A STUDY OF GENOTYPE-ENVIRONMENT INTERACTIONS IN COTTON AND THEIR IMPLICATIONS ON FUTURE VARIETAL TESTING IN OKLAHOMA

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CHAPTER I

INTRODUCTION

The presence of genotype by environment interactions among replicated field trials is a problem frequently encountered in plant breeding work. Such interactions occur when two or more genotypes fail to behave consistently in relation to one another under differential environmental conditions. Therefore, when the breeder tests lines or varieties (or both) to determine their relative performance, it is important for him to adequately sample the environments under which those genotypes are expected to be grown. The number and distribution of those test environments will depend largely upon which interactions are important and on their relative magnitudes. In replicated field trials, environments are commonly subdivided into years and locations. It is the responsibility of the breeder to determine and use the best combination of those two variables in testing his material.

Large and statistically significant interactions for a character indicate that conclusions as to the relative merits among a set of genotypes for that character in one environment may not hold in another environment. If genotype by year interactions are important, it is essential that testing be conducted over as many years as will adequately sample yearly variations. If genotype by location interactions are prevalent, the breeder may have to subdivide the area in question for breeding and testing purposes with the result that a different variety or varietal type would be recommended for each subdivision. Since most breeders attempt to develop varieties as widely adapted as possible, it is imperative that the testing locations differ in such factors as available moisture, fertility levels, and soil type. Large genotype by location interactions would hinder efforts to develop a variety superior throughout the area in question. If genotype by location by year interactions are important, tests in multiple environments are necessary. However, this interaction implies nothing as to how those tests should be distributed over years and locations. Examination of the first-order interactions should show whether years or locations or both should be emphasized. If neither of the first-order interactions are important, it is probably of benefit to the breeder to stress locations rather than years since to do so would increase his breeding progress per unit of time by allowing more frequent selections to be made per unit of time, assuming the same amount of test information.

However, if one or more of the genotype by environment interactions are not important within the breeding area, the number of tests can be reduced since implications made in one or a few environments will apply equally as well in numerous ones. This also implies an accompanying reduction in experimental cost and time required for the breeder to determine the potential utility of a strain or variety. As a result, more lines or varieties can be screened than would be possible otherwise, thereby increasing the probability of obtaining superior germplasm.

At the present time in Oklahoma, upland cotton (*Gossypium hirsutum* L.) is grown over a wide range of environments under both irrigated and dryland conditions. The Oklahoma Agricultural Experiment Station spends considerable time and effort in the evaluation of varieties and strains of cotton. This evaluation could be conducted in a more scientific manner if it were determined which traits of cotton are most influenced by genotype by environment interactions in Oklahoma, how many tests are required to determine relative performance for those traits, and how those tests should be distributed over locations and years. A preliminary study of this type has previously been conducted within the state. The primary purpose of this research is to confirm or contradict the earlier work using more recently developed varieties and an expanded number of test locations. A character not reported previously, uniformity ratio, will also be included in the study. Attempts will be made as well to determine how irrigated versus dryland conditions affect genotype by environment interactions. Secondary aims include the estimation of the degree of bias encountered when tests are analyzed over a limited number of locations and years and of the effect of varietal number on the magnitudes of the interaction effects.

CHAPTER II

REVIEW OF LITERATURE

Genotype-Environment Interactions in General

Although plant breeders have long been aware of the existence of genotype by environment interactions in field experimentation, only recently have quantitative methods been used to estimate their magnitudes. In 1951-52, Comstock and Robinson (11,12) recognized the fact that variances resulting from the interaction of genotype and environment are frequently sources of upward bias in estimates of genetic variance, and they proposed the use of a components-of-variance method assuming a random sample of years and locations to arrive at more precise estimates of those effects. Hanson (19) studied biases introduced when data were analyzed as though they had been collected from a random sample of environments when in fact they came in a non-random fashion from a universe of environments. Through the use of intraclass correlations, he determined that one should be able to analyze associated environments as random effects without unduly biasing the estimates of genetic components, provided that present methods are used to select locations.

Comstock and Robinson (11) demonstrated that satisfactory agreement existed between actual sample estimates of variance components and estimates computed assuming normality and homogeneity of variances.

Kelleher, Robinson, and Comstock (23) considered the effects of non-normality and lack of homogeneity of variances on the precision of variance component estimates when the precision had been estimated previously on the basis of those assumptions. The estimates were generally unaffected by non-normality up to the level considered. It was also concluded that the variability of estimates of the components can be computed with the assumption of common variances in parent distributions if sampling is conducted within years.

Mather and Jones (26) described the interaction of genotype and environment in terms of genetic parameters when one gene pair was involved in two environments. This simple case was then extended to include three or more environments and multiple gene pairs. Haldane (15) characterized the types of interaction possible between two stocks and two environments. For the more general case of m genotypes and n environments, he suggested that there are $(mn)!/(m!\,n!)$ possible types of interaction, although the breeder or geneticist may not be concerned with or be able to detect each one individually.

Hanson, Robinson, and Comstock (18) used a procedure to eliminate bias due to genotype-environment interactions in estimates of genetic variance for two characters in Korean lespedeza. By the use of the analysis of variance, the components of variation due to interaction were separated from the genetic component of variance, and accurate estimates of broad-sense heritability and genetic advance were obtained. This procedure has been described by others and can be extended to varietal testing for the purpose of estimating the importance of genotype-environment interactions (4,10,12,13). Comstock and Moll (10) have pointed out several advantages in getting precise estimates of the magnitude of genetic variation. They felt it unnecessary to obtain estimates of this parameter for every genetic population in a breeding program because reasonably accurate inferences could be made from a limited number of good estimates in similar material.

Allard and Bradshaw (6) considered genotype by location interactions to be in the predictable category of environmental variations and the genotype by year and genotype by location by year interactions to be unpredictable. The latter group was thought to be more "interesting" to the plant breeder since the effects of those interactions are more difficult to combat.

According to the analysis of variance for a typical variety trial, the number of replications, locations, and years must each be a minimum of two for one to obtain unconfounded estimates of the principle interaction components (10). This does not mean, however, that field trials should consist of this absolute minimum. Sprague and Federer (37) considered it important to use fewer replications per location with an increase in number of locations and years if cost was not a factor. Jones, Matzinger, and Collins (22) generally agreed with this viewpoint stating that the optimum plot allocation for tobacco for proper variety evaluation was two years with five locations per year and three replications per test.

Matzinger (27) noted that where genetic material is grown in a limited area of adaptation, the magnitude of the genotype by location interaction was small and the second-order interaction for yield was the predominant type <u>regardless</u> of the species and without regard to whether the product was vegetative, lint, or seed. He suggested that it might be simpler to analyze such experiments as genotypes and environments with no distinction being made between years and locations.

Knowledge of the basic causes of unfavorable genotype-environment interactions would be helpful to the breeder in developing "genetic cures" (6). As yet, however, the best means for coping with unpredictable fluctuations in environments has been to increase the genetic variability in a population or to create population buffering which will give the variety or strain stability over a wide range of environments (5).

Genotype-Environment Interactions in Cotton

The importance of genotype-environment interactions has been ascertained in such crops as corn (37), soybeans (21,36), oats (20), tobacco (22), sorghum (24), small grains (25), lespedeza (18), and others. In cotton, early studies with highly heritable characters have shown that, in general, varietal or genetic variances overshadow variances due to environment or to genotype-environment interactions. Relative varietal differences among such characters as oil, nitrogen, and protein content of the seed (16,34); lint percentage and boll weight (28,29,30); seed fuzz (34); and fiber and spinning properties (7,17,34) have been fairly stable over locations and years. Lowly heritable traits, particularly yield, have been affected to a greater extent by differential environments. For this reason, a rather lengthy discussion of lint yield will be presented, followed by a review of the more important fiber traits in cotton. The terms "significant" and "highly significant" will be used henceforth to designate the 0.05 and 0.01 probability levels of statistical significance, respectively, unless otherwise stated. It should also be understood that some bias may well exist in comparing results of certain traits obtained by various workers due to differences in their scales of measurement for those traits.

Lint Yield

Al-Jibouri, Miller, and Robinson (3) evaluated 92 F_3 progenies derived from an interspecific cross at two locations in North Carolina within a single year. They found the variance due to the interaction of progenies and locations made up 16% of the total phenotypic variance for lint yield (the highest percentage among the traits studied). Miller *et al*. (30) also in North Carolina estimated variance components for three different populations grown at two locations over two years. The genetic components of variance were considerably larger than the interaction components except in one population where the progeny by location by year component was of sufficient magnitude to be of importance. Murray and Verhalen (31) tested 62 breeding lines for two years at two locations in Oklahoma. The combined interaction components of variance were larger than the genetic component which led the authors to suggest that testing in multiple years or locations or both would enable more accurate differentiation of relative lint yield among lines. However, estimates of the relative efficiency of two versus one year's testing before making selections indicated that selections should be made at the end of each year to maximize selection progress per unit of time.

Richmond and Lewis (35) in the Brazos River Valley of Texas found a highly significant mean square for the variety by year interaction when 16 varieties were grown at the same location for two years. A more extensive study in North Carolina by Miller, Williams, and Robinson (29) of 15 varieties at nine locations for three years indicated that first-order interactions were small and non-significant while the second-order interaction was of sizable magnitude and highly significant. From these data the necessity of testing cotton varieties over several environments was strongly suggested. However, because of the lack of importance of the variety by location interaction, a subdivision of the state for breeding and testing purposes was deemed unwarranted. Results which approach those found in North Carolina have been reported by Bridge, Meredith, and Chism (8) for the Mississippi Delta. After eight varieties were grown at three locations for three years, it was determined that no subdivision of the area was necessary. However, the authors pointed out that a test composed of a broader base of varieties than what they utilized might be more accurate in detecting genotype-environment interactions. Walton (41) reported similar findings with respect to lint yield in Uganda where he tested five varieties at 13 locations over three years. He agreed with Miller _et al_. (29) that the significance of second-order interactions indicated that a differential varietal response existed under different environmental conditions and that those conditions were not associated with the influence of either location or year alone but were a result of particular combinations of both.

Sixteen varieties were evaluated by Miller, Robinson, and Pope (28) at 11 locations from North Carolina to Texas over three years for the purpose of sampling a wider range of Cotton Belt environments. The second-order interaction component of variance was large and highly significant while the first-order interactions were small, although the variety by location component was significant. A reanalysis of the data omitting the three Texas locations reduced the variety by location component to the extent that it was nonsignificant, resulting in the conclusion that the major portion of the variety by location interaction was due to those three locations. In the most extensive investigation of genotype-environment interactions yet undertaken, Abou-El-Fittouh, Rawlings, and Miller (2) studied four varieties in 101 environments representing 39 locations across the Cotton Belt. The data indicated that the variety by location and variety by location by year interactions were larger than the genotypic variance while the variety by year interaction was of little importance. When each region of the Cotton Belt was analyzed separately, the variety by location interaction decreased in relative magnitude; and the second-order interaction became more important, and in one case (the Plains region) it exceeded the genotypic component of variance.

Murray and Verhalen (32) analyzed the relative performance of 11 varieties of cotton over three years at three locations in Oklahoma. Their results suggested a subdivision of the state (possibly into dryland and irrigated production areas) for testing and breeding purposes due to the presence of a large and significant variety by location interaction. The second-order interaction was of substantial size and highly significant, conforming to the results of most other research workers. In a diallel analysis involving 10 varieties of upland cotton grown in Oklahoma for two years at one location, Verhalen _et al._ (40) tested the specific assumption of no genotype by year interactions for the additive and dominance components of variation. For lint yield no significant mean squares were found for either component. A location effect was confounded in these results, however, since only one location was utilized in the experiments.

Miller et al. (29) suggested that differential varietal response among individual tests might be due to patterns of rainfall distribution and insect infestation. Abou-El-Fittouh et al. (2) considered temperature to be the major environmental factor associated with genotype by environment interactions for lint yield. Elevation, available moisture, insects, diseases, and soil fertility were considered less important. In an attempt to minimize genotype by location interactions for yield within a specific geographical area, Abou-El-Fittouh, Rawlings, and Miller (1) divided the Cotton Belt into zones through the use of cluster analysis. As a result, the boundaries of the present zoning system were modified somewhat, one such difference being the shifting of Stillwater, Oklahoma, from the Central region into the Plains region within which the remainder of the Oklahoma cotton variety tests were already located.

Fiber Length

The evaluation of breeding lines for fiber length by various workers (3,30,31) has clearly shown that genotypic variances greatly overshadow interaction variances (even when interaction mean squares were significant). It is generally agreed that a small number of tests adequately determines relative performance for fiber length.

Data from variety tests in North Carolina (29) and in the Mississippi Delta (8), two rather small areas, indicate that the same conclusions drawn from breeding lines are also applicable to varieties. In each case the three-factor interaction was larger than the two-factor interactions but did not approach the magnitude of the varietal component. Miller et al. (28) when considering varietal performance over a large area of the Cotton Belt obtained results very similar to those cited above, indicating relative varietal stability for this trait from North Carolina to Texas. A further extension of the analysis of variance to include 101 environments from North Carolina to California was undertaken by Abou-El-Fittouh et al. (2). Their estimated components of variance, arranged in descending order of importance as shown by relative magnitudes were: the varietal component, the variety by location by year component, the variety by location component, and the variety by year component. A major portion of the variety by environment interaction sum of squares for this trait was associated with temperature, and only a minor portion with the other environmental variables studied. El-Sourady, Worley, and Stith (14) compared genotype-environment interactions within different regions and across the Cotton Belt using ratios of the pertinent variance components to the error component as a basis for making comparisons. Their purpose was to eliminate bias due to differences in magnitude of the error components found in individual regions. However, their conclusions with respect to fiber length differed little from those of previous researchers.

