of recurrent selection for general combining ability in sweetclover. He also compared these results with those of the first cycle. The mean yield in percent of the variety Madrid was 121% and 152% for the first and second cycle, respectively. He also reported there appeared to be no reduction in variation among plants, as measured by open-pollination progeny. In conclusion, Johnson stated: "... the opportunities for further genetic advance might be as great in the third as in each of the two previous cycles."

Fetooh (6) compared recurrent selection with the pedigree method in a study of breeding for high and low fiber strength in populations derived from a three species hybrid, Gossypium arboreum-thurberi-hirsutum. The pedigree system was more effective than recurrent selection in producing strains with higher and lower fiber strength, respectively. The pedigree strains with a high fiber strength were inferior to the low fiber strength strains in yield, lint percent, boll size, and the locks were less fluffy. Both the high and low strength strains produced by the pedigree system appeared to be relatively homozygous.

Recurrent selection was slower and less effective in moving the mean for fiber strength but produced strains having more favorable combinations of characters. The high fiber strength recurrent selection strains were twice as high in yield as the high fiber strength pedigree strains and had a higher lint percentage, larger bolls and more fluffy locks. Also there was a considerable amount of variation remaining in the recurrent selection strains.

In view of the results obtained in this study Fetooh stated:

> ...pedigree selection is recommended when the main object is to produce strains with exceptionally high levels of a certain character. Recurrent selection, on the other hand, is more effective for selection on a broad base, especially in material derived from interspecific hybrids.

Henderson (10) selected from an F_2 population six cotton plants that were above the average in respect to four economic quantitative characters in which the parents differed. These characters were length and strength of fiber, weight of seed and weight of fiber per unit of surface area on the seed. F_3 lines from the six F_2 plants were grown the following year and intercrossed in all possible combinations. A progeny row of each intercross was grown and tested by individual plants for the four characteristics. In the original F_2 population the frequency of plants above the average of the parents for all four characteristics was only seven percent. After one cycle of recurrent selection the frequency was increased to 23 percent. However the 15 intercrosses differed in relative frequency of the characteristics, the lowest progeny row having no superior plants while the highest intercross progeny row had 43 percent of plants above the parental average in all 4 characters. Henderson concluded that recurrent selection can be effective in self-fertilized plants in raising the frequency of superior gene combinations considerably over that found in an F_2 population.

Selection-While-Inbreeding

This breeding method, commonly called the pedigree method by breeders of naturally self-pollinated crops, the progeny row method by cotton breeders, and the ear-row (or pedigree) method by corn breeders, is based largely upon the principles of the pure line theory as set forth by Johannsen. According to Hays and Immer (9) Johannsen defined a pure line as the descendants of a single, homozygous, self-fertilized organism.

If the crop under selection is self-fertilized, "pure lines" are automatically formed. However in the case of cross-pollinated crops the pure lines must be brought about by effecting self-pollination. In either case the result is the same; there is theoretically an approach to complete homozygosity of the selected lines. Therefore selection will be most effective immediately after inbreeding is begun in the case of cross-pollinated crops and in the first few generations subsequent to crossing in the case of self-pollinated crops. It should also be noted that in an inbreeding program the initial selection forms a "potential ceiling" above which further change by selection is impossible. This potential ceiling is determined by the amount and nature of the heterozygosity within the plant or plants selected as parents for future generations.

Several experiments have been conducted with cotton in attempts to determine the effects of inbreeding on various characters. Results, and conclusions, of these various experiments have not always been in agreement.

Kearney (19) drew the following conclusions from a study of open-pollinated Pima cotton versus Pima cotton inbred for five or seven generations:

> No evidence was obtained that the fertility of Pima cotton had been impaired by strict inbreeding during five or seven successive generations. The inbred families were not inferior to the continuously open-pollinated stocks in viability of the pollen; number of ovules; daily flower production; percentage of bolls retained; size, weight, and seed content of the bolls; weight and viability of the seeds; and abundance of the fiber.

Humphrey (13) studied 2- and 7-year inbreds and reported little increase in uniformity after two years of inbreeding. He stated: "Inbreeding of cotton varieties rapidly segregates many types that become relatively uniform after two or three generations, the inbred lines being much more uniform in all cases than the varieties from which they arose." He observed that varieties were very nonuniform, particularly for fiber characteristics. The result of 1 year of testing indicated six 7-year inbred lines of Rowden to be superior in yield and performance to all of the established Arkansas varieties. All six strains were highly uniform in lint percentage and staple length.

A study of the effects of inbreeding cotton for ten years was reported by Brown (1). Since his experimental procedure was unique it will be briefly outlined: (a) Two bolls were self-pollinated on each of 50 plants in each of eight varieties; (b) two bolls on each of the same 50 plants were cross-pollinated with pollen from other plants within the same variety; (c) the seed from the selfed bolls were massed into one lot, the seed from the cross-pollinated bolls were massed into another lot; (d) alternate rows were grown from the selfed and crossed seed; (e) repetition of the cycle was continued each year for ten years.

The results of the study brought out the following points: (a) Inbreeding had no consistent effect on seed germination; (b) on the average for the 10-year period, the plants of the crossed strains were slightly taller than the selfed strains but the difference was not significant. The lateral spread of the crossed plants was slightly greater than that of the selfed. (c) For the 10-year period the crossed plants bloomed 6.2% more; (d) two of the varieties were nearly equal in boll size but for the other six varieties the difference was greater with the crossed strains being the larger. Taking the average for all varieties, the crossed bolls were consistently heavier every year. The crossed bolls averaged 9.3% heavier than the selfed bolls. (e) The crossed strains averaged 28.7% earlier than the selfed strains; (f) staple length difference between the crossed and selfed strains was not consistent and not considered significant; (g) the 10-year average lint percentage for the crossed strains was 32.5% and for the selfed strains 32.2%; the difference was considered by Brown as probably not being significant. (h) The crossed strains produced more lint during 9 of the 10 years, the margin being a significant 9.3%.

In his discussion Brown pointed out that since open-pollinated cotton flowers have a high percentage of their ovules self-fertilized normally, the difference in production between the inbred and open-pollinated strains would probably not have been so great as the difference obtained in this experiment.

Brown observed that his selfed strains became less uniform as inbreeding progressed. He explained this as being the result of massing seed from all saved plants (i.e., no selection was practiced) and all segregates and forms were preserved. The crossed strains became more uniform in subsequent generations. This, according to Brown, was probably due to a continuous "blending" of the characters from different plants.

Simpson and Duncan (28) studied the effect of selecting within selfed lines on yield and other characters in cotton. They grew and evaluated the 1st, 4th, 7th, and 10th selfed generations of the four varieties that appeared to be the best of 390 varieties and strains carried through 10 years of selfing and selection.

In spite of selection pressure to improve the desirable properties of these cottons, there was no appreciable gain in any character except fiber length. This gain was not sufficient to offset the loss in value due to yield reduction. Average values of the four varieties indicated a loss of 15% in yield of seed cotton and minor losses in lint index, lint percent, strength of fiber, and seed weight. The authors indicated that the commercial value of the varieties was less after 10 years of selfing and selection than at the beginning.

They suggested that the superior performance of the early generations was in part the result of heterosis and that loss occurred as homozygosity was approached.

Mass Selection

There appears to be a dearth of literature dealing with mass selection as a breeding method. This suggests that other methods are superior to it and are more widely used, particularly in more recent times.

In the following review, work dealing with some of the modified mass selection breeding methods is given in addition to some of those dealing with mass selection *per se*.

Lush (20) gave some of the theoretical considerations of mass selection:

> Mass selection is expected to cause the average of each generation to exceed the average of the preceding generation by the amount (M) which is equal to the heritability fraction σ_G^2/σ_O^2 of the selection differential (s), the latter being the average merit of those selected to be parents minus the average of the whole generation from which they were taken.

He stated further that the obstacles to rapid progress fall into two groups: (a) Circumstances or practices which make s small and (b) circumstances which lower heritability.

Cook (4) believed that mass selection was the first breeding method to be practiced, being employed either consciously or unconsciously by very primitive people. He gave the following definition of the method:

> Mass selection is a process of reproducing from the better individuals of a stock. A separation may be made by discarding inferior individuals or by assembling good individuals, but the selected individuals have different characters, their progenies are not kept apart, and the resulting population continues to be diverse, even after many generations of mass selection.

Harland (7, 8) devised and employed the "mass pedigree system" of breeding for the improvement of Peruvian Tanguis cotton. A brief description of the method was given by Richmond (27) as follows:

> ... (a) the growing of progeny of a large number of selected plants; (b) determining the mean of each progeny for the characters under consideration; (c) arraying the progeny means for each character, and selecting progenies whose means fall on a certain segment of the distribution

curve (the segments to be chosen by the breeder on the basis of the relative importance of one character as compared to the others, and to the original variability of the material, etc.); and finally, (d) massing of all the selected lines to form a bulk planting from which another selection cycle may be started.

