GENOTYPE BY ENVIRONMENT INTERACTION STUDY I. OF AGRONOMIC TRAITS AND II. OF FIBER AND YARN PROPERTIES IN COTTON IN THE PLAINS REGION OF OKLAHOMA AND TEXAS AND III. INHERITANCE OF LINT PERCENTAGE IN COTTON

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TABLE OF CONTENTS

LIST OF TABLES

Table | Page

Chapter I

Table		Page

Table Page

Chapter II

Table | Page

Table Page

Chapter III

LIST OF FIGURES

Figure Page

Chapter III

INTRODUCTION

The three chapters of this dissertation are separate and complete manuscripts to be submitted to Crop Science for publication. The format of each manuscript conforms to the style of that journal.

CHAPTER I

Genotype by Environment Interaction Study of Agronomic Traits in Cotton in the Plains Region of Oklahoma and Texas

Genotype by environment Interaction Study

of Agronomic Traits in Cotton

in the Plains Region

of Oklahoma and Texas[1]

ABSTRACT

Cotton (*Gossypium hirsutum L.*) cultivar trials have been conducted in the Plains Region of Oklahoma and Texas for many years. This study evaluated a number of such trials for genotype by environment interactions [particularly cultivar by location (CL)] interactions for the four agronomic traits of lint yield, lint percentage, boll size, and seed index. Analyses were performed on data from the 15, 11, and 11 National and Regional Standard cotton cultivars tested at eight locations in the Plains Region of OK and TX in 1981-1983, 1984-1986, and 1987-1989, respectively. All data for each 3-year period were analyzed first, followed by subdivisional analyses into Rolling vs. High Plains subregions, states, and irrigated vs. dryland production. If a significant CL interaction was observed, the data were analyzed further. Cluster analyses were performed on lint yield data from each 3-interactions were detected for lint yield in the Plains Region in 1981-

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

1983 and 1984-1986. Clustering locations based on lint yield did not reveal consistently meaningful associations, though Lamesa dryland in 1981-1983 and in 1984-1986 (except for Altus) and Lamesa irrigated in 1987-1989 were quite different from the other locations. If Lamesa were excluded, this Region would likely become more homogeneous in terms of cotton lint yield response. Significant CL were observed for lint percentage in 1981-1983 and 1984-1986; for boll size in 1984-1986; and for seed index in 1984-1986. Cultivar by year (CY) interactions were relatively more important in Oklahoma for lint yield, while CY interactions were less important than CL in Texas.

INTRODUCTION

Cotton (*Gossypium hirsutum*) production has been a major agricultural enterprise in the Plains Region of Oklahoma and Texas for well over 75 years. This Region is characterized by a number of environmental limitations which greatly influence the quantity and quality of fiber which can be produced (40). Because this Region is on the Northern edge of the Cotton Belt, cooler temperatures in late spring and early fall are common. Those lower temperatures slow growth, increase susceptibility to disease and cut short the growing season. Because this Region is in the transition zone between the high rainfall areas of the Southeast and the arid deserts of the Southwest, droughts are recurrent and often severe. Lack of rainfall is frequently <u>the</u> limiting factor in cotton production in the Region. The development of short-season cultivars has been a major objective in breeding programs of the Region especially since the arrival of the boll weevil (*Anthonomus grandis* Boheman) in the early 1900. The subsequent emergence of other late-season insects such as the bollworm [*Helicoverpa zea* (Boddie)] and tobacco budworm [*Heliothis virescens* (F.)] have merely reemphasized that trend.

Cotton cultivar evaluations have been conducted in the Region for many years under irrigated and dryland conditions (42), and genotype by environment (GE) interactions have been studied for lint yield and other traits (36,38,41). A more complete understanding of GE interaction in the Plains Region may lead to better strategies of breeding as well as making recommendations among cultivars for commercial production.

Many of the earlier investigations of GE interaction in cotton were conducted to study the nature and magnitude of various interaction components. Miller et al. (34) conducted GE studies in upland cotton in North Carolina using 15 cultivars, 9 locations, and 3 years and later using 11 cultivars, 16 locations and 3 years (33). The results of those analyses were strikingly similar. In both analyses lint yield showed the greatest GE while interactions were of lesser importance for lint percentage and boll size. The second-order interaction among genotypes, locations, and years was significant and large for all three characters compared to the two first-order interactions. Significant genotype by location (GL) and genotype by year (GY) components were derived for lint percentage and boll size, but not lint yield.

Abou-El-Fittouh et al. (1) analyzed the performance of four cotton cultivars

over 101 environments which represented 3 years and 39 locations across the Cotton Belt. The characters studied included lint yield, lint percentage, boll size, and seed index. For all characters except yield, the largest interaction factor was the second-order interaction, but these were small and relatively unimportant compared to the genotypic component. For yield, the GL component was the largest of the interaction components. An analysis of the Plains Region, using 12 cultivars for lint yield, showed that of all interaction components were significant, but that based on magnitude, the second-order interaction was the most important. It was also greater than the genotypic component.

Bridge et al. (7) analyzed 8 cotton cultivars, 3 locations and 3 years in the Mississippi Delta. Significant second-order interactions were obtained for lint yield, lint percentage, and boll size as well as significant genotypic components for those three characters. For yield, the genotypic component was smaller than the second-order component; and for the other characters, was larger.

An analysis by Murray and Verhalen (38), based on data from 11 cultivars, 3 locations, and 3 years in Oklahoma, gave significant GL and genotype by location

by year (GLY) interactions for lint yield. They concluded that testing for lint yield over locations was more important than testing over years and suggested that the state should be subdivided into dryland vs. irrigated production for cultivar testing and breeding purposes. Morrison and Verhalen (38), in a later Oklahoma study, involving 23 cultivars, 5 locations, and 2 years found that testing for lint yield over years was more important than testing over locations. This conclusion conflicted with that made previously by Murray and Verhalen (38). Apparently, testing and breeding implications can differ depending on the set of cultivars and/or years and/or locations used in the analyses.

Given the existence of a GL interaction, division of a larger group of locations into smaller zones by reducing that interaction could be used as a strategy to optimize the selection process. Horner and Frey (26) showed that GL in oat (*Avena sativa* L.) could be reduced by 11%, 21%, 30%, and 40%, by dividing 9 locations in Iowa into 2, 3, 4, and 5 subregions, respectively.

Classification of locations according to similarity of interactions within a set of cultivars can be the first step in controlling GE interaction, without requiring any specific knowledge of the environmental factors involved (1).

Numerous attempts have been made to classify genotypes and/or locations in GE interaction studies [Abou-El-Fittouh et al. (2), Mungomery et al. (37), Byth et al. (8), and more recently by Lin (27), Lin and Binns (28), Lin and Butler (29), and Calinski and Corten (9)]. Similarity or dissimilarity measures used include Euclidean and standardized distances (2), the dissimilarity index (27), and the correlation coefficient. Clustering methods used included, an unweighted group-average clustering strategy (39), an incremental sum-of-squares clustering strategy (8), and others.

Most clustering methods have been applied to the classification of genotypes. Lin and Thompson (31) utilized an extended regression approach to group genotypes. They applied an unweighted pair-group cluster analysis to a special dissimilarity index, obtained from the test statistic for differences among regressions. The groups of genotypes so derived showed a general pattern of response to various environments. Lin (27) proposed a cluster method to group genotypes according to their response to environment. He used a dissimilarity index between a pair of genotypes defined in terms of the distance adjusted for average effects. The clustering algorithm of Sokal and Michener (39) was used. Lin (27) showed that this new index is mathematically equivalent to the within group GE interaction mean square used in a two-way ANOVA. He used the F value as an empirical stopping criterion for clustering and showed that there will be no significant GE interaction within groups and that genotypes can be compared on the basis of their average effects. Both Lin and Thompson (31) and Lin (27) grouped individuals (genotypes) for similarity of their response (interaction) based on the two-way classification model (31) and were aimed at revealing the interaction structure of the data. Lin and Butler (29) suggested that in grouping locations, similarity on the basis of GL may be more meaningful.

Cluster analysis has been criticized for the diversity of classification, clustering methods and clustering strategies used by researchers (43). The consequence of such diversity has resulted in different clustering groups which pose difficulties in decision making. The forcing of unwarranted structure can be imposed by clustering methods and this has been another criticism.

Abou-El-Fittouh et al. (1) applied cluster analysis to classify locations cotton lint yield data derived from National Cotton Variety (i.e., Cultivar) Trials. They used two dissimilarity measures, distance coefficient and the product-moment correlation coefficient, and a variable group clustering strategy. They indicated that the former was a more efficient measure of similarity. Based on their analyses, they suggested that the Cotton Belt could be divided into seven regions (as opposed to the five then in use) with an average reduction of GE within-region components of approximately 50%.

The objectives of this study are to evaluate cultivar by location (CL) interactions for four agronomic traits in upland cotton in the Plains Region of Oklahoma and Texas and to examine the division of the Plains Region into subregions for breeding and testing purposes.

MATERIALS AND METHODS

Description of Data

Data analyzed in this study were from the National and Plains Regional Cotton Variety Tests of the years 1981-1983, 1984-1986, and 1987-1989. These tests are conducted annually by the United States Department of Agriculture in cooperation with the Agricultural Experiment Stations in the Cotton Belt. Data obtained in the Plains Region represented 10 different experiments (combinations of location and of irrigated vs. dryland production). Both irrigated and dryland tests were conducted at some locations; data used in this study came from tests which provided adequate data in at least 2 years of the 3-year span. Those Oklahoma and Texas locations for each 3-year period are listed in Table 1 as are their code numbers in the National system. The moisture regime for each location is specified along with the soil (including taxonomic identification) for each.

Fifteen cultivars were analyzed in the 1981-1983 time span with 11 cultivars in the 1984-1986 and in 1987-1989 (Table 2). Those cultivars included the four National Standards common to all regions for each of the three 3-year periods. The remaining cultivars were Plains Regional Standards. Only cultivars common to all locations for a given 3-year period were utilized in this study. Their code numbers in the National system are indicated in Table 2.

Randomized complete-block designs with three to six replications were used in each experiment. Five replications were used in all Oklahoma trials. Plot sizes also varied among tests. Planting, thinning (if any), cultural practices (including weed control), insect control, irrigation (where applicable), and harvesting were conducted by the experiment station personnel at all locations included in this study and followed the generally recommended procedures for those areas of Oklahoma (4,5,6,20,21,22,23,24,25) and Texas (11,12,13,14,15,16,17,18,19).

Data were taken by station personnel for lint yield, lint percentage, boll size, and seed index. Lint yield per plot was determined by multiplying the weight of pulled or picked cotton per plot in pounds by the appropriate lint percentage. Lint yield per plot was then converted to kilograms per hectare. Lint percentage, boll size, and seed index were derived from a 15- to 25-boll sample from two replications of each cultivar at each location. Lint percentage was measured as lint weight in grams converted into a percentage of the seedcotton weight; boll size was calculated as the weight of seedcotton in grams per boll; and seed index was estimated as the weight of 100 fuzzy (or undelinted) seeds in grams. Lint percentage and boll size are components of lint yield, and seed index is a component of seed yield.

Statistical Analyses

The methods outlined by Comstock and Moll (10) were used to analyze the data for all traits combining all locations and years for each 3-year period. Cultivars, locations, and years were assumed to be random variables. The sources of variation were partitioned into main effects and their interactions. Statistical significance of the pertinent sources of variation were determined, and mean squares were partitioned into variance components. After the initial analysis within each 3-year time period further analyses were made by subdividing locations into Rolling Plains and High Plains subregions, states, and irrigated vs. dryland production. If significant CL interactions were obtained for either of the two subdivisions, they were further partitioned into irrigated vs. dryland production. If significant CL was obtained in the case of irrigated and/or dryland locations, those data sets were subdivided into states. Analyses were conducted on further subdivisions, if significant CL were still present for any of the subsequent analyses.

Cluster analyses were conducted for lint yield using two-way classification data for each 3-year period to group locations on the basis of their similarity of CL only according to Lin et al. (27). This clustering process was achieved using S116 program from Agriculture Canada (30).

RESULTS AND DISCUSSION

Significant cultivar by location by year (CLY) indicates fluctuations in ranking of genotypes associated with individual location-year combinations and requires testing genotypes over both locations and years. Significant cultivar by location (CL) interactions suggest wide fluctuations in the ranking of genotypes across locations and requires testing genotypes over a range of locations. Significant cultivar by year (CY) interactions is indicative of inconsistent ranking among genotypes and requires testing genotypes over years. The lack of significant interaction components suggests that genotypes perform consistently across location-year combinations and testing in one or few locations would be adequate.

Lint Yield

Significant CLY and CL interactions for lint yield were obtained in a combined analysis over all locations and years in the Plains Region for 1981-1983 (Table 3). Subdivision of the Plains Region into subregions (i.e. Rolling Plains vs. High Plains) gave a significant CLY interaction and cultivar component for the Rolling Plains and a significant CL interaction component for the High Plains. In the states subdivision, CLY interactions were significant in Oklahoma with the only significant variance component detected in Texas being CL. Partitioning the

Region into dryland vs. irrigated locations resulted in detection of a significant CL interaction for the dryland locations and significant CLY for the irrigated locations. The Texas locations were further analyzed since they appeared to be the source of CL in this time span (Table 4). All three analyses involving Lamesa gave significant CL interactions. Apparently, Lamesa was the major source of CL interaction during this time span. The CL component was also significant in the analysis involving Halfway and Chillicothe. However, neither location provided a significant CL interaction when analyzed with Lubbock.

Analysis of the 1984-1986 period over years and locations in the Plains Region indicated that all components of variance were significant (Table 5). The CLY interaction was the largest of all these components. The interpretation of significant CLY, CL, and C components was the same as earlier. The cultivar by year (CY) interaction indicated that testing over multiple years (at least two) was necessary during this time period. In the major subdivision analyses, CL interaction components were significant on the Rolling Plains, in Oklahoma, in Texas, and in the irrigated locations. Further subdivisions of those major subdivisions are reported in (Table 6). Significant CL interaction components were detected between the two Oklahoma irrigated locations and between the Lubbock and Chickasha irrigated locations, but not between the Lubbock and Altus irrigated locations. Apparently, the Chickasha irrigated location was the major source of significant CL interactions during this time span.

Significant components of variance were obtained for all except CL when an analysis was performed on the 1987-89 data over all locations and years (Table

7). However, because of the magnitude of the CL component relative to the CY component, major subdivision analyses were performed despite the lack of significance for CL. The interpretations of the C, CY, and CLY components remain as before. Significant CL components were detected in the High Plains, Texas, and irrigated location analyses. Further subdivision of those data subsets resulted in no CL interaction components (Table 8). Subdivision of Texas into dryland vs. irrigation location analyses was instructive in that the CL component was no longer significant. Apparently, the source of the CL interaction was between dryland vs. irrigated tests in Texas. Some was also apparently present in the irrigated experiments in Oklahoma vs. Texas. Examination of means and variance components indicate that the cultivars evaluated in this period had greater genetic diversity than the other two time periods which impacted on the GE interaction variances (32).

Comparing the relative magnitude of CL vs. CY components in the Oklahoma vs. Texas analyses (Tables 3, 5, and 7) leads to the conclusion that CY interactions were relatively more important in Oklahoma while CL interactions were more important in Texas.

Further analysis of the Oklahoma data was accomplished by examining the performance of each cultivar average over years and locations (Table 9). For the 1981-1983 data (Table 3), the CY variance component was negative indicating that this interaction was actually a very small positive number or zero. Table 9 also shows that a substantial portion of the CY interaction sum of squares over cultivars and locations can be attributed to 1986. Four cultivars contributed substantially to this sum of squares. They were 'Paymaster 145', 'Stoneville 213', and Cascot L-7 which showed large positive responses while 'Lankart LX 571' showed a large negative response relative to their 1985 performance. The 1987-1989 data shows an even larger CY interaction sum of squares compared to the two previous 3-year periods most of which can be attributed to 1989 (Table 9). Three cultivars contributed substantially to this interaction. These were 'Cencot', 'Tamcot SP21S' and Paymaster 145.

Analysis of the CL interactions which were relatively more important in Texas (Table 3, 5, and 7) was accomplished by examining the performance of each cultivar averaged over locations and years (Table 12) and of each location averaged over cultivars and years (Table 11). Lamesa and to a lesser extent Lubbock contributed greatly to the CL interaction in the 1981-1983 (Table 11). Table 12 suggests that five cultivars were the main contributors to that interaction. Lankart LX 571, 'Lockett 77', and 'Paymaster 303' showed negative responses at Lamesa; whereas, 'Coker 5110' and Stoneville 213 exhibited positive performances. In 1984-1986 the relative contribution of locations to the CL interaction component was more evenly distributed than in 1981-1983. Lamesa and Halfway contributed slightly more than did Lubbock followed by Chillicothe (Table 11). Five cultivars were apparently the main contributors to the CL interaction component (Table 12). These were Lankart LX 571, Stoneville 213, 'Dunn 219', and 'Acala SJC-1', showing predominantly negative performances at higher yield levels. Cascot L-7 showed moderate increases with increasing yield levels. The majority of the CL interaction for 1987-1989 can be attributed to the

Lamesa irrigated experiment followed by Chillicothe and Lamesa dryland (Table 11). Four cultivars were the main contributors. These were Lankart LX 571 and Cencot whose performances were negative, and 'Paymaster HS 26', 'Deltapine SR-383', and Paymaster 145 whose performances were positive at Lamesa under irrigation. Because CL interaction in these analyses is relatively important among Texas locations and because this source of variation (CL) is predictable to some extent (3), the state would probably benefit from development of cultivars adapted to specific areas. Analyses suggest that Lamesa location is considerably different from the others and should probably not be considered in the same group with the others.