In Oklahoma Verhalen and Murray (39) found no evidence of genotype by year interaction in a test involving 10 varieties, two years, and one location. Later work by Murray and Verhalen (32), involving a different set of varieties, locations, and years, exhibited no significant interaction mean squares with the exception of the variety by year interaction, and it was quite small in relation to the varietal component.

Fiber Length Uniformity

An extensive search of the literature has failed to uncover any investigation of genotype by environment interactions concerning fiber length uniformity.

Fiber Fineness

Al-Jibouri et al. (3) found that the progeny by location interaction component made up 12% of the total phenotypic variance for this trait among 92 F_3 progenies tested at two North Carolina locations in one year. Another study (30) in North Carolina of two different populations composed of 95 and 92 lines, respectively, evaluated over two locations and two years indicated that no significant genotype by environment interaction existed. However, Murray and Verhalen (31) tested 62 families for two years at two locations in Oklahoma and detected a second-order interaction component larger than the genetic component. The results suggested that testing over years would be more informative than testing at several locations for this character in this population.

In North Carolina Miller et al. (29) reported highly significant first-order interaction variance components, although they were overshadowed considerably in magnitude by the varietal component. In the Mississippi Delta (8), however, there was evidence of a large and significant second-order interaction, with first-order interactions posing no problems. When variety tests from across the Cotton Belt were analyzed, Abou-El-Fittouh et al. (2) found that the variety by location by year component of variance was larger than the varietal component, although they did not consider genotype-environment interactions as a whole to be as important for fiber fineness as for lint yield. In this experiment temperature was considered the most important environmental variable associated with the interaction sum of squares. Of the traits studied, however, fiber fineness had the smallest proportion of this environmental variable affected by temperature. When El-Sourady et al. (14) analyzed varieties common to each region of the Cotton Belt using the modified procedure of comparison previously described, they discovered that variety by environment interactions, the second-order interaction in particular, were more important in the Plains and Western regions than in the Eastern, Central, and Delta regions.

Verhalen and Murray (39) showed evidence of an interaction occurring between years and additive effects as well as between years and dominance effects at a single location in Oklahoma. The authors pointed out that since only one location was used, the test for interaction could have been biased upwards by a confounding of the second-order interaction with the interaction designated as genotype by year. Recent research by Murray and Verhalen (32) in Oklahoma tends to confirm that possibility. When 11 varieties were evaluated at three Oklahoma locations for three years, the variety by location by year interaction mean square was highly significant, while the first-order interactions were non-significant. It was inferred that tests in multiple environments were necessary for this trait, but that it made little or no difference how those tests were distributed over locations and years.

Fiber Strength

Al-Jibouri et al. (3) reported that for T_1 (1/8-inch gauge Stelometer) fiber strength the progeny by environment interaction made up a very small portion (1%) of the total phenotypic variance among 92 F_3 lines of interspecific origin when tested at two locations in one year. They admitted, however, that large sampling error was possible in estimating the interaction variance because of the limited number of environments. In two populations of 95 and 92 breeding lines, evaluated at two North Carolina locations over two years, Miller et al. (30) found no significant genotype by environment interactions for strength measured as Pressley Index. Data presented by Murray and Verhalen (31) in Oklahoma exhibited a large family by location interaction for T_0 (0-inch gauge Stelometer) fiber strength with the other interactions being of lesser magnitude. When the T_1 measurement was analyzed, there were no important family by environment interactions present.

Variety tests conducted and analyzed for fiber strength measured in pounds per square inch by Miller et al. (29) at nine locations in North Carolina over a three-year period were found to contain a small but highly significant variety by location by year interaction. Bridge et al. (8) reported similar results in the Mississippi Delta with T_1 fiber strength, except that the second-order interaction was not significant. Abou-El-Fittouh et al. (2) calculated variance components for T_1 fiber strength which involved 101 environments across the cotton growing region of the United States. The results suggested that genotype-environment interactions were important for this trait. Using the method devised for comparing variance components described earlier, El-Sourady et al. (14) studied the stability of varieties from different regions across the Cotton Belt and found that the varieties studied tended to be more stable for T_0 than for T_1.

In an analysis of 10 cotton varieties grown at one location in Oklahoma for two years (39), the assumption of no genotype by year interactions for T_0 and T_1 was tested and could not be rejected. Later research by Murray and Verhalen (32) on genotype by environment interactions in Oklahoma indicated a significant variety by year interaction mean square for T_1. Because of the small size of the interaction mean squares relative to the varietal mean squares for T_0 and T_1, it was considered unnecessary to test for this trait over locations or years.

CHAPTER III

MATERIALS AND METHODS

Experimental Procedures

Irrigated cotton variety tests were conducted in 1968 and 1969 at Chickasha and Altus, Oklahoma, on Reinach silt loam and Hollister clay loam soils, respectively. Dryland tests were also conducted over the same two-year period at Chickasha on Reinach silt loam, at Mangum on Meno loamy fine sand, and at Perkins on Vanoss loam. The test locations and seasons were selected to sample environments likely to be encountered in the cotton growing area of the state. Included in these tests were stormproof and open-boll varieties currently being grown commercially over the Cotton Belt. The varieties included in subsequent analyses are listed in Table I. Ten varieties were common to all locations over both years. The irrigated experiments had nine additional varieties in common. In four of the six dryland tests (Chickasha and Mangum in 1968 and 1969) seven additional varieties were included and could be evaluated therein.

A randomized complete-block design with six replications was used in each test. Plots were two rows wide and 50 feet long with a 40-inch spacing between rows. Two border rows were grown between each plot to equalize interplot competition, and at least four rows were grown on each side of the experiment to reduce border effects. Planting,

TABLE I

COTTON VARIETIES INCLUDED IN THE GENOTYPE-ENVIRONMENT INTERACTION STUDY

Varieties Common to All Locations		Additional Varieties At Irrigated Locations		Additional Varieties At Dryland Locations*	
Acala 1517D	(1)†	Deltapine 16	(15)	HyBee 300	(21)
Coker 201	(2)	Deltapine 45A	(19)	Lankburn	(20)
Coker 4104	(6)	Gregg 45A	(17)	Lankart 57	(14)
Dunn 56C	(4)	Lankart 57	(14)	Lankart 57 LX	(12)
Lankart 3840	(9)	Lankart 57 LX	(12)	Paymaster 54B	(23)
Lockett 4789A	(8)	Lockett BXL	(13)	Paymaster 101A	(11)
Paymaster 111	(5)	Lockett 4789	(16)	Western Stormproof	(22)
Paymaster 202	(10)	Paymaster 101A	(11)		
Stoneville 7A	(3)	Stoneville 213	(18)		
Westburn	(7)				

*Excluding Perkins

†Variety code numbers are utilized in the figures found in Chapter IV. The numbers do not imply any sort of varietal rank or relative merit.

thinning, cultural practices, insect control, irrigation (if any), and harvesting were carried out by various experiment station personnel at each location following the recommended procedures for that portion of the state.

Data were collected and evaluated for lint yield and the following fiber traits: length, length uniformity, fineness, and two measures of strength. Lint yield was determined by multiplying the weight of snapped cotton per plot in pounds by the pulled lint percentage of that entry in that experiment to arrive at pounds of lint per plot. Yield per plot was then converted into pounds of lint per acre. For fiber measurements a 15 to 25 boll sample of seed cotton was harvested from each plot, ginned on an experimental saw gin, and lint therefrom was forwarded to the Oklahoma State University Fiber Laboratory for measurement of the major fiber characteristics. Fiber length was measured in inches on the digital fibrograph as 2.5% span length. Fiber length uniformity was calculated by dividing 50% span length (also measured on the digital fibrograph in inches) by 2.5% span length, and then multiplying by 100. Fiber fineness was measured on the micronaire in micronaire units. Fiber strength was measured on the stelometer at the zero and one-eighth inch gauge settings in grams per grex, commonly referred to as T_0 and T_1, respectively.

Fiber data for the Mangum test in 1969 was unavailable due to a mistake in sampling made by the personnel at that station. Consequently, the fiber data from this location in that year could not be used in subsequent analyses. The result was that only one trait, lint yield, could be statistically analyzed whenever the analyses involved the 1969 Mangum experiment.

Statistical Analyses

The data were punched on IBM data cards and analyses of variance were then conducted on a computer. For each trait an analysis of variance was performed on the data, combining all locations and years, using those varieties common to all tests. Since the Mangum fiber data in 1969 were unavailable, a statistical analysis for the fiber traits was made combining only the remaining four locations over years. The form of the analysis follows that of Comstock and Moll (10) using the notation of Murray and Verhalen (32) and is shown in the first portion of Table II. The choice of a suitable error term for the F-test of each source of variation was made in accordance with the procedures described by Steel and Torrie (38). For the varieties source of variation, when significant interactions are present, the appropriate F-test and calculation of degrees of freedom have been described by Cochran (9), and that procedure was used where applicable.

Variance components were estimated by algebraic manipulation of calculated mean squares based on the components of the expected mean squares. They were computed as follows for the analyses over multiple locations and years:

Varietal or genotypic component = $\sigma_V^2 = (M_5 + M_2 - M_3 - M_4)/rly$,

Variety by year interaction component = $\sigma_{VY}^2 = (M_4 - M_2)/rl$,

Variety by location interaction component = $\sigma_{VL}^2 = (M_3 - M_2)/ry$,

Variety by location by year interaction component

$= \sigma_{VLY}^2 = (M_2 - M_1)/r$, and

Error component = $\sigma_E^2 = M_1$

TABLE II

FORMS FOR THE ANALYSES OF VARIANCE FOR MULTIPLE LOCATIONS AND YEARS, MULTIPLE LOCATIONS IN ONE YEAR, MULTIPLE YEARS IN ONE LOCATION, AND ONE LOCATION IN ONE YEAR

Sources	Degrees of Freedom*	Mean Square	Expected Mean Square†
Multiple Locations and Years			
Varieties	(v-1)	M_5	$\sigma^2_E + r\sigma^2_{VLY} + ry\sigma^2_{VL} + r1\sigma^2_{VY} + r1y\sigma^2_V$
Varieties by years	(v-1)(y-1)	M_4	$\sigma^2_E + r\sigma^2_{VLY} + r1\sigma^2_{VY}$
Varieties by locations	(v-1)(1-1)	M_3	$\sigma^2_E + r\sigma^2_{VLY} + ry\sigma^2_{VL}$
Varieties by locations by years	(v-1)(1-1)(y-1)	M_2	$\sigma^2_E + r\sigma^2_{VLY}$
Error	1y(r-1)(v-1)	M_1	σ^2_E
Multiple Locations in One Year			
Varieties	(v-1)	M_5	$\sigma^2_E + r(\sigma^2_{VLY} + \sigma^2_{VL}) + r1(\sigma^2_{VY} + \sigma^2_V)$
Varieties by locations	(v-1)(1-1)	M_3	$\sigma^2_E + r(\sigma^2_{VLY} + \sigma^2_{VL})$
Error	1(r-1)(v-1)	M_1	σ^2_E

*The letters v, r, 1, and y represent number of varieties, replications, locations, and years, respectively.

†σ^2_E is the error variance; σ^2_{VLY} the variance component due to the interaction of varieties, locations, and years; σ^2_{VL} the variance component due to the interaction of varieties and locations; σ^2_{VY} the variance component due to interaction of varieties and years; and σ^2_V the component of variance due to genetic differences among varieties.

(TABLE II (Continued)

Sources	Degrees of Freedom*	Mean Square	Expected Mean Square†
Multiple Years in One Location			
Varieties	(v-1)	M_5	$\sigma^2_E + r(\sigma^2_{VLY} + \sigma^2_{VY}) + ry(\sigma^2_{VL} + \sigma^2_V)$
Varieties by years	(v-1)(y-1)	M_4	$\sigma^2_E + r(\sigma^2_{VLY} + \sigma^2_{VY})$
Error	y(r-1)(v-1)	M_1	σ^2_E
One Location in One Year			
Varieties	(v-1)	M_5	$\sigma^2_E + r(\sigma^2_{VLY} + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_V)$
Error	(r-1)(v-1)	M_1	σ^2_E

*The letters v, r, l, and y represent number of varieties, replications, locations, and years, respectively.

†σ^2_E is the error variance; σ^2_{VLY} the variance component due to the interaction of varieties, locations, and years; σ^2_{VL} the variance component due to the interaction of varieties and locations; σ^2_{VY} the variance component due to interaction of varieties and years; and σ^2_V the component of variance due to genetic differences among varieties.

where M_1, M_2,..., M_5 are calculated mean square values for the appropriate sources of variation (Table II) and where r, l, and y are numbers of replications, locations, and years, respectively.