Smith and Brunson (29) compared mass selection and ear-row breeding methods in corn over a ten-year period. They concluded that continuous selection by the ear-row breeding plot method could not be recommended as a means of increasing the yield of a well adapted variety of corn. They also concluded that the yield of a well adapted variety of corn could be maintained and perhaps somewhat increased by continuous mass selection.

Richey (26), after an extensive review of literature on corn breeding practices, concluded: "... the evidence shows that mass selection on the basis of production and quality, at least from the standpoint of production and quality, is entirely warranted."

Sprague (31) in discussing mass selection as a corn breeding method stated: "Mass selection has been effective in modifying ear and plant type, chemical composition and maturity. It has been rather ineffective in increasing acre yield."

MATERIALS AND METHODS

Description of Environments and Associated Plant Types

Since each of the three tests to be discussed in these studies was grown in two different environments, a description of the environments is given here.

The term "Environment I" will be used to denote the environmental conditions of the year 1955. Tests conducted in that year were grown in a silt loam soil at the Cotton Research Station, Chickasha, Oklahoma. The tests were planted on June 3 and were harvested during the first week of November. All tests were sprinkler irrigated when necessary to maintain a high level of soil moisture. Rainfall in inches for the season was as follows: May, 10.27; June, 1.69; July, 0.40; August, 5.29; September, 5.41; October, 5.01. Of special significance is the 5.29 inches of rain which fell in August. Approximately 4 inches of this amount fell within 24 hours after an application of about 4 acre inches of irrigation water.

As a result of wide plant spacing and untimely rainfall, the plants in all tests were very tall and highly vegetative. The number of bolls per plant was extremely low in proportion to plant size.

The term "Environment II" will be used to denote the environmental conditions of the year 1956. Tests in that year were grown in a very fine sandy loam soil at the Perkins Agronomy Farm, near Perkins, Oklahoma. The tests were planted on June 2 and harvested over the period from October 1 to October 13. The tests were furrow irrigated on August 11 and again on

August 25. Approximately 4 acre inches of water were applied with each irrigation. Rainfall in inches during the season was as follows: May, 4.70; June, 1.91; July, 1.64; August, 0.31; September, 0.18; October 1 through October 13, 0.00.

The plants were small and were wilting slightly in late afternoon before it was possible to irrigate them. The plants had only a few bolls when the first irrigation water was applied. The smallest of these bolls (approximately one-fourth to three-eights inches in diameter) abscised. Very little vegetative growth was produced as a result of the first irrigation but the bolls that had not abscised enlarged rapidly. The second irrigation provided sufficient moisture to allow the enlarged bolls to mature and the plant to produce a slight amount of secondary growth.

Fiber Coarseness

(1) Method of measurement

Fiber coarseness was determined in all cases by use of the Micronaire[1/]. The procedure used was as follows: Enough clean, fluffed cotton was taken from the lint sample to make a total weight of 50 grains. The weighed sample was then placed in a chamber and compressed to a predetermined volume. Compressed air was passed through the sample at a constant pressure. The amount of air passing through the sample determined the height to which a float in a scaled tube arose. The reading, expressed as micrograms per inch of fiber, was taken directly from the scaled tube as indicated by the height of the float. The entire procedure was

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[1/] A description of this instrument may be found in Cotton Production, Marketing and Utilization. Published by W. B. Andrews, State College, Mississippi. 1950. p. 299.

repeated to obtain a second reading. The average of the two readings was recorded as the relative coarseness (or fineness) of the sample.

(2) Studies of gene action, heritability, and inheritance

In order to more critically evaluate the respective breeding methods used in this study it was deemed desirable to have information about the type of inheritance (quantitative or qualitative), the type of gene action involved (arithmetic or geometric), and the heritability of fiber coarseness. Since very little pertinent information was found in the literature a test was conducted for the purpose of obtaining this information.

The two parent strains of the populations used for this study may be characterized as follows.

The 4-24-3-8-B[2/] strain was derived from a single bacterial blight [Xanthomonas malvacearum (E.F.S.) Dowson] resistant plant selected in 1950 from C.A. 122. It has a small, storm-resistant boll and a plant type adapted to stripper harvest. It has a staple length of about thirty-one thirty-seconds of an inch and produces relatively fine fiber. It has not been evaluated for yield.

The CR-2 strain was developed from the variety Acala 5. It has a staple length of seven-eighths to twenty-nine thirty-seconds of an inch and produces moderately coarse fiber. It has non-storm-resistant bolls, a short stalk and is medium late in maturity.

These strains, CR-2 and 4-24-, were crossed during the summer of 1954.

[2/]The 4 indicates the code number of the original variety, C.A. 122, and the numbers following 4 indicate the plant saved in a given year. The B indicates that the row was bulked in that year. For brevity 4-24-3-8-B will subsequently be designated 4-24-.

F_1 seed, along with seed of the two parents, was planted at Iguala, Mexico, in the fall of 1954. In Mexico the F_1 generation was self-pollinated to produce F_2 seed. It was also crossed to each of the parents to produce backcross seed. (The parents were also re-crossed to produce more F_1 seed.) Utilizing the seed thus produced, the following entries were subsequently grown in Environments I and II: The parents (CR-2 and 4-24-), the F_1, F_2, and two backcrosses. The experimental design was a randomized complete block with 10 replications. The plots were 2 rows wide and 20 feet long. The rows were spaced 40 inches apart. Two or 3 seed were planted at approximately 2-foot intervals. Subsequently the plots were thinned to 1 plant approximately every 2 feet. Each plant was harvested individually and the seed cotton placed in a paper bag. The number of bolls harvested, replication number, entry number, row number, and plant number were recorded on the bag. A minimum of 3 and a maximum of 10 bolls, and a minimum of 3 and a maximum of 5 bolls were harvested from each of the plants grown in Environment I and Environment II, respectively. Plants with fewer than 3 bolls were not harvested. The seed cotton was ginned on a small 7-saw gin. Lint coarseness was determined for each sample by the procedure described above; however, all Micronaire values for samples with fewer than 5 bolls were omitted from the analyses[3].

All analyses of variance were made using the procedure given by Snedecor (30). For the tests grown in Environments I and II, the row-mean Micronaire values were used for analysis as the number of plants per row

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[3]/Hancock, N. J. Variations in length, strength and fineness of cotton fibers from bolls of known flowering dates, locks, and nodes. Jour. Amer. Soc. Agron. 39:122-134. 1947. He stated that at least 4 bolls should be taken in order to have a sample that will represent the plant.

was not constant. A combined analysis was made on entry totals from the tests grown in the two environments. A test to determine which means differed significantly was made using Duncan's multiple range test (5). Within-row variance (an estimate of genetic variance) was calculated for all entries. These were tested for homogeneity by Bartlett's test as outlined by Snedecor (30). Standard deviations, standard errors of means, coefficients of variation and means were computed on an individual plant basis. A test for type of gene action was made using the method of Charles and Smith (2). The formulae used were as follows:

Generation	Expected Means: Arithmetic	Expected Means: Geometric
F_1	$\frac{\bar{\bar{P}}_1 + \bar{\bar{P}}_2}{2}$ [4]	$\sqrt{\bar{\bar{P}}_1 \cdot \bar{\bar{P}}_2}$
F_2	$\frac{\bar{\bar{P}}_1 + 2\bar{\bar{F}}_1 + \bar{\bar{P}}_2}{4}$	———
$F_1 \times P_1$	$\frac{\bar{\bar{P}}_1 + \bar{\bar{F}}_1}{2}$	$\sqrt{\bar{\bar{P}}_1 \cdot \bar{\bar{F}}_1}$
$F_1 \times P_2$	$\frac{\bar{\bar{P}}_2 + \bar{\bar{F}}_1}{2}$	$\sqrt{\bar{\bar{P}}_2 \cdot \bar{\bar{F}}_1}$

Heritability was estimated using Warner's method (35). He gave the following formula:

Heritability $= \frac{(\frac{1}{2}D)}{V_{F_2}}$ where $(\frac{1}{2}D) = \left[2(\text{variance of } F_2) - (\text{variance of } B_1 + \text{variance of } B_2)\right]$; B_1 = variance of $(F_1 \times P_1)$; B_2 = variance of $(F_1 \times P_2)$; and V_{F_2} = variance of the F_2.

Conclusions concerning the type of inheritance were drawn from the means and frequency distributions of Micronaire values.

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[4] Not given by Charles and Smith.

Recurrent Selection vs. Selection-While-Inbreeding

The parent strains of the population used to initiate this study were CR-2 and 4-24-3-8-B, described on page 16. A single plant, 4-24-3-8-B-9, was crossed with several plants of CR-2. The original cross was made in 1952 to begin a breeding program to combine such desirable characteristics as plant type adapted to stripper harvest, staple length, storm-resistant boll type, fiber coarseness and bacterial blight resistance. The crossed seed were planted in Mexico and the resulting F_1 population self-pollinated to produce F_2 seed. These F_2 seed were planted at the Cotton Research Station, Chickasha, Oklahoma, in 1953 and the resulting population inoculated and rogued for bacterial blight susceptible plants. Several of the remaining plants were self-pollinated by enclosing the individual squares (buds) in small cloth bags equipped with a draw string.