Because these data were not orthogonal since data were not available from some locations for at least one of the three years, it was important to determine if this had an impact on the CL interaction. In the 1981-1983 period, the Lamesa location was present in 1981 and 1982 only. Similarly, for the 1984-1986 period, Lubbock was present only in 1984 and 1985. Table 13 shows that exclusion of Lamesa from the analyses reduced the CL variance components considerably and increased the CLY components. It appears likely that this location alone is largely responsible for the large and significant CL. Whether this was a consequence of its absence from the 1983 year was tested. In an analysis using only 1981 and 1982 data, a significant CL interaction effect was observed when Lamesa was included; it was reduced by more than half when that location was omitted. The other year combinations gave similar results. Effects were pronounced because Lamesa was the location contributing the most to CL interaction in that period.

A similar analysis of the 1984-1986 data with and without the Lubbock location gave similar results to those obtained for the 1981-1983 data (Table 14). Analyses over all years and locations were very similar for the CL interaction. This lack of influence could have been predicted because the Lubbock location ranked third of the four locations in contribution to the CL interaction.

A cluster analysis of the 1981-1983 lint yield data, using the GEIN model (Lin and Butler, 31) shows that the locations in that time span can be classified into two groups based on CL interaction with Lamesa in one group and the remaining locations in the other group (Table 15). With this group of genotypes and years, there were no significant departure from relative ranking of genotypes except for Lamesa in cluster cycle 7. In this analysis, the two locations in western Oklahoma, i.e., Altus irrigated and Mangum dryland, showed the greatest similarities when averaged over years (cluster cycle 1). The locations being in proximity must have experienced generally similar climatic conditions over the 3-year period. However, the moisture regimes at the two locations are quite different since that area is in a semiarid environment. Lubbock, an irrigated location on the Texas High Plains, and Chickasha, a dryland location on the Rolling Plains, were also very similar in ranking of genotypes (cluster cycle 2).

Clustering the 1984-1986 locations suggests that four groups of locations could be formed (Table 15). The three dryland locations on the Rolling Plains, i.e., Chickasha, Mangum, and Chillicothe, formed one group with Chickasha irrigated; Altus irrigated on the Rolling Plains and Lamesa dryland on the High

Plains formed another; and Lubbock irrigated, Halfway dryland, and Chickasha irrigated formed the two others.

Clustering of the 1987-1989 locations resulted in the formation of three large groups, Lamesa irrigated in one group; Altus and Chickasha irrigated in another, and the other five locations in the last group (Table 15). The cluster cycles produced interesting grouping. For example, cluster cycle 2 consists of all the dryland locations in Texas and cluster cycle 3 contains of all the dryland locations in the Plains Region suggesting that relative performances in this set of genotypes were similar under these conditions. Altus and Chickasha irrigated locations though differing considerably formed a cluster in cycle 5. The location most different from the others was Lamesa irrigated.

Clustering locations based on CL interactions using two-way classification data averaged over years did not generally reveal meaningful associations. What they did reveal is that locations in different states, in some cases, show greater similarities in terms of genotypes behavior than do neighboring locations within the same state! These inconsistencies were to some extent expected because of the prevalence of significant CLY interactions observed for yield. Generally, this classification suggests that all locations other that Lamesa are appropriately zoned in the Plains Region which is similar to those obtained by Abou-El-Fittouh et al. (1), except that Lamesa was not included in their study.

Lint Percentage

In an analysis of 1981-1983 lint percentage data in the Plains Region over years and locations, significant C, CL, and CLY components were detected (Table 16). Interpretations for these components are as described earlier. In all analyses, the C component was significant and larger than all interaction components combined. The only significant CL interaction for lint percentage among major subdivisions was detected in the analyses for irrigated locations. Subdivision of the irrigated locations into Oklahoma vs. Texas locations resulted in non significant CL interaction components (Table 17). However, there were significant CLY interactions for all pairs of combinations of irrigated locations between the two states, except between Chillicothe and Altus, both of which are on the Rolling Plains.

Analysis of the 1984-1986 lint percentage data over all locations and years resulted in significance for all variance components (Table 18). The largest interaction component was CL. Significant CL components were detected in all major subdivision analyses except among the Oklahoma locations. In all analyses, the C component was significant and substantially larger than all the interaction components combined. Further analyses of the High Plains of Texas dryland locations resulted in significant CL components for analyses involving Lamesa but not in those without it (Table 19). Subdivision of the Rolling Plains into irrigated vs. dryland produced a significant CL interaction only for the irrigated locations. Analyses of the Lubbock irrigated location with the Oklahoma irrigated locations separately detected significant CL interactions, but not with Chillicothe dryland (Table 20).

No significant CL components were detected for lint percentage in the

1987-1989 analysis over years and locations nor in the major subdivision analyses (Table 21). In all subdivision analyses, except for dryland, the C component was significant. In contrast to the two earlier time periods, it was generally smaller compared to the total of the interaction components.

Boll Size

In the 1981-1983 analysis of the Plains Region for boll size over locations and years the CL component was not significant (Table 22). Subdividing the region also failed to detect such interactions. A significant CL interaction component was detected in the 1984-1986 analysis of the Plains Region over all locations and years as well as in the Texas subdivision (Table 23). Because the magnitude of the CL component was so small relative to the C component, subanalyses of the Texas locations were not pursued.

Significant CL components were not obtained for boll size for the 1987-1989 analysis of the Plains Region as a whole nor for any of its subdivisions (Table 24).

Seed Index

Significant CL interaction components for seed index were not detected when the Plains Region was analyzed over all location and years nor when subdivided in 1981-1983 (Table 25). The analysis of seed index in the Plains Region for 1984-1986 over all locations and years indicated that the CL interaction component was significant (Table 26). However, it was not significant in any major subdivision of the Region during that time span. For the 1987-1989 period, significant CL component were not detected in the combined analysis nor in any subdivision analysis (Table 27). The C component was larger than the total of the interaction components in every case.

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Table 1. Locations included in the Plains Region genotype-environment interaction study of agronomic traits in cotton over three 3-year periods.

State	1981-1983	1984-1986	1987-1989
Oklahoma			
	Altus I† [16]‡§	Altus I [16]	Altus I [16]
	Chickasha D [38]¶	Chickasha D [38]	Chickasha D [38]
	Chickasha I [41]	Chickasha I [41]	Chickasha I [41]
	Mangum D [39]#	Mangum D [39]	
Texas			
	Chillicothe I [15]††	Chillicothe D [52]	Chillicothe D [52]
	Halfway D [13]‡‡	Halfway D [13]	Lamesa D [163]
	Lamesa D [163]	Lamesa D [163]	Lamesa I [187]§§
	Lubbock I [12]¶¶	Lubbock I [12]	Lubbock I [12]
			Lubbock D [159]

† I = irrigated vs. D = dryland experiments.
‡ National Cotton Variety Testing Program location code numbers are in the brackets.
§ Hollister clay loam (fine, mixed, thermic Pachic Paleustoll).
¶ Reinach silt loam (coarse-silty, mixed, thermic Pachic Haplustoll).
# Meno loamy fine sand (loamy, mixed, thermic Aquic Arenic Haplustalf).
†† Abilene clay loam (fine, mixed, thermic Pachic Argiustoll).
‡‡ Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll).
§§ Amarillo fine sandy loam (fine-loamy, mixed, thermic Aridic Paleustalf).
¶¶ Amarillo or Olton loam (fine, mixed, thermic Aridic Paleustoll).

Table 2. Cotton cultivars included in the Plains Region genotype-environment interaction study of agronomic traits over three 3-year periods.

1981-1983	1984-1986	1987-1989
Acala SJ-5† [4]‡	Acala SJC-1† [8]	Acala 1517-75† [3]
Lockett 77† [6]	McNair 235† [4]	Coker 139† [11]
McNair 235† [12]	Paymaster 145† [6]	Deltapine 50† [9]
Stoneville 213† [1]	Stoneville 213† [1]	Paymaster 145† [8]
Coker 5110 [3]	Cascot L-7 [10]	All-Tex WM-571 [2]
Dunn 219 [13]	Deltapine SR-383 [9]	Cencot [5]
GSA 71 [7]	Dunn 219 [5]	Deltapine SR-383 [10]
Lankart LX 571 [2]	GSA 71 [3]	GP 1005 [6]
Paymaster 145 [14]	Lankart LX 571 [2]	Lankart LX 571 [1]
Paymaster 303 [5]	Paymaster 404 [11]	Paymaster HS-26 [7]
Pioneer Brand PR-68 [9]	Stoneville 302 [7]	Tamcot SP21S [4]
Stoneville 302 [15]		
Stripper 31A [8]		
Tamcot SP21S [10]		
Westburn M [11]		

† National Standard cultivars; remainder are Plains Regional Standards.
‡ National Cotton Variety Testing Program cultivar code numbers are in the brackets.

Table 3. Variance components for lint yield in the Plains Region and its major subdivisions, 1981-1983.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,15,16, 38,39,41,163	15,16, 38,39,41	12, 13,163	16,38, 39,41	12,13, 15,163	13,38, 39,163	12,15, 16,41
σ^2_C	1143**	1350**	588	1967**	258	837*	1231**
σ^2_{CY}	0§	0§	0§	0§	58	170	0§
σ^2_{CL}	534**	25	2008**	0§	1388**	1352**	116
σ^2_{CLY}	1457**	1805**	210	2130**	430	221	2390**
σ^2_E	4574	2963	8829	3392	6036	6387	3107

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha D; 39 is Mangum D; 41 is Chickasha I; and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 4. Variance components for lint yield after further dividing the Texas subdivision of the Plains Region, 1981-1983.

Variance component†	Texas locations					
	12‡,13	12,163	12,15	13,15	13,163	15,163
σ^2_{C}	1105**	0§	269	0§	232	0§
σ^2_{CY}	0§	561	0§	401	358	0§
σ^2_{CL}	7	3594**	0§	778*	3310*	2665**
σ^2_{CLY}	1627**	0§	889	674*	0§	295
σ^2_{E}	6258	8991	2609	3967	11571	5865

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 5. Variance components for lint yield in the Plains Region and its major subdivisions, 1984-1986.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,16,38, 39,41,52,163	16,38, 39,41,52	12, 13,163	16,38, 39,41	12,13, 52,163	13,38, 39,52,163	12, 16,41
σ^2_C	1851**	1281*	3183*	2040*	1384	918	3475**
σ^2_{CY}	1150**	1566**	1908	1748**	1320*	1177**	769
σ^2_{CL}	1257**	1203**	950	1311**	1347*	559	2284**
σ^2_{CLY}	1952**	1133**	2591**	890**	2415**	1912**	2253**
σ^2_E	7699	7429	8395	7233	8310	8788	5994

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 16 is Altus I; 38 is Chickasha D; 39 is Mangum D; 41 is Chickasha I; 52 is Chillicothe D; and 163 is Lamesa D.

Table 6. Variance components for lint yield after further dividing major subdivisions of the Plains Region, 1984-1986.

Variance component†	Rolling Plains dryland	Oklahoma		Texas dryland	Irrigated	
		Dryland	Irrigated			
	38‡,39,52	38,39	16,41	13,52,163	12,16	12,41
σ^2_C	448	1182	3359*	303	3615*	3457*
σ^2_{CY}	1879	2124*	580	1096	1318	384
σ^2_{CL}	67	0§	1347*	1395	1849	2785**
σ^2_{CLY}	927**	695	2415**	2294**	2816**	2165**
σ^2_E	8214	8246	8310	9258	6492	5237

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 16 is Altus I; 38 is Chickasha D; 39 is Mangum D; 41 is Chickasha I; 52 is Chillicothe D; and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 7. Variance components for lint yield in the Plains Region and its major subdivisions, 1987-1989.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,16,38,41, 52,159,163,187	16,38, 41,52	12,159, 163,187	16, 38,41	12,52,159, 163,187	38,52, 159,163	12,16, 41,187
σ^2_{C}	7131**	7505**	8957**	7864**	6636**	4425**	10368**
σ^2_{CY}	951*	1957	1200	6168**	1559*	0§	1923
σ^2_{CL}	1197	0§	2195*	1314	2226**	0§	3309*
σ^2_{CLY}	5963**	6892**	2366**	2741**	2771**	5618**	6680**
σ^2_{E}	10141	11671	7698	13939	6668	10618	9650

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus, irrigated (I); 38 is Chickasha dryland (D); 41 is Chickasha I; 52 is Chillicothe D; 159 is Lubbock D; 163 is Lamesa D; and 187 is Lamesa I.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 8. Variance components for lint yield after further dividing major subdivisions of the Plains Region, 1987-1989.

Variance component†	Texas			Oklahoma irrigated
	Dryland		Irrigated	
	52‡,159,163	159,163	12,187	16,41
σ^2_C	2980*	3959**	14642*	10787**
σ^2_{CY}	2529*	1572	1584*	3725
σ^2_{CL}	0§	0§	3981	1350
σ^2_{CLY}	2213**	1576**	2206**	6492**
σ^2_E	6466	8463	6993	11469

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 41 is Chickasha I; 52 is Chillicothe, dryland (D); 159 is Lubbock D; 163 is Lamesa D; and 187 is Lamesa I.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 9. Contribution of each year to the CY interaction SS from an analysis of variance of lint yield means averaged over cultivars and locations for three 3-year periods in Oklahoma.

1981-1983		1984-1986		1987-1989	
Year	SS	Year	SS	Year	SS
1981	1618	1984	6648	1987	44271
1982	7536	1985	12369	1988	49229
1983	6872	1986	27522	1989	83401
Total	16026		46539		176901

Table 10. Contribution of each cultivar to the CY interaction SS from an analysis of variance of lint yield means averaged over years and locations for three 3-year periods in Oklahoma.

1981-1983		1984-86		1987-89	
Cultivar	SS	Cultivar	SS	Cultivar	SS
Stoneville 213†	573	Stoneville 213†	9716	Lankart LX 571	7637
Lankart LX 571	4309	Lankart LX 571	14133	All-Tex WM-571	9122
Coker 5110	1505	GSA 71	13	Acala 1517-75†	8923
Acala SJ-5†	2064	McNair 235†	653	Tamcot SP21S	39960
Paymaster 303	614	Dunn 219	600	Cencot	48137
Lockett 77†	372	Paymaster 145†	9122	GP 1005	11230
GSA 71	1242	Stoneville 302	1465	Paymaster HS-26	2577
Stripper 31A	129	Acala SJC-1†	2848	Paymaster 145†	40582
Pioneer Brand PR-68	718	Deltapine SR-383	1768	Deltapine 50†	904
Tamcot SP21S	1108	Cascot L-7	5518	Deltapine SR-383	7088
Westburn M	680	Paymaster 404	803	Coker 139†	742
McNair 235†	160				
Dunn 219	1322				
Paymaster 145	1205				
Stoneville 302	26				
Total	16027		46639		176902

† National Standard cultivars; remainder are Plains Regional Standards.

Table 11. Contribution of each location to the CL interaction SS from an analysis of variance of lint yield means averaged over cultivars and years for three 3-year periods in Texas.

1981-1983		1984-1986		1987-1989	
Location	SS	Location	SS	Location	SS
Chillicothe I†	9728	Chillicothe D	18970	Chillicothe D	33458
Halfway D	10981	Halfway D	25541	Lubbock I	11197
Lubbock I	23210	Lubbock I	22630	Lubbock D	17735
Lamesa D	52603	Lamesa D	25982	Lamesa D	26406
				Lamesa I	97667
Total	96522		93123		186463

† I = irrigated vs. D = dryland experiments.

Table 12. Contribution of each cultivar to the CL interaction SS from an analysis of variance of lint yield means averaged over locations and years for three 3-year periods in Texas.

1981-1983		1984-1986		1987-1989	
Location	SS	Location	SS	Location	SS
Stoneville 213†	9053	Stoneville 213†	12072	Lankart LX 571	23199
Lankart Lx 571	15263	Lankart LX 571	15073	All-Tex WM-571	1108
Coker 5110	10811	GSA 71	3258	Acala 1517-75†	3538
Acala SJ-5†	7835	McNair 235†	4842	Tamcot SP21S	13713
Paymaster 303	11742	Dunn 219	10760	Cencot	34534
Lockett 77†	9363	Paymaster 145†	7374	GP 1005	13457
GSA 71	5873	Stoneville 302	7494	Paymaster HS-26	28585
Stripper 31A	7036	Acala SJC-1†	9072	Paymaster 145†	22524
Pioneer Brand PR-68	4377	Deltapine SR-383	4597	Deltapine 50†	15614
Tamcot SP21S	443	Cascot L-7	9700	Deltapine SR-383	24603
Westburn M	2274	Paymaster 404	8880	Coker 139†	5589
McNair 235†	3432				
Dunn 219	3146				
Paymaster 145	3387				
Stoneville 302	2486				
Total	96521		93122		186464

† National Standard cultivars; remainder are Plains Regional Standards.