Analyses of variance for each trait were also performed combining the irrigated tests (two locations and two years) and the dryland tests (three locations and two years). All possible combinations of the three dryland locations taken two at a time (i.e., Perkins and Chickasha, Perkins and Mangum, and Chickasha and Mangum) were also analyzed over years. Again, only lint yield could be analyzed where the Mangum test in 1969 was involved. In order to compare the results with previous research reports in Oklahoma (32), an analysis of variance was conducted over years for lint yield combining the three locations involved in that earlier study (i.e., Chickasha irrigated, Mangum dryland, and Perkins dryland). Procedures identical to those discussed above were used to estimate the appropriate components of variance.

In all of the combinations of locations and years, analyses of variance could be conducted including 10 varieties, while in some it was possible to include as many as 17 or 19 varieties (Table I). In those cases combined analyses of variance were conducted and components of variance estimated using the 10 varieties common to all tests and, in addition, using the larger number of varieties common to the particular locations involved. Comparisons were then made between the variance components obtained from the 10-variety analyses and from the 17- or 19-variety analyses.

Analyses of variance were also performed within the dryland locations and within the irrigated ones combining locations in each year and years in each location. For the three dryland locations all possible combinations of locations were analyzed in each year. Where possible, two analyses were made for each combination; one using 10 common varieties and the other using either 17 or 19. The forms of these analyses are shown in the middle portion of Table II. For two or more locations in one year the following components of variance were calculated:

$$(\sigma_V^2 + \sigma_{VY}^2) = (M_5 - M_3)/rl,$$

$$(\sigma_{VL}^2 + \sigma_{VLY}^2) = (M_3 - M_1)/r, \text{ and}$$

$$\sigma_E^2 = M_1.$$

For two years in one location the following estimates were possible:

$$(\sigma_V^2 + \sigma_{VL}^2) = (M_5 - M_4)/ry,$$

$$(\sigma_{VY}^2 + \sigma_{VLY}^2) = (M_4 - M_1)/r, \text{ and}$$

$$\sigma_E^2 = M_1.$$

All notation is as previously defined. The magnitude of these variance components was then compared to those derived from analyses involving multiple locations and years in order to determine the amount of bias incurred by testing at only one location or in only one year.

Separate analyses of variance were also conducted on lint yield and fiber properties (where possible) within each location-year combination. As before, when feasible, two analyses were made for each test environment, one with 10 varieties and the other with 17 or 19. The effect of increasing the number of varieties on the magnitude of variance components was again determined. The form of this analysis of variance is given in the latter part of Table II. Components of variance were calculated in the following manner:

$$(\sigma_V^2 + \sigma_{VL}^2 + \sigma_{VY}^2 + \sigma_{VLY}^2) = (M_5 - M_1)/r$$

$$\sigma_E^2 = M_1,$$

with all notation as before. From these variance components, the amount of additional bias present, if any, was determined when estimating genotypic variance from data at only one location within a single year.

CHAPTER IV

RESULTS AND DISCUSSION

Computation of standard errors for variance components was considered unnecessary since Murray and Verhalen (32) found that inferences made from examining mean squares were the same as those obtained from studying variance components. Therefore, statistical significance of mean squares and relative magnitudes of estimated variance components were the main criteria used in weighing the importance of the sources of variation in these analyses.

Lint Yield

Estimates of the pertinent variance components for lint yield computed from analyses of variance involving multiple locations over years are presented in Table III. When all locations and both years were combined, no significant differences among varieties were detected. This result was unexpected since the varieties tested were considered to be representative of a wide range of different genotypes adapted to different regions of the Cotton Belt. The variety by location interaction though larger than the varietal source of variation was also non-significant. Indications here point to little change in response of varieties relative to one another from location to location in Oklahoma over these two years. Based on these results, a subdivision of the state for breeding and testing purposes would not be expected

TABLE III

VARIANCE COMPONENTS FOR LINT YIELD UTILIZING VARIOUS COMBINATIONS OF LOCATIONS OVER YEARS†

Variance Component	Locations‡ 1,2,3,4,5	1,2,4,5	1,3,5	1,4 10 Var.	1,4 19 Var.	2,3,5	2,5	3,5	2,3 10 Var.	2,3 17 Var.
σ^2_V	337	565	0ϕ	0ϕ	67	608	1018*	0ϕ	810	312
σ^2_{VL}	438	245	537	579	608	385	153	765	235*	479**
σ^2_{VY}	1230**	1029**	1800**	2215*	1449*	672*	199	887	931**	816**
σ^2_{VLY}	795**	974**	499*	712**	1078**	751**	880**	991**	382	89
σ^2_E	2892	2160	3238	2804	2824	2952	1515	3547	3793	4519

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 3 is Mangum, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

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

to add greatly to the efficiency of the breeding program. However, the variety by year interaction was highly significant, the estimated variance component being approximately four times as large as the varietal component. The obvious implications are that relative varietal rank in 1968 and 1969 differed considerably with respect to lint yield and that varietal evaluation over years is essential. The second-order interaction was also highly significant and over twice the size of the varietal component. Thus, a large and significant portion of the interactions exhibited by this character could not be attributed to effects constant over locations or over years. Unlike most other data reported in the literature for this trait, this interaction was not the largest in magnitude; but it was of sufficient size to be important. These data indicate that testing in Oklahoma over multiple environments is necessary and that greater emphasis should be placed on evaluation over years rather than over locations.

A reanalysis of the data, leaving out the Mangum location, produced the same results as in the overall analysis. That is, the variety and the variety by location interaction sources of variation were relatively small and non-significant, and the variety by year and variety by location by year interactions were quite large and highly significant. Because the Mangum soil is partially infested by a fusarium wilt and root-knot nematode problem, it was thought that the experimental error could be reduced somewhat in the analysis if this location were removed. This was the case, but the implications from the results as compared to those of the earlier analysis remained virtually unchanged. These results would also tend to discount the possibility of bias being introduced by analyzing an unbalanced number of dryland versus irrigated environments at the same time.

An analysis of variance combining the three locations over years used in an earlier study in Oklahoma (32) indicated no basic change in conclusions from those of the two previous analyses discussed above. The only difference in the results was that the variety by location by year interaction was significant at the 5% rather than the 1% level. However, when the variance components in this analysis were compared to those of the earlier study, the implications were somewhat different. The major points of divergence in the two sets of data are in the first-order interactions. In the earlier study the variety by location interaction was considered large enough to facilitate some subdivision of the state into subareas for breeding and testing purposes, while the variety by year interaction was considered relatively unimportant. In this research the opposite was found to be true; i.e., the variety by year interaction was of considerable importance and the variety by location interaction was negligible. Another contrast in the two studies lies in the magnitude of the second-order interaction, which was considerably more important in the earlier work.

One logical reason for the differences in results between the two studies could be that a different set of varieties was tested in each case. Since the results in a strict sense, apply only to the genetic material involved, it is conceivable that the genotype-environment interactions were greatly influenced by the germplasm evaluated. However, when the two sets of varieties are compared, many of the varieties in one set are seen to be closely related though not identical to those in the other set, making this point a less weighty one than it would otherwise be. Another contributing factor, and probably a more significant one, as far as the differences in results, especially in regard to the variety by year interaction, is that the seasons of 1968-1969 were different in nature from those of 1962-1964. As with any biological data, there could be any number of environmental causes, suspected or unsuspected, which are responsible for the discrepancies in the results.

Table III also gives estimated variance components for the two irrigated locations analyzed over years. Separate analyses, involving first 10 and then 19 varieties, apparently had little effect on significance levels or relative magnitudes of the various sources of variation. In each analysis, the variety and the variety by location interaction components were small and non-significant. The variety by year interactions were both significant, and the three-factor interactions were highly significant. The relative magnitudes of the variance components in the two cases remained approximately the same, with the possible exceptions that the second-order interaction for the 19-variety analysis increased slightly and the variety by year interaction decreased.

Variance component estimates of the three dryland locations combined over years leads to different conclusions. The major change from previous analyses is that the variety by year interaction, although significant, was smaller than the second-order interaction, the latter being highly significant. Both interaction components were of the approximate size of the varietal component and were, therefore, of sufficient magnitude to be important. The varietal component and the variety by location component were non-significant, as before.

The only major difference realized from subdividing into irrigated and dryland locations and analyzing over years was a change in the variety by year interaction component of variance (see columns 1, 4, and 6 of Table III). Inspection of comparable analyses indicates that the variety by year interaction nearly doubled in size when analyzed over irrigated locations and years and decreased by one-half when analyzed over dryland locations and years. This suggests that more emphasis should be placed on testing over years if the experiments are irrigated than if they are not.

Examination of variance components when all possible combinations of the three dryland locations taken two at a time were analyzed over years produced some surprising results. The Chickasha-Perkins combination over years was unique in that the varieties source of variance was significant. This might be partially explained by the fact that the error variance was one-half to one-third of that in the other analyses. The first-order interactions were both small and non-significant, while the second-order interaction was highly significant and approached the magnitude of the varietal component. The variance components for the Mangum-Perkins combination over years were similar in that the variety by location and variety by year interactions were non-significant and the second-order interaction was highly significant. However, no differences could be detected statistically among varietal means. This data indicates that emphasis need not be specifically placed on either years or locations, but a combination of both should probably be employed.

The data from the Chickasha-Mangum combination over years was also unique. Two analyses involving 10 and 17 varieties, respectively, differed little from each other, but were substantially different when compared to previous combinations of locations and years. In both cases the varietal variance and the second-order interaction were non-significant, the former being considerably larger each time. The variety by location interaction was significant at the 5% level for the 10-variety analysis and at the 1% level for the 17-variety analysis. This interaction was more important when the larger number of varieties was included in the analysis; that is, it was greater than the varietal component in the latter analysis. The most important source of variation, the variety by year interaction, was highly significant and larger than the varietal component in both analyses. The results suggest that varieties should be tested at each location with special emphasis on evaluation over years.

In order to determine which varieties were responsible for the large interactions observed without the complications of location and year effects, the variety means in subsequent figures were adjusted using the technique developed by Patterson (33). Figure 1 gives varietal response between years over all five locations. It is obvious that large variety by year interactions were present. Those varieties with a sharp positive response from 1968 to 1969 were Stoneville 7A, Coker 4104, and Coker 201. Those with a sharp negative response during the same time period were Lankart 3840 and, to a lesser extent, Lockett 4789A and Paymaster 202. The remaining varieties were more consistent from year to year. Two possible reasons readily come to mind for these reactions. Of the growing seasons, the drier was 1968. Varieties grown at dryland locations adapted to producing under drought conditions would tend to perform better in 1968 than those requiring more moisture. By the same token, those varieties requiring additional moisture would

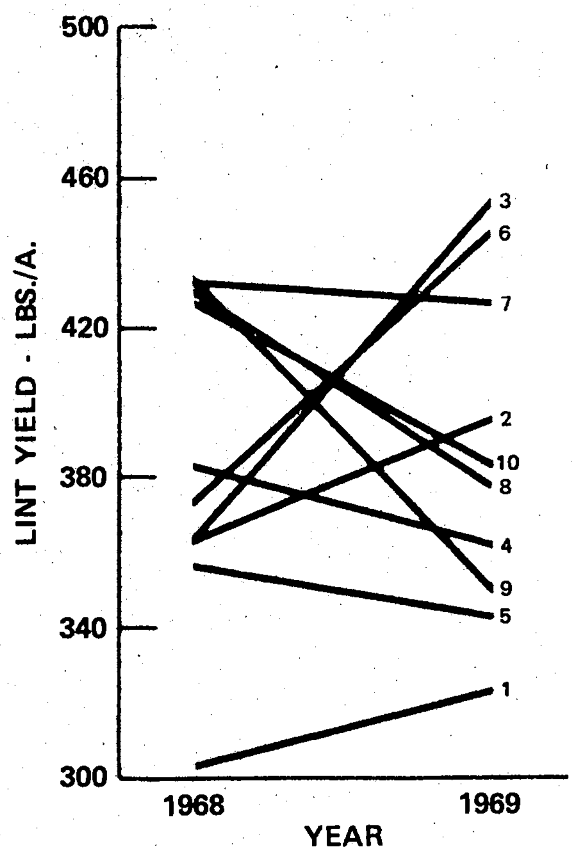

FIGURE 1. VARIETAL RESPONSE BETWEEN YEARS OVER THE FIVE LOCATIONS FOR LINT YIELD.

be more productive in the wetter season. Another difference between the two years was an early frost in 1968. Because irrigation tends to delay maturity, genetically later maturing varieties grown under conditions of ample moisture would have been more severely penalized in 1968. Under a longer growing season such as 1969, these same varieties would respond positively. The higher yielding varieties in 1968 were adapted to the Plains region while the more productive varieties in 1969 were bred specifically for the Eastern and Delta regions.

Adjusted varietal means can be compared in Figure 2 for the 19 varieties common to the irrigated tests. A sharp positive varietal response from 1968 to 1969 is evident for Stoneville 7A, Coker 4104, Stoneville 213, and Deltapine 45A. Some of the more negative responses came from Lankart 3840, Paymaster 101A, and Paymaster 202. In these tests, moisture was not a limiting factor; but it is conceivable that earliness was an important trait in determining varietal performance in these particular years. Nevertheless, in 1969 some Plains varieties were penalized while varieties adapted to other regions were favored.

Varietal response between years over the three dryland locations is shown in Figure 3. Sharp increases in yield were apparent in 1969 for Stoneville 7A, Coker 4104, and Coker 201 while pronounced decreases were evident for Lockett 4789A, Lankart 3840, and Paymaster 202. In these tests moisture availability could be a factor responsible for differential response.