The present study was begun by selecting, on the basis of desirable agronomic type, 83 plants having some self-pollinated bolls and 18 with no self-pollinated bolls. All 101 plants were harvested individually. In harvesting the plants having both self- and open-pollinated bolls, the seed cotton from the self-pollinated bolls was placed in one paper bag and the seed cotton from the open-pollinated bolls was placed in another paper bag. Each bag was appropriately identified. The samples were ginned as outlined in the previous section. The self- and open-pollinated seed were maintained separately; however the lint from the self- and open-pollinated bolls from the same plant was combined to make a sample large enough for Micronaire analysis. One sample was too small for Micronaire analysis and was discarded. As soon as the Micronaire values were determined for the 100 samples the 10 plants that had produced the coarsest lint were transplanted to the greenhouse at Chickasha. One plant did not survive. The remaining plants were intercrossed in 28 of the 36 possible combinations. Self-pollinated seed from each of the nine plants were saved. Sixty seed of each intercross combination were planted in 2" x 2" x 3½" wooden bands filled with soil. These were transplanted to the field when the plants were about 3 to 5 inches in height. The individual intercross combinations were set out in 50-foot rows and replicated one time. Intercrosses were kept separate in order that the degree of inbreeding could be determined for the second cycle of recurrent selection. The plots were furrow irrigated. In the fall 100 plants were selected on the basis of desirable agronomic type. Plants were selected, in varying numbers, from all 28 of the intercross combinations. The harvesting, ginning and fiber testing was done in the manner previously described. The 10 plants that had produced the coarsest fiber were transplanted to the greenhouse. Two plants failed to survive. The 8 remaining plants were intercrossed in all 28 of the possible combinations. Seed of each of the 28 intercross combinations, and self-pollinated seed from each of the 8 parent plants were saved.

Self-pollinated seed were available from 7 of the 10 F_2 plants used to initiate the recurrent selection program. To initiate the selection-while-inbreeding program the self-pollinated seed from each of these seven plants were planted in individual F_3 progeny rows in Mexico in the winter of 1953-54. Each progeny row contained approximately 15 plants. Self-pollination was effected on all plants by wiring the tips of the corollas prior to blooming. At time of harvest, one row was discarded as the plants were of undesirable agronomic type. The remaining plants were harvested individually, the seed cotton ginned, and the lint coarseness determined. Self-pollinated seed from 19 plants (representing 5 of of the original 7 F_3 lines) that had produced the coarsest lint were planted at Chickasha in 1954 in the same manner as described above for the recurrent selection program. The resulting F_4 plants were self-pollinated. At time of harvest 98 plants were selected, within and among 18 of the 19 F_4 lines, on the basis of desirable agronomic type. Seed cotton from open-pollinated bolls from each of these 98 plants was ginned and the Micronaire values determined. Self-pollinated seed from the 11 plants (representing 8 F_4 lines) that had produced the coarsest lint were planted in Mexico in the winter of 1954-55. The resulting F_5 progeny rows were handled in the same manner as were the F_3 progenies. Self-pollinated seed from the 10 plants (representing only 3 of the F_5 lines) that had produced the coarsest lint were saved.

Field testing and data analysis

To make the comparison of the relative effectiveness of the two breeding methods a test was grown in Environment I and repeated, with a different randomization, in Environment II. The experimental design was a randomized complete block design with 8 replicates. The plots were 2 rows wide and 20 feet long. Row width was 40 inches. Planting and thinning procedures were the same as those given above under the section "Studies of gene action, ..." The source of seed for the 8 entries of the tests are listed in table I. The abbreviations, shown in parenthesis, will subsequently be used when referring to the various recurrent selection populations. The plants were harvested individually, the seed cotton ginned, and the Micronaire values determined in the manner described under the section "Studies of gene action, ..."

TABLE I

SOURCES OF SEED FOR ENTRIES GROWN TO DETERMINE THE RELATIVE PROGRESS MADE BY RECURRENT SELECTION AND SELECTION-WHILE-INBREEDING

Entry	Source of Seed
CR-2	Breeder's seed
4-24-	Bulked self-pollinated seed
F_4	Bulked sample of equal quantities of remnant self-pollinated seed from each of the 19 F_3 plants selected from the 1953-54 Mexico planting
F_6	Bulked sample of equal quantities of self-pollinated seed from each of the 10 F_5 plants selected from the 1954-55 Mexico planting
Recurrent Selection I (R.S. I)	Bulked sample of equal quantities of remnant seed from each of the 28 intercrosses made in the greenhouse during the winter of 1953-54
Recurrent Selection I Parents (R.S. I P.)	Bulked sample of equal quantities of self-pollinated seed from each of the nine plants intercrossed to produce R.S. I seed
Recurrent Selection II (R.S. II)	Bulked sample of equal quantities of seed from each of the 28 intercrosses made in the greenhouse during the winter of 1954-55
Recurrent Selection II Parents (R.S. II P.)	Bulked sample of equal quantities of self-pollinated seed from each of the eight plants intercrossed to produce R.S. II seed

Each plant that was harvested from the test grown in Environment II was classified as being either a desirable or undesirable agronomic type. After the Micronaire values were available, they were divided into two groups, high and low, within each entry. A chi-square test for independence of plant type (i.e., desirable or undesirable) and Micronaire value (i.e., high or low) was made.

All analyses of variance and other statistical computations were made in the manner described in a previous section.

The coefficient of inbreeding for the second recurrent selection cycle was calculated using a formula given by Sprague et al. (33).

The formula is:

$$\frac{12.5\left[\frac{a_1(a_1-1)}{2}+\frac{a_2(a_2-1)}{2}+\ldots\frac{a_n(a_n-1)}{2}\right]}{\frac{N(N-1)}{2}}$$

Where a_1, $a_2 \ldots a_n$ represents the number of times each of the a_n lines saved from the previous cycle is represented in the current selected sample and N represents the total number of lines saved. The figure 12.5 represents the average amount of inbreeding expected in crosses between two lines which had one line in common in their immediate intercross parentage.

Recurrent Selection vs. Mass Selection

The parent varieties of the populations used in this study may be characterized by the following descriptions.

Oklahoma Special is a small bolled strain developed from Acala 5 and is suited for hand harvest only. It is an early maturing, open bolled variety with a staple length of fifteen-sixteenth to thirty-one thirty-seconds inches. Its lint is moderately coarse. It is a high yielding variety but due to lack of storm resistance of its bolls it was grown on a limited scale for only a few years.

Lankart 57 is a variety widely grown in southwestern Oklahoma and in northern Texas. The variety has been improved in various characteristics since the original cross (Oklahoma Special x Lankart 57) was made in 1950. The following description applies to the variety at that time. This variety had large, storm resistant bolls and was well adapted for stripper harvest. It was late in maturity, had a staple length of fifteen-sixteenths to thirty-one thirty-seconds inches and produced finer lint than Oklahoma Special.

The purpose of the original cross was to initiate a breeding program to combine such desirable characters as yield, large, storm-resistant bolls, early maturity, fiber length and coarseness, and a plant type adapted to stripper harvesting into one strain. The F_1 generation of this cross was grown in 1951 and the plants self-pollinated. Ninety self-pollinated seed were planted in Iguala, Mexico, in the winter of 1951-52. From this population, self-pollinated seed from 42 F_2 plants were harvested. These were planted in individual F_3 progeny rows at Perkins Farm in 1952 and desirable plants were self-pollinated. In 1953 self-pollinated seed from each of 59 of these plants were planted in F_4 progeny rows (in isolation) at the Paradise Farm (approximately 17 miles southwest of Stillwater, Oklahoma).

The present study was begun in 1953 by selecting 100 plants, within and among the 59 F_4 lines, on the basis of desirable agronomic type. Fifty-four of the 59 lines were represented in the 100 plants selected. The seed cotton from the open-pollinated bolls was harvested from the individual plants, ginned, and the seed saved. Micronaire values were determined for the lint from each plant. The 10 plants (representing 10 different F_2 lines) that had produced the coarsest lint were transplanted to the greenhouse at Chickasha. During the winter of 1953-54 the 10 plants were intercrossed in 30 of the 45 possible combinations. Self-pollinated seed from each of the 10 plants were saved. In 1954 60 seed of each intercross combination were planted in 2" x 2" x 3½" wooden bands filled with soil. From this point through harvesting of the plants in the fall, the procedures used were identical with those used for the recurrent selection vs. selection-while-inbreeding program outlined above. From the 100 plants harvested in the fall, the 10 that had produced the coarsest lint were transplanted to the greenhouse at Chickasha. During the winter of 1954-55 these 10 plants were inter-crossed in 42 of the 45 possible combinations. Seed of each inter-cross combination and self-pollinated seed from each of the 10 plants were saved.

