MAGNITUDE AND CONSISTENCY OF HETEROSIS IN CROSSES AMONG PLAINS-TYPE COTTON CULTIVARS

By

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This thesis is a complete manuscript to be submitted to _Crop Science_ for publication. The format of the manuscript conforms to the style of that journal.

MAGNITUDE AND CONSISTENCY OF HETEROSIS IN CROSSES AMONG PLAINS-TYPE COTTON CULTIVARS

ABSTRACT

This study was conducted to determine the magnitude and consistency of midparent (MP) and high parent (HP) heterosis over locations and/or years on cotton (Gossypium hirsutum L.) lint yield, lint percents, and fiber properties. The parents, F_1s, and F_2s for all possible crosses among five Plains-type cultivars, ignoring reciprocals, were evaluated in replicated experiments conducted at three irrigated locations in Oklahoma for 3 years. Additional analyses were performed to determine general (GCA) vs. specific combining ability (SCA) effects of heterosis and the consistency of heterosis over locations, years, or both. MP heterosis in the F_1 and F_2 was detected for all traits except uniformity index in the F_1; HP heterosis in the F_1 was reported for all traits. MP heterosis for lint yield was relatively large with increases up to 173 kg/ha (34.0% heterosis) in the F_1 and 102 kg/ha (18.6%) in the F_2; and in the F_1, HP heterosis ranged up to 145 kg/ha (26.6%). Generally, heterosis was relatively small for the remaining traits in this study. Based on overall mean heterosis, among the 10 crosses studied, three could be eliminated from consideration, four displayed one or more negative trends, and three were highly promising for hybrid production. In the F_2, GCA effects for heterosis were found for all traits except 50% span length (SL) and micronaire while SCA effects for heterosis were found for all traits except lint yield, 50% SL, and 1/8-inch gauge stelometer (T_1). Environmental interactions with GCA and SCA were observed for all traits except 50% SL and T_1. Significant inconsistencies over environments occurred for MP and/or HP heterosis for all traits except uniformity index and T_1.

Additional index words: *Gossypium hirsutum* L., Combining ability, Genotype by environment interaction, Lint yield, Lint percent, Fiber length, Fiber length uniformity, Fiber fineness, Fiber strength.

INTRODUCTION

A considerable number of plant breeders in the U.S. are attempting to develop cotton (Gossypium hirsutum L.) hybrids for commercial production. Because of the high seed costs involved, heterosis (especially for lint yield) must be relatively large and consistently expressed over years and locations for hybrids to be economically feasible. Additional analyses were performed to determine general vs. specific combining ability effects of heterosis and the consistency of heterosis over locations, years, or both.

Loden and Richmond (7) reviewed heterosis studies in cotton conducted prior to 1951. In summarizing those findings, they concluded that heterosis was maximized in the F_1 with little expectation of subsequent generations providing significant increases, especially in yield. The heterosis studies in cotton cited here were largely published after that time and were investigations in multiple environments, i.e., in at least 2 years and/or locations.

Kime and Tilley (5) found that six of six crosses gave significantly higher seedcotton yields for the F_1 compared to the most productive parent in each cross when averaged over 3 years at one location. However, those yield differences were not significant for all crosses during all years. Lint yields followed a similar pattern. Mean lint percent of the F_1, averaged over 2 years, was slightly less than that of the high parent (HP). Heterosis was not expressed for fiber length or strength.

Turner (15) recorded a significant increase in year 1 of mean seedcotton yield for six of 21 F_1 hybrids over the best adapted cultivar. When the test was repeated the following year at the same location, only one of the hybrids exceeded the check. In year 1, seven hybrids also displayed a significant increase in number of bolls/plot; six of the seven corresponded to those hybrids with significant increases in seedcotton yield. None showed a significant increase in boll size. However, in 1950, 12 hybrids demonstrated a significant increase in boll size. None of the 12 corresponded with the single hybrid having a significant increase in seedcotton yield. The only hybrid with a significant increase in number of bolls/plot matched the higher yielding hybrid. Seedcotton yield increases were attributed to increases in number of bolls, not to boll size.