Table 13. Variance components for lint yield over all years and locations in the Plains Region and over all combinations of years with and without the Lamesa dryland location, 1981-1983.

	All locations				All locations except Lamesa			
Variance component†	1981-1983	1981-1982	1981, 1983	1982-1983	1981-1983	1981-1982	1981, 1983	1982-1983
σ^2_C	1143**	1089**	1296**	1063**	1267**	1248*	1403**	1147**
σ^2_{CY}	0‡	34	0‡	0‡	0‡	16	0‡	0‡
σ^2_{CL}	534**	1148**	512	0‡	45	475**	11	0‡
σ^2_{CLY}	1457**	663**	1785**	2118**	1712**	955**	1895**	2292**
σ^2_E	4574	4158	4188	5421	3659	2720	3657	4599

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Zero or negative estimate for which the most reasonable value is zero.

Table 14. Variance components for lint yield over all years and locations in the Plains Region and over all combinations of years with and without the Lubbock irrigated location, 1984-1986.

	All locations				All Locations except Lubbock			
Variance component†	1984-1986	1984-1985	1984, 1986	1985-1986	1984-1986	1984-1985	1984, 1986	1985-1986
σ^2_C	1851**	900**	3070**	1617**	1528**	505*	2451**	1652**
σ^2_{CY}	1150**	842**	1250**	1456**	1163**	659**	1427**	1466**
σ^2_{CL}	1257**	1412**	1810**	584	1278**	1491**	1490**	862
σ^2_{CLY}	1952**	1350**	2314**	2220**	1918**	1190**	2431**	2166**
σ^2_E	7699	7639	6192	9255	7524	7381	5657	9506

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

Table 15. Clustering of locations in the Plains Regions for 1981-1983, 1984-1986, and 1987-1989 lint yield data using an anova model (GEIN).

3-year period	Cluster cycle	Locations grouped†	Smallest index	Calculated F-value
1981-1983	1	16,39	360.02	0.29
	2	12,38	363.88	0.84
	3	15,(12,38)	408.64	1.02
	4	(16,39),(15,12,38)	527.08	0.72
	5	13,(16,39,15,12,38)	702.04	0.84
	6	41,(13,16,39,15,12,38)	877.62	1.06
	7	163,(13,16,39,15,12,38,41)	1614.41	1.63
1984-1986	1	38,39	710.98	0.91
	2	52,(38,39)	1020.75	1.08
	3	16,163	1402.20	0.77
	4	41,(38,39,52)	1448.43	1.66
	5	12,13	1847.70	3.14
	6	(16,163),(38,39,52,41)	2125.24	1.94
	7	(12,13),(38,39,52,41,16,163)	2632.89	1.99
1987-1989	1	52,159	920.75	0.83
	2	163,(52,159)	1488.35	0.83
	3	38,(52,159,163)	1761.77	0.55
	4	12,(38,52,159,163)	2240.30	0.89
	5	16,41	2634.20	1.30
	6	(16,41),(12,38,52,159,163)	3441.40	1.10
	7	187,(16,41,12,38,52,159,163)	5127.89	1.37

† Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha D; 39 is Mangum D; 41 is Chickasha I; 52 is Chillicothe D; 159 is Lubbock D; 163 is Lamesa D; 187 is Lamesa I.

Table 16. Variance components for lint percentage in the Plains Region and its major subdivisions, 1981-1983.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,15,16, 38,39,41,163	15,16, 38,39,41	12, 13,163	16,38, 39,41	12,13, 15,163	13,38, 39,163	12,15, 16,41
σ^2_C	1.38**	1.16**	1.78**	1.03**	1.92**	1.33**	1.34**
σ^2_{CY}	0.04	0.11	0.18	0.13	0.03	0.11	0.01
σ^2_{CL}	0.16*	0.22	0.08	0.07	0.11	0.12	0.31*
σ^2_{CLY}	0.63**	0.79**	0.06	0.96**	0.19*	0.58**	0.63**
σ^2_E	1.05	1.26	0.65	1.29	0.77	0.56	1.49

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha D; 39 is Mangum D; 41 is Chickasha I; and 163 is Lamesa D.

Table 17. Variance components for lint percentage after further dividing major subdivisions of the Plains Region, 1981-1983.

	Oklahoma	Oklahoma-Texas				Texas
	Irrigated	Irrigated				Irrigated
Variance component†	16‡,41	12,16	12,41	15,16	15,41	12,15
σ^2_C	0.87**	0.92**	1.57**	0.87*	1.57**	2.26**
σ^2_{CY}	0.00§	0.02	0.03	0.24	0.00§	0.00§
σ^2_{CL}	0.06	0.38	0.30	0.57*	0.43**	0.12
σ^2_{CLY}	1.04**	0.82*	0.52**	0.48	0.41*	0.48**
σ^2_E	2.16	1.92	0.76	2.22	1.06	0.82

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 15 is Chillicothe I; 16 is Altus I; and 41 is Chickasha I.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 18. Variance components for lint percentage in the Plains Region and its major subdivisions, 1984-1986.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,16,38, 39,41,52,163	16,38, 39,41,52	12, 13,163	16,38, 39,41	12,13, 52,163	13,38, 39,52,163	12, 16,41
σ^2_{C}	1.17**	1.13*	1.61**	1.09**	1.29**	0.92**	1.41**
σ^2_{CY}	0.08**	0.10*	0.20**	0.11	0.14*	0.09	0.05
σ^2_{CL}	0.38**	0.28**	0.18**	0.25	0.49**	0.31**	0.54**
σ^2_{CLY}	0.11*	0.11	0.00§	0.12*	0.00§	0.18*	0.06
σ^2_{E}	0.68	0.74	0.57	0.57	0.79	0.73	0.62

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 16 is Altus I; 38 is Chickasha D; 39 is Mangum D; 41 is Chickasha I; 52 is Chillicothe D; and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 19. Variance components for lint percentage after further dividing major subdivisions of the Plains Region, 1984-1986.

	Rolling Plains		High Plains				Texas	
	Dryland	Irrigated	Dryland	Irrigated-Dryland			dryland	
Variance component†	38,39,52	16,41	13‡,163	12,163	12,13	13,52,163	13,52	52,163
σ^2_C	0.85**	1.59**	1.23**	1.73**	1.80**	1.05**	1.05**	0.95*
σ^2_{CY}	0.03	0.05	0.12	0.26*	0.25*	0.13	0.32	0.13
σ^2_{CL}	0.18	0.25**	0.35*	0.12*	0.12	0.56**	0.44	0.70**
σ^2_{CLY}	0.32*	0.04	0.02	0.00§	0.00§	0.03	0.00§	0.04
σ^2_E	0.89	0.55	0.45	0.59	0.67	0.80	1.05	0.89

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 16 is Altus I; 38 is Chickasha D; 39 is Mangum (D); 41 is Chickasha I; 52 is Chillicothe D; and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 20. Variance components for lint percentage after further dividing major subdivisions of the Plains Region, 1984-1986.

			Texas
	Irrigated		Irrigated-Dryland
Variance component†	12‡,16	12,41	12,52
σ^2_C	1.58**	1.08**	0.22**
σ^2_{CY}	0.11	0.00§	0.02
σ^2_{CL}	0.83**	0.54**	0.03
σ^2_{CLY}	0.00§	0.21	0.01
σ^2_E	0.69	0.62	0.06

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 41 is Chickasha I; and 52 is Chillicothe, dryland D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 21. Variance components for lint percentage in the Plains Region and its major subdivisions, 1987-1989.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,16,38,41, 52,159,163,187	16,38, 41,52	12,159, 163,187	16, 38,41	12,52,159, 163,187	38,52, 159,163	12,16, 41,187
σ^2_C	0.71^{**}	0.59^{*}	0.99^{**}	0.74^{**}	1.06^{*}	0.99	0.46^{*}
σ^2_{CY}	0.58^{**}	0.52	0.80^{**}	0.21^{*}	0.95^{**}	0.46	0.36^{**}
σ^2_{CL}	0.00§	0.00§	0.03	0.01	0.00§	0.00§	0.22
σ^2_{CLY}	0.46	0.67	0.00§	0.11	0.46	0.87	0.20
σ^2_E	3.27	4.59	1.78	0.47	5.01	5.34	0.94

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); 41 is Chickasha I; 52 is Chillicothe D; 159 is Lubbock D; 163 is Lamesa D; and 187 is Lamesa I.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 22. Variance components for boll size in the Plains Region and its major subdivisions, 1981-1983.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,15,16, 38,39,41,163	15,16, 38,39,41	12, 13,163	16,38, 39,41	12,13, 15,163	13,38, 39,163	12,15, 16,41
σ^2_C	0.15**	0.15**	0.17**	0.16**	0.14**	0.16**	0.13**
σ^2_{CY}	0.01	0.01	0.01	0.02	0.00§	0.01	0.01
σ^2_{CL}	0.00§	0.00§	0.00§	0.00§	0.00§	0.00§	0.00§
σ^2_{CLY}	0.06**	0.07**	0.06	0.06**	0.06**	0.07**	0.06**
σ^2_E	0.16	0.19	0.10	0.20	0.11	0.16	0.16

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha D; 39 is Mangum D; 41 is Chickasha I; and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 23. Variance components for boll size in the Plains Region and its major subdivisions, 1984-1986.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,16,38, 39,41,52,163	16,38, 39,41,52	12, 13,163	16,38, 39,41	12,13, 52,163	13,38, 39,52,163	12, 16,41
σ^2_C	0.31**	0.37**	0.25**	0.39**	0.24**	0.28**	0.35**
σ^2_{CY}	0.01	0.01	0.01	0.00§	0.02*	0.00§	0.00§
σ^2_{CL}	0.02**	0.00§	0.01	0.00§	0.02*	0.02	0.029
σ^2_{CLY}	0.00§	0.00§	0.01	0.00§	0.01	0.01	0.00§
σ^2_E	0.12	0.08	0.14	0.16	0.07	0.08	0.16

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 16 is Altus I; 38 is Chickasha D; 39 is Mangum D; 41 is Chickasha I; 52 is Chillicothe D; and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 24. Variance components for boll size in the Plains Region and its major subdivisions, 1987-1989.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,16,38,41, 52,159,163,187	16,38, 41,52	12,159, 163,187	16, 38,41	12,52, 159,163,187	38,52, 159,163	12,16, 41,187
σ^2_{C}	0.34**	0.40**	0.30**	0.56**	0.25**	0.27**	0.44**
σ^2_{CY}	0.01	0.02	0.01	0.01	0.00§	0.01	0.01
σ^2_{CL}	0.02	0.03	0.00§	0.00§	0.00§	0.02	0.00§
σ^2_{CLY}	0.09**	0.09**	0.06**	0.07**	0.11**	0.08**	0.10**
σ^2_{E}	0.08	0.09	0.07	0.08	0.08	0.09	0.07

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); 41 is Chickasha I; 52 is Chillicothe D; 159 is Lubbock D; 163 is Lamesa D; and 187 is Lamesa I.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 25. Variance components for seed index in the Plains Region and its major subdivisions, 1981-1983.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,15,16, 38,39,41,163	15,16, 38,39,41	12, 13,163	16,38, 39,41	12,13, 15,163	13,38, 39,163	12,15, 16,41
σ^2_{C}	0.38^{**}	0.28^{**}	0.59^{**}	0.28^{**}	0.53^{**}	0.47^{**}	0.27^{**}
σ^2_{CY}	0.01	0.06	0.00§	0.10	0.00§	0.02	0.04
σ^2_{CL}	0.00§	0.00§	0.00§	0.00§	0.03	0.03	0.00§
σ^2_{CLY}	0.36^{**}	0.44^{**}	0.13^{**}	0.53^{**}	0.07^{*}	0.18^{**}	0.48^{**}
σ^2_{E}	0.35	0.39	0.29	0.40	0.30	0.40	0.31

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha D; 39 is Mangum D; 41 is Chickasha I; and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 26. Variance components for seed index in the Plains Region and its major subdivisions, 1984-1986.

	Plains Region	Plains subregion: Rolling Plains	Plains subregion: High Plains	State: Oklahoma	State: Texas	Moisture regime: Dryland	Moisture regime: Irrigated
Variance component†	12‡,13,15,16, 38,39,41,163	15,16, 38,39,41	12, 13,163	16,38, 39,41	12,13, 15,163	13,38, 39,163	12,15, 16,41
σ^2_C	1.08**	1.05**	1.21**	1.14**	1.06**	1.03**	1.17**
σ^2_{CY}	0.04*	0.05*	0.07	0.03	0.04	0.00§	0.03
σ^2_{CL}	0.05*	0.01	0.01	0.00§	0.06	0.05	0.03
σ^2_{CLY}	0.09**	0.04	0.14*	0.04**	0.16**	0.14**	0.08
σ^2_E	0.29	0.28	0.30	0.32	0.25	0.23	0.37

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 16 is Altus I; 38 is Chickasha D; 39 is Mangum D; 41 is Chickasha I; 52 is Chillicothe D; and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 27. Variance components for seed index in the Plains Region and its major subdivisions, 1987-1989.

	Plains Region	Plains subregion		State		Moisture regime	
		Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,16,38,41, 159,163,187	16, 38,41	12,159, 163,187	16, 38,41	12,159, 163,187	38, 159,163	12,16, 41,187
σ^2_C	0.76**	0.83**	0.73**	0.83**	0.73**	0.70**	0.83**
σ^2_{CY}	0.04*	0.06	0.09*	0.06	0.09*	0.00§	0.05
σ^2_{CL}	0.01	0.01	0.00§	0.01	0.00§	0.02	0.00§
σ^2_{CLY}	0.17**	0.09**	0.19**	0.09**	0.19**	0.23**	0.16**
σ^2_E	0.22	0.26	0.19	0.26	0.19	0.15	0.28

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); 41 is Chickasha I; 52 is Chillicothe D; 159 is Lubbock D; 163 is Lamesa D; and 187 is Lamesa I.
§ Zero or negative estimate for which the most reasonable value is zero.

CHAPTER II

Genotype by Environment Interaction Study of Fiber and Yarn Properties in Cotton in the Plains Region of Oklahoma and Texas

Genotype by Environment Interaction Study

of Fiber and Yarn Properties

in Cotton

in the Plains Region

of Oklahoma and Texas[1]

ABSTRACT

Fiber properties are becoming increasingly important in cotton production because of the premium prices often received for high quality. New spinning technology has also increased the emphasis on fiber strength. This study was conducted to evaluate the effect of genotype by environment interactions [particularly cultivar by location (CL) interactions] on six fiber properties [2.5% and 50% span length, uniformity ratio, T_1 fiber strength, E_1 fiber elongation, and fiber fineness (micronaire)] and yarn tenacity. Data utilized were of the 15, 11, and 11 National and Plains Regional Standard cotton cultivars tested at six, four, and four locations respectively in 1981-1983, 1984-1986, and 1987-1989. Analyses of variance were performed for the entire Region on data from each 3-year period with subsequent subdivisional analyses into Rolling vs. High Plains subregions, states, and irrigated vs. dryland production. Significant cultivar (C)

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components were detected for every trait in every time span for the Plains Region as a whole. A significant cultivar by location by year (CLY) component was detected for all

fiber properties in at least two of the three 3-year periods in the Region. For yarn tenacity, the CLY component was significant only in 1981-1983. The CY components were relatively small, but significant, in two of the three time spans in the Region for micronaire and in only one time span for 2.5% span length, fiber elongation, and fiber strength. The CL components were small, but significant, in all three time spans for yarn tenacity and in only one for micronaire. Results suggest that testing over multiple environments is helpful for most traits but with no clear indication as to how those tests should be distributed over locations and years. Testing in fewer environments than are currently used (i.e., four) should be sufficient for yarn tenacity.

INTRODUCTION

Cotton cultivar trials have been conducted for many years in the Plains Region of Oklahoma and Texas under irrigated and dryland conditions (31). In Oklahoma, significant genotype by environment (GE) interactions have been observed for the fiber measurements 2.5 % span length, T_1 fiber strength, and fiber fineness (30,31). Uniformity index was also affected (30). Morrison and Verhalen (30) proposed that in Oklahoma fiber properties could be ranked by the decreasing importance of their GE interactions as fineness > length uniformity > strength > length.

Premium prices for lint of 'Acala' cultivars indicate that a market exists for cotton (*Gossypium hirsutum* L.) with the "right kind" of fiber properties. As a consequence, most breeding programs in cotton place emphasis on fiber quality (25). Over the last 1 to 2 decades, greater emphasis has been placed on fiber properties because the relatively new technology of "open-end spinning" offers several advantages over the traditional "ring spinning" (24). A general consensus ranks fiber length > fiber strength > fiber fineness (i.e., micronaire) for use in open-end spinning with fiber strength > fiber fineness > length for ring spinning (36). Strength is of great importance in both systems.

Miller et al. (27) obtained a significant cultivar by location by year (CLY) interaction component for 2.5% span length in their analysis of 15 cotton cultivars at 9 in North Carolina locations over 3 years. That component was about twice the size of the cultivar by year (CY) component. The cultivar by location (CL) component was very small. However, the cultivar (C) component was approximately twice the size of the CLY component. Miller et al. (28) also detected a significant CLY component for staple length which was much greater than either first-order component in an analysis of 16 cotton cultivars at 11 locations over 3 years. The CY component was also significant. The C component was again much larger than any of the interaction components. The C component was larger than the GE interactions combined when assessed across four cultivars and 101 environments in the USA by Abou-El-Fittouh et al. (1). All temperature variables, particularly maximum temperatures, contributed significantly in their study to the GE interaction sum of squares for this trait.