In a strict sense, the "causes" for these reactions cannot be determined. It is noteworthy that, in general, most varieties reacted in the same manner in each analysis; i.e., positive in all cases or negative in all cases, regardless of whether combined over all locations

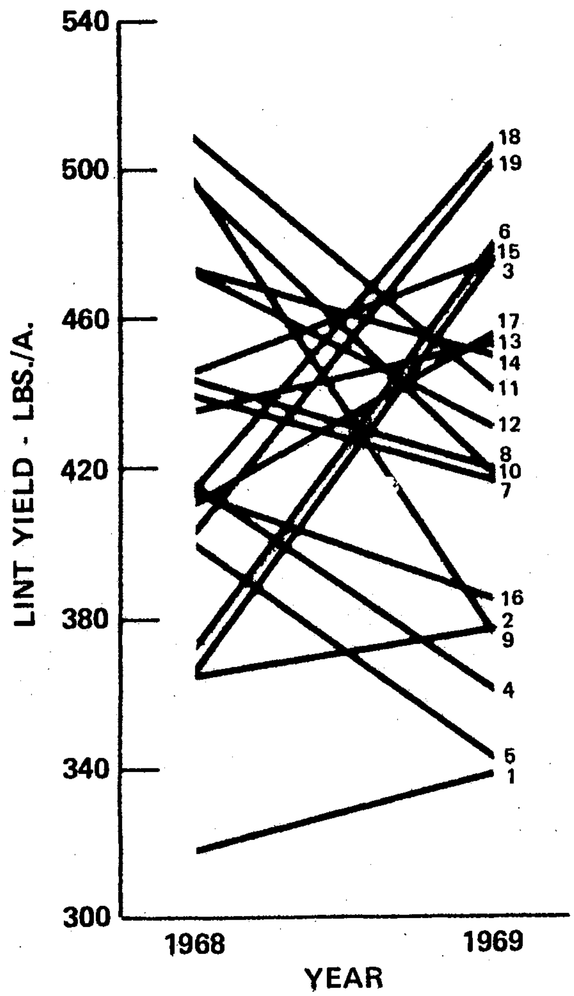

FIGURE 2. VARIETAL RESPONSE BETWEEN YEARS OVER THE IRRIGATED LOCATIONS FOR LINT YIELD.

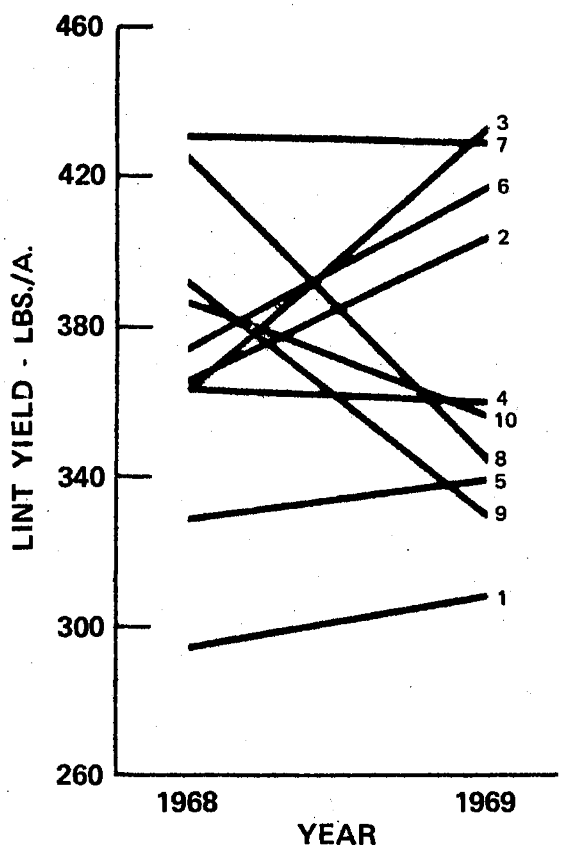

FIGURE 3. VARIETAL RESPONSE BETWEEN YEARS OVER THE DRYLAND LOCATIONS FOR LINT YIELD.

or subdivided into irrigated and dryland locations (Figures 1 through 3). Apparently, the relative length of the growing seasons in these two particular years was of greater importance than was the availability of moisture.

Because of the highly significant first-order interactions found when the Chickasha and Mangum tests were analyzed over years, it was necessary to look at varietal response over years at each location and over locations in each year. The two graphs in Figure 4 indicate that relative varietal rank from 1968 to 1969 changed considerably more at Mangum than at Chickasha. At the latter location there were only two or three varieties which were highly inconsistent from year to year while at the former location those affected were more on the order of seven or eight. The general trend observed in respect to Plains varieties versus those adapted to other regions of the United States did not strictly apply in this instance. Varieties such as Western Stormproof, Lankart 57 LX, and Lankburn (all adapted to the Plains region) showed sharp positive reactions to the 1969 growing season. However, Lankburn and Western Stormproof are known to be later in maturity than most Plains varieties. Others such as Lockett 4789A, Paymaster 54B, Stoneville 7A, and Coker 4104 conformed to previous observations.

In Figure 5 relative varietal response can be studied in each year across the Chickasha and Mangum dryland locations to determine which varieties contributed the most to that analyses' large variety by location interaction. There were no clear-cut trends in variety reaction as moisture availability decreased from Chickasha to Mangum, Varieties such as Lockett 4789A, Paymaster 54B, and Paymaster 202 reacted negatively to the drier conditions at Mangum in both years

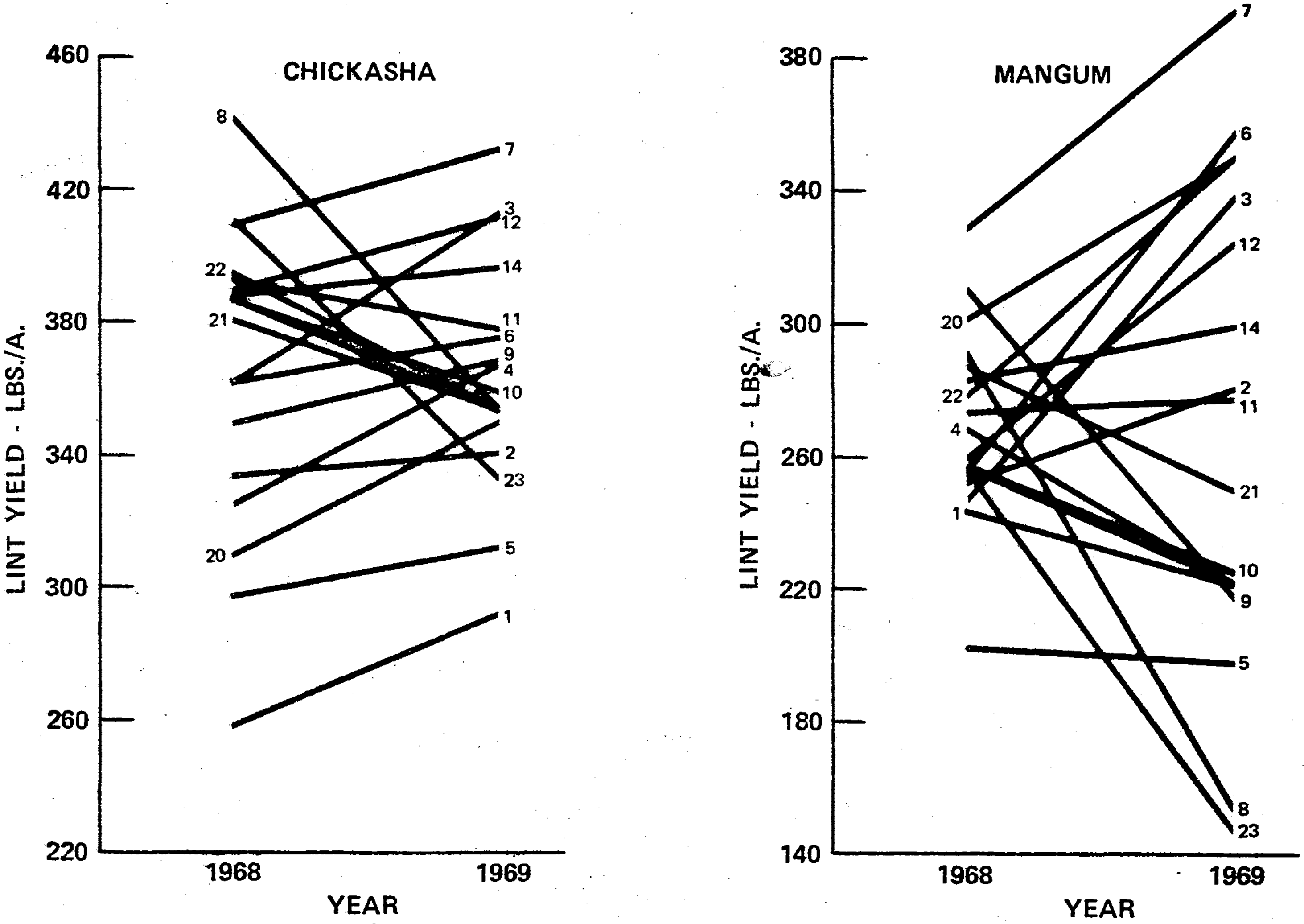

FIGURE 4. VARIETAL RESPONSE BETWEEN YEARS AT THE CHICKASHA AND MANGUM DRYLAND LOCATIONS FOR LINT YIELD.

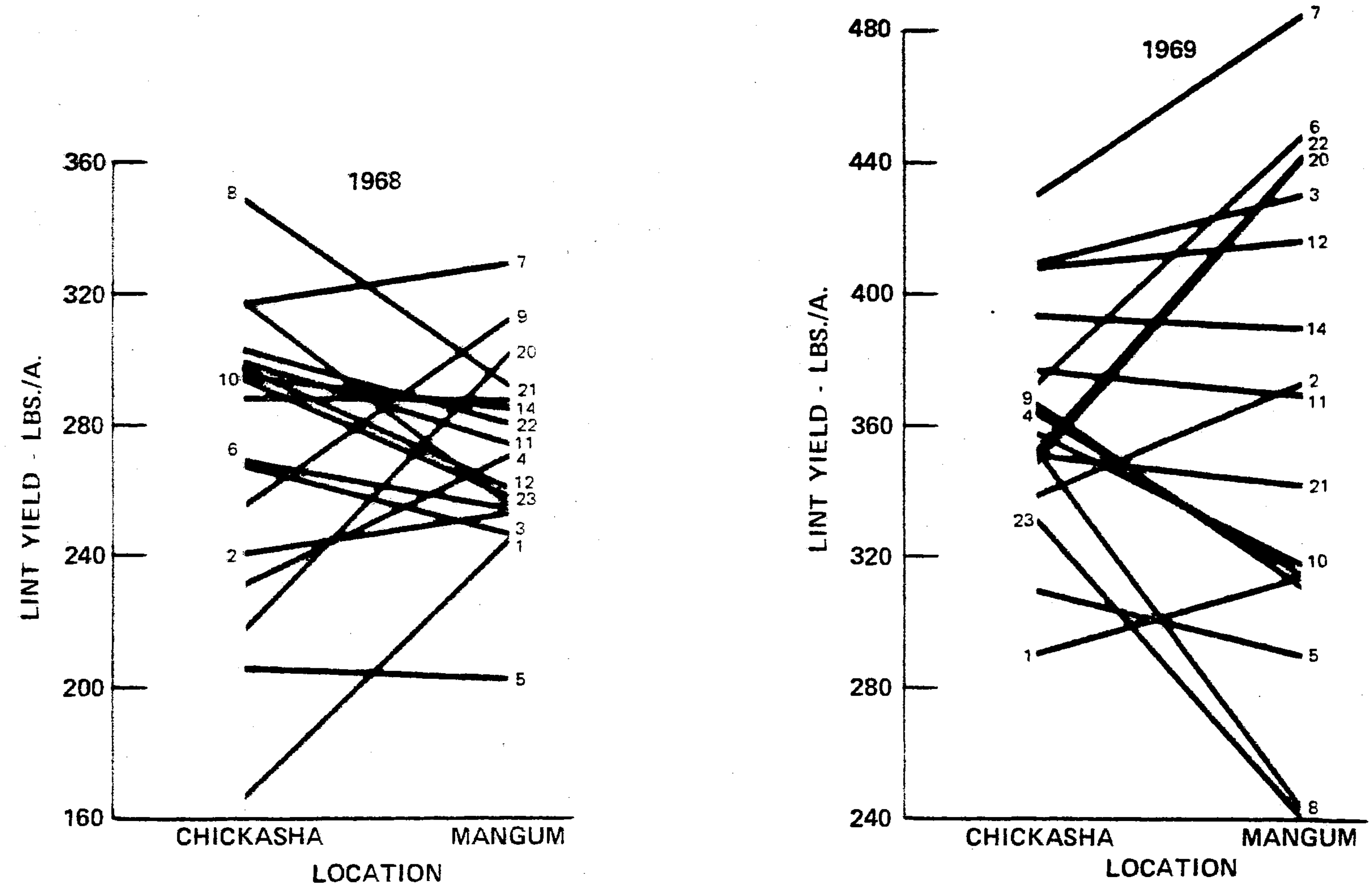

FIGURE 5. VARIETAL RESPONSE BETWEEN THE CHICKASHA AND MANGUM DRYLAND LOCATIONS IN SEPARATE YEARS FOR LINT YIELD.

whereas Lankburn, Acala 1517D, and Westburn reacted positively each year. Mixed responses were shown by Lankart 3840, Stoneville 7A, Coker 4104, Lankart 57 LX, and Western Stormproof; in one year positive reactions were exhibited while in the other year the reverse was true.