Turner (16) estimated the midparent (MP) heterotic effect in four yield-related variables for the 21 hybrid combinations. Heterosis was reported as a percent of the MP with the MP equaling 100%. Boll number in individual crosses ranged from 105 to 177% heterosis, boll size from 99 to 116%, seed/boll from 104 to 121%, and seedcotton yield from 108 to 182%. The degree of heterosis shown for boll number and seedcotton yield was much higher than for the other two variables. Percent heterosis averaged over crosses declined from the F_1 to the F_2 from 25 to 4% for boll number, from 7 to 0% for boll size, from 12 to 3% for seed/boll, and from 33 to 9% for seedcotton yield.

Miller and Marani (12) reported significant MP heterosis for all characters measured when averaged over crosses. However, no hybrid significantly exceeded the best parent line for lint yield. Average heterotic effects over two locations in 1 year were greatest for lint yield (27.5%) and relatively small for fiber length (3.6%), fiber strength (3.3%), and lint percent (1.5%). Significant inbreeding depression was noted in the F_2 for all the above traits except fiber strength.

In a study of top-cross hybrids, Miller and Lee (11) concluded that MP heterosis was important for lint yield (18.0 to 19.6%), but not for lint percent or fiber length, strength, or fineness (i.e., 1.5% or less). HP heterosis ranged from 11.0 to 14.9% for lint yield, but it was 1.0% or less for the other variables. Average MP heterosis for lint yield over crosses ranged from 13.0 to 28.8% depending upon the environment. "An analysis of variance of heterotic effects (F_1 minus mid-parent values) over the different environments indicated that although the average heterotic effects were highly significant at each environment, there were no significant differences in the magnitude of heterosis recorded for the different yield-level environments." Heterosis for lint yield averaged over environments for individual top-cross hybrids was expressed as a percent of the tester ('Coker 100A'); values ranged from 100 to 128%.

Hawkins et al. (4) reported lint yield increases in four of six F_1 hybrids which ranged from 18.4 to 24.2% over the better parent when averaged over 3 years at one location. The least consistent cross in their study varied from 4.2 to 50.5% HP heterosis between years; whereas, the most consistent heterotic cross varied from 15.2 to 33.4%. Heterosis was not observed for lint percent.

Young and Murray (21) utilized four highly inbred strains of the tetraploid species, G. hirsutum, and of the diploid species, G. arboreum L., in a study of MP heterosis and inbreeding depression conducted over 3 years at one location. In the first year, G. hirsutum heterosis for lint yield was significant in four of six crosses ranging from 43.6 to 53.2%. In the subsequent 2 years, heterosis for lint yield was not significant, demonstrating a lack of consistency over years. G. arboreum heterosis for lint yield was significant in five of six crosses in the first year; it ranged from 34.7 to 50.8%. The G. arboreum crosses studied in the succeeding 2 years all expressed significant heterosis for lint yield corresponding in general magnitude to that of the first year. An examination of heterotic effects on fiber properties revealed that one of six G. hirsutum hybrids gave a significant increase in fiber length in year 1, two of two in year 2, and no significant differences in year 3. Four of six G. arboreum hybrids displayed a significant increase in fiber length in the first year, one of one in the second year, and none in the last. One of six G. hirsutum hybrids showed a significant increase in fiber fineness in year 1, one of two in year 2, and none in year 3. None of the G. arboreum hybrids significantly affected fiber fineness in any year. Fiber strength was significantly reduced in one of six G. hirsutum hybrids in year 1, but no significant differences were observed in years 2 and 3. Three of six G. arboreum hybrids showed a significant increase in fiber strength in the first year, one of one in the second year, and none in the last year. The G. hirsutum hybrids exhibited less heterosis and inbreeding depression than G. arboreum, presumably this was a function of their respective ploidy levels.