Bridge et al. (5), in an evaluation of 8 cotton cultivars over a 3-year period at three Mississippi locations obtained a significant C component for fiber length which was substantially larger than the interaction components. The second-order component was larger than either of the first-order ones, CL or CY. Murray and Verhalen (32) studying 11 cultivars over 3 years at three Oklahoma locations obtained a significant CY component for 2.5% span length which was larger than the CL or CLY. This component was, however, much smaller than the C component. Morrison and Verhalen (30) in an analysis of 2.5% span length over 2 years and four Oklahoma location and 10 cultivars obtained significant CLY and CY components. The CLY component was the larger of the two, but even it was substantially smaller than the C component. Subdivision of the state into irrigated vs. dryland production gave similar results with respect to the CLY and C components, however, the CY component was considerably reduced and no longer significant. Meredith and Bridge (25) found a significant GE interaction mean square for fiber length which was much smaller than the C mean square. They were unable to relate this interaction to environmental changes or to cultivars. In addition, they detected a significant cultivar by harvest date interaction which suggested to them that early sampling might lead to overestimation of differences for the trait.

Bridge et al. (5) obtained a significant C component which was much larger than the CL and CLY components for 50% span length. The CY component was half that of the C component and substantially larger than the CLY component. Meredith and Bridge (25) detected a significant GE interaction mean square for this character; however, it was much smaller than the C mean square. They were unable to relate the interaction to environmental changes or specific cultivars. A significant cultivar by harvest date interaction in their analysis indicated that early sampling might lead to overestimation of differences for the trait.

A significant CLY component was obtained for uniformity index by Morrison and Verhalen (30). The CL component was slightly smaller but not significant. All GE components combined were much smaller than the significant C component. Meredith and Bridge (25) detected a significant GE interaction mean square for this character which was considerably smaller than the C mean square. A relationship was not detected between this interaction and environmental changes or cultivars. No significant cultivar by harvest date interaction was detected but they again suggested that early sampling might lead to overestimation of the trait. Without significant interactions, we interpret the situation to mean that relative performances for this trait are unlikely to change significantly from one sampling date to another.

Miller et al. (27) for fiber strength found a significant CLY component with considerably smaller first-order interactions. The C component was much larger than the GE components. Bridge et al. (5) observed a significant C component that was approximately twice the size of the CLY interaction component which was substantially larger than the first-order interaction components. Similar observations were made by Abou-El-Fittouh et al. (1). All temperature variables contributed significantly to the GE interaction sum of squares for this trait.

Murray and Verhalen (32) obtained a significant CY variance for fiber strength in Oklahoma. This component was slightly larger than the CL component which in turn was slightly larger than CLY. The C component was significant and substantially larger than the GE interaction components combined. In Oklahoma experiments, a significant CLY component was derived by Morrison and Verhalen (30) which was larger than the first-order interactions with CL > CY. The C component was significant and larger than any of the others. Analysis of the irrigated locations gave similar results except that the CY > CL. Meredith and Bridge (25) detected a significant GE mean square for this character which was much smaller than the C mean square. This interaction could not be related to environmental changes or cultivars.

Bridge et al. (5) obtained a significant C component which was considerably larger than the interaction components combined. The CL and CY components were both larger than CLY. Elongation was affected by temperature variables, the temperature in the third period (fruit development stage) being most important (Abou-El-Fittouh et al., 1). Meredith and Bridge (25) detected significant GE interaction mean squares for elongation which were comparatively smaller than the C mean square. Those interactions could not be attributed to known environmental changes or cultivars. No significant cultivar by harvest date interaction was detected for elongation. According to them, the lack of an interaction suggested that early sampling might lead to underestimation of the trait. On the contrary, we interpret it to mean that sampling date has no influence on this trait.

Miller et al. (27) in their analysis of fiber fineness (i.e., micronaire) obtained significant first-order components larger than the CLY component. The CL component was much larger than for CY. Both were much smaller than the C component. Bridge et al. (5) obtained a significant CLY component which was considerably larger than CL or CY and slightly smaller than C which was also significant. Abou-El-Fittouh et al. (1) found that the CLY variance for fiber fineness was the largest component in their analyses over the Cotton Belt. The C was substantially larger than CL or CY. A significant CLY component was obtained by Murray and Verhalen (32) which was smaller than the CY component. The C component was significant and substantially larger than any of the interaction components.

Morrison and Verhalen (30) also obtained a significant CLY component for fiber fineness larger than CL or CY. The C component was significant and much larger than any of the interaction components. An analysis of the irrigated locations produced significant CY and CL components, both considerably larger than the CLY component. The CL component was the larger of the first-order components. It was slightly smaller than the significant C component. The CLY and C components were both significant for the Oklahoma dryland locations analyses, the C component being about twice as large. Murray and Verhalen (32) suggested that this trait requires multiple testing across environments in Oklahoma, a conclusion also reached by Morrison and Verhalen (30) who concluded that this was particularly necessary among dryland locations. Meredith and Bridge (25) found a significant cultivar by environment interaction mean square for this character that was much smaller than the C mean square. They were unable to relate this interaction to environmental changes or cultivars. A significant cultivar by harvest date interaction was detected for micronaire with genetic variability being greatest in the early season. This suggested that early sampling might lead to overestimation of the differences for this trait.

Abou-El-Fittouh et al. (1) found that the C component for yarn tenacity was several times larger than the interaction components combined and that CLY was larger either CL or CY. All temperature variables made a significant contribution to the GE interaction sum of squares. Meredith and Bridge (25) found a significant cultivar by environment interaction mean square for this character, which was much smaller than the C mean square. They were unable to relate this interaction to environmental changes or cultivars. They detected a significant cultivar by harvest date interaction with genetic variability being greatest in the early season.

The objectives of this study are to evaluate CL interactions for seven fiber and yarn properties in upland cotton in the Plains Region of Oklahoma and Texas and to consider the possible division of the Region into subregions for breeding and testing purposes.

MATERIALS AND METHODS

Description of Data

Data utilized in this study were from the National and Plains Regional Cotton Variety Tests for the years of 1981-1983, 1984-1986, and 1987-1989. These tests are conducted annually by the USDA in cooperation with Agricultural Experiment Stations throughout the Cotton Belt. Data from the Plains Region represented six, four, and four locations for the respective time spans. The locations provided data in at least two years of the 3-year span in question. Those Oklahoma and Texas locations for each 3-year period of this study in Table 1 including their code number in the National system. The moisture regime is specified for each location as is the soil (including taxonomic definition).

Fifteen cultivars were included in the 1981-1983 study with 11 cultivars in 1984-1986 and in 1987-1989 (Table 2). Those cultivars included the four National Standards common to all regions for each of the three 3-year period. The remaining cultivars for each period were Plains Regional Standards. Only cultivars common to all locations for a given 3-year period were used in this study. The code numbers in the National system are also indicated in the table 2.

Randomized complete-block designs with three to six replications were used in each experiment. Five replications were used in the Oklahoma trials. However, only two of the replications in each test were sampled for the purpose of fiber and yarn measurements. Plot sizes also varied among tests. Planting, thinning (if any), cultural practices (including weed control), insect control, irrigation (where applicable), and harvesting were conducted by the experiment station personnel at those locations and followed the generally recommended procedures for those areas of Oklahoma (2,3,4,17,18,19,20,21,22) and Texas (8,9,10,11,12,13,14,15,16).

Fiber and yarn data were measured by Starlab, Inc., Knoxville, TN, from 15-to-25 boll samples of lint per entry (cultivar), per replication per locations. The six fiber characters studied were 2.5% and 50% span lengths, uniformity index, T_1 fiber strength, E_1 elongation and fiber fineness (micronaire). The yarn character studied was yarn tenacity. Fiber length was measured on the digital fibrograph as 2.5% and 50% span length, in inches. Those measurements are multiplied by 25.4 to convert them into millimeters. Uniformity index was calculated as the ratio of 50% to 2.5% span lengths, expressed as a percentage. Fiber strength [measured on the 1/8-inch (3.175 mm) gauge stelometer] as T_1 expressed in grams force per tex and then converted into kilonewton meters per kilogram. Fiber elongation prior to break (E_1) was also measured on the stelometer and expressed as a percentage. Fiber fineness was measured by a fibronaire instrument and expressed in standard (curvilinear scale) micronaire units. Yarn tenacity was determined in small-scale, ring-spin tests as the force (in kilonewton meters per kilogram) required to break a skein of 27 tex yarn.

Statistical Analyses

The methods described by Comstock and Moll (6) were used to analyze the data for all traits combining all locations and years for each 3-year period. Cultivars, locations and years were assumed to be random variables. The sources of variation were partitioned into main effects and interactions. Statistical significance of the pertinent sources of variation were determined, and mean squares were partitioned into variance components. After the initial analysis, within each 3-year time period, further analyses were made by subdividing locations into High Plains vs. Rolling Plains subregions, states, and irrigated vs. dryland production. In the 1984-1986 and 1987-1989 data, the subregion division of locations and the states subdivision were identical. Analysis of the data by subregions corresponded to analysis of the data by states.

RESULTS AND DISCUSSION

2.5% Span Length

In the Plains Region and subregion analyses for 2.5% span length 1981-1983 (Table 3) the cultivar by location by year (CLY) interaction variance component was significant only in the overall analysis. The cultivar by location (CL) interaction component was not significant in any analysis. The cultivar by year (CY) interaction component was significant in the Rolling Plains and irrigated analyses. The C was large and significant in every analysis. In 1984-1986, significant CLY and CY components were obtained in the combined analysis of the Plains Region over all locations, but in no subdivision analyses (Table 4). Significant CL components were obtained in the analyses among dryland and among irrigated locations. In all analyses, the C component was larger and significant. The 1987-1989 results were considerably different from those obtained in the two earlier 3-year periods (Table 5). For the overall analysis, none of estimates were significant. In the subregion analyses, the only significant C component was obtained in the Rolling Plains and the irrigated locations. The only significant CLY component was obtained in the analysis of irrigated locations.

Testing for this trait would probably be successful from few locations in the Plains Region. Results for the 1981-1983 and 1984-1986 overall analyses (with significant CLY components) suggest that multiple environments are necessary and that (with its significant CY component in 1984-1986) more emphasis should be placed on years in evaluating this trait. Morrison and Verhalen (30), Abou-El-Fittouh et al. (1), and Thomson and Cunningham (35) also found CLY to be the largest of the GE interaction components for length. Murray and Verhalen (31,32) obtained a CLY component smaller than the two first-order components. These results are comparable with those of Verhalen and Murray (38), and Morrison and Verhalen (30). Fiber length was higher in the Northern Plains in years where temperatures were warmer (7,35).

50% Span Length

The 1981-1983 results for 50% span length were similar in that significant CLY and C components were obtained in almost all analyses (Table 6). No first-order interaction components were significant. In the 1984-1986 analyses, the C component was significant in all cases; whereas, CLY was significant only in the overall and irrigated analyses (Table 7). No first-order interaction components were significant in any analysis. The only significant component from analysis of the combined 1987-1989 data were for the C component (Table 8). In fact, C was significant in all analyses. The only significant interaction component was CLY under dryland conditions.

Testing in multiple environments was implied for this character in the Plains Region in 1981-1983, to a lesser extent in 1984-1986, and to almost no extent in 1987-1989. The analyses provided no guidance as to how those environments should be distributed over locations and years. Because C was generally so much greater than CLY, a few environments should be sufficient. Meredith et al. (26) have pointed out that cultivar and seasonal effects are the two major factors influencing fiber properties. Research findings have indicated that the C component for this trait is generally larger than the GE interaction components (5).

Uniformity Index

In the 1981-1983 analysis, C was significant in all analyses of uniformity index, except for Oklahoma (Table 9). The CLY interaction was significant in the overall analysis as well as in those of the Rolling and High Plains. No CL or CY components were significant. Significant C components were obtained in all analyses for 1984-1986 (Table 10). The CLY component was significant in the overall, High Plains, and irrigated analyses. Again, CL and CY were not significant in any analysis. The analyses in 1987-1989 gave significant estimates of C in every case and of no CY, CL, or CLY components (Table 11).

The analyses for this trait suggest testing in multiple environments with no guidance as to how they should be distributed over locations and/or years. Probably several experiments per year will suffice because the C component is generally somewhat larger than the CLY component.

Fiber Strength

The C component for fiber strength was significant in every 1981-1983 analysis (Table 12). Significant CLY components were obtained in the overall, High Plains, Texas, dryland, and irrigated analyses. The CY component was significant in the High Plains and Texas analyses. The CL was not significant in any analysis. Analyses of the 1984-1986 data (Table 13) were similar except for the Oklahoma locations in which the C component was not significant and in the irrigated analysis where the CLY component was not significant. Neither CY nor CL were significant in any case. In 1987-1989 C was significant in every analysis and CLY was significant in the overall and High Plains analyses. The first-order interaction components were not significant in any case.

Analyses suggest that testing over multiple environments (with no clear emphasis on years or locations) is the best approach toward evaluating this trait. The results in 1987-1989 for Oklahoma and Texas relate more closely to those obtained by Morrison and Verhalen (30) and are similar to those of most other researchers (1,5,25,27).

Fiber Elongation

Significant C, CY, and CLY components were obtained for fiber elongation from overall analysis of the Plains Region in 1981-1983 (Table 15). The C component was significant in all Plains subdivisions. The CY component was significant in analyses of the High Plains and irrigated analyses. The CLY component was significant in analyses of the Rolling Plains, Oklahoma, irrigated, and dryland. The CL component was not significant in any instance. In 1984-1986, C was significant in every analysis; CLY was significant in all analyses except irrigated; and CY and CL were significant in none (Table 16). The pattern of significant differences in 1987-1989 was identical to the previous 3-year period except that CLY was no longer significant on the Rolling Plains (Table 17).

In evaluating this character, multiple environments appear necessary. Only in the first 3-year period were years indicated as being more important than locations. Because the C components in most cases were larger than the interaction components combined, relatively few experiments would appear to be necessary. Significant GE interaction components or mean squares, considerably smaller than the cultivar component or mean square, have generally been found by others (1,5,25).

Fiber Fineness (Micronaire)

The C component was significant for fiber fineness in 1981-1983 in all analyses as was the CLY component (Table 18). The CY and CL components were not significant in any instance. The C component were significant in all analyses of the 1984-1986 data (Table 19). The CLY component was not significant in any analysis. The CY component was significant in the overall and in dryland analyses. The CL component was significant in the overall, dryland, and the irrigated analyses. The 1987-1989 investigations detected significant C in all analyses, CY in the overall and High Plains analyses, CLY in the overall and irrigated analyses, and CL in none (Table 20).

Cultivar differences were important in every analysis in every data set. Because GE interactions were important in almost all analyses, testing in multiple environments is essential. The first data set provided no guidance as to how those environments should be distributed over locations and years. The second data set indicated that both years and locations were important with perhaps more emphasis on locations. The third data set indicated that years (especially on the High Plains) were more important. To be more sure of ones results, testing over years over locations would appear necessary.

Yarn Tenacity

Significant GE interaction and C components were obtained from the analysis of yarn tenacity over all locations for the 1981-1983 period (Table 21). The C component was substantially larger than the interaction components combined. Subdivision analyses provided significant estimates of C in every case; of CY in the High Plains, Texas, and irrigated analyses; of CL in the High Plains and Texas analyses; and of CLY in the Rolling Plains, Oklahoma, dryland, and irrigated analyses.

Table 22 shows the 1984-1986 analyses in which a significant C component was obtained in every analysis. The CY component was not significant in any analyses whereas, the CL was significant in the overall and irrigated analyses. The CLY component was significant in Rolling Plains and dryland analyses. The overall analysis for 1987-1989 resulted in significant C and CL components (Table 23). In the subdivisional analyses, the C component was significant in every case and the only significant interaction component was CLY on dryland. The analyses suggest that testing for this trait in a few locations would be adequate as the C component was substantially larger than the interaction components combined in every case.

Based on an examination of overall means for each trait in each time period (not shown), conditions on the Rolling Plains favor fiber development more so than do those on the High Plains. Temperature is probably a major factor in this case, particularly minimum temperature. Abou-El-Fittouh et al. (1) have shown that minimum temperatures have a strong effect on fiber properties. This position has drawn support from Gannaway et al. (7) and Ray et al. (33). Lewis and Kerr (23) pointed out that some of the lowest micronaires in the Cotton Belt are obtained in the Plains Region, suggesting that this is a consequence of the cultivars planted and the environment of the Region. Cultural factors such as planting date and irrigation practices, also affect fiber length and micronaire (35). Moisture stress which is unpredictable in the Plains Region has a direct and dramatic effect on micronaire (34).

Results from the analyses over the three 3-year time periods showed some general trends, but there were many inconsistencies. Those inconsistencies may be partly due to the fact that cultivars used in the three time spans were largely different. With greater genetic diversity, the magnitude of GE interaction becomes relatively less important compared to genotypic differences.