Because of the radical behavior of the varieties at these locations and years, no attempt was made to correlate varietal response with region of adaptability. It may be noted that the analyses involving these two locations over years produced results which were unlike any of the other dryland combinations. Varietal type alone is apparently not sufficient to predict how a genotype will respond to a given set of locations and years.

When one year's data is analyzed over locations, the varietal component of variance may be biased upwards by the magnitude of the variety by year interaction. A clear-cut estimate of the variety by location interaction is not possible because of confounding with the variety by location by year interaction. The degree of bias introduced when varieties were analyzed in such a manner can be determined from Table IV. In 1968 the variety mean squares in all combinations of irrigated and dryland locations were significant in most cases at the 1% level. In combined analyses over years, this had not generally been the rule (Table III). It is quite evident that the varieties source of variance was biased upwards by the variety by year interaction which was known to be large in most instances. Conclusions drawn about relative varietal performance could have been erroneous if data were considered only within that one year. In 1969 variety mean squares were generally non-significant for most sets of locations considered. One exception was that of the Chickasha-Mangum dryland combination. In

TABLE IV

VARIANCE COMPONENTS FOR LINT YIELD OVER IRRIGATED LOCATIONS IN EACH YEAR AND OVER DRYLAND LOCATIONS IN EACH YEAR†

Year and Variance Component	Locations‡						
	1,4					2,3	
	10 Var.	19 Var.	2,3,5	2,5	3,5	10 Var.	17 Var.
1968							
$(\sigma^2_V + \sigma^2_{VY})$	3000**	2085**	1403**	2080**	928*	1201**	603**
$(\sigma^2_{VL} + \sigma^2_{VLY})$	505*	555**	365**	188	495*	411	350
σ^2_E	1932	2064	1996	1331	1914	2742	3442
1969							
$(\sigma^2_V + \sigma^2_{VY})$	1174	947	1158	353	839	2281*	1652*
$(\sigma^2_{VL} + \sigma^2_{VLY})$	2077**	2818**	1907**	1877**	3018**	825*	786*
σ^2_E	3676	3584	3908	1700	5181	4843	5596

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 3 is Mangum, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

this case, regardless of whether 10 or 17 varieties were involved in the analysis, bias was introduced by the large variety by year interaction. Estimates of the variety by location interaction were likewise inflated in some cases by the second-order interaction. In three different combinations of locations in 1968 and four in 1969 the variety by location interaction was significant. From combined analyses over years, these particular location sets had small and relatively unimportant variety by location interactions. No trend in the amount of bias could be detected when comparing combinations of irrigated locations with dryland locations nor when comparing analyses involving 10 varieties with those having 17 or 19.

Analysis of data over years at one location confounds the varietal variation with the variety by location interaction, and the variety by year interaction with the variety by location by year interaction. From Table V, it is possible to determine the bias introduced when varieties are tested at one location over years. In six of the nine analyses conducted the varietal component was non-significant. These results were expected since it was determined that variety components and variety by location interaction components were generally small. However, in three cases there was sufficient inflation of the variety mean squares to permit the conclusion that real differences among varieties existed. The estimate of variety by year interaction was expected to be large since it also contained the second-order interaction. In previous analyses estimates of each revealed that both were generally large and important (Table III). It was not surprising, therefore, that all estimates of the variety by year interaction were significant at either the 5% or 1% levels regardless of the number of

TABLE V

VARIANCE COMPONENTS FOR LINT YIELD OVER YEARS AT EACH LOCATION

Variance Component	Locations Over Years								
	Chickasha, Irrigated		Chickasha, Dryland		Mangum, Dryland		Altus, Irrigated		Perkins, Dryland
	10 Var.	19 Var.	10 Var.	17 Var.	10 Var.	17 Var.	10 Var.	19 Var.	10 Var.
$(\sigma^2_V + \sigma^2_{VL})$	0†	0†	1456*	918*	636	664	1343	1951*	887
$(\sigma^2_{VY} + \sigma^2_{VLY})$	3139**	2854**	513**	490**	2114**	1320*	2716**	2200**	1643**
σ^2_E	2619	2753	1761	1904	5824	7133	2988	2894	1270

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

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

varieties in the analysis. An examination of irrigated versus dryland tests uncovered no differences in the degree to which the results were biased under the two sets of environmental conditions. It is also noteworthy that no significant differences among varieties were found at Altus when 10 varieties were analyzed. However, when 19 varieties were included in the analysis, real differences were detected. This case was an exception since the other analyses changed little by increasing the number of varieties.

Considering the variance components computed in Tables IV and V, it should be emphasized that testing in one year across locations or in one location over years can introduce a significant amount of bias into interpretations of relative varietal performance. Within this experiment the bias was greater when testing in one year than when testing in one location.

Evaluation of varieties in a single environment will result in a possible error in interpretation of results if any of the interaction effects are large. Variance components estimated for each test environment are given in Table VI. It is readily apparent that the variety mean square is biased upwards in almost every case. Results from the the combined analyses of variance indicate that genotype-environment interactions were responsible for the inflated variances. Only in the 1968 Mangum test involving 17 varieties was the variety mean square non-significant, indicating little effect of interactions in that particular test. It is easily seen that for lint yield testing in one or a few environments seriously affects the ability of the plant breeder to determine relative varietal performance.

TABLE VI

VARIANCE COMPONENTS FOR LINT YIELD AT EACH LOCATION IN EACH YEAR

Year and Variance Component	Locations								
	Chickasha, Irrigated		Chickasha, Dryland		Mangum, Dryland		Altus, Irrigated		Perkins, Dryland
	10 Var.	19 Var.	10 Var.	17 Var.	10 Var.	17 Var.	10 Var.	19 Var.	10 Var.
1968									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	3201**	2820**	2457**	1749**	768*	157	3809**	2459**	2078**
σ^2_E	1912	2008	2160	2618	3325	4265	1951	2120	502
1969									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	2192**	1686**	1480**	1066**	4732**	3810**	4310**	5843**	2981**
σ^2_E	3326	3498	1362	1191	8324	10000	4025	3668	2037

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

Fiber Traits

Since the fiber data from the 1969 Mangum variety test were unavailable because of a sampling error, the analyses of variance conducted for the five fiber traits were necessarily fewer than could be made for lint yield. The analyses performed, however, were considered adequate to determine the relative importance of genotype by environment interactions for those traits.

Length

Variance components computed from analyses involving four locations over years, two irrigated locations over years and two dryland locations over years are given in Table VII. When combined over all locations and years, the varieties and the second-order interaction were highly significant. The variety by year interaction was significant at the 5% level while the variety by location interaction was not significant. A look at variance components indicated that the three-factor interaction was larger than either first-order interaction. However, all three were greatly overshadowed by the magnitude of the varietal component. Implications from these data are that varietal evaluation at multiple locations and years is not necessary for fiber length but rather that results from a single test are adequate to determine relative varietal performance. These data generally agree with those of Murray and Verhalen (32) in Oklahoma, with the exception that they did report a non-significant second-order interaction.

The analysis of variance of irrigated locations over years differed little from the above, the only exception being that the variety by

TABLE VII

VARIANCE COMPONENTS FOR 2.5% SPAN LENGTH OVER LOCATIONS OVER YEARS†

Variance Components⊙	Locations‡			
		1,4		
	1,2,4,5	10 Var.	19 Var.	2,5
σ^2_V	.323**	.318**	.334**	.345**
σ^2_{VL}	.006	.000ϕ	.000ϕ	.000ϕ
σ^2_{VY}	.007*	.006	.002	.000ϕ
σ^2_{VLY}	.011**	.020**	.012**	.011*
σ^2_E	.053	.044	.045	.062

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

⊙ Each calculated variance component has been multiplied by 10^2.

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

year interaction was reduced to a level where significance could not be detected. Increasing the number of varieties to 19 and reanalyzing the data did not alter relative magnitudes of the interaction effects. Likewise, an analysis over years of the two available dryland locations failed to produce results contradictory to the other analyses. Apparently, it made little difference whether varieties are evaluated under irrigated or dryland conditions, i.e., conclusions obtained remained the same.

Because of the lack of importance of genotype by environment interactions for this trait, the amount of bias introduced when evaluating means across locations in one year, over years at one location, or in a single environment would be expected to be negligible. These anticipations are confirmed when an examination of the results in Tables VIII through X is made. In the first case, where locations are combined in each year (Table VIII), the only erroneous conclusion that one might make is in regard to the variety by location interaction. Findings in Table VII made it clear that this component of variance was the smallest and least important source of variation. Because of being confounded with the three-factor interaction, the variety by location interaction was significant in the majority of analyses conducted. Nevertheless, when compared to the varietal source of variation (which was only slightly biased upwards by the variety by year interaction), the degree of bias introduced was small. A comparison of the sets of variance components involving the 1968 Mangum variety test with those of the other combinations not including this location, reveals that the above conclusions are generally identical.

In Table IX results are presented for varieties evaluated over

TABLE VIII

VARIANCE COMPONENTS FOR 2.5% SPAN LENGTH OVER IRRIGATED LOCATIONS IN EACH YEAR AND OVER DRYLAND LOCATIONS IN EACH YEAR†

Year and Variance Component∅	Locations‡						
	1,4					2,3	
	10 Var.	19 Var.	2,3,5	2,5	3,5	10 Var.	17 Var.
1968							
$(\sigma^2_V + \sigma^2_{VY})$	.289**	.307**	.237**	.311**	.186**	.213**	.370**
$(\sigma^2_{VL} + \sigma^2_{VLY})$	.016**	.008*	.025**	.003	.043**	.030*	.030**
σ^2_E	.053	.056	.100	.060	.114	.125	.140
1969							
$(\sigma^2_V + \sigma^2_{VY})$	.359**	.366**	----	.376**	----	----	----
$(\sigma^2_{VL} + \sigma^2_{VLY})$	.020**	.015**	----	.013*	----	----	----
σ^2_E	.034	.035	----	.065	----	----	----

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 3 is Mangum, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

∅ Each calculated variance component has been multiplied by 10^2.

TABLE IX

VARIANCE COMPONENTS FOR 2.5% SPAN LENGTH OVER YEARS AT EACH LOCATION

Variance Component†	Locations Over Years: Chickasha, Irrigated 10 Var.	Chickasha, Irrigated 19 Var.	Chickasha, Dryland 10 Var.	Chickasha, Dryland 17 Var.	Mangum, Dryland 10 Var.	Mangum, Dryland 17 Var.	Altus, Irrigated 10 Var.	Altus, Irrigated 19 Var.	Perkins, Dryland 10 Var.
$(\sigma^2_V + \sigma^2_{VL})$	.338**	.338**	.388**	.495**	----	----	.294**	.328**	.295**
$(\sigma^2_{VY} + \sigma^2_{VLY})$	.036**	.020**	.006	.014**	----	----	.016**	.009**	.013*
σ^2_E	.046	.047	.076	.073	----	----	.041	.043	.049

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

† Each calculated variance component has been multiplied by 10^2.

years at each location. The variety by year interaction was biased upwards by the second-order interaction to the extent that it was highly significant in the majority of analyses. A comparison of this interaction to the varietal component (very slightly biased by the variety by location interaction) shows that the latter is from 10 to 40 times the magnitude of the former. Therefore, the degree to which the confounded interaction would affect findings in respect to varietal merit is practically nil.

The varieties mean square was highly significant in every case where a specific location-year analysis of variance was conducted (Table X). From the combined analyses of variance over locations and years (Table VII), identical results were obtained. This analogy is additional evidence that conclusions for fiber length based on data from a single test are generally applicable to the state as a whole.

Length Uniformity

Variance components computed from analyses combining locations and years are given in Table XI. The varieties mean square for the four-location, two-year analysis was large and highly significant indicating that real differences could be detected among varieties. The first-order interactions were small and non-significant, while the second-order interactions, though slightly larger and significant, did not approach the magnitude of the varietal component. Indications are that genotype by environment interactions for this trait were not important in this material. These results corresponded rather closely with those in the previous section for fiber length.

When irrigated locations were analyzed over years, little

TABLE X

VARIANCE COMPONENTS FOR 2.5% SPAN LENGTH AT EACH LOCATION IN EACH YEAR

Year and Variance Component†	Locations								
	Chickasha, Irrigated		Chickasha, Dryland		Mangum, Dryland		Altus, Irrigated		Perkins, Dryland
	10 Var.	19 Var.	10 Var.	17 Var.	10 Var.	17 Var.	10 Var.	19 Var.	10 Var.
1968									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	.299**	.293**	.327**	.515**	.159**	.286**	.311**	.337**	.299**
σ^2_E	.061	.059	.071	.062	.179	.217	.046	.052	.049
1969									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	.448**	.424**	.461**	.503**	----	----	.311**	.337**	.317**
σ^2_E	.032	.035	.081	.083	----	----	.037	.034	.049

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

† Each calculated variance component has been multiplied by 10^2.