Lee et al. (6) found significant MP heterosis for lint yield (26.0%), lint percent (1.7%), and fiber length (2.8%), but not for fiber strength and fineness based on average performance over two locations and 2 years. In 4 of 6 years, Marani (8) found G. hirsutum F_1 hybrids gave small, but significant, average MP heterosis for upper half mean (UHM) length ranging from 1.0 to 2.4%. In 2 of 6 years, significant MP heterosis was obtained for mean length ranging from 1.6 to 2.1%. Heterosis for fiber strength was not significant in any year. Only in 1 year were the F_1 hybrids significant for heterosis for fiber fineness. The

G. barbadense hybrids displayed significant MP heterosis for UHM length in all 6 years which ranged from 1.1 to 4.5%. In 2 of 6 years, heterosis for mean length was significant ranging from 3.2 to 4.0%. In 4 of 6 years, the F_1s exhibited significant heterosis for fiber strength (1.4 to 4.9%) while heterosis for fiber fineness was significant in only 1 year (2.6%).

Marani (9) used four cultivars of G. hirsutum and G. barbadense L. and their respective intraspecific crosses in all combinations in the F_1 and F_2 to study MP heterosis. Heterosis in G. hirsutum for yield of seedcotton (13.8 to 20.2%) and for yield of lint (15.1 to 24.1%) was significant in both experiments in which those traits were evaluated while heterosis for lint percent (1.4 to 3.4%) was significant in two of three experiments. G. barbadense heterosis for seedcotton yield and lint yield was significant in the two tests harvested and ranged from 18.9 to 25.9% and from 21.1 to 28.1%, respectively. Heterosis for lint percent was significant in all three experiments and ranged from 1.6 to 1.9%.

Meredith and Bridge (10) reported significant MP heterosis for lint yield in six of six crosses ranging from 7.1 to 47.0% (averaged over four locations in 1 year). "Useful" heterosis in three crosses ranged from 7.5 to 15.0%. The latter measure of heterosis was defined as 100 X (F_1 - DPL)/DPL (where DPL = 'Deltapine 16', a high performance cultivar in the region where these experiments were conducted). Among the six crosses, MP heterosis was observed for two in lint percent, four in 50% span length (SL), and four in 2.5% SL, but with none for fiber strength or fineness. "Useful" heterosis was found for one in lint percent, three in 50% SL, five in 2.5% SL, five in fiber strength, and three in fiber fineness. Averaged over all six crosses, MP heterosis was significant for lint yield (22.7%), lint percent (1.1%), 50% SL (3.1%), and 2.5% SL (2.8%), but not for fiber strength or fineness. "Useful" heterosis was significant for lint yield (3.9%), 50% SL (4.4%), 2.5% SL (3.9%), and fiber strength (9.6%).

Baker and Verhalen (2) found 18 of 45 F_1s displayed significant MP heterosis for lint yield when averaged over 2 years at one location. Mean heterosis for lint yield over all F_1s was 14.0%. Low levels of heterosis for lint percent (1.6%), 2.5% SL (1.9%), 50% SL (1.5%), and uniformity index (-0.4%) were also significant over crosses and years; whereas, those for fiber fineness and strength were not. The level of heterosis varied from year to year for all characters measured except 2.5% SL. Wells and Meredith (19) reported a 14% increase in lint yield of F_1 hybrids over the parental lines when averaged across three harvests and three environments at one location. No significant differences were found for lint percent.

Combining ability papers cited were from cotton studies conducted in multiple environments. Turner (16) estimated general (GCA) and specific combining ability (SCA) variances for the seedcotton yield of 21 F_1 hybrids, and those computations suggested that SCA was considerably more important. Miller and Marani (12) estimated GCA and SCA variance components for the F_1 and F_2 and found that GCA was significant for lint yield, lint percent, fiber length, and fiber strength in both generations. SCA was not significant for any trait in the F_1, but it was for lint yield and lint percent in the F_2. A comparison of GCA vs. SCA for each character showed that GCA was usually much larger, thus, more important. In the F_2, a significant GCA by location interaction occurred for lint percent. All other interactions of combining ability with locations were small and nonsignificant.

Hawkins et al. (4) calculated GCA for four cultivars over 3 years at one location "from the average of the character of the single crosses involving a given variety". GCA was not significant for lint yield. By investigating lint yield relationships among means for each cross, SCA was also shown to be nonsignificant. Estimates of GCA and SCA variances made by Young and Murray (21) for seedcotton yield and fiber length of F_1 hybrids in two species, _G. hirsutum_ and _G. arboreum_, indicated that SCA was much more important than GCA in both.