The mass selection program was begun by bulking 19 grams of the open-pollinated seed from each of the 10 plants used to initate the recurrent selection program. The remaining seed of these 10 plants were saved. The bulked sample of seed was planted in 1954, at a low seeding rate, in a small, isolated block at the Perkins Farm. The plants were grown in isolation in order that bees might effect cross-pollination among plants within the block without danger of bringing in undesired pollen. (The amount of cross-fertilization, due to bee activity, has been estimated to be approximately 30% for this area.) In the fall 100 plants were selected on the basis of desirable agronomic type, the seed cotton harvested and ginned, and the Micro-naire values determined for the individual lint samples. Nineteen grams of open-pollinated seed from each of the plants that had pro-duced the coarsest lint were bulked. The remainder of the open-pollinated seed from the 10 plants was saved. The bulked sample was planted in an isolated block in 1955. The planting, selection, harvesting, ginning and fiber testing procedures were repeated. Open-pollinated seed from the 10 plants that had produced the coarsest lint were saved.

Field testing and data analysis

To make the comparison of the relative effectiveness of the two breeding methods a test was grown in Environment I and repeated, with a different randomization and one additional entry, in Environment II. The experimental design was a randomized complete block with 8 replicates. The plots were 2 rows wide and 20 feet long; row width was 40 inches. Planting and thinning procedures were the same as those given under the section "Studies of gene action..."

The sources of seed for the entries grown in the tests are listed in table II. The abbreviations, given in parenthesis, will subsequently be used when referring to the various entries. The plants were harvested, the seed cotton ginned, and the Micronaire values determined in the manner described under the section "Studies of gene action..."

Each plant that was harvested from the test grown in Environment II was classified as being either a desirable or undesirable agronomic type. After the Micronaire values were available, they were divided into two groups, high and low, within each entry. A chi-square test for independence of agronomic type (desirable or undesirable) and Micronaire value (high or low) was made.

The analysis of variance, for the tests grown in different environments, was made using row-mean Micronaire values as the number of plants per row was not constant. An analysis of variance was also made of the

TABLE II

SOURCES OF SEED FOR ENTRIES GROWN TO DETERMINE THE RELATIVE PROGRESS MADE BY RECURRENT SELECTION AND MASS SELECTION

Entry	Source of Seed
Oklahoma Special (O.S.)	Breeder's seed
Lankart 57 (L.57)	Registered seed
Recurrent Selection I (R.S. I)	Bulked sample of equal quantities of remnant seed of each of the 30 intercrosses made in the greenhouse during the winter of 1953-54
Recurrent Selection I Parents (R.S. I P.)	Bulked sample of equal quantities of self-pollinated seed from each of the 10 plants intercrossed to produce R.S. I seed
Recurrent Selection II (R.S. II)	Bulked sample of equal quantities of seed from each of the 42 intercrosses made in the greenhouse during the winter of 1954-55
Recurrent Selection II Parents (R.S. II P.)	Bulked sample of equal quantities of self-pollinated seed from each of the 10 plants intercrossed to produce R.S. II seed
Mass Selection I (M.S. I)	Bulked sample of equal quantities of remnant open-pollinated seed from the 10 F_4 plants selected in 1953
Mass Selection II (M.S. II)	Bulked sample of equal quantities of remnant open-pollinated seed from the 10 plants selected from the isolated block in 1954
Mass Selection III 1/ (M.S. III)	Bulked sample of equal quantities of open-pollinated seed from the 10 plants selected from the isolated block in 1955

1/Grown in Environment II only.

row-mean Micronaire values of the test grown in Environment II, omitting the entry, M.S. III. These data and those of the test grown in Environment I were combined and an analysis of variance made. Other statistical computations were made in the manner previously outlined.

The coefficient of inbreeding for the second cycle of recurrent selection was calculated.

RESULTS

Studies of Gene Action, Heritability, and Inheritance

The analyses of variance and entry means for tests grown in Environment I and Environment II, and for their combined data are given in table III. There were highly significant differences among entries in each environment as well as in the average of the two environments. The results of the multiple range test, also given in table III, indicate that a test for type of gene action with these data will be open to criticism.

The entry mean Micronaire values obtained from the tests grown in the two environments, and those obtained from their combined data are given in table IV with the means expected assuming arithmetic and geometric gene action. The parents differed by 0.32, 0.40, and 0.36 Micronaire units in Environment I, Environment II, and the combined data, respectively. These small differences explain why the expected arithmetic and geometric means are practically the same. However, the observed values were within one standard error of the expected values in 5 of the 12 possible comparisons for arithmetic gene action; in only 2 of the 9 possible comparisons for geometric gene action were the observed values within one standard error of the expected values.

There was no consistent indication of dominance in the tests. In Environment I the F_1 value was below the mid-parent, and in Environment II it was above the mid-parent. The F_2 and backcross generations did not indicate dominance any more clearly than the F_1 generations.

TABLE III

RESULTS OF ANALYSES OF VARIANCE OF ROW-MEAN MICRONAIRE VALUES OF CR-2, 4-24-, AND FOUR POPULATIONS DERIVED FROM A CROSS BETWEEN THEM

Data Source	Source of Variation	d.f.	Mean Square	F Value	Entry	Mean	Multiple Range[1/] 1% 5%
Environment I					CR-2	4.16	
	Entries	5	0.3770**	7.49	F_1 x CR-2	4.11	
	Rows within Plots	60	0.0229		F_1	3.91	
					F_2	3.89	
	Error	45	0.0504		F_1x4-24-	3.88	
					4-24-	3.84	
Environment II					CR-2	5.13	
	Entries	5	0.5543**	5.18	F_1	5.13	
	Rows within Plots	60	0.0530		F_1 x CR-2	5.08	
					F_2	4.95	
	Error	45	0.1070		F_1x4-24-	4.89	
					4-24	4.71	
Combined	Environments	1	62.0370		CR-2	4.65	
	Entries	5	0.7944**	10.09	F_1 x CR-2	4.60	
	Entries x Environments	5	0.1369	1.74	F_1	4.52	
					F_2	4.42	
	Error (pooled)	90	0.0787		F_1x4-24-	4.38	
					4-24-	4.27	

1/Any two means paralleled by the same line are not significantly different.

TABLE IV

MEAN MICRONAIRE VALUES OF CR-2, 4-24-, AND FOUR POPULATIONS DERIVED FROM A CROSS BETWEEN THEM, COMPARED WITH EXPECTED VALUES ASSUMING ARITHMETIC AND GEOMETRIC GENE ACTION

Data Source	Type of Population	Number of Individuals	Observed Mean[1]	Expected Mean Arithmetic	Expected Mean Geometric
Environment I	4-24	168	3.83 ± .02994	---	---
	F_1	165	3.90 ± .03450	3.99	3.99
	F_2	142	3.94 ± .04232	3.95	---
	F_1 x 4-24-	175	3.86 ± .03219	3.87	3.89
	F_1 x CR-2	156	4.10 ± .04003	4.03	4.05
	CR-2	135	4.15 ± .04052	---	---
Environment II	4-24-	149	4.72 ± .03263	---	---
	F_1	165	5.10 ± .03317	4.92	4.92
	F_2	169	4.93 ± .05090	5.01	---
	F_1 x 4-24-	172	4.87 ± .03786	4.91	4.82
	F_1 x CR-2	183	5.07 ± .04097	5.11	5.02
	CR-2	155	5.12 ± .04429	---	---
Combined	4-24-	317	4.28 ± .02205	---	---
	F_1	330	4.50 ± .02392	4.46	4.45
	F_2	311	4.44 ± .03379	4.48	---
	F_1 x 4-24-	347	4.37 ± .02480	4.39	4.36
	F_1 x CR-2	339	4.58 ± .02878	4.57	4.54
	CR-2	290	4.64 ± .03028	---	---

[1]Calculated on an individual plant basis

Heritability estimates were 30.35%, 73.57% and 60.72%, for Environment I, Environment II, and their combined data, respectively.

The Micronaire frequency distribution, mean (on a per plant basis) and within-row variance ("genetic variance") for each entry in each environment are given in table V. All entries had wide ranges. On the average these ranges were wider in Environment II than in Environment I. Frequency distributions were unimodal for all entries.

Bartlett's test showed the within-row variances of both tests to be heterogeneous. The variances, on the average, were lower in Environment I than in Environment II.

Recurrent Selection vs. Selection-While-Inbreeding

Chi-square tests indicated "desirable" and "undesirable" agronomic types of plants to be independent of "high" and "low" Micronaire values.

The analyses of variance and entry mean Micronaire values for the tests grown in Environment I and Environment II, and for their combined data, are shown in table VI. The "entries x environments" interaction was highly significant. The effects of the different environments on the entries was reflected in the change in rank of most of the entry means from Environment I to Environment II. The effects are further illustrated in figures 1, 2, and 3. The Micronaire class centers of Environment II have been shifted to the left so the means of CR-2 in the two environments fall on the same ordinate.