Evaluating fiber properties in a minimum number of locations should be required considering the relatively large size of the genotypic (i.e., cultivar) variance compared to GE components (29). Considering the environmental and cultural variables in the Plains Region as a whole (see 2,3,4,17,18,19,20,21,22 for

Oklahoma and 8,9,10,11,12,13,14,15,16 for Texas), the current system of testing for these traits cannot be faulted.

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Table 1. Locations included in the Plains Region genotype-environment interaction study of fiber and yarn properties in cotton over three 3-year periods.

State	1981-1983	1984-1986	1987-1989
Oklahoma			
	Altus I† [16]‡§	Altus I [16]	Altus I [16]
	Chickasha D [38]¶	Chickasha D [38]	Chickasha D [38]
Texas			
	Chillicothe I [15]#		
	Halfway D [13]††		
	Lamesa D [163]‡‡	Lamesa D [163]	Lamesa D [163]
	Lubbock I [12]§§	Lubbock I [12]	Lubbock I [12]

† I = irrigated vs. D = dryland experiments.
‡ National Cotton Variety Testing Program location code numbers are in the brackets.
§ Hollister clay loam (fine, mixed, thermic Pachic Paleustoll).
¶ Reinach silt loam (coarse-silty, mixed, thermic Pachic Haplustoll).
# Abilene clay loam (fine, mixed, thermic Pachic Argiustoll).
†† Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll).
‡‡ Amarillo fine sandy loam (fine-loamy, mixed, thermic Aridic Paleustalf).
§§ Amarillo or Olton loam (fine, mixed, thermic Aridic Paleustoll).

Table 2. Cotton cultivars included in the Plains Region genotype-environment interaction study of fiber and yarn properties three 3-year periods.

1981-1983	1984-1986	1987-1989
Acala SJ-5† [4]‡	Acala SJC-1† [8]	Acala 1517-75† [3]
Lockett 77† [6]	McNair 235† [4]	Coker 139† [11]
McNair 235† [12]	Paymaster 145† [6]	Deltapine 50† [9]
Stoneville 213† [1]	Stoneville 213† [1]	Paymaster 145† [8]
Coker 5110 [3]	Cascot L-7 [10]	All-Tex WM-571 [2]
Dunn 219 [13]	Deltapine SR-383 [9]	Cencot [5]
GSA 71 [7]	Dunn 219 [5]	Deltapine SR-383 [10]
Lankart LX 571 [2]	GSA 71 [3]	GP 1005 [6]
Paymaster 145 [14]	Lankart LX 571 [2]	Lankart LX 571 [1]
Paymaster 303 [5]	Paymaster 404 [11]	Paymaster HS-26 [7]
Pioneer Brand PR-68 [9]	Stoneville 302 [7]	Tamcot SP21S [4]
Stoneville 302 [15]		
Stripper 31A [8]		
Tamcot SP21S [10]		
Westburn M [11]		

† National Standard cultivars; remainder are Plains Regional Standards.
‡ National Cotton Variety Testing Program cultivar code numbers are in the brackets.

Table 3. Variance components for 2.5% span length in the Plains Region and its major subdivisions, 1981-1983.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,15, 16,38,163	15, 16,38	12, 13,163	16,38	12,13, 15,163	13, 38,163	12, 15,16
σ^2_C	0.0010**	0.0007**	0.0014**	0.0005**	0.0014**	0.0011**	0.0009**
σ^2_{CY}	0.0001	0.0004*	0.0001	0.0004	0.0000§	0.0001	0.0003*
σ^2_{CL}	0.0001	0.0000§	0.0001	0.0000§	0.0001	0.0002	0.0000§
σ^2_{CLY}	0.0002*	0.0002	0.0001	0.0003	0.0002	0.0002	0.0002
σ^2_E	0.0010	0.0015	0.0005	0.0016	0.0007	0.0011	0.0010

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha, D; and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 4. Variance components for 2.5% span length in the Plains Region and its major subdivisions, 1984-1986.

		Plains subregion (State)			
		Rolling	High	Moisture regime	
	Plains Region	Plains (OK)	Plains (TX)	Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	0.0009**	0.0010**	0.0011**	0.0008**	0.0009**
σ^2_{CY}	0.0002*	0.0002	0.0001	0.0002	0.0001
σ^2_{CL}	0.0001	0.0000§	0.0000§	0.0002*	0.0002*
σ^2_{CLY}	0.0001**	0.0001	0.0001	0.0001	0.0001
σ^2_E	0.0005	0.0005	0.0005	0.0005	0.0005

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 5. Variance components for 2.5% span length in the Plains Region and its major subdivisions, 1987-1989.

		Plains subregion (State)		Moisture regime	
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	0.0040	0.0020**	0.0000§	0.0000§	0.0015**
σ^2_{CY}	0.0000§	0.0001	0.0061	0.0014	0.0000§
σ^2_{CL}	0.0000§	0.0000§	0.0014	0.0000§	0.0000§
σ^2_{CLY}	0.0139	0.0001	0.0000§	0.0031	0.0005**
σ^2_E	0.3751	0.0004	0.6874	0.6875	0.0004

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 6. Variance components for 50% span length in the Plains Region and its major subdivisions, 1981-1983.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,15, 16,38,163	15, 16,38	12, 13,163	16,38	12,13, 15,163	13, 38,163	12, 15,16
σ^2_C	0.0002**	0.0002**	0.0003**	0.0002**	0.0003**	0.0003**	0.0002**
σ^2_{CY}	0.0001	0.0000§	0.0000§	0.0000§	0.0000§	0.0000§	0.0001
σ^2_{CL}	0.0000§	0.0000§	0.0000§	0.0000§	0.0000§	0.0000§	0.0000§
σ^2_{CLY}	0.0001**	0.0002**	0.0001*	0.0003**	0.0001*	0.0001	0.0001*
σ^2_E	0.0004	0.0005	0.0003	0.0004	0.0004	0.0003	0.0004

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha, D; and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 7. Variance components for 50% span length in the Plains Region and its major subdivisions, 1984-1986.

		Plains subregion (State)			
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Moisture regime	
				Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	0.0004**	0.0004**	0.0004**	0.0004**	0.0004**
σ^2_{CY}	0.0000§	0.0000§	0.0000§	0.0000§	0.0000§
σ^2_{CL}	0.0000§	0.0000§	0.0000§	0.0000§	0.0000§
σ^2_{CLY}	0.0001**	0.0001	0.0001	0.0001	0.0001**
σ^2_E	0.0003	0.0004	0.0002	0.0003	0.0003

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 8. Variance components for 50% span length in the Plains Region and its major subdivisions, 1987-1989.

		Plains subregion (State)		Moisture regime	
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	0.0005**	0.0005**	0.0005**	0.0005**	0.0004**
σ^2_{CY}	0.0000§	0.0000§	0.0001	0.0000§	0.0000§
σ^2_{CL}	0.0002	0.0000§	0.0000§	0.0000§	0.0000§
σ^2_{CLY}	0.0000§	0.0000§	0.0000§	0.0001*	0.0000§
σ^2_E	0.0002	0.0002	0.0003	0.0002	0.0002

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 9. Variance components for uniformity index in the Plains Region and its major subdivisions, 1981-1983.

	Plains Region	Plains subregion: Rolling Plains	Plains subregion: High Plains	State: Oklahoma	State: Texas	Moisture regime: Dryland	Moisture regime: Irrigated
Variance component†	12‡,13,15, 16,38,163	15, 16,38	12, 13,163	16,38	12,13, 15,163	13, 38,163	12, 15,16
σ^2_C	0.32^{**}	0.21^{**}	0.46^{*}	0.00§	0.47^{**}	0.49^{**}	0.22^{**}
σ^2_{CY}	0.00§	0.00§	0.00§	0.15	0.00§	0.00§	0.00§
σ^2_{CL}	0.00§	0.00§	0.00§	0.06	0.00§	0.00§	0.02
σ^2_{CLY}	0.31^{*}	0.48^{*}	0.32^{*}	0.15	0.30	0.32	0.39
σ^2_E	1.59	1.93	1.26	1.83	1.45	1.44	1.75

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha, D; and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 10. Variance components for uniformity index in the Plains Region and its major subdivisions, 1984-1986.

		Plains subregion (State)			
		Rolling	High	Moisture regime	
	Plains	Plains	Plains		
	Region	(OK)	(TX)	Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	0.88**	0.63**	1.00**	0.90**	0.87**
σ^2_{CY}	0.00§	0.07	0.00§	0.00§	0.00§
σ^2_{CL}	0.00§	0.00§	0.01	0.00§	0.00§
σ^2_{CLY}	0.62**	0.33	0.93**	0.33	1.03**
σ^2_E	1.31	1.62	1.01	0.16	1.47

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 11. Variance components for uniformity index in the Plains Region and its major subdivisions, 1987-1989.

		Plains subregion (State)		Moisture regime	
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	1.09**	1.19**	1.27**	0.98**	0.99**
σ^2_{CY}	0.06	0.00§	0.00§	0.04	0.20
σ^2_{CL}	0.00§	0.02	0.00§	0.00§	0.21
σ^2_{CLY}	0.13	0.00§	0.44	0.25	0.00§
σ^2_E	1.12	0.95	1.27	0.98	1.29

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 12. Variance components for T_1 fiber strength in the Plains Region and its major subdivisions, 1981-1983.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,15, 16,38,163	15, 16,38	12, 13,163	16,38	12,13, 15,163	13, 38,163	12, 15,16
σ^2_C	0.08**	0.08**	0.09**	0.07**	0.09**	0.05**	0.11**
σ^2_{CY}	0.01	0.02	0.06*	0.00§	0.04**	0.02	0.00§
σ^2_{CL}	0.00§	0.00§	0.00§	0.00§	0.00§	0.00§	0.00§
σ^2_{CLY}	0.08**	0.04	0.08**	0.05	0.08**	0.07**	0.13**
σ^2_E	0.11	0.16	0.07	0.19	0.07	0.10	0.12

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha, D; and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 13. Variance components for T_1 fiber strength in the Plains Region and its major subdivisions, 1984-1986.

		Plains subregion (State)		Moisture regime	
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	0.03**	0.00§	0.06*	0.02*	0.04*
σ^2_{CY}	0.00§	0.01	0.03	0.00§	0.02
σ^2_{CL}	0.00§	0.01	0.00§	0.00§	0.02
σ^2_{CLY}	0.10**	0.09**	0.05**	0.18**	0.02
σ^2_E	0.08	0.07	0.08	0.07	0.09

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 14. Variance components for T_1 fiber strength in the Plains Region and its major subdivisions, 1987-1989.

		Plains subregion (State)		Moisture regime	
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	0.64**	0.54**	0.78**	0.60**	0.65*
σ^2_{CY}	0.03	0.06	0.00§	0.08	0.02
σ^2_{CL}	0.01	0.00§	0.00§	0.02	0.06
σ^2_{CLY}	0.04**	0.00§	0.14**	0.02	0.00§
σ^2_E	0.25	0.32	0.19	0.21	0.30

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 15. Variance components for E_1 fiber elongation in the Plains Region and its major subdivisions, 1981-1983.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,15, 16,38,163	15, 16,38	12, 13,163	16,38	12,13, 15,163	13, 38,163	12, 15,16
σ^2_C	155.09**	167.26**	153.11**	121.32**	182.44**	145.51**	153.94**
σ^2_{CY}	15.03*	4.71	9.50*	0.00§	9.80	12.54	33.80*
σ^2_{CL}	0.00§	0.00§	4.56	0.00§	8.04	0.00§	0.00§
σ^2_{CLY}	48.05**	113.34**	5.06	134.57**	8.60	58.83**	28.22*
σ^2_E	88.31	138.84	39.11	139.75	58.24	73.18	103.84

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha, D; and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 16. Variance components for E_1 fiber elongation in the Plains Region and its major subdivisions, 1984-1986.

		Plains subregion (State)		Moisture regime	
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	254.07**	341.48**	183.56**	279.48**	206.78**
σ^2_{CY}	0.00§	0.00§	7.66	0.00§	16.18
σ^2_{CL}	7.40	2.83	0.00§	29.74	6.94
σ^2_{CLY}	50.00**	84.36**	32.38**	77.23**	0.25
σ^2_E	69.71	95.03	44.38	80.68	58.73

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 17. Variance components for E_1 fiber elongation in the Plains Region and its major subdivisions, 1987-1989.

		Plains subregion (State)		Moisture regime	
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	383.21**	399.09**	358.90**	438.16**	310.92**
σ^2_{CY}	0.00§	0.00§	0.00§	16.44	0.00§
σ^2_{CL}	0.00§	41.37	0.00§	1.46	4.79
σ^2_{CLY}	23.31*	8.14	35.82**	24.52*	0.00§
σ^2_E	70.05	98.63	46.22	59.81	82.33

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 18. Variance components for fiber fineness (micronaire) in the Plains Region and its major subdivisions, 1981-1983.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,15, 16,38,163	15, 16,38	12, 13,163	16,38	12,13, 15,163	13, 38,163	12, 15,16
σ^2_C	0.08**	0.06**	0.10**	0.03**	0.1159**	0.0664**	0.0993**
σ^2_{CY}	0.01	0.02	0.01	0.01	0.0083	0.0045	0.0000§
σ^2_{CL}	0.00§	0.00§	0.00§	0.00§	0.0003	0.0005	0.0000§
σ^2_{CLY}	0.03**	0.03*	0.03**	0.05**	0.0234**	0.0297**	0.0497**
σ^2_E	0.07	0.08	0.05	0.09	0.0538	0.0774	0.0536

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha, D; and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 19. Variance components for fiber fineness (micronaire) in the Plains Region and its major subdivisions, 1984-1986.

		Plains subregion (State)			
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Moisture regime: Dryland	Moisture regime: Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	0.06**	0.06**	0.08**	0.05**	0.06**
σ^2_{CY}	0.01*	0.01	0.00§	0.02*	0.00§
σ^2_{CL}	0.02**	0.01	0.00§	0.02**	0.03*
σ^2_{CLY}	0.00§	0.00§	0.01	0.00§	0.00§
σ^2_E	0.06	0.09	0.03	0.05	0.08

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 20. Variance components for fiber fineness (micronaire) in the Plains Region and its major subdivisions, 1987-1989.

		Plains subregion (State)		Moisture regime	
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	0.09**	0.08**	0.11**	0.08**	0.10**
σ^2_{CY}	0.01*	0.00§	0.03*	0.01	0.02
σ^2_{CL}	0.01	0.00§	0.00§	0.01	0.01
σ^2_{CLY}	0.02**	0.02	0.01	0.02	0.02*
σ^2_E	0.04	0.05	0.02	0.04	0.03

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 21. Variance components for yarn tenacity in the Plains Region and its major subdivisions, 1981-1983.

		Plains subregion		State		Moisture regime	
	Plains Region	Rolling Plains	High Plains	Oklahoma	Texas	Dryland	Irrigated
Variance component†	12‡,13,15, 16,38,163	15, 16,38	12, 13,163	16,38	12,13, 15,163	13, 38,163	12, 15,16
σ^2_C	127**	95**	151**	60**	180**	112**	135**
σ^2_{CY}	12**	15	10**	1	6*	7	18*
σ^2_{CL}	9*	3	6*	0§	12**	6	13
σ^2_{CLY}	25**	67**	0§	95**	0§	38**	16*
σ^2_E	55	62	48	62	51	54	57

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 13 is Halfway, dryland (D); 15 is Chillicothe I; 16 is Altus I; 38 is Chickasha, D; and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

Table 22. Variance components for yarn tenacity in the Plains Region and its major subdivisions, 1984-1986.

		Plains subregion (State)			
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Moisture regime	
				Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	162**	199**	126**	175**	154**
σ^2_{CY}	1	1	4	0§	8
σ^2_{CL}	7**	5	7	0§	13**
σ^2_{CLY}	1	11**	0§	14**	0§
σ^2_E	39	22	56	24	53

*, ** Significant mean squares at the 0.05 and 0.01 levels of probability, respectively.
† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).
‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.
§ Zero or negative estimate for which the most reasonable value is zero.

Table 23. Variance components for yarn tenacity in the Plains Region and its major subdivisions, 1987-1989.

		Plains subregion (State)		Moisture regime	
	Plains Region	Rolling Plains (OK)	High Plains (TX)	Dryland	Irrigated
Variance component†	12‡,16, 38,163	16,38	12,163	38,163	12,16
σ^2_C	156**	171**	148**	168**	141**
σ^2_{CY}	1	7	9	0§	0§
σ^2_{CL}	5**	5	0§	14	1
σ^2_{CLY}	5	0§	0§	10**	8
σ^2_E	26	26	27	31	22

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

† The subscripts refer to cultivars (C), years (Y), locations (L), and error (E).

‡ Location no. 12 is Lubbock, irrigated (I); 16 is Altus I; 38 is Chickasha, dryland (D); and 163 is Lamesa D.

§ Zero or negative estimate for which the most reasonable value is zero.