TABLE XI

VARIANCE COMPONENTS FOR UNIFORMITY RATIO OVER LOCATIONS OVER YEARS†

Variance Component	Locations‡			
		1,4		
	1,2,4,5	10 Var.	19 Var.	2,5
σ^2_V	1.57**	1.74**	1.52**	1.49**
σ^2_{VL}	.12	.40**	.14**	.00ϕ
σ^2_{VY}	.03	.05	.00ϕ	.00ϕ
σ^2_{VLY}	.16*	.00ϕ	.11	.50**
σ^2_E	1.52	1.52	1.60	1.52

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

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

difference could be found between variance components in the 10-variety and 19-variety analyses. The varieties and variety by location interaction sources of variation were highly significant in both analyses, but the latter was substantially smaller and, therefore, not of great importance. The variety by year and second-order interactions were non-significant and approached zero in each analysis. A combination and analysis of two dryland locations over years suggested again that the varieties mean square was by far the most important source of variance, it being highly significant. The second-order interaction was larger than either first-order interaction and was highly significant. Yet, it was only one-third the size of the varietal component. Estimates of the first-order interactions were negative, and they were assumed to approximate zero.

A comparison of the first, second, and fourth columns of Table XI indicates that the varietal and variety by year interaction components changed relatively little when the combined, the irrigated, and the dryland analyses were examined. The variety by location interaction increased under irrigated conditions, and the three-factor interaction was more important under dryland conditions. However, regardless of how the tests were analyzed, one basic fact is evident; that is, genotype-environment interactions were not large enough for length uniformity to warrant testing for that trait in multiple environments.

Table XII reveals that only a small amount of bias was introduced into the irrigated analyses when combined over locations in each year. This result is not unexpected for the reason that the variety by year and variety by location by year interactions which are confounded with the varietal and variety by location interaction components,

TABLE XII

VARIANCE COMPONENTS FOR UNIFORMITY RATIO OVER IRRIGATED LOCATIONS IN EACH YEAR AND OVER DRYLAND LOCATIONS IN EACH YEAR†

Year and Variance Component	Locations‡						
	1,4					2,3	
	10 Var.	19 Var.	2,3,5	2,5	3,5	10 Var.	17 Var.
1968							
$(\sigma^2_V + \sigma^2_{VY})$	2.38**	3.62**	1.70**	1.74*	1.28	2.10*	1.95**
$(\sigma^2_{VL} + \sigma^2_{VLY})$	.27	.18	.76**	.42*	.94**	.92**	.80**
σ^2_E	2.01	2.33	2.37	2.29	2.46	2.35	2.08
1969							
$(\sigma^2_V + \sigma^2_{VY})$	1.19*	1.18**	----	.93**	----	----	----
$(\sigma^2_{VL} + \sigma^2_{VLY})$	.54**	.33**	----	.08	----	----	----
σ^2_E	1.02	.88	----	.76	----	----	----

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 3 is Mangum, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

respectively, were small in those analyses where an unconfounded estimate was possible. It is noteworthy that most of the variety by location interaction at these two locations occurred in 1969. A comparison of the dryland analyses in each year for the Chickasha-Perkins combination with that of the same two locations combined over years suggests that the second-order interaction was responsible for the inflated estimate of the variety by location interaction in 1968 but had little effect on the same estimate in 1969. In the other combinations of dryland locations analyzed in 1968, it was not possible to say how much the variance component estimates were biased. In most of those combinations the confounded estimate of varietal variation overshadowed that of the variety by location interaction. However, in one instance (the Mangum-Perkins analysis) the variety by location interaction approached the magnitude of the varietal component. It is unknown whether testing in only one year was responsible for this result, but the thought that it might be deserves consideration.

The degree to which variance components were biased when varieties were evaluated over years at each location can be determined from the results presented in Table XIII. In the irrigated experiments combined over years the variety by location interaction was the largest of any of the interaction effects. Nevertheless, this interaction had little influence on the variance contributed by varietal differences, since this source was considerably large to begin with. Although the second-order interaction was relatively unimportant in the irrigated locations combined over years, it contributed enough variance to the variety by year interaction component in the 19-variety Chickasha irrigated analysis to make this interaction significant. In the two dryland

TABLE XIII

VARIANCE COMPONENTS FOR UNIFORMITY RATIO OVER YEARS AT EACH LOCATION

Variance Component	Locations Over Years: Chickasha, Irrigated		Chickasha, Dryland		Mangum, Dryland		Altus, Irrigated		Perkins, Dryland
	10 Var.	19 Var.	10 Var.	17 Var.	10 Var.	17 Var.	10 Var.	19 Var.	10 Var.
$(\sigma^2_V + \sigma^2_{VL})$	1.34**	1.30**	1.29*	1.29**	----	----	2.94**	2.03**	1.18**
$(\sigma^2_{VY} + \sigma^2_{VLY})$	.19	.25*	.58**	.40**	----	----	.00†	.00†	.11
σ^2_E	1.45	1.40	1.59	1.49	----	----	1.59	1.80	1.46

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

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

analyses conducted at Chickasha over years, the variety by year interaction was biased upwards by the second-order interaction which previously had been found highly significant over both locations over years.

Other than specific instances mentioned where some bias could be detected, little harm from analysis in one year over locations or at one location over years would be expected. The knowledge that varietal component estimates in Table XIV are confounded with three sources of interaction variation might imply that bias exists. It is true that those estimates were all highly significant. However, in the combined analysis over all locations and years (Table XI), where unconfounded estimates of the varietal components were possible, varieties were also found to exhibit significant differences. These results are analogous to those obtained for fiber length where it was determined that evaluating varieties for that trait in multiple environments was unnecessary.

Fineness

Data computed from a combined analysis of variance over four locations and two years are shown in Table XV. Also included are results from separate analyses of irrigated and dryland locations over years. By combining all possible locations and years, it was evident that the varieties and second-order interaction sources of variation were highly significant while the first-order interaction effects were not significant at all. The varietal component of variance was approximately four times the size of the second-order interaction component which in turn was larger than either of the first-order interactions. Implications are that varietal performance is relatively stable from environment to environment but that small gains can be expected from tests in

TABLE XIV

VARIANCE COMPONENTS FOR UNIFORMITY RATIO AT EACH LOCATION IN EACH YEAR

Year and Variance Component	Locations: Chickasha, Irrigated 10 Var.	Chickasha, Irrigated 19 Var.	Chickasha, Dryland 10 Var.	Chickasha, Dryland 17 Var.	Mangum, Dryland 10 Var.	Mangum, Dryland 17 Var.	Altus, Irrigated 10 Var.	Altus, Irrigated 19 Var.	Perkins, Dryland 10 Var.
1968									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	2.13**	2.16**	2.96**	2.53**	3.08**	2.97**	3.16**	1.82**	1.36**
σ^2_E	2.23	2.27	2.18	1.68	2.52	2.47	1.80	2.38	2.40
1969									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	.92**	.93**	.77**	.86**	----	----	2.53**	2.08**	1.23**
σ^2_E	.67	.53	1.00	1.30	----	----	1.38	1.22	.51

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

TABLE XV

VARIANCE COMPONENTS FOR FIBER FINENESS OVER LOCATIONS OVER YEARS†

Variance Component	Locations‡			
		1,4		
	1,2,4,5	10 Var.	19 Var.	2,5
σ^2_V	.0601**	.0422*	.0261*	.0850**
σ^2_{VL}	.0094	.0273**	.0215**	.0000ø
σ^2_{VY}	.0045	.0063*	.0123**	.0000ø
σ^2_{VLY}	.0157**	.0000ø	.0026	.0452**
σ^2_E	.0488	.0553	.0782	.0423

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

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

multiple environments. Murray and Verhalen (32) found that the second-order interaction was more important, contributing as much variance as did the varieties. The present study differed from the earlier one in growing seasons, in varieties, and in locations, there being only two of the latter in common between the two investigations.

The analyses of irrigated locations over years produced surprisingly different results. For the 10-variety analysis the variety by location and variety by year interactions were significant at the 1% and 5% levels, respectively, while the variety by location by year interaction was not significant. Significant differences among varieties were also found. Similar results were obtained when 19 varieties were evaluated at the same two locations over years, with the exception that the variety by year interaction was significant at the 1% rather than the 5% level. A close study of the relative magnitudes of the first-order interactions indicates that together they make up a sizable portion of the total experimental variance, the sum of their variances in the 19-variety analysis being larger than that of the varietal variance. From these data it is apparent that when only irrigated conditions are involved, it is necessary to test over multiple years and locations, with perhaps slightly more emphasis being placed on the latter. There are indications that genotype-environment interactions were more important when 19 varieties were evaluated than when 10 were analyzed. These observations provide solid evidence that varietal make-up in a test may have a pronounced effect on the importance of various interactions between variety and environment.

In the combined dryland analysis over years, the varieties and second-order interaction components were highly significant, whereas the first-order interactions were not. The varietal component was the most important source of variation followed by the second-order interaction, which was approximately one-half as large. Estimates of variety by location and variety by year interaction components were negative, and these quantities were assumed to be estimates of zero. These data imply that if varieties are to be tested under dryland conditions, it apparently makes little difference how those tests are distributed over locations and years, but that some testing over multiple environments may be necessary.

A specific trend was detected upon comparing the 10-variety irrigated analysis to the dryland analysis. In the latter case, the interactions present could not be attributed to any one effect, while in the former, both locations and years were responsible for the majority of the varietal fluctuations. However, when the four locations were combined over years, a diluting effect occurred resulting in none of the interactions being of major importance.

Because of the large variety by location and variety by year interactions detected when the Altus and Chickasha tests were combined over years, an attempt was made to determine the specific varieties responsible. In Figure 6 varietal response for fiber fineness is shown at each location between years. These graphs confirm that variety by year interactions were indeed present. For example, Dunn 56C and Lankart 57 changed considerably in ranking at each location from 1968 to 1969. No trend could be observed, however, in how a particular type of variety reacted to different growing seasons, i.e., early versus late-maturing types. Figure 7 gives an indication of varietal performance in each year across locations. It is clear that variety by

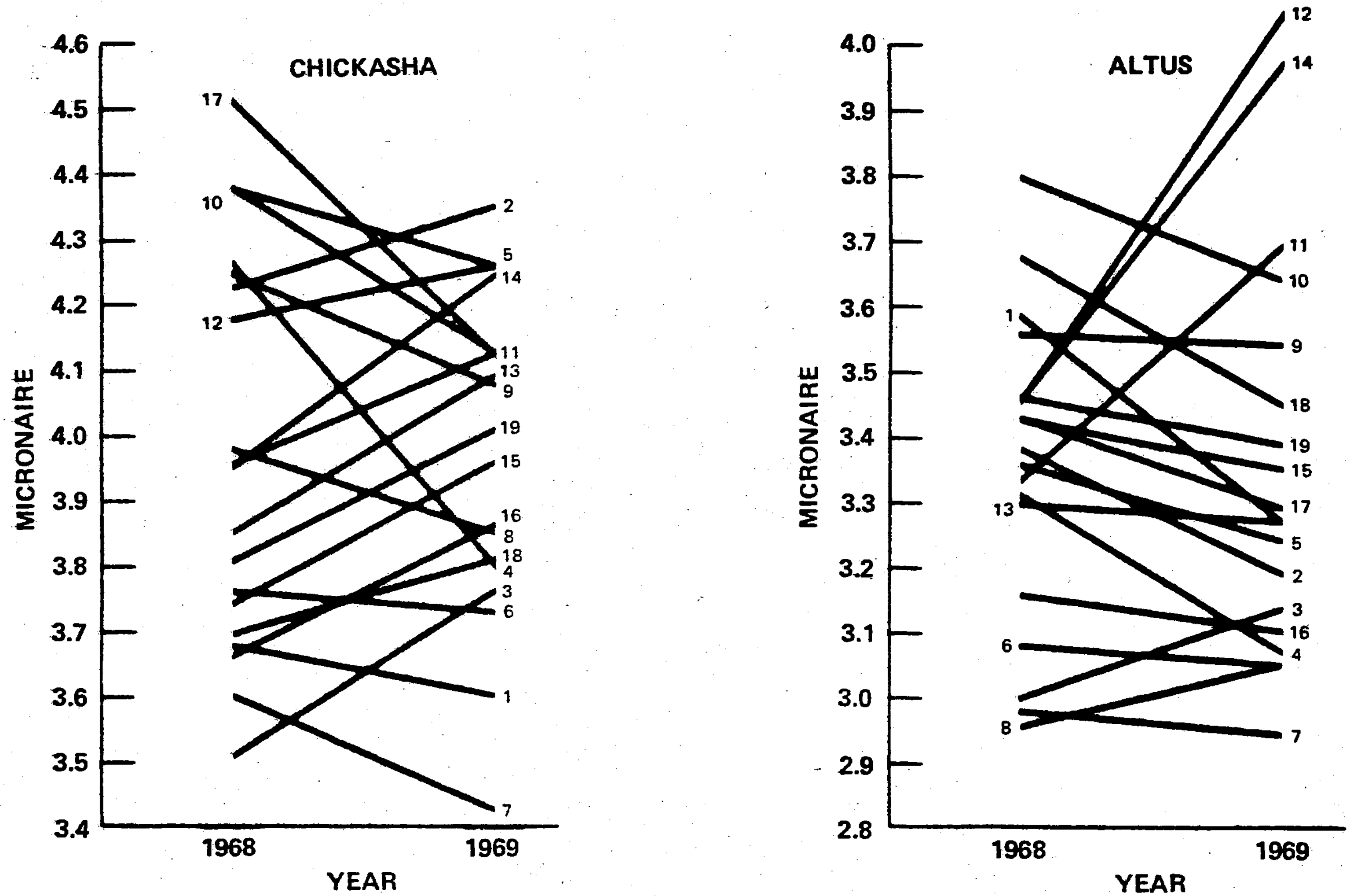

FIGURE 6. VARIETAL RESPONSE BETWEEN YEARS AT THE IRRIGATED LOCATIONS FOR FIBER FINENESS.