Figure 1 shows the frequency distribution curves for the high parent (CR-2) and the F_4 and F_6 generations. The mean of the F_4 generation and CR-2 were identical in Environment I but the F_4 was significantly higher than CR-2 in Environment II. In both environments

TABLE V

MEANS, WITHIN-ROW VARIANCES, AND FREQUENCY DISTRIBUTIONS OF MICRONAIRE VALUES OF CR-2, 4-24-, AND FOUR POPULATIONS DERIVED FROM A CROSS BETWEEN THEM

Environment	Type of Population	Class Centers of Micronaire Values 2.7	3.0	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6.0	6.3	6.6	Mean	Within-Row Variance
I	4-24-	--	5	21	54	36	37	14	1	--	--	--	--	--	--	3.83	0.1506
	CR-2	1	5	4	13	30	36	29	13	2	1	--	1	--	--	4.15	0.2217
	F_1	3	2	21	34	49	33	13	7	2	1	--	--	--	--	3.90	0.1963
	F_2	--	8	17	28	34	27	13	7	8	--	--	--	--	--	3.94	0.2543
	F_1 x 4-24-	1	5	30	35	42	38	18	5	1	--	--	--	--	--	3.86	0.1814
	F_1 x CR-2	--	3	12	29	36	28	22	16	8	2	--	--	--	--	4.10	0.2500
II	4-24-	--	--	2	2	8	15	34	39	40	5	4	--	--	--	4.72	0.1586
	CR-2	--	--	1	3	4	6	15	31	26	28	25	13	2	1	5.12	0.3039
	F_1	--	--	--	2	1	8	20	25	45	36	19	6	3	--	5.10	0.1815
	F_2	--	1	2	5	10	13	28	24	34	22	16	11	3	--	4.93	0.4379
	F_1 x 4-24-	--	--	1	2	6	17	30	37	41	26	8	4	--	--	4.87	0.2465
	F_1 x CR-2	--	1	1	2	8	13	16	31	39	34	22	12	3	1	5.07	0.3071

TABLE VI

RESULTS OF ANALYSES OF VARIANCE OF ROW-MEAN MICRONAIRE VALUES OF ENTRIES GROWN TO DETERMINE THE RELATIVE EFFECTIVENESS OF RECURRENT SELECTION AND SELECTION-WHILE-INBREEDING

Data Source	Source of Variation	d.f.	Mean Square	F Value	Entry	Mean	Multiple Range[1/] 1%	Multiple Range[1/] 5%
					F_6	4.68		
					F_4	4.32		
	Entries	7	0.7003**	16.27	CR-2	4.32		
Environment I	Rows within				R.S. II P.	4.19		
	Plots	64	0.0352		R.S. II	4.16		
	Error	49	0.0431		R.S. I P.	4.12		
					4-24-	4.05		
					R.S. I	4.04		
					F_6	6.12		
					R.S. II	5.52		
	Entries	7	2.3879**	35.86	F_4	5.48		
Environment II	Rows within				R.S. II P.	5.40		
	Plots	64	0.0345		R.S. I P.	5.33		
	Error	49	0.0666		R.S. I	5.27		
					CR-2	5.11		
					4-24-	4.76		
					F_6	5.40		
	Environments	1	83.2086		F_4	4.90		
	Entries	7	2.5652*	4.90	R.S. II	4.84		
Combined	Entries x				R.S. II P.	4.79		
	Environments	7	0.5230**	9.54	R.S. I P	4.72		
	Error				CR-2	4.71		
	(pooled)	98	0.0548		R.S. I	4.65		
					4-24-	4.41		

1/Any two means paralleled by the same line are not significantly different

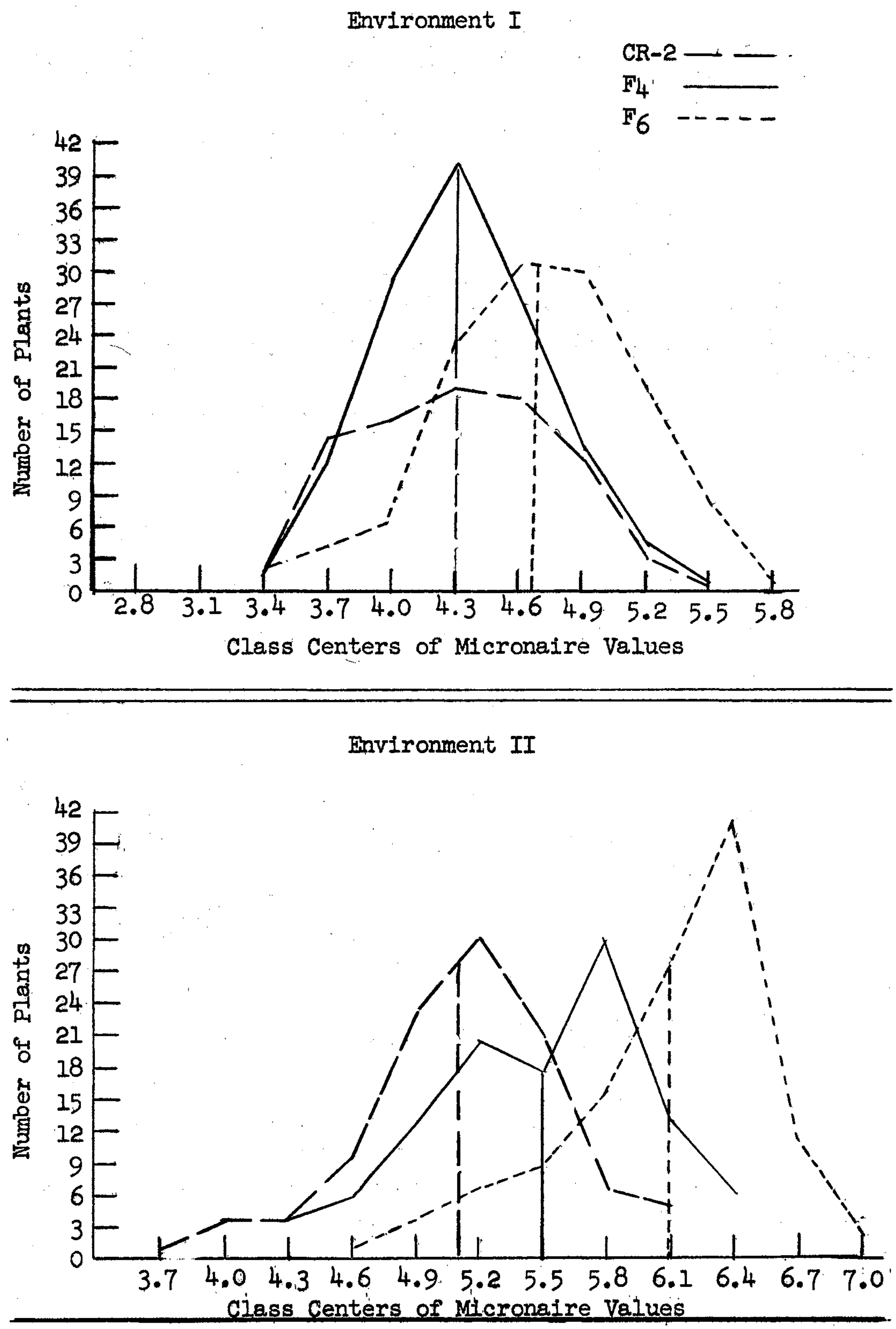


Fig. 1 Frequency distribution of the high parent of Cr-2 x 4-24- and the F_4 and F_6 populations when grown in two different environments.