CHAPTER III

Inheritance of Lint Percentage

in Cotton

Inheritance of Lint Percentage in Cotton[1]

ABSTRACT

Understanding the inheritance of lint percentage and its relationship with other important traits in upland cotton (*Gossypium hirsutum* L.) will permit the improvement of this trait while minimizing adverse effects on those other characters. Four parents, designated A, B, E, and F, derived from a common genetic background were classified into low, low to intermediate, intermediate to high, and high lint percentage, respectively, and crossed in all possible combinations without reciprocals. Lint yield, boll size, boll number and fiber strength were studied in the parental lines, F_1s, F_2s, BC_1s, and BC_2s. Mid-parental (MP) and high-parental (HP) heterosis, degree of dominance, and broad-sense heritabilities were calculated for each trait. Phenotypic correlations were calculated for all combinations of traits in each population. Regression analyses were performed by relating broad-sense heritabilities onto parental differences for each trait. The parental lines exhibited differences for lint percentage with consistent rankings at both test locations. Generally, negative MP and HP heterosis were obtained for lint percentage. A lack of dominance effects suggested additive and/or epistatic effects for that trait. Broad-sense heritabilities

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calculated for lint percentage ranged from 0.08 to 0.44. Large positive relationships were obtained between lint yield vs. boll number, a moderate relationship between lint yield and boll size and a low relationship between lint yield and lint percentage. The relationship between broad-sense heritability and parental differences was best described by a quadratic equation for all traits. Within limits, as parental differences increased, broad-sense heritability increased. The relationship was highest in this study for lint percentage.

INTRODUCTION

Lint percentage in cotton (*Gossypium hirsutum* L.) is the weight of lint ginned from a sample of seedcotton, expressed as a percentage of the seed cotton weight. It is a component of lint yield influencing harvesting and ginning costs. Along with the yield components "boll number" and "boll size" (the weight of seedcotton in grams per boll), lint percentage can be used geometrically to describe lint yield in a manner similar to that employed by Maner et al., (12). Lint yield itself is probably the most important factor that producers must consider when deciding which cotton cultivars to grow. With higher yield, however, fiber strength generally tends to decline. The above five characters, with emphasis on lint percentage, were investigated in this paper.

An F_2 population in the 1985 cotton breeding nursery near Perkins , Oklahoma, displayed an unusually wide range of variability for lint percentage. This fortuitous observation led to the idea that it might be possible to select an array of lines from this parental combination with different levels of lint percentage. Those lines could then be used to study the inheritance of different degrees of lint percentage on a generally similar genetic background. Previous studies of lint percentage have entailed different genetic backgrounds (7,10,11).

Lint percentage showed a small mid-parent heterosis of 1.5% on the average (6,16). Al-Rawi and Kohel (2) obtained small, but significant, mid-parent heterosis for lint percentage. Overdominance for lint percentage was detected by Baker and

Verhalen (3) them.

Lint percentage involves predominantly additive gene action. White and Kohel (27) and Lee (8) found large and significant additive genetic components for lint percentage. Ramey and Miller (23) in a cotton population of interspecific origin obtained substantial amounts of additive genetic variance for lint percentage in addition to small, positive estimates of dominance genetic variance. Estimates indicated partial dominance towards high lint percentage for this trait. Al-Rawi and Kohel (2) obtained a significant additive genetic component for lint percentage. Baker and Verhalen (3) observed significant genotype by environment interactions (GE) for the additive components of variation influencing lint percentage. Meredith and Bridge (16) also observed that additive effects predominated for lint percentage. Al-Jibouri et al. (1) and Miller et al. (20) obtained heritabilities of 0.90 for lint percentage, indicating that the trait is highly heritable. Baker and Verhalen (4) and Murray and Verhalen (21) obtained a heritability of 0.28 and 0.10 and 0.24, respectively for this same trait showing that environmental factors can exert considerable influence.

Lint yield has exhibited the highest mid-parent heterosis of 18% on the average (16) of all cotton traits studied, ranging from as low as 3.5 to 39.3% (2,3,4,9). A recent study by Thomson and Luckett (25) detected heterosis ranging from 0 to 1.7% for lint yield, a comparatively lower value. Al-Rawi and Kohel (2) obtained small, but significant, mid-parent heterosis for lint percentage. Lint yield heritability studies suggest that this trait is low to moderately heritable (1,2,19) but it can be highly influenced by the environment (4).

Meredith (14) showed MP heterosis values for boll size averaged 8.3, ranging from as low as 5.4 to 13.4. Boll size broad-sense heritability studies suggest that this trait is moderate to highly heritable (1,2,19). Murray and Verhalen (21) obtained contrasting MP heterosis values of 0.81 and 0.20 for this trait in Oklahoma in 1961 and 1962, respectively.

Boll number MP heterosis ranged from 4.1 to 33.9 and averaged 13.5 as reported by Meredith (14).

Verhalen and Murray (26) found that additive gene action conditioned fiber strength. Similar results were obtained by Marani (13) in a study of intraspecific crosses among cultivars of *G. hirsutum* and of *G. barbadense* L. No significant heterosis for fiber strength was observed in *G. hirsutum*. Mainly partial dominance for fiber strength were observed, but the dominance relationships among parents were not consistent from year to year Baker and Verhalen (4). Miller and Marani (18) also found significant mid-parent heterosis for fiber strength. The magnitude of heterosis was, however, relatively small for those two traits compared to traits such as lint yield, boll size and boll number. Research findings suggest that fiber strength is highly heritable (1,2,19), although environmental factors could have some influence (21).

Phenotypic and genotypic correlations in cotton have been about the same in terms of direction and magnitude and are themselves highly correlated (16). Al-Jibouri et al. (1) found positive correlations between lint percentage and yield, negative correlations with boll size, and negative correlations with strength. Correlations between lint percentage and lint yield were also found to be positive by

Miller et al. (20) and Woodward and Malm (28), boll number per plant was positive, boll size negative and strength, negative. Woodward and Malm (28) also obtained positive correlations between lint yield and boll number but none between fiber strength vs. lint percentage and vs. boll number.

The purpose of this research was primarily to investigate the heterosis, degree of dominance, and heritability of lint percentage in upland cotton among lines with different levels of performance for lint percentage as derived from a generally similar genetic background, particularly heterosis and heritability obtained from crosses between parental lines of different levels of lint percentage. The inheritance of lint yield, boll size, boll number and fiber strength were also determined. Phenotypic correlations were computed for all possible combinations . Broad-sense heritabilities were related to parental differences for all five traits.

MATERIALS AND METHODS

Genetic Materials

A cross was initiated in 1984 between the lines V83-115 (i.e., 'Deltapine SR-2' X 'Stoneville 213' F_5) and the line MD65-11S (15) from Mississippi. Seed from this cross were sent to Mexico over the 1984-85 winter season and advanced to the F_2 generation. Those seed were then planted in the 1985 cotton breeding nursery near where selfing was conducted and individual plant selections were made using the pedigree method. The soil at that location is a Teller loam (a fine-loamy, mixed, thermic Udic Argistoll). Selfing and plant and/or progeny row selections were repeated in subsequent years (except for 1987 when the nursery was not planted) until lines had attained a high level of uniformity and homozygosity. Observations indicated that an unusually wide range of variability for lint percentage existed among the F_2 plants of this particular pedigree, i.e., from 25.7 to 45.6%. Six lines ultimately designated A through F, from very low to very high lint percentage respectively were last harvested as individual plants from F_7 progeny rows in 1990. Individual plants in 1990 ranged from 22.7 to 48.7% in lint percentage with lines ranging from an average of 33.4 for A to 45.0% for F. Selections from those lines were planted as F_8 progeny rows in the summer of 1991, and crosses were made among the A, B, E, and F groups in a diallel arrangement, ignoring reciprocals. The C and D lines were eliminated due to lack of funds. Seed from the parents and crosses were sent to Mexico during the 1991-1992 winter season for increase and to obtain F_2s and backcross populations as well as additional F_1s.

Experimental Procedures and Data Collection

The F_2 populations and four parental lines were planted on 16th June and 17th June, 1993 at Tipton and Chickasha, OK, respectively, in a randomized complete block designs with four replications. F_1 and backcross populations were also included at Chickasha. A similar test at Perkins could not be planted due to excessive rainfall at planting time. The soil at Tipton is a Tipton silt loam (a fine-loamy, mixed, thermic Pachic Argistoll); that at Chickasha is a Reinach silt loam (a coarse-silty, mixed, thermic Pachic Haplustoll). Plots were 9.1 m in length and varied from a single row for populations with limited seed to four rows for the F_2s. Rows were 1.0 m apart. Plants were thinned approximately 15 cm apart on 8 July at Tipton and 9 and 10 July, 1992 at Chickasha. The experiments were not irrigated. Plants were harvested individually in on 5, 6, 30 and 31 Jan. at Tipton, and 9 Feb. and 8 Mar., 1993 at Chickasha. Up to 20 plants with a minimum of two or three (preferably three) open bolls were chosen randomly from each plot at Tipton and up to 15 at Chickasha. All open bolls with one or more fluffy locks were harvested from those plants.

The traits measured were:

1. Lint percentage = (lint weight from the three most mature bolls ÷ seedcotton weight in grams from those bolls) X 100.
2. Lint yield plant^{-1} = lint weight in grams from the three most mature bolls + lint weight in grams from the remaining bolls with one or more fluffy locks.

3. Boll size = seedcotton weight in grams from the three most mature bolls ÷ three.

4. Boll number = the three most mature bolls + number of remaining bolls with one or more fluffy locks.

5. Fiber strength = T_1 stelometer fiber strength in grams per tex (the weight in grams of 1000 meters of fiber converted to kilonewton meter per kg) of lint from the three most mature bolls.

Statistical Analyses

Analyses of variance were performed for each trait and population at each location. Parental means for each trait were tested for the probability of differences among them at each location. Mid-parent (MP) and high-parent (HP) heterosis, degree of dominance, and broad-sense heritability (BS) were calculated for each trait on a plant basis in each population, replication, and location.

Formulas used for calculating MP and HP heterosis, degree of dominance and broad-sense heritabilities were:

1. MP heterosis (%) = $[(F_2 - MP) \div MP] \times 200$

2. HP heterosis (%) = $[(F_2 - HP) \div HP] \times 200$

3. Degree of dominance = $(F_2 - MP) \times 2$

4. BS = $\sigma^2F_2 - [(\sigma^2P_1 + \sigma^2P_2) \div 2] \div \sigma^2F_2$

Estimates of MP and HP heterosis and degree of dominance were obtained as described in the equation above, based on the knowledge that heterosis in the F_2 is half as great as that shown in the F_1 (7). Those estimates were then subjected to analyses of variance at each location. MP and HP heterosis were tested for significant difference from their parental mean and high parent, respectively. Degree of dominance and the heritabilities were tested for significant differences from zero. Phenotypic linear correlation coefficients were calculated among all combinations of traits taken two at a time for each parental line, population, and location. Regression analysis was used to relate trait differences for each parental combination with their respective BS heritabilities at each location.

RESULTS AND DISCUSSION

Mean squares for lint percentage and other selected traits are presented for each generation at Chickasha and Tipton (Table 1). Significant population mean squares were obtained in all analyses at Chickasha except for lint yield and boll number among the parental lines; boll size and boll number among the F_1s; and boll size among both backcross populations. These results may reflect in part the effects of late maturity coupled with a freeze as all population mean squares were significant at Tipton. It is noteworthy that lint percentage differences were significant among populations in all generations at both locations.

Lint Percentage

Lint percentages for the parents were generally higher at Tipton than at Chickasha (Table 2). Significant differences among parents were detected at both Chickasha and Tipton for lint percentage (Table 1). The ranking of parents at both locations was consistent. The pattern of significant differences for this trait at Chickasha was $A < B < E < F$; whereas at Tipton it was $A = B < E < F$ (Table 2). Because those differences among parental lines were generally significant and in the predicted order, the genetic study could proceed. The selections resulting in the four parental lines were effective in establishing different levels of lint percentage from a population with a generally similar pedigree. MP heterosis of lint percentage values were generally negative at both locations, except for A X F combination at

Chickasha and A X B and A X E combinations at Tipton (Table 3). All except A X B combination at Tipton produced negative HP heterosis values which were significantly different from zero. Degree of dominance values followed a similar pattern to the heterosis values. Broad sense heritability values ranged from 0.08 to 0.44 at Chickasha and 0.11 to .40 at Tipton. Those value are in the range obtained by Baker and Verhalen (4) and much lower than those obtained by Al-Jibouri et al. (1) and Miller et al. (20). No consistent pattern was observed for any of these quantitative evaluations.

Lint Yield

Lint yields for the parents were generally higher at Tipton than at Chickasha. However, differences in lint yield among the parental lines were significant only at Tipton (Table 1). The pattern of differences among the parents at that location was B < A = E < F. Parent B was lower yielding than A at Tipton even though both displayed similar lint percentages at that location. One would suspect that B was lower than A in at least one of the other two yield components. In fact, it was lower than A in both boll size and boll number (Table 2). MP heterosis values were all positive and ranged from 13.5 to 43.8 at Chickasha and 2.3 to 23.6 at Tipton (Table 4). These were comparable to those obtained by previous researchers (3,4,13,17). HP heterosis were also mainly positive values. Degree of dominance values were all positive with significantly different values detected for E X F combination at Chickasha. Broad-sense heritability was higher at Chickasha where they were moderate than at Tipton and were generally comparable with those of Baker and

Verhalen (4).

Boll Size

Boll sizes were larger for all parents at Chickasha than at Tipton (Table 2). Significant differences among parents were detected at both locations (Table 1). The pattern of significant differences among parents for boll size at Chickasha were A = B > E (with F = A, B, and E) and at Tipton A > B > E (with F = A and B) (Table 2). MP heterosis for boll size varied from -4.5 to 2.4 at Chickasha and from 3.0 to 11.4 at Tipton (Table 5). HP heterosis values were all negative at Chickasha and the A X B and E X F combinations negative at Tipton. Degree of dominance values were generally positive and not significantly different from zero. BS heritability values at Tipton ranged from 0 to 0.23 compared with 0.10 to 0.42 at Chickasha.

Boll Number

Boll numbers were lower at Chickasha for the parents than at Tipton (Table 2) where the pattern of differences was B < A = E = F (Table 2). MP heterosis varied form 15.2 to 39.8 at Chickasha and -6.1 to 27.9 at Tipton (Table 6). HP heterosis showed a similar trend. Degree of dominance values were generally positive with significance being detected for all combinations involving the E parent at Chickasha. Three combinations, A X E, B X E, and E X F at Chickasha had degree of dominance values greater than zero. BS heritability ranged from 0.01 to 0.20 at Tipton and from 0.29 to 0.53 at Chickasha.

Fiber Strength

Fiber strength of the parents was generally higher at Tipton than at Chickasha (Table 2) with significant differences detected among parents at both locations (Table 1). The pattern of differences among parents were E < B = A (with F = A and B) at Chickasha and E < F < A < B at Tipton (Table 2). The relationship of A to E, B to E, and F to E was the same at both locations. F was equal to or weaker than A and B; whereas, the relationship of A to B was reversed between locations. MP heterosis was positive for all combinations at both locations, ranging from 1.3 to 8.3 at Chickasha and 1.8 to 11 at Tipton (Table 7). HP heterosis were all negative for both locations. The A X F combination showed the highest deviation at both locations. BS heritability varied from 0.03 to 0.15 at Tipton and from 0.18 to 0.45 at Chickasha.

Heritability values for all traits except lint percentage showed apparent location differences which may be a consequence of one or more environmental factors. Selection for all traits would be more effective at Chickasha than at Tipton based on broad-sense heritability values, but at both locations environmental effects dominated.

The general lack of significant dominance deviations suggests that gene action may be additive, or epistatic, or both.

Phenotypic Correlations

In parent A, correlations with lint percentage were positive vs. fiber strength and with lint yield vs. boll size and boll number at both locations (Table 8). A positive correlation between boll size and boll number was also noted at Tipton. Correlations involving parent B were positive for lint percentage vs. lint yield and vs. boll size at the two locations and vs. boll number at Tipton. Positive estimates were also calculated for lint yield vs. boll size and vs. boll number. A negative correlation was detected between lint yield and fiber strength at Chickasha. Boll size and boll number were positively related at Chickasha. Boll size vs. fiber strength was puzzling in that it was negative at one location, but positive at the other, and significantly different from zero at both. In parent E, lint percentage was negatively correlated with boll size at Tipton. Lint yield was positively correlated with boll size and boll number at both locations. Boll size was positively related to boll number at Tipton. A positive correlation between lint percentage and fiber strength was obtained for parent F at Chickasha; lint yield and boll size were positively correlated at Tipton, and lint yield with boll number at both locations. Boll size (as it was in parent B) was negatively correlated with fiber strength at Chickasha, but positively correlated with it at Tipton.

Within these parents, it was unanimous, or very nearly so, that lint yield was highly correlated with boll number and moderately correlated with boll size. Little or no relationship existed between lint percentage vs. boll number, lint yield vs. fiber strength, and boll number vs. fiber strength.

In all the F_1s at Chickasha were found a large positive relationship between lint yield vs. boll number (Table 9). No relationships in any F_1s were detected between lint percentage vs. fiber strength, lint yield vs. fiber strength, boll size vs. boll number, and boll number vs. fiber strength. Analyses of the A X B F_1s gave positive correlations between lint percentage vs. lint yield, lint yield vs. boll size, and a negative relationship between boll size vs. fiber strength. The A X E F_1s showed positive correlations between lint percentage vs. lint yield and vs. boll size. Correlations for the A X F_1s were positive for lint yield vs. boll size. Lint percentage was positively correlated with lint yield and with boll number in the B X E F_1s. Other than for lint yield vs. boll number (mentioned earlier), no other significant correlations were obtained for the B X F and E X F_1s.