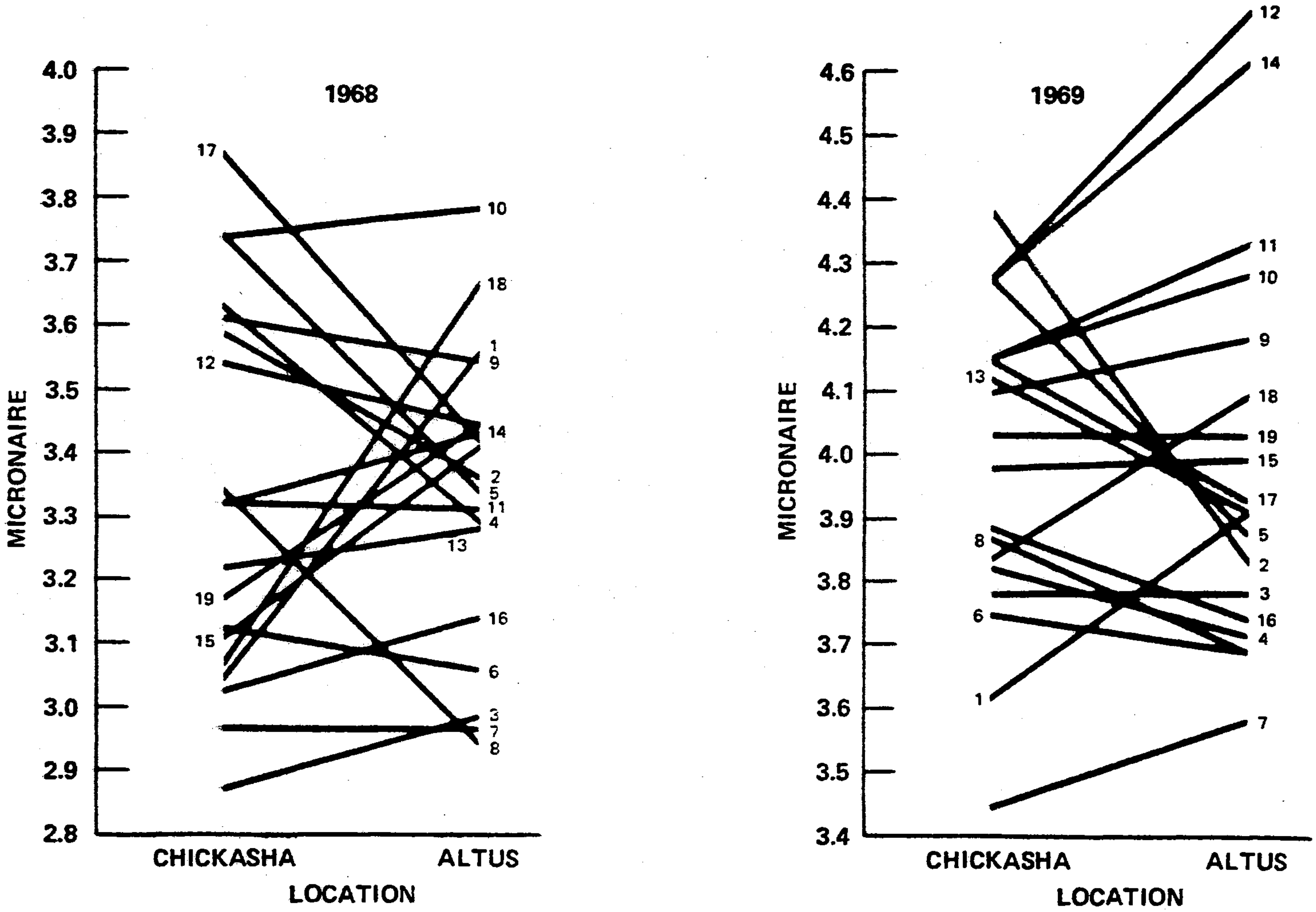

FIGURE 7. VARIETAL RESPONSE BETWEEN THE IRRIGATED LOCATIONS IN SEPARATE YEARS FOR FIBER FINENESS.

location interactions occurred in each growing season. The varieties, Coker 201 and Stoneville 213, are good illustrations of such varietal fluctuations from location to location. Again, no obvious trend in performance by varieties of a given type could be detected. Apparently, the adaptability of varieties to a particular region does not dictate its response with respect to fiber fineness at a particular location or in a particular season. The answer to this response remains linked to the individual genotype of each variety.

Variance components computed after subdividing into irrigated and dryland environments and analyzing over locations in each year are given in Table XVI. It was determined from a consideration of irrigated locatipns in each year that the amount of bias introduced by evaluation in a single year was too small to be of major importance. Of the four analyses involving irrigated locations with 10 and 19 varieties, only the 1969 analysis conducted on the larger number was changed in any great respect. In this instance the varieties mean square was inflated upwards by the variety by year interaction to the point where it was highly significant. The remaining varieties mean squares were not appreciably changed. Estimates of a variety by location interaction in each of the four analyses were not greatly affected by the second-order interaction because in the analyses conducted over irrigated locations and years this component was near zero.

The data from the dryland analyses included results from the 1968 Mangum test. It was possible, therefore, to obtain more information regarding interactions of varieties and dryland locations in that year. The Chickasha-Perkins analyses in 1968 and 1969 were the only ones which could be compared to the combined analysis of these two locations

TABLE XVI

VARIANCE COMPONENTS FOR FIBER FINENESS OVER IRRIGATED LOCATIONS IN EACH YEAR AND OVER DRYLAND LOCATIONS IN EACH YEAR†

Year and Variance Component	Locations‡						
	1,4					2,3	
	10 Var.	19 Var.	2,3,5	2,5	3,5	10 Var.	17 Var.
1968							
$(\sigma^2_V + \sigma^2_{VY})$	.0606*	.0296*	.0903**	.0657*	.1235**	.0816	.0807**
$(\sigma^2_{VL} + \sigma^2_{VLY})$	.0269**	.0268**	.0385**	.0464**	.0127	.0563**	.0426**
σ^2_E	.0721	.0975	.1011	.0622	.1020	.1393	.1412
1969							
$(\sigma^2_V + \sigma^2_{VY})$	.0362*	.0471**	----	.0839**	----	----	----
$(\sigma^2_{VL} + \sigma^2_{VLY})$	.0259**	.0214**	----	.0129**	----	----	----
σ^2_E	.0385	.0588	----	.0224	----	----	----

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 3 is Mangum, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

over years. The varietal source of variation in that analysis was unaffected by the variety by year interaction since that source of variance was found to be zero in the combined analysis over years. However, the estimates of variety by location interaction in each year were biased upwards by the large three-factor interaction previously shown to be present. In both years the mean squares for this source of variation were highly significant, whereas significance could not be detected beforehand. From the additional combinations of dryland locations in 1968 on which an analysis was conducted, it was only possible to speculate that some bias did occur. How much could not be determined. In the Chickasha-Mangum 10-variety analysis, no significant differences among varieties were found. This indicates that the variance due to varieties as well as that due to the variety by year interaction were small. In the 17-variety analysis as well as in the remaining dryland combinations this peculiarity was not found. The variety by location interaction for the Mangum-Perkins combination was not significant indicating that this interaction and the three-factor interaction were small. In the other dryland analyses the estimated interaction variance components were of the approximate size and significance of the Chickasha-Perkins analysis. A comparison of the irrigated versus the dryland analyses reveals that more evidence of bias is available in the dryland tests, especially when estimating the variety by location interaction.

Table XVII presents variance components calculated from analyses of variance combining years at each location. The varieties mean squares of the four irrigated experiments appeared to be biased upwards by the variety by location interaction. These results are not

TABLE XVII

VARIANCE COMPONENTS FOR FIBER FINENESS OVER YEARS AT EACH LOCATION

Variance Component	Location Over Years: Chickasha, Irrigated 10 Var.	Chickasha, Irrigated 19 Var.	Chickasha, Dryland 10 Var.	Chickasha, Dryland 17 Var.	Mangum, Dryland 10 Var.	Mangum, Dryland 17 Var.	Altus, Irrigated 10 Var.	Altus, Irrigated 19 Var.	Perkins, Dryland 10 Var.
$(\sigma^2_V + \sigma^2_{VL})$	.0822**	.0510**	.0593	.0389*	----	----	.0566**	.0441**	.0796**
$(\sigma^2_{VY} + \sigma^2_{VLY})$	.0113*	.0158**	.0478**	.0454**	----	----	.0000†	.0140*	.0222**
σ^2_E	.0460	.0565	.0629	.0606	----	----	.0646	.0998	.0217

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

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

unexpected since previous estimates of the latter component were large even where it was not affected by confounding. The variety by year interaction appeared to be unchanged in relative magnitude with the exception that at Altus in the 10-variety analysis it actually decreased in size. In the three dryland analyses there was no evidence of inflation of the varieties components of variation. This could have been predicted since the variety by location interaction was found to be unimportant in dryland tests. In fact, the varieties mean square in the Chickasha 10-variety test was found to be non-significant. The estimates of variety by year interaction were inflated in every case, however. It is evident that the three-factor interaction was responsible for this bias introduced.

The data in Tables XVI and XVII indicate that the varietal variance for this trait is affected more by the variety by location than by the variety by year interaction under irrigated conditions. When varieties were evaluated under dryland conditions, neither first-order interaction biased the varietal variance to any appreciable extent. Therefore, more gain can be expected from testing over locations than over years when ample moisture is available, whereas when moisture is limiting, it apparently makes little difference how the tests are distributed as far as usefulness of information is concerned. However, to maximize breeding progress per unit of time, it would probably be of advantage to the breeder to emphasize locations rather than years.

The data in Table XVIII are results of analyses of variance conducted on individual tests in each environment. The varieties mean squares were highly significant in all cases. Interaction effects confounded in this mean square appeared to affect the irrigated tests more

TABLE XVIII

VARIANCE COMPONENTS FOR FIBER FINENESS AT EACH LOCATION IN EACH YEAR

Year and Variance Component	Locations: Chickasha, Irrigated		Chickasha, Dryland		Mangum, Dryland		Altus, Irrigated		Perkins, Dryland
	10 Var.	19 Var.	10 Var.	17 Var.	10 Var.	17 Var.	10 Var.	19 Var.	10 Var.
1968									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	.1026**	.0770**	.1137**	.0924**	.1622**	.1543**	.0724**	.0357**	.1104**
σ^2_E	.0711	.0829	.0995	.0926	.1791	.1899	.0730	.1120	.0248
1969									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	.0844**	.0566**	.1004**	.0762**	----	----	.0398**	.0804**	.0932**
σ^2_E	.0208	.0300	.0263	.0286	----	----	.0562	.0876	.0185

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

than the dryland tests. This can be explained by the fact that irrigated experiments were found to contain substantial two-factor interactions which were greater in magnitude and importance than the second-order interaction found in the dryland tests. Even though considerable bias was detected in some of the preceding analyses of variance, in almost every case, the varietal variation was the most important source of variation. It is apparent that conclusions based on an individual irrigated test appear to be less sound than are those from a single dryland experiment.

Strength

Calculated variance components derived from analyses of variance combining multiple locations and years are presented in Tables XIX and XX for zero and one-eighth inch gauge stelometer fiber strengths (T_0 and T_1), respectively. For the four-location, two-year analyses the variances among varieties were highly significant and greatly overshadowed those due to genotype-environment interactions, regardless of the measurement of fiber strength used. The variety by location and variety by year interactions were significant at the 1% and 5% levels, respectively, for T_0 and neither were significant for T_1. The reverse was true for the second-order interaction, that is, it was non-significant for T_0 and significant for T_1. Practical implications are that no problem should be encountered in testing varieties or lines for this trait in single environments. These results correspond very closely to those of Murray and Verhalen (32) and of the other researchers, indicating that this character is fairly stable from one environment to another.