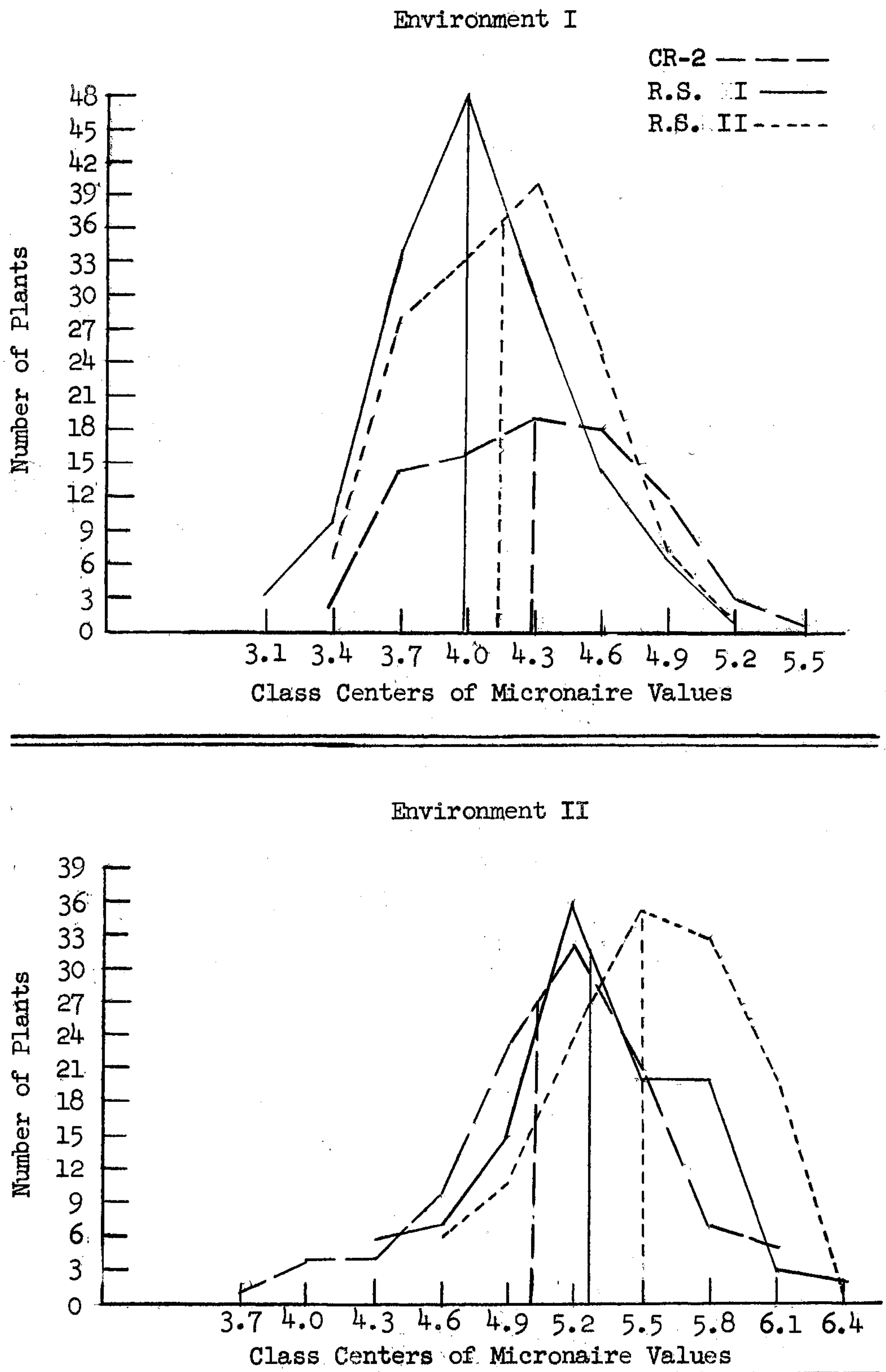


Fig. 2 Frequency distribution of the high parent of CR-2 x 4-24- and the R.S. I and R.S. II populations when grown in two different environments.

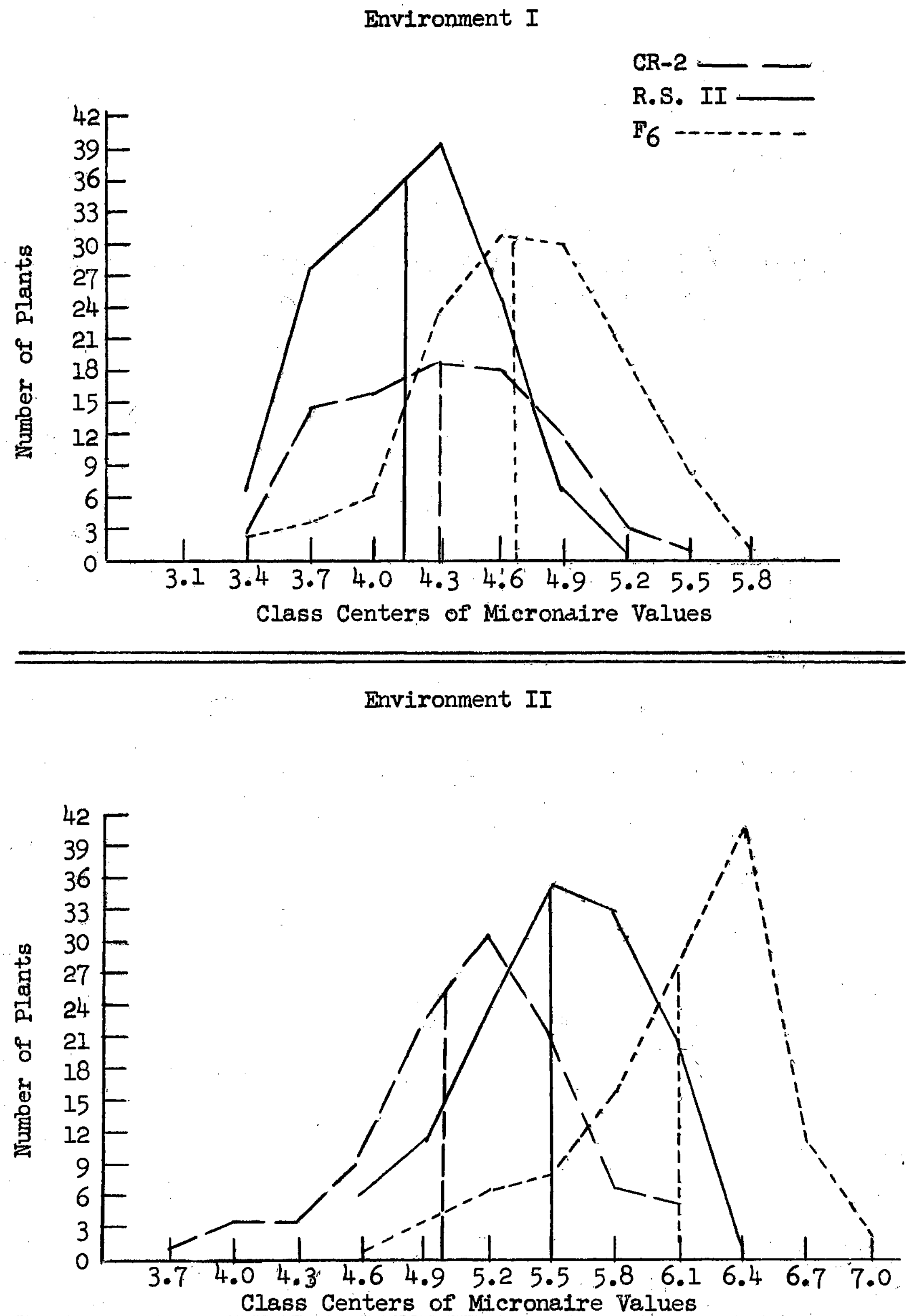


Fig. 3 Frequency distribution of the high parent of CR-2 x 4-24- and the R.S. II and F_6 populations when grown in two different environments.

the F_6 generation was significantly higher than the F_4 generation and CR-2.

Figure 2 shows the frequency distribution curves of CR-2, R.S. I and R.S. II. In Environment I CR-2 was significantly higher than R.S. I but not significantly different from R.S. II. R.S. I and R.S. II were not significantly different in this environment. CR-2 and R.S. I were not significantly different in Environment II. However, R.S. II was significantly higher than CR-2 at the 1% level of probability, and significantly higher than R.S. I at the 5% level of probability in this environment.

The frequency distribution curves of R.S. II and the F_6 generation are given in figure 3. As stated above R.S. II was not significantly different from CR-2 in Environment I, but was significantly higher than CR-2 in Environment II. The F_6 generation was significantly higher than R.S. II and CR-2 in both environments.

In neither environment were the R.S. parents significantly different from their respective R.S. intercross populations.

Further general effects of environment can be seen by comparing the within-row variances, means, and coefficients of variation for entries when grown in two different environments and by noting the percent-gain in Micronaire value for the entries when grown in Environment II. These values are given in table VII. All means were higher in Environment II than in Environment I although the percent increase varied. The two parents showed the smallest percent increase. On the average the within-row variances were higher in Environment II than in Environment I and, with one exception, the coefficients of variation were lower. Bartlett's test showed the within-row variances to be

TABLE VII

VARIANCES, MEANS, AND COEFFICIENTS OF VARIATION ON A PER PLANT BASIS FOR ENTRIES GROWN TO DETERMINE THE RELATIVE EFFECTIVENESS OF RECURRENT SELECTION AND SELECTION-WHILE-INBREEDING, AND PERCENT INCREASE IN MICRONAIRE VALUE OF ENTRIES WHEN GROWN IN ENVIRONMENT II

Entry	Environment	Number of Indiv.	Variance	Mean	Percent Increase in Environment II	Coefficient of Variation
CR-2	I	85	0.2035	4.32	18.8	10.44
	II	106	0.2183	5.13		9.12
4-24-	I	133	0.1889	4.04	18.3	10.76
	II	79	0.1256	4.78		7.42
F_4	I	128	0.1568	4.32	26.9	9.17
	II	109	0.2470	5.48		9.07
F_6	I	124	0.1647	4.69	29.9	8.65
	II	118	0.1536	6.09		6.43
R.S. I	I	146	0.1379	4.03	30.8	9.21
	II	109	0.1737	5.27		7.90
R.S. I P.	I	132	0.1322	4.11	29.2	8.86
	II	122	0.1766	5.31		7.91
R.S. II	I	141	0.1368	4.15	33.0	8.92
	II	130	0.1469	5.52		6.94
R.S. II P.	I	125	0.1751	4.18	28.9	10.02
	II	96	0.3096	5.39		10.32

heterogeneous in each environment.