In the F_2 all (or almost all) parental combinations exhibited a large positive relationship between lint yield and boll number, a moderate relationship between lint yield and boll size, and a low relationship between lint percentage and lint yield (Table 10). Little or no relationship was shown between lint percentage vs. boll size, lint yield vs. fiber strength, and boll number vs. fiber strength. Lint percentage was also positively correlated with boll number at both locations and with boll size vs. boll number and boll size vs. fiber strength at Tipton for the A X B F_2. Boll size was positively correlated with boll number and with fiber strength at Tipton in the A X E F_2. Lint percentage for the A X F_2 was negatively correlated with fiber strength at Tipton . Boll size was positively correlated with boll number at Tipton, and negatively correlated with fiber strength at Chickasha. A positive correlation for B X E F_2 was detected between lint percentage and boll number at Tipton and also between boll size vs. boll number. Significant correlations were detected between boll size and fiber strength at both locations, however, they differed in sign. In the B X F_2, boll size vs. boll number and vs. fiber strength were positively related at Tipton. In the E X F_2, lint percentage vs. boll number at Tipton and vs. fiber strength at

Chickasha were positively correlated. Boll size and boll number and with fiber strength were positively related at Tipton, and negatively related with fiber strength at Chickasha.

In the backcross populations at Chickasha, all exhibited large positive relationships between lint yield and boll number (Table 11). Little or no relationships were shown between lint percentage vs. boll size, vs. boll number, and vs. fiber strength. The same was true for boll size vs. boll number and for fiber strength vs. lint yield, vs. boll size, and vs. boll number. A negative correlation for A X B BC_1 was detected between lint percentage vs. fiber strength, and a positive estimate was obtained between lint yield and boll size. Lint yield was positively correlated with boll size in both A X E backcross populations and in the BC_1 population of A X F. Lint percentage was positively correlated with lint yield for B X E BC_2 and with boll size for the BC_1. Lint yield was related to boll size in the BC_1. Lint percentage was positively correlated with lint yield in the B X F BC_2 as was lint yield with boll size in the BC_1. Boll size was negatively correlated with fiber strength in the BC_2.

The B parent was the only one in which a positive relationship was obtained between lint percentage and lint yield. This correlation may be reflected to some extent in the F_1 and F_2 populations. However, because the B parent had the lowest lint yields at Tipton, this observation may not be very important. Of great importance, however, is large, positive relationship observed between lint yield and boll number in all populations, suggesting that lint yield is highly dependent on that yield component (Tables 8 to 11). This finding corresponds with those of Ramey

(22), Ramey and Worley (24), and Maner et al. (12). The relationship between lint yield and boll size was somewhat less important, and the relationship between lint yield and lint percentage was of lesser importance still. The correlations between lint percentage and lint yield were generally smaller than those reported by other researchers (1,13,17,19). Correlations of contrasting sign were occasionally obtained which may reflect on the influence of environmental factors on these traits.

Parental Differences Versus Heritability

Parental differences for a particular trait and genetic combination were generally higher at Tipton except for boll size. A relationship existed between broad-sense heritability and parental differences for each trait at each location. Those relationship could best be explained by quadratic equations for all characters. For example, at Chickasha for lint percentage, where $R^2 = 0.99$, 45% higher than the calculated R^2 for a linear relationship , while at Tipton the R^2 of 0.28 was 4% higher than the linear relationship (Fig. 1.). The differences observed between the two locations were primarily due to the A X B at Tipton where the parental differences were negligible and the broad-sense heritability higher than expected. Removal of the A X B data point doubled the R^2 value for the quadratic equation to 0.57. Differences in environments appear to have some influence. For lint yield $R^2 = 0.29$ at Tipton, equal to the linear R^2 compared to an $R^2 = 0.29$ at Chickasha which was 23% greater than the linear R^2 (Fig. 2). An $R^2 = 0.56$ at Tipton for boll size, 55% better than the linear R^2 at that location, compared to an $R^2 = 0.16$ at Chickasha which was 15% better (Fig. 3). For boll number $R^2 = 0.33$ at Tipton 14% better than the linear R^2, compared to an $R^2 = 0.08$, at Chickasha, 7% better (Fig. 4). For fiber strength, $R^2 = 0.10$ at Tipton and 0.37 at Chickasha. Those estimates were 2% higher than the linear R^2 and 32% at those respective locations (Fig. 5).

The relationship between parental differences and broad-sense heritabilities at the respective locations was very strong for lint percentage at Chickasha and reasonably well explain the Tipton results if the A X B point was ignored. A quadratic relationship appears to exist suggesting that, within limits, higher heritabilities would be obtained as parental differences increased. The relationships expressed with other traits is probably not as good since parental differences were emphasized only for lint percentage. Additionally, crossing lines derived from a similar genetic background may have some inbreeding in the F_2 generation which would most likely reduce lint yield. Environmental limitations at Tipton (some drought stress) and at Chickasha (season shortened by an early killing freeze) prevented these lines from performing anywhere near their full genetic potential, thus probably reducing the relationship between the two variables.

The F parental line clearly has a high lint percentage which can be utilize into commercial material with some backcrossing. This line also produces high lint yields which are desirable. Fiber strengths are moderate and could be improved using the appropriate parental material. Breeding procedures effective with additive gene action could be employed to utilize this high lint percentage.

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Table 1. Mean squares for lint percentage and other selected traits at Chickasha and Tipton.

				Mean squares				
Location	Generation	Source	df	Lint percentage	Lint yield	Boll size	Boll number	Fiber strength
Chickasha	Parents	Population	3	445.29**	2.76	7.46**	0.00	49.62**
		Replication	3	17.70*	6.52	0.64	1.47	25.56**
		Error	311	6.11	4.61	0.70	1.30	1.93
	F_1	Population	5	62.52**	19.47*	0.42	8.29	16.99**
		Replication	2	72.44**	138.74**	0.41	42.08**	4.63
		Error	146	7.61	14.80	0.83	4.43	1.94
	F_2	Population	5	669.60**	35.30**	4.28**	13.05**	132.87**
		Replication	3	18.37	51.12**	1.29	13.40**	12.39**
		Error	1352	9.24	8.86	0.74	2.48	2.12
	BC_1	Population	5	36.01**	39.08**	0.81	13.32**	11.93**
		Replication	2	0.85	29.25	0.97*	6.81	3.39
		Error	160	7.42	11.00	1.01	3.24	2.16
	BC_2	Population	5	149.86**	42.45**	0.63	24.17**	27.72**
		Replication	2	2.94	41.11*	5.08*	6.78	15.43**
		Error	154	9.08	9.85	0.75	2.80	1.99
Tipton	Parents	Population	3	1019.43**	106.03**	7.56**	54.29**	122.57**
		Replication	3	17.37*	4.34	1.57	1.33	25.00**
		Error	376	5.90	9.10	1.03	5.36	2.15
	F_2	Population	5	1103.04**	115.43**	6.83**	48.49**	43.37**
		Replication	3	24.28*	42.46**	4.64*	8.02	111.27**
		Error	1750	8.19	9.52	1.01	5.15	2.50

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

Table 2. Means and standard errors for lint percentage and other selected traits of the parents at Chickasha and Tipton.

Parent	Lint percentage	Lint yield	Boll size	Boll number	Fiber strength
	%	g $plant^{-1}$	g $boll^{-1}$	no.	kN m kg^{-1}
			Chickasha		
A†	29.6 (0.24) d*	5.5 (0.21) a	6.0 (0.07) a	3.2 (0.11) a	20.8 (0.13) a
B	31.4 (0.27) c	5.5 (0.24) a	5.7 (0.09) a	3.2 (0.13) a	20.4 (0.15) a
E	33.1 (0.24) b	5.5 (0.21) a	5.3 (0.08) b	3.2 (0.11) a	19.2 (0.14) b
F	37.4 (0.56) a	6.2 (0.49) a	5.6 (0.19) ab	3.1 (0.26) a	20.4 (0.31) a
			Tipton		
A	30.4 (0.21) c	6.97 (0.26) b	4.75 (0.09) a	6.1 (0.20) a	21.8 (0.13) b
B	30.7 (0.22) c	5.48 (0.27) c	4.49 (0.09) b	4.7 (0.21) b	22.2 (0.14) a
E	34.3 (0.21) b	6.91 (0.26) b	4.20 (0.09) c	6.1 (0.20) a	19.9 (0.13) d
F	38.8 (0.39) a	8.45 (0.49) a	4.70 (0.16) ab	5.6 (0.38) a	20.5 (0.24) c

* Within columns within locations, values followed by the same letter are not significantly different at the 0.05 probability level using the probability difference test.

† A, parent selected for low lint percentage; B, low to intermediate; E, intermediate to high; and F, high.

Table 3. Mean heterosis, degree of dominance, and heritability for lint percentage in each parental combination at Chickasha and Tipton.

Parental combination	Mid-parent heterosis		High-parent heterosis		Degree of dominance		Broad-sense heritability	
	Chickasha	Tipton	Chickasha	Tipton	Chickasha	Tipton	Chickasha	Tipton
	%							
A X B‡	-0.7 ab†	1.7 a	- 6.3* a	0.8 a	-0.22	0.49	0.13	0.23
A X E	-0.8 ab	1.0 a	-11.3** ab	-10.5** b	-0.28	0.31	0.34	0.22
A X F	6.1* a	-3.0 a	-15.4** c	-25.2** c	2.02	-1.06	0.33*	0.40*
B X E	-0.8 ab	-3.0 a	- 5.8* a	-13.4** b	-0.27	-0.96	0.08	0.11
B X F	-3.9 b	-2.3 a	-19.7** bc	-23.9** c	-1.35	-0.81	0.44	0.23*
E X F	-2.6 b	-4.6* b	-14.0** ab	-16.8** bc	-0.93	-1.70	0.40*	0.35

*, ** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.
† Within columns, values followed by the same letter are not significantly different at the 0.05 probability level.
‡ A, parent selected for low lint percentage; B, low to intermediate; E, intermediate to high; and F, high.

Table 4. Mean heterosis, degree of dominance, and heritability for lint yield in each parental combination at Chickasha and Tipton.

Parental combination	Mid-parent heterosis		High-parent heterosis		Degree of dominance		Broad-sense heritability	
	Chickasha	Tipton	Chickasha	Tipton	Chickasha	Tipton	Chickasha	Tipton
	%							
A X B‡	16.4 a†	2.3 a	18.4 a	-19.4 a	0.77	0.08	0.40*	0.23*
A X E	26.5 a	22.4 a	27.1**a	22.7 a	1.45	1.59	0.47*	0.13
A X F	21.3 a	8.1 a	7.5 a	9.8 a	1.11	0.48	0.45*	0.15
B X E	36.1* a	10.6 a	38.2**a	-11.8 a	2.06	0.68	0.39*	0.13
B X F	13.5 a	23.6 a	- 0.7 a	1.2 a	0.73	0.97	0.32*	0.20
E X F	43.8**a	11.9 a	29.5**a	16.8 a	2.58**	0.75	0.50**	0.20

*,** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.

† Within columns, values followed by the same letter are not significantly different at the 0.05 probability level.

‡ A, parent selected for low lint percentage; B, low to intermediate; E, intermediate to high; and F, high.

Table 5. Mean heterosis, degree of dominance, and heritability for boll size in each parental combination at Chickasha and Tipton.

Parental combination	Mid-parent heterosis		High-parent heterosis		Degree of dominance		Broad-sense heritability	
	Chickasha	Tipton	Chickasha	Tipton	Chickasha	Tipton	Chickasha	Tipton
	%							
A X B‡	2.2 a†	3.0 a	- 3.4 a	-3.4 a	0.12	0.14	0.10	0.23**
A X E	0.5 a	11.4 a	-10.4 a	0.1 a	0.02	0.52	0.28**	0.00
A X F	-4.5 a	10.0 a	- 7.0 a	6.0 a	-0.29	0.44	0.24*	0.06
B X E	2.4 a	7.6 a	- 3.4 a	3.6 a	0.13	0.32	0.24**	0.06
B X F	0.2 a	3.8 a	- 2.3 a	2.6 a	0.01	0.11	0.33**	0.02
E X F	-3.2 a	5.0 a	-11.3*a	-0.7 a	-0.19	0.20	0.42**	0.06

*,** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.
† Within columns, values followed by the same letter are not significantly different at the 0.05 probability level.
‡ A, parent selected for low lint percentage; B, low to intermediate; E, intermediate to high; and F, high.

Table 6. Mean heterosis, degree of dominance, and heritability for boll number in each parental combination at Chickasha and Tipton.

Parental combination	Mid-parent heterosis		High-parent heterosis		Degree of dominance		Broad-sense heritability	
	Chickasha	Tipton	Chickasha	Tipton	Chickasha	Tipton	Chickasha	Tipton
	%							
A X B‡	15.3 a†	- 6.1 a	17.5 a	-27.4 a	0.42	-0.38	0.43**	0.08
A X E	31.5* a	14.6 a	33.9*a	15.0 a	0.98*	0.89	0.53**	0.14
A X F	15.2 a	- 1.0 a	19.7 a	-16.6 a	0.39	-0.03	0.37**	0.01
B X E	39.8** a	9.0 a	42.0** a	-14.6 a	1.29**	0.48	0.45**	0.17
B X F	16.8 a	27.9 a	19.3 a	34.7 a	0.47	1.10	0.29	0.20*
E X F	51.3** a	8.1 a	57.3** a	- 9.0 a	1.55**	0.42	0.48**	0.11

*,** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.
† Within columns, values followed by the same letter are not significantly different at the 0.05 probability level.
‡ A, parent selected for low lint percentage; B, low to intermediate; E, intermediate to high; and F, high.

Table 7. Mean heterosis, degree of dominance, and heritability for fiber strength in each parental combination at Chickasha and Tipton.

Parental combination	Mid-parent heterosis		High-parent heterosis		Degree of dominance		Broad-sense heritability	
	Chickasha	Tipton	Chickasha	Tipton	Chickasha	Tipton	Chickasha	Tipton
	%							
A X B‡	2.0 a†	1.1 a	-1.9 a	-0.9 a	-5.31	-0.38	0.18	0.06
A X E	8.3^{**}a	9.8^{**}a	-7.6^{**}a	-8.9^{**}a	-5.22	-7.26	0.21^{*}	0.03
A X F	3.1 a	8.0^{**}a	-2.9 a	-7.3^{**}a	6.21	10.47	0.45^{**}	0.15^{*}
B X E	6.2^{*} a	11.0^{**}a	-5.8^{*} a	-9.7^{**}a	2.62	-5.58	0.24^{*}	0.15^{*}
B X F	1.3 a	9.2^{**}a	-0.9 a	-8.1^{**}a	4.47	3.08	0.35^{**}	0.05
E X F	5.2^{*} a	1.8 a	-4.7^{*} a	-1.6 a	-3.50	-1.65	0.44^{**}	0.24^{**}

*,** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.
† Within columns, values followed by the same letter are not significantly different at the 0.05 probability level.
‡ A, parent selected for low lint percentage; B, low to intermediate; E, intermediate to high; and F, high.

Table 8. Phenotypic correlations among traits for the parents at Chickasha and Tipton.

Trait	Parent	Lint yield		Boll size		Boll number		Fiber strength	
Lint percentage	A†	0.10‡	0.12§	-0.08‡	-0.05§	-0.07‡	-0.01§	0.28**‡	0.24**§
	B	0.29*	0.42**	0.28*	0.24**	-0.08	0.18*	-0.16	0.12
	E	0.13	0.08	-0.21	-0.16*	0.07	0.03	0.17	-0.00
	F	0.15	0.06	-0.19	0.25	-0.10	-0.20	0.50*	-0.15
Lint yield	A			0.37**	0.65**	0.91**	0.87**	0.08	0.01
	B			0.38**	0.77**	0.82**	0.78**	-0.26*	0.12
	E			0.37**	0.73**	0.95**	0.87**	-0.04	0.04
	F			0.18	0.61**	0.91**	0.83**	0.14	0.21
Boll size	A					0.14	0.35**	0.06	0.07
	B					-0.11	0.33**	-0.33**	0.21*
	E					0.14	0.43**	-0.10	0.10
	F					-0.10	0.14	-0.48*	0.36*
Boll number	A							0.02	-0.06
	B							-0.08	-0.04
	E							-0.01	-0.07
	F							0.13	0.11

*,** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.
† A, parent selected for low lint percentage; B, low to intermediate; E, intermediate to high; and F, high.
‡ Chickasha estimates are provided in this column.
§ Tipton estimates are provided in this column.

Table 9. Phenotypic correlations among traits for the F_1s at Chickasha.†

Trait	F_1	Lint yield	Boll size	Boll number	Fiber strength
Lint per-	A X B‡	0.62*	0.33	0.30	-0.37
cent-	A X E	0.39*	0.44*	0.23	0.29
age	A X F	0.28	0.06	0.00	0.26
	B X E	0.53**	-0.14	0.52**	0.06
	B X F	-0.12	-0.17	-0.24	0.03
	E X F	-0.06	-0.23	-0.18	0.11
Lint yield	A X B		0.57*	0.76**	-0.16
	A X E		0.19	0.95**	0.35
	A X F		0.48*	0.74**	-0.21
	B X E		0.18	0.98**	-0.32
	B X F		0.34	0.95**	-0.28
	E X F		0.24	0.95**	-0.22
Boll size	A X B			-0.06	-0.66**
	A X E			-0.11	-0.05
	A X F			-0.12	-0.08
	B X E			0.01	-0.18
	B X F			0.13	0.37
	E X F			0.05	-0.32
Boll num-	A X B				0.41
ber	A X E				0.36
	A X F				-0.24
	B X E				-0.29
	B X F				-0.38
	E X F				-0.12

*,** Significantly different from zero correlations at the 0.05 and 0.01 levels of probability, respectively.