Lee et al. (6) used variance components to estimate GCA and SCA and their interactions with 2 years and two locations. GCA by locations was the only significant response observed for lint yield. Significant GCA effects were reported for lint percent and for fiber length, strength, and fineness. The only significant SCA effect detected was an SCA by years by locations interaction for lint percent. The latter was interpreted to mean that some combinations were occasionaly outstanding for lint percent, but were not consistent over years and locations.

Meredith and Bridge (10) studied the gene action involved in heterosis among six inbred lines crossed with 'Deltapine 16' using data collected from four locations in 1 year . Three of six crosses showed primarily additive gene effects for lint yield, two crosses displayed dominant gene effects, and the remaining cross exhibited only an additive by location interaction. Additive gene effects prevailed in four crosses apiece for lint percent, fiber strength, and fiber fineness. Roughly two-thirds additive and one-third dominant effects were observed for 50% SL while additive effects predominated for 2.5% SL. A study conducted by Baker and Verhalen (2) of GCA and SCA effects and their interactions with 2 years at one location revealed that significant GCA and SCA effects were present for lint yield, lint percent, fiber length, uniformity index, fineness, and strength. GCA by years and SCA by years interactions were significant for all traits except for GCA by years for uniformity index and fiber strength. The GCA/SCA ratios of variance components indicated that GCA was more important for fiber length, uniformity index, fineness, and strength while GCA and SCA were of nearly equal importance for lint percent. SCA was of much greater importance than GCA for lint yield.

Wilson and George (20) conducted a combining ability study in 2 years at one location using two cultivars and four stocks selected for pink bollworm [*Pectinophora gossypiella* (Saunders)] resistance. GCA was significant for five of the six entries for lint yield in 1977 and 1978. All six entries displayed significant GCA for lint percent in both years. Five of six exhibited significant GCA effects for 2.5% SL in 1977 and 1978 while four of six in 1977 and two of six in 1978 did so for 50% SL. Fiber strength GCA effects were significant for five of six entries in both years. Four of six entries in 1977 and three of six in 1978 had significant GCA effects for fiber fineness. SCA effects were calculated; but due to the method of presentation, those effects could not be delineated as was done for GCA.

In a Beltwide study of genotype by environment (GE) interactions, Abou-El-Fittouh et al. (1) compared four cultivars of upland cotton over 39 locations representing 101 environments. Only lint yield exhibited a larger genotype by location (GL) interaction than genotype by year by location (GYL) interaction. The larger number and diversity of environments than are normally analyzed in such experiments was credited with producing this unusual result. This observation was not true for lint percent or for fiber length, fineness, and strength. Interaction components were highly important for yield, lint percent, and fiber fineness, but less so for the other traits. Lint yield was analyzed further by regions of the U.S. Cotton Belt. All interactions were significant except the genotype by year (GY) and GL interactions in the Western region. Genetic variation for yield was more important than GE interactions in the Eastern and Western regions; whereas, the opposite was true in the Delta, Central, and Plains regions.

Verhalen and Murray (18) analyzed 10 cultivars of cotton in Oklahoma over 2 years at one location for fiber properties. In the analyses (confounded with a location effect), they detected no significant GY interactions for 2.5% SL or two measures of fiber strength. Fiber fineness displayed a significant GY interaction. In a later paper by the same two authors and others (17), the agronomic properties from the above study were presented. Analyses revealed no significant interactions for yield of lint or seedcotton; however, a significant GY interaction was observed for lint percent.

Murray and Verhalen (14) conducted a GE interaction study of 11 cotton cultivars in Oklahoma at three locations over 3 years. They calculated significant GY interactions for 2.5% SL and fiber strength, a GL interaction for lint yield, and GYL interactions for lint yield and fiber fineness. They concluded that lint yield and fiber fineness should be evaluated in tests conducted in different environments with more emphasis placed on multiple locations when evaluating yield.