In comparing the progress made by the two breeding methods, the selection-while-inbreeding procedure raised the mean Micronaire value significantly above the mean value of the high parent in both environments. Recurrent selection, on the other hand, raised the mean Micronaire value significantly above the high parent only in Environment II. Also R.S. II did not exceed the mid-parent value significantly except in Environment II.

The coefficient of inbreeding in R.S. II was very low, being 4.72%. The F_4 generation was composed of 19 lines derived from 5 F_2 plants and the F_6 generation was composed of 10 lines derived from 3 F_2 plants. Six of the F_6 lines traced to 1 F_2 plant, 3 lines traced to a second F_2 plant, and the remaining F_6 line traced to the third F_2 plant. Thus the F_6 generation was highly inbred and had a narrow "genotypic" base.

Recurrent Selection vs. Mass Selection

Chi-square tests indicated "desirable" and "undesirable" agronomic plant types to be independent of "high" and "low" Micronaire values.

The analyses of variance and entry mean Micronaire values for the tests grown in Environment I and Environment II, and for their combined data are shown in table VIII.

The change in rank among the entries from Environment I to Environment II was reflected in the highly significant mean square for "entries x environments." The most significant change was in M.S. II. In Environment I it was third in rank and not significantly different from R.S. II or O.S. However, in Environment II it was sixth in rank

TABLE VIII

RESULTS OF ANALYSES OF VARIANCE OF ROW-MEAN MICRONAIRE VALUES OF ENTRIES GROWN TO DETERMINE THE RELATIVE EFFECTIVENESS OF RECURRENT SELECTION AND MASS SELECTION

Data Source	Source of Variation	d.f.	Mean Square	F Value	Entry	Mean	Multiple Range[1] 1%	Multiple Range[1] 5%
					R.S. II P.	4.00		
					O.S.	3.96		
	Entries	7	0.2371**	4.05	M.S. II	3.94		
Environment I	Rows within				R.S. II	3.93		
	Plots	64	0.0414		R.S. I P.	3.92		
	Error	49	0.0586		M.S. I	3.86		
					R.S. I	3.76		
					L. 57	3.63		
					M.S. III	5.25		
					O.S.	5.15		
Environment II (All the Entries)	Entries	8	0.9928**	21.68	R.S. II	5.09		
	Rows within				R.S. II P.	5.07		
	Plots	72	0.0333		M.S. I	4.96		
	Error	56	0.0458		R.S. I	4.96		
					M.S. II	4.85		
					R.S. I P.	4.83		
					L. 57	4.39		
					O.S.	5.15		
					R.S. II	5.09		
Environment II (Omitting M.S. III)	Entries	7	0.9028**	17.98	R.S. II P.	5.07		
	Rows within				M.S. I	4.96		
	Plots	64	0.0351		R.S. I	4.96		
	Error	49	0.0502		M.S. II	4.85		
					R.S. I P.	4.83		
					L. 57	4.39		
					O.S.	4.56		
	Environments	1	68.6412		R.S. II P.	4.53		
	Entries	7	0.9439*	4.82	R.S. II	4.51		
Combined	Entries x				M.S. I	4.41		
	Environments	7	0.1960**	3.60	M.S. II	4.40		
	Error				R.S. I. P.	4.37		
	(pooled)	98	0.0544		R.S. I	4.36		
					L. 57	4.01		

[1]Any two means paralleled by the same line are not significantly different.

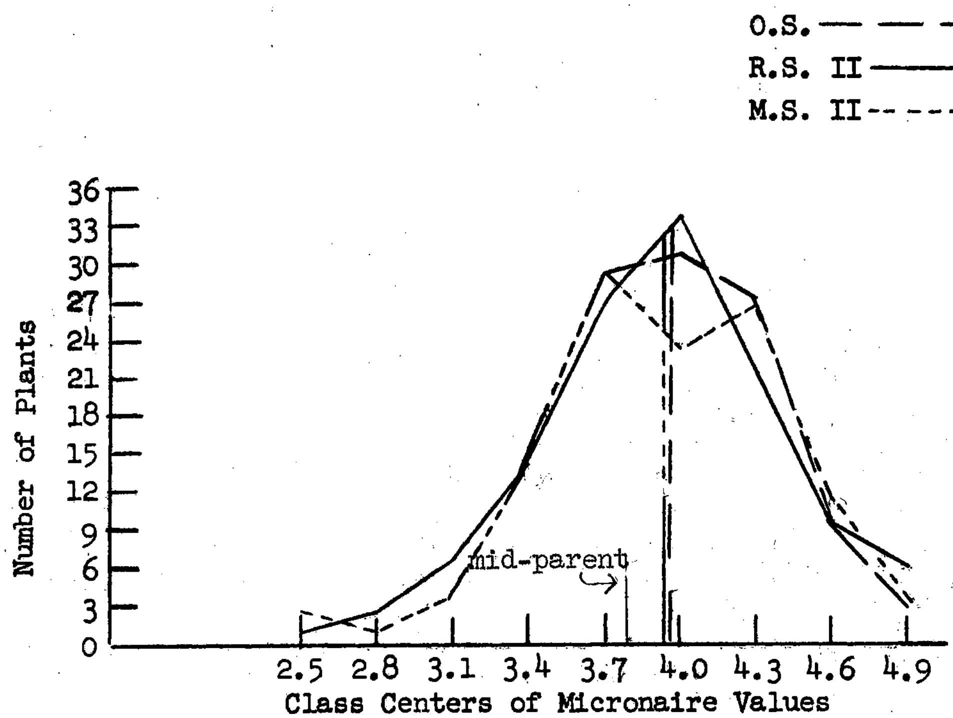
(omitting M.S. III) and was significantly lower than R.S. II and O.S. This change in rank is illustrated in figure 4. The Micronaire class centers of Environment II have been shifted to the left so the means of O.S. in the two environments fall on the same ordinate.

Further effects of environment can be seen by comparing the within-row variances, means, and coefficients of variation for entries when grown in two different environments, and by noting the percent gain in Micronaire value for the entries when grown in Environment II. These values are given in table IX. In general the within-row variances were larger in Environment II than in Environment I, and the coefficients of variation were smaller in Environment II than in Environment I. Each entry had a higher mean when grown in Environment II. The percent increases in Micronaire values in Environment II over Environment I were variable. L. 57 showed the smallest increase whereas O.S. was second largest in amount of increase, being exceeded slightly by R.S. I.

Both breeding procedures were apparently effective in increasing the frequency of genes for fiber coarseness. In Environment II, M.S. III and R.S. II were significantly above the mid-parent in mean Micronaire value. They were not significantly different from the high parent, O.S. In Environment I and in the combined data none of the entries were significantly different from the mid-parent.

The coefficient of inbreeding was 5.83% for R.S. II. There was no method for estimating the amount of inbreeding for the mass selection populations.

Environment I



Environment II

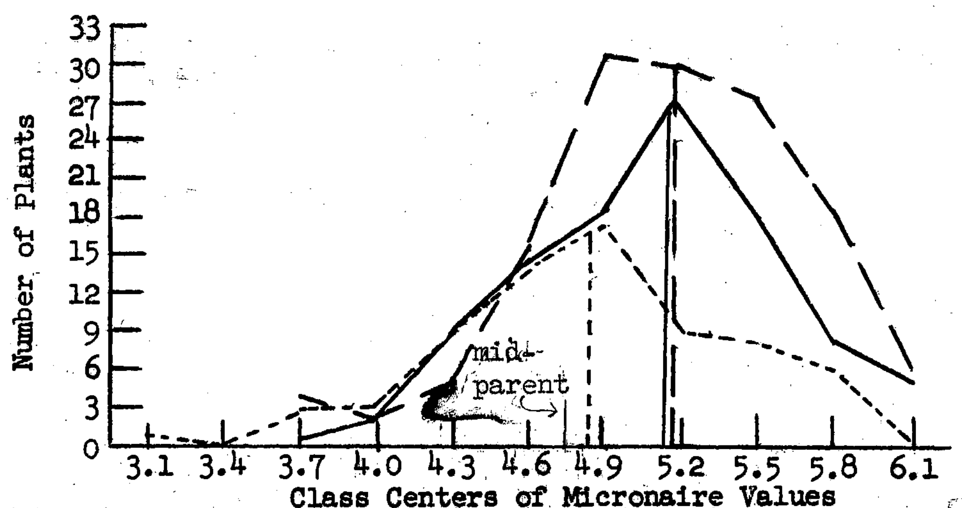


Fig. 4 Frequency distribution of the high parent of O.S. x L. 57 and two derived populations when grown in two different environments.