† Insufficient seed to include F_1s at Tipton.

‡ A, parent selected for low lint percentage; B, low to intermediate; E, intermediate to high; and F, high.

Table 10. Phenotypic correlations among traits for the F_2s at Chickasha and Tipton.

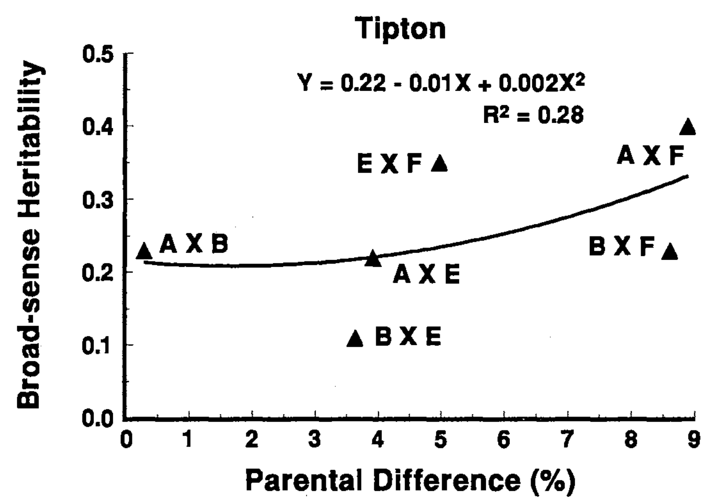
Trait	F_2	Lint yield	Boll size	Boll number	Fiber strength
Lint percentage	A X B†	0.32**‡ 0.33**§	0.16‡ 0.09§	0.17*‡ 0.22**§	0.10‡ 0.08§
	A X E	0.28** 0.22**	-0.05 -0.05	0.15 0.08	0.01 -0.06
	A X F	0.11 0.22**	0.09 0.04	-0.01 0.03	-0.10 -0.11*
	B X E	0.16* 0.26**	-0.17 0.05	0.06 0.16**	-0.01 -0.06
	B X F	0.20** 0.19**	0.04 -0.02	-0.01 0.08	-0.04 0.04
	E X F	0.23** 0.24**	-0.15 -0.08	0.12 0.14*	0.23** -0.04
Lint yield	A X B		0.40** 0.72**	0.95** 0.80**	-0.08 0.04
	A X E		0.34** 0.55**	0.94** 0.88**	-0.05 0.06
	A X F		0.35** 0.64**	0.92** 0.81**	0.00 0.02
	B X E		0.32** 0.66**	0.91** 0.85**	-0.06 0.18**
	B X F		0.38** 0.64**	0.88** 0.85**	-0.06 0.07
	E X F		0.44** 0.60**	0.92** 0.85**	0.02 0.09
Boll size	A X B			0.15 0.35**	0.01 0.12*
	A X E			0.11 0.29**	0.00 0.22**
	A X F			0.04 0.25**	-0.33** 0.06
	B X E			0.00 0.30**	-0.18** 0.26**
	B X F			0.02 0.27**	-0.13 0.25**
	E X F			0.16 0.26**	-0.32** 0.19**
Boll number	A X B				-0.09 -0.01
	A X E				-0.07 -0.04
	A X F				0.12 0.03
	B X E				0.01 0.03
	B X F				-0.01 -0.07
	E X F				0.06 0.01

*,** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.
† A, parent selected for low lint percentage; B, low to intermediate; E, intermediate to high; and F, high.
‡ Chickasha estimates are provided in this column.
§ Tipton estimates are provided in this column.

Table 11. Phenotypic correlations among traits for the BC_1s and BC_2s at Chickasha.†

Trait	BC_1 and BC_2	Lint yield		Boll size		Boll number		Fiber strength	
Lint percentage	A X B‡	0.20§	0.31¶	0.04§	0.19¶	-0.03§	0.22¶	-0.42*§	-0.12¶
	A X E	0.39	0.13	0.21	-0.25	0.05	-0.00	0.31	0.16
	A X F	0.13	0.49	0.09	0.03	-0.13	0.37	-0.29	-0.19
	B X E	0.11	0.41*	0.37*	-0.16	-0.07	0.36	-0.21	0.06
	B X F	0.34	0.36*	0.02	0.18	0.24	0.17	0.31	0.29
	E X F	0.26	0.30	0.18	-0.20	0.14	0.20	-0.11	0.12
Lint yield	A X B			0.34	0.50*	0.79**	0.95**	0.01	0.00
	A X E			0.36**	0.48**	0.80**	0.91**	0.11	-0.10
	A X F			0.44*	0.25	0.83**	0.89**	-0.02	-0.32
	B X E			0.46**	0.26	0.97**	0.96**	0.03	-0.08
	B X F			0.48**	0.26	0.91**	0.93**	0.06	0.01
	E X F			0.21	0.25	0.95**	0.92**	0.07	0.04
Boll size	A X B					-0.24	0.25	-0.17	-0.29
	A X E					-0.19	0.22	-0.21	0.02
	A X F					-0.07	-0.12	-0.12	-0.14
	B X E					0.27	0.06	-0.28	-0.17
	B X F					0.19	-0.04	0.21	-0.23*
	E X F					-0.05	-0.09	-0.34	-0.02
Boll number	A X B							0.23	0.03
	A X E							0.14	-0.17
	A X F							0.09	-0.09
	B X E							0.07	-0.10
	B X F							-0.01	0.09
	E X F							0.23	0.03

*,** Significantly different from zero correlations at the 0.05 and 0.01 levels of probability, respectively.
† Insufficient seed to include BC_1s and BC_2s at Tipton.
‡ A, parent selected for low lint percentage; B, low to intermediate; E, intermediate to high; and F, high.
§ BC_1 estimates are provided in this column (backcrosses to low parents).
¶ BC_2 estimates are provided in this column (backcrosses to high parents).



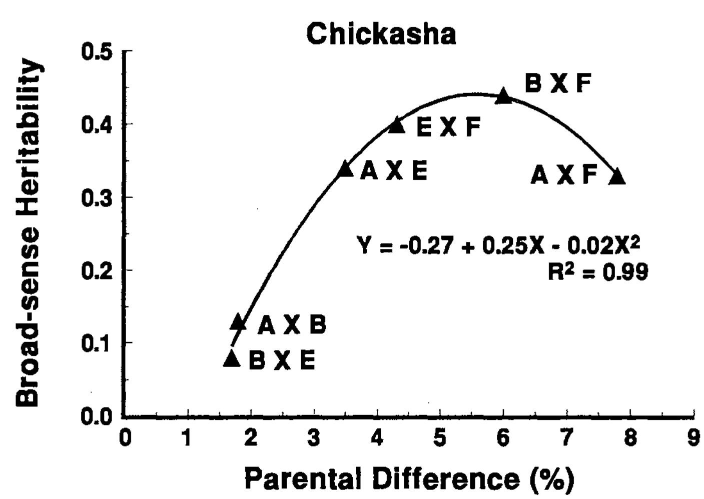
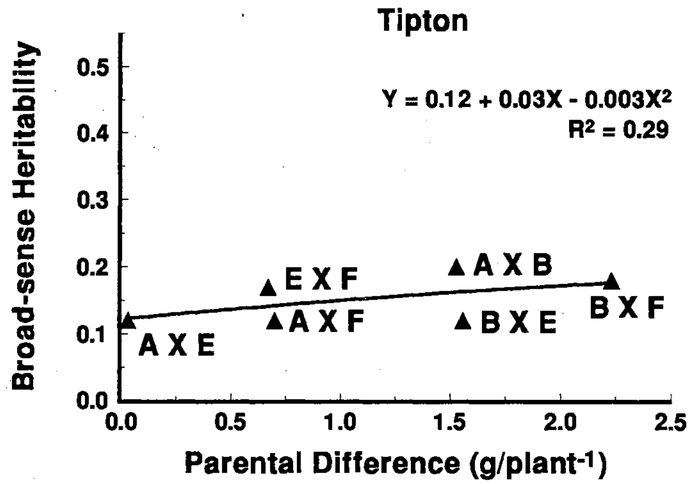


Fig. 1. Relationship between broad-sense heritability and parental difference for lint percentage.



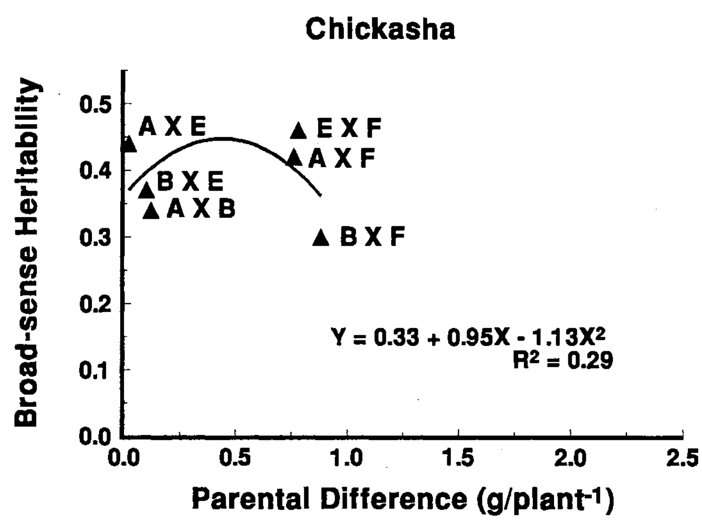
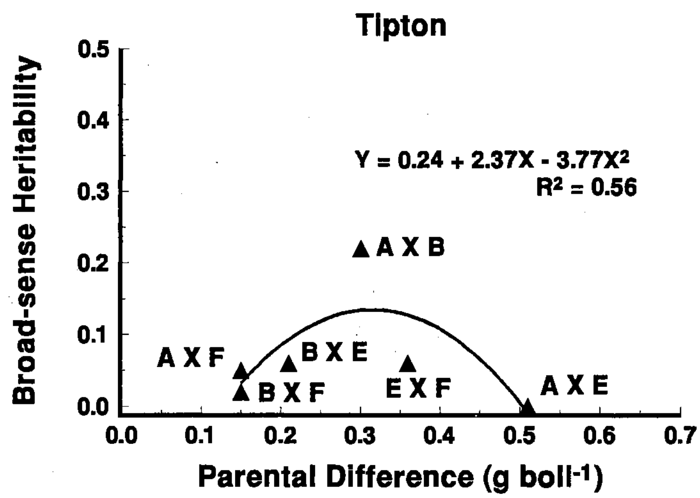


Fig. 2. Relationship between broad-sense heritability and parental difference for lint yield.



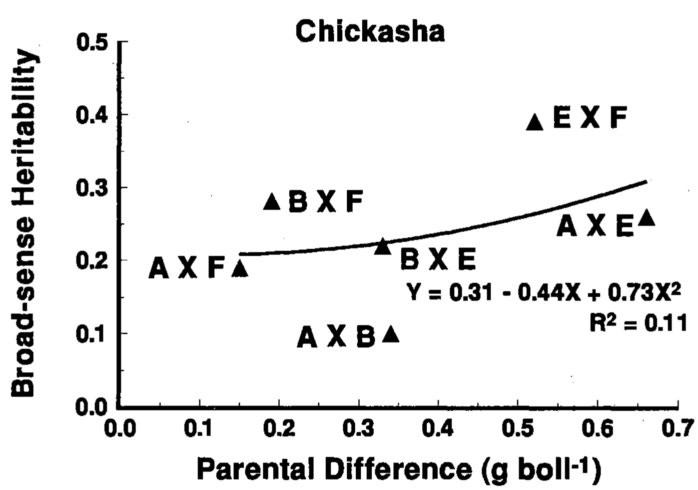
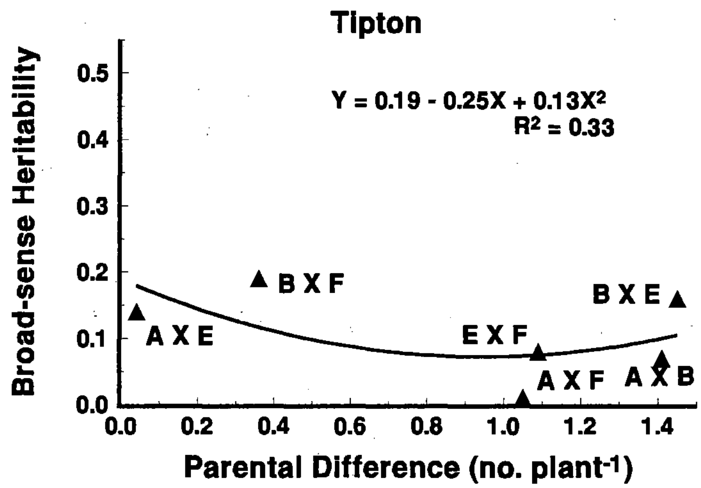


Fig. 3. Relationship between broad-sense heritability and parental difference for boll size.



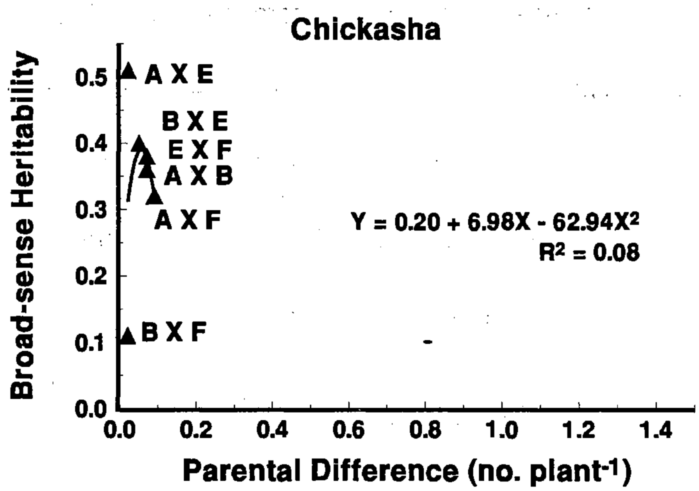
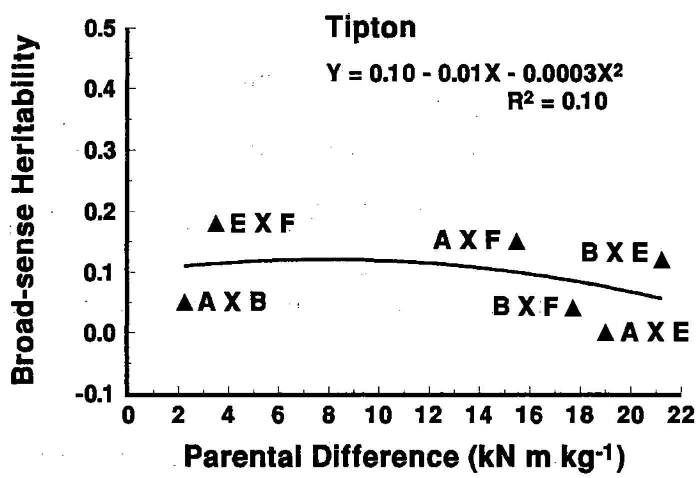


Fig. 4. Relationship between broad-sense heritability and parental difference for boll number.



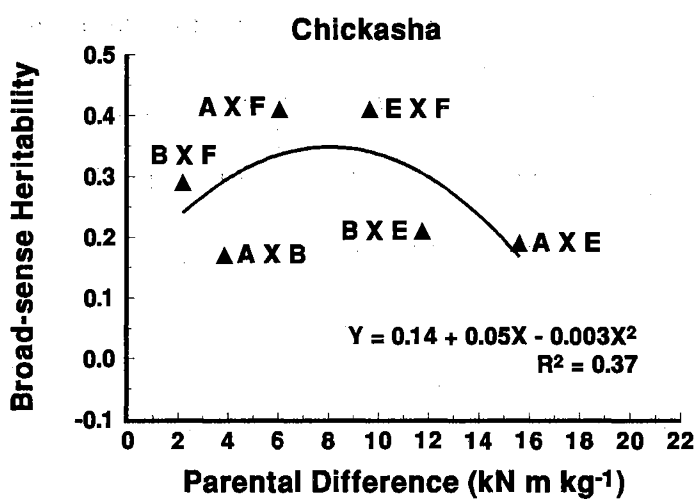


Fig. 5. Relationship between broad-sense heritability and parental difference for fiber strength.

VITA

Orville Agard Wickham

Candidate for the Degree of

Doctor of Philosophy

Thesis: GENOTYPE BY ENVIRONMENT INTERACTION STUDY I. OF AGRONOMIC TRAITS AND II. OF FIBER AND YARN PROPERTIES IN COTTON IN THE PLAINS REGION OF OKLAHOMA AND TEXAS AND III. INHERITANCE OF LINT PERCENTAGE IN COTTON

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