TABLE XIX

VARIANCE COMPONENTS FOR 0" GAUGE FIBER STRENGTH OVER LOCATIONS OVER YEARS†

Variance Component	Locations‡			
		1,4		
	1,2,4,5	10 Var.	19 Var.	2,5
σ^2_V	.0331**	.0176**	.0334**	.0546**
σ^2_{VL}	.0046**	.0016*	.0020**	.0017
σ^2_{VY}	.0006*	.0015*	.0015*	.0018
σ^2_{VLY}	.0004	.0001	.0002	.0000$^{\phi}$
σ^2_E	.0257	.0195	.0196	.0319

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

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

TABLE XX

VARIANCE COMPONENTS FOR 1/8" GAUGE FIBER STRENGTH OVER LOCATIONS OVER YEARS†

Variance Component	Locations‡			
		1,4		
	1,2,4,5	10 Var.	19 Var.	2,5
σ^2_V	.0293**	.0215**	.0174**	.0392**
σ^2_{VL}	.0006	.0000ϕ	.0000ϕ	.0000
σ^2_{VY}	.0003	.0014	.0004	.0000ϕ
σ^2_{VLY}	.0011*	.0018*	.0015**	.0000ϕ
σ^2_E	.0109	.0081	.0080	.0137

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

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

A reanalysis of the data combining irrigated locations over years, using both 10 and 19 varieties, resulted in no basic change in the magnitude of the variance components for T_0 and T_1. Differences of interpretation due to comparisons of 10-variety versus 19-variety analyses were at a minimum. When the two dryland locations were analyzed over years, significance levels in some of the interactions were different from those above. For T_0 and T_1 the varieties mean square was highly significant while the interaction effects were all small and non-significant. Whether the tests were conducted under irrigation or on dryland apparently caused no contradiction with previous results.

A closer inspection of the second and fourth columns in Table XIX shows that the variety by location and variety by year interactions for T_0 were more important under irrigated than dryland conditions while the second-order interaction was affected very little. A glimpse at the same two columns of Table XX indicates that the three-factor interaction for T_1 was more important under irrigated conditions while the remaining interaction variance components were generally unaffected by moisture availability.

Tables XXI and XXII present variances computed from analyses of irrigated and dryland locations within each year. Biases due to confounding were small and not generally evident in estimation of varietal and variety by location interaction variances for T_0. Estimates of T_1 for the variety by location interaction for the two irrigated analyses in 1969 were significant. Since there had been no evidence of this interaction being significant in the combined analyses over years, it is probable that the second-order interaction was responsible for the added variation detected. For the Chickasha-Perkins dryland analysis

TABLE XXI

VARIANCE COMPONENTS FOR 0" GAUGE FIBER STRENGTH OVER IRRIGATED LOCATIONS IN EACH YEAR AND OVER DRYLAND LOCATIONS IN EACH YEAR†

Year and Variance Component	Locations‡						
	1,4					2,3	
	10 Var.	19 Var.	2,3,5	2,5	3,5	10 Var.	17 Var.
1968							
$(\sigma^2_V + \sigma^2_{VY})$	.0139**	.0318**	.0394**	.0537**	.0341**	.0305**	.0515**
$(\sigma^2_{VL} + \sigma^2_{VLY})$	.0017	.0028*	.0015	.0000ø	.0056	.0000ø	.0019
σ^2_E	.0259	.0240	.0397	.0351	.0417	.0424	.0401
1969							
$(\sigma^2_V + \sigma^2_{VY})$	.0242**	.0380**	----	.0590**	----	----	----
$(\sigma^2_{VL} + \sigma^2_{VLY})$	.0016	.0016	----	.0012	----	----	----
σ^2_E	.0131	.0151	----	.0286	----	----	----

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 3 is Mangum, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

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

TABLE XXII

VARIANCE COMPONENTS FOR 1/8" GAUGE FIBER STRENGTH OVER IRRIGATED LOCATIONS IN EACH YEAR AND OVER DRYLAND LOCATIONS IN EACH YEAR†

Year and Variance Components	Locations‡						
	1,4					2,3	
	10 Var.	19 Var.	2,3,5	2,5	3,5	10 Var.	17 Var.
1968							
$(\sigma^2_V + \sigma^2_{VY})$	.0226**	.0170**	.0243**	.0364**	.0210**	.0154**	.0214**
$(\sigma^2_{VL} + \sigma^2_{VLY})$	.0005	.0009	.0034**	.0007	.0057**	.0038**	.0029**
σ^2_E	.0107	.0101	.0141	.0159	.0181	.0084	.0101
1969							
$(\sigma^2_V + \sigma^2_{VY})$	.0233**	.0185**	----	.0411**	----	----	----
$(\sigma^2_{VL} + \sigma^2_{VLY})$	.0014*	.0010*	----	.0000ø	----	----	----
σ^2_E	.0054	.0059	----	.0114	----	----	----

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

† Analyses involved 10 varieties unless otherwise stated (see text).

‡ Location 1 is Chickasha, irrigated; location 2 is Chickasha, dryland; location 3 is Mangum, dryland; location 4 is Altus, irrigated; location 5 is Perkins, dryland.

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

of T_1 in each year no inflation of estimates was apparent. The remaining dryland combinations had not been analyzed over years and, therefore, could not be compared to those obtained in the one year, 1968. The magnitude to which the varietal and variety by location interaction variances were inflated in each instance cannot be determined.

Estimates of variance components from combined analyses for T_0 and T_1 fiber strength at each location over years are given in Tables XXIII and XXIV. When T_0 is considered, a comparison of results obtained by combining locations over years with those from years combined at each location (Table XIX versus Table XXIII) indicates that any bias introduced into the data by growing varieties at one location was not of sufficient magnitude to be detected statistically. More evidence of upward bias is available for T_1, especially when estimates of the variety by year interaction for the irrigated locations are examined. In all four analyses that source of variation was highly significant, yet in the combined irrigated analyses (Table XX) a non-significant variety by year interaction was found. Clearly, the second-order interaction is responsible for the inflated estimates. However, the varietal components were much more important sources of variation, lessening the effect of the biased variances. A glimpse at the dryland locations confirms the fact that genotype by environment interactions were small for T_1 under this set of conditions; no upward bias of any variance component was observed.

The degree to which variety by environment interactions were a problem in individual tests can be determined from Tables XXV and XXVI. In every instance, highly significant differences among varieties were found for fiber strength. These conclusions were also reached in the

TABLE XXIII

VARIANCE COMPONENTS FOR 0" GAUGE FIBER STRENGTH OVER YEARS AT EACH LOCATION

Variance Component	Locations Over Years								
	Chickasha, Irrigated		Chickasha, Dryland		Mangum, Dryland		Altus, Irrigated		Perkins, Dryland
	10 Var.	19 Var.	10 Var.	17 Var.	10 Var.	17 Var.	10 Var.	19 Var.	10 Var.
$(\sigma^2_V + \sigma^2_{VL})$	.0190**	.0390**	.0443**	.0707**	----	----	.0194**	.0317**	.0682**
$(\sigma^2_{VY} + \sigma^2_{VLY})$	.0021	.0027**	.0019	.0013	----	----	.0010	.0007	.0000†
σ^2_E	.0142	.0139	.0361	.0349	----	----	.0248	.0253	.0276

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

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

TABLE XXIV

VARIANCE COMPONENTS FOR 1/8" GAUGE FIBER STRENGTH OVER YEARS AT EACH LOCATION

Variance Component	Locations Over Years								
	Chickasha, Irrigated		Chickasha, Dryland		Mangum, Dryland		Altus, Irrigated		Perkins, Dryland
	10 Var.	19 Var.	10 Var.	17 Var.	10 Var.	17 Var.	10 Var.	19 Var.	10 Var.
$(\sigma^2_V + \sigma^2_{VL})$	.0187**	.0173**	.0339**	.0351**	----	----	.0225**	.0164**	.0445**
$(\sigma^2_{VY} + \sigma^2_{VLY})$	.0021**	.0014**	.0000†	.0000†	----	----	.0044**	.0023**	.0000†
σ^2_E	.0053	.0058	.0100	.0114	----	----	.0108	.0102	.0173

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

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

TABLE XXV

VARIANCE COMPONENTS FOR 0" GAUGE FIBER STRENGTH AT EACH LOCATION IN EACH YEAR

Year and Variance Component	Locations: Chickasha, Irrigated		Chickasha, Dryland		Mangum, Dryland		Altus, Irrigated		Perkins, Dryland
	10 Var.	19 Var.	10 Var.	17 Var.	10 Var.	17 Var.	10 Var.	19 Var.	10 Var.
<u>1968</u>									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	.0166**	.0382**	.0433**	.0764**	.0163**	.0306**	.0145**	.0310**	.0632**
σ^2_E	.0164	.0155	.0358	.0333	.0490	.0468	.0354	.0325	.0344
<u>1969</u>									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	.0254**	.0453**	.0490**	.0675**	----	----	.0263**	.0337**	.0715**
σ^2_E	.0121	.0123	.0365	.0366	----	----	.0141	.0180	.0207

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

TABLE XXVI

VARIANCE COMPONENTS FOR 1/8" GAUGE FIBER STRENGTH AT EACH LOCATION IN EACH YEAR

Year and Variance Component	Locations: Chickasha, Irrigated 10 Var.	Chickasha, Irrigated 19 Var.	Chickasha, Dryland 10 Var.	Chickasha, Dryland 17 Var.	Mangum, Dryland 10 Var.	Mangum, Dryland 17 Var.	Altus, Irrigated 10 Var.	Altus, Irrigated 19 Var.	Perkins, Dryland 10 Var.
1968									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	.0197**	.0194**	.0296**	.0354**	.0088**	.0132**	.0264**	.0164**	.0446**
σ^2_E	.0069	.0070	.0062	.0087	.0106	.0115	.0145	.0132	.0257
1969									
$(\sigma^2_V + \sigma^2_{VL} + \sigma^2_{VY} + \sigma^2_{VLY})$	.0219**	.0180**	.0365**	.0341**	----	----	.0275**	.0210**	.0442**
σ^2_E	.0037	.0047	.0139	.0140	----	----	.0072	.0071	.0089

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

combined analyses of variance conducted across locations and years. Although one test's data may be biased to some degree, the results of these investigations certainly would indicate that multiple testing is not necessary to adequately evaluate relative varietal performance for fiber strength.

CHAPTER V

SUMMARY AND CONCLUSIONS

Conclusions as to the importance of genotype by environment interactions for the six traits studied were based on relative magnitudes of estimated variance components and on whether the appropriate mean squares were statistically significant. Large and important interactions of varieties with years were found for lint yield in most combinations of locations over years analyzed, leading to the conclusion that testing for this trait in multiple years is necessary. A differential response to growing seasons by opposite varietal types was considered to be a factor contributing to a large portion of those interactions. These findings were contradictory to those reported earlier in Oklahoma (32) where variety by location interactions were more prevalent. It will be necessary, in light of data from the two studies, to continue the present methods of testing varieties and lines in the state, that is, no reduction or increase in number of experiments can be justified. The extent to which genotype-environment interactions affected the fiber traits in decreasing order of importance were: fineness, length uniformity, strength, and length, with multiple testing across environments probably necessary only for fineness.

A subdivision of locations into irrigated versus dryland and a reanalysis of the data over years was used to determine the effect of differences in moisture availability upon interaction magnitudes. For lint yield the variety by location interaction was increased in one dryland combination (Chickasha-Mangum), the variety by year interaction was generally larger under irrigated than under dryland conditions, and the second-order interaction was fairly stable except for the Chickasha-Mangum dryland combination where it was reduced. More emphasis should be made in evaluating yield over multiple years when testing under irrigated conditions. Genotype-environment interactions for fiber length and both measures of fiber strength (T_0 and T_1) were relatively unimportant, regardless of the level of moisture availability. Length uniformity was affected slightly; the variety by location interaction becoming larger under irrigated conditions and the three-factor interaction increasing on dryland. The magnitude of genotype-environment interactions for fiber fineness was increased under irrigation to the extent that tests at Altus and Chickasha were recommended with some emphasis being placed on testing over years. For dryland tests evaluation in multiple environments was also suggested for fineness, but specific emphasis need not be placed on how the tests are distributed over locations and years.

The bias introduced by genotype-environment interactions to estimates of genotypic variance when evaluation of varieties was not conducted at least at two locations and over two years was determined by comparing variance component estimates derived from combined analysis over all environments with those derived from individual sets of environments. Definite cases of inflated estimates of varietal variance were discovered for lint yield in particular with results from a single test being shown highly unreliable. Increasing the number of growing seasons rather than the number of locations over which varieties are to be evaluated would increase confidence in the results in most cases and reduce bias. Conclusions based on one test were found to be the same as those based on multiple tests when fiber length, length uniformity, and strength (T_0 and T_1) were considered. For fiber fineness there were indications that varietal variance was biased upwards by the variety by location interaction under irrigated conditions. Second-order interactions were also important for this trait, especially at dryland locations. Estimates of varietal performance for fineness should be made from data at more than one location if moisture is not a limiting factor and from multiple tests over locations and years if moisture is limiting.

In those cases where analyses of variance were conducted using both 10 and 17 or 19 varieties, the effect of different sets of varieties on the magnitude of genotype-environment interactions was determined. For lint yield it made very little difference whether the number of varieties was larger or smaller in most cases, i.e., the implications remained the same. In three of eighteen possible comparisons, however, different conclusions were possible. One such comparison was the 10- and 17-variety analyses involving the Chickasha and Mangum dryland locations over years. Analysis of the large number of varieties increased the importance of the first-order interactions considerably. In the fiber traits, with the exception of fineness, no important changes were observed upon comparing analyses differing only in variety number. For the latter character, however, an analysis of 19 varieties across two irrigated locations (Altus and Chickasha) indicated that first-order interactions were of greater importance than in the 10-variety analysis. Except for these rather rare instances, implications from analyses of variance for all traits were altered little by increasing varietal number.

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