TABLE IX

VARIANCES, MEANS, AND COEFFICIENTS OF VARIATION ON A PER PLANT BASIS FOR ENTRIES GROWN TO DETERMINE THE RELATIVE EFFECTIVENESS OF RECURRENT SELECTION AND MASS SELECTION, AND PERCENT INCREASE IN MICRONAIRE VALUE OF ENTRIES WHEN GROWN IN ENVIRONMENT II

Entry	Environ-ment	Number of Indiv.	Variance	Mean	Percent Increase in Environment II	Coefficient of Variation
O.S.	I	119	0.1248	3.96		8.92
	II	141	0.2616	5.16	30.30	9.92
L. 57	I	72	0.1304	3.67		9.85
	II	82	0.1199	4.40	19.89	7.87
R.S. I	I	130	0.1446	3.76		10.10
	II	117	0.1416	4.99	32.71	7.54
R.S. I P.	I	118	0.1213	3.90		8.92
	II	91	0.1776	4.80	23.08	8.78
R.S. II	I	123	0.1889	3.93		11.07
	II	105	0.2128	5.09	29.52	9.06
R.S. II P.	I	120	0.1914	4.01		10.92
	II	114	0.2096	5.09	26.93	9.00
M.S. I	I	128	0.1444	3.86		9.85
	II	107	0.2343	4.95	28.24	9.77
M.S. II	I	115	0.1994	3.93		11.35
	II	71	0.3775	4.85	23.41	12.67
M.S. III	I					
	II	107	0.2269	5.26		9.05

DISCUSSION

In interpreting the results of the study of the type of action of the genes controlling fiber coarseness, certain limitations must be imposed. The need for these limitations was pointed out in experimental results. Despite the imposed limitations it is interesting to note the rather close fit of observed values to those expected assuming arithmetic gene action. In terms of standard errors, these expected values approached more closely the observed values than did the expected geometric values. There was no clear indication of dominance, as indicated by the relationships of the observed means of F_1 and segregating generations to the calculated values. Stith (34) made a study of the cross Acala x Hopi and concluded that the genes for fiber coarseness acted in an additive manner and showed no dominance.

The frequency distributions of Micronaire values were unimodal in all populations, indicating quantitative inheritance for fiber coarseness. Stith (34) and Nakornthap (25) reported similar findings.

Heritability estimates made from the data obtained from the respective environments differed greatly. The estimate made from Environment II data was more than twice as large as the estimate made from Environment I data. This was the result of a greater increase, in Environment II, of within-row variance of the F_2 than in the two backcross populations. The estimate made from the combined data, 60.72%, probably has the widest application since it represents the "average" of data from two completely different environments, i.e., the genotypes had a greater range of conditions in which to be expressed. This figure for heritability is comparable to those obtained by Stith (34) but is somewhat higher than those reported by Manning (23) and Nakornthap (25).

The character under selection in these breeding studies, as pointed out above, is quantitative in inheritance, has a high heritability, and is apparently independent of plant phenotype; therefore, selection on an individual plant basis (without progeny testing) should be effective in increasing the frequency of genes for this character regardless of the breeding procedure employed. The results of the breeding method studies reported herein indicate this to be a correct assumption.

In four generations of selection and inbreeding the mean fiber coarseness was raised significantly above the mean of the high parent. The limit of improvement was probably not reached but was theoretically being approached, as the F_6 generation was highly inbred. An indication that "leveling-off" has been reached was shown by the coefficients of variation for the F_6 generation. It had the smallest coefficient of variation in each of the respective environments. However, it should be pointed out that none of the coefficients of variation were very large.

The total change in gene frequency effected by the recurrent selection procedure was not so great as by the selection-while-inbreeding procedure. The mean of R.S. II exceeded the mid-parent and mean of the high parent only in Environment II. However, the best indication of the relative progress made by the respective breeding methods can be obtained by comparing the means of the F_4 generation with those of R.S. II. In this case each breeding procedure will have been through an equal number of generations. If this comparison is made neither method seems superior to the other, although both have been effective in increasing the frequency of genes for lint coarseness.

It should be pointed out that two cycles of recurrent selection with a slight amount of inbreeding, was as effective as two generations of selection-while-inbreeding in which the degree of inbreeding was rather high. This would indicate that the frequency of genes for fiber coarseness could be increased without excessive inbreeding.

The results of this phase are not directly comparable to those of other workers since the characters and/or crop under consideration differed. However, some comparison will be made. Fetooh (6) reported the pedigree (selection-while-inbreeding) method to be more effective than recurrent selection in changing the mean for fiber strength in cotton. Sprague et al. (33) found two cycles of recurrent selection to be more effective than five generations of selection-while-inbreeding in corn. However, his selection-while-inbreeding procedures differed from those used in this study.

Results of the recurrent selection vs. mass selection study failed to indicate superiority, from the standpoint of progress, for either method. None of the mass selection or recurrent selection populations were significantly different from the mid-parent value in Enviroment I or in the combined data. However, in Environment I, R.S. II and M.S. II were much nearer to the high parent value than to the mid-parent value. This indicates the breeding methods had increased the frequency of genes for lint coarseness. In Environment II, the means of R.S. II and M.S. III were significantly higher than the mid-parent but the mean of M.S. II was not.

The coefficients of variation did not indicate a decline in variability in any of the recurrent selection or mass selection populations.

There are no published reports of studies comparing recurrent selection and mass selection directly comparable to this study. However, the results of Johnson and Goforth's work (18) with sweetclover may be mentioned. These authors inferred, with reference to combining ability, that one cycle of recurrent selection based upon progeny performance was superior to four generations of visual (mass) selection for desirable plants.

The relative progress made in increasing frequency of genes for fiber coarseness was essentially the same in the two breeding studies, i.e., recurrent selection vs. selection-while-inbreeding, and recurrent selection vs. mass selection. However, the length of time and amount of labor necessary for the production of a cycle, or generation, was not the same for the respective breeding methods. One "growing season" and approximately 20 man-hours of labor were required for a cycle of mass selection; one growing season and approximately 60 man-hours of labor were required for one generation of selection-while-inbreeding; and two growing seasons and approximately 300 man-hours of labor were required for one cycle of recurrent selection (assuming the intercross seed could have been planted directly in the field).

Thus in evaluating the respective breeding methods from the standpoint of progress made and time and labor required, mass selection was the most efficient of the three methods used in these studies. However, if it were desired to determine which breeding method could increase the frequency of genes for fiber coarseness to the highest level (ultimate maximum gain) then additional generations, and cycles, of the respective methods would be necessary.

SUMMARY AND CONCLUSIONS

An attempt was made to determine the relative effectiveness of recurrent selection, selection-while-inbreeding, and mass selection for increasing the frequency of genes for fiber coarseness. For the study of recurrent selection vs. selection-while-inbreeding two cycles of recurrent selection and four generations of selection-while-inbreeding were completed beginning with an F_2 population of CR-2 x 4-24-3-8-B-9. For the study of recurrent selection vs. mass selection, two cycles of recurrent selection and three cycles of mass selection were completed, beginning with an F_4 population of Oklahoma Special x Lankart 57

The relative progress made by the respective breeding methods was determined by growing, in each of two environments, replicated tests composed of appropriate entries; also the breeding methods were compared as to time and labor requirements.

To better evaluate the respective breeding methods it was deemed necessary to have some information as to the type of gene action and type of inheritance that determines fiber coarseness and to have an estimate of the heritability of this character. To obtain this information a replicated test was grown in each of two environments. The test entries were parents, F_1, F_2, and backcrosses of the cross CR-2 x 4-24-3-8-B.

The conclusions drawn from these studies may be summarized as follows:

(a) Fiber coarseness is quantitatively inherited and the gene action is probably arithmetic with no dominance; heritability for this character was found to be relatively high.

(b) All three breeding methods were effective in increasing the frequency of genes for fiber coarseness.

(c) From the standpoint of time and labor required, mass selection was the most efficient method, followed by selection-while-inbreeding and recurrent selection, respectively.

(d) As indicated by the F_6 generation, selection-while-inbreeding was leading to the least variable populations, with respect to fiber coarseness.

(e) A genotype-environment interaction was indicated by the changes in rank among the entries from environment to environment.

(f) Additional cycles, or generations, of the respective methods would be necessary to determine which breeding method could effect the maximum increase in frequency of genes for fiber coarseness.

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VITA

James D. Bilbro, Jr.

Candidate for the Degree of

Doctor of Philosophy

Thesis: COMPARATIVE EFFECTIVENESS OF THREE BREEDING METHODS IN MODIFYING COARSENESS OF COTTON FIBER

Major Field: Plant Breeding and Genetics

Biographical:

Personal data: Born in Forgan, Oklahoma, August 5, 1930, the son of J. D. and Lillie Alice Bilbro.

Education: Attended grade school in and near Forgan, Oklahoma; graduated from Forgan High School in 1947; received the Bachelor of Science degree from Panhandle Agricultural and Mechanical College, with a major in Agriculture, in May, 1951; received the Master of Science degree from Oklahoma Agricultural and Mechanical College, with a major in Field Crops, in May, 1953; completed the requirements for the Doctor of Philosophy degree in May, 1957.

Professional experience; Was employed by the Oklahoma Agricultural Experiment Station from September 1, 1954, to October 15, 1954; and jointly by the Oklahoma Agricultural Experiment Station and the U. S. Department of Agriculture from October 16, 1954, to February 1, 1956. Tour of duty was at the Oklahoma Cotton Research Station, Chickasha, Oklahoma; duties involved primarily cotton breeding and varietal testing.