A GE study by Morrison and Verhalen (13) conducted at five locations in Oklahoma over 2 years resulted in significant GYL interactions for lint yield, 2.5% SL, uniformity index, and one measure of fiber strength. GY interactions were generally important for lint yield and 2.5% SL, but GL interactions were not. Fiber fineness, depending upon the locations included in the calculations, displayed significant GYL interactions for two location combinations and significant GY and GL interactions for another.

Baker and Verhalen (2) conducted analyses of variance over 2 years at one location in Oklahoma for 10 parents and 45 F_1s; they obtained significant GY interactions (confounded with a location effect) for lint yield, lint percent, 2.5% SL, uniformity index, and fiber fineness, but not for 50% SL and fiber strength.

This study was conducted to determine the magnitude and consistency of MP and HP heterosis over locations and/or years on cotton lint yield, lint percents, and fiber properties. The parents, F_1s, and F_2s for all possible crosses among five Plains-type cultivars, ignoring reciprocals, were evaluated in replicated experiments conducted at three irrigated locations in Oklahoma for 3 years. Additional analyses were performed to determine GCA vs. SCA effects of heterosis and the consistency of heterosis over locations, years, or both.

MATERIALS AND METHODS

In the winter of 1975-1976, at Iguala, Mexico, five cotton cultivars (i.e., 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M') were used as parents to construct a diallel set of crosses, ignoring reciprocals, thereby obtaining 10 hybrid combinations. In the winter of 1976-1977, the parents and 10 hybrids were sent to Iguala, Mexico, where additional F_1s were made and the 10 hybrids were selfed to obtain F_2 seed. Over the next 2 years, seed of the parents and F_1s were returned to Mexico, as necessary, to maintain seed supplies.

In the spring of 1977, 1978, and 1979, the parents, F_1s, and F_2s were planted in a randomized complete-block experimental design in a split-plot arrangement with 10 whole plots randomly assigned in each replication. Each whole plot consisted of a parental combination with four subplots randomly assigned to the two parents, the F_1, and the F_2 of that combination. Four replications/experiment were originally planned, but quantities of F_1 seed often resulted in the reduction of replications planted using the above configuration. Therefore, in one to two replications/experiment, the whole plot consisted of the two parents and the F_2 of that parental combination. In all experiments the subplots were single rows 9.1 m in length and 1.0 m apart.

Irrigated experiments were conducted at three locations: Perkins, OK, on a Teller loam soil (a fine-loamy, mixed, thermic Udic Argiustoll); Chickasha, OK, on a Reinach silt loam soil (a coarse-silty, mixed, thermic Pachic Haplustoll); and Tipton, OK, on a Tipton silt loam soil (a fine-loamy, mixed, thermic Pachic Argiustoll). Cultural practices including irrigation were applied as judged necessary in each experiment.

Prior to harvest, 15 mature bolls/subplot were sampled from the midportion of competitive plants (i.e., plants not bordering the ends or skips in the row). Those samples were ginned using an eight-saw gin, and the fiber properties of the lint were tested at the Cotton Quality Res. Lab. at Oklahoma State Univ. Using data collected during ginning, picked lint percent (lint weight divided by seedcotton weight, expressed as a percentage) and pulled lint percent (lint weight divided by total boll weight, expressed as a percentage) were calculated. In the Cotton Quality Res. Lab., the digital fibrograph was utilized to measure 2.5 and 50% span length (SL) in inches, converted into mm. Uniformity index was calculated by dividing 50% SL by 2.5% SL and expressing that number as a percentage. The micronaire was used to measure fiber fineness and was reported in standard micronaire units. Fiber strength was determined using the 1/8-inch (3.175 mm) gauge stelometer in grams-force/tex and converted into kilonewton meters/ kilogram [(kN m)/kg].

After sampling, each subplot was individually harvested; and total boll weights were recorded. All tests were only harvested once. Pulled lint percents were used to convert total boll weights/subplot into lint yield in kg/ha.

Heterosis was calculated for each trait within each parental combination relative to the midparent (MP) and high parent (HP). MP heterosis was calculated using two methods: one, as a simple deviation, whether positive or negative in direction, of the filial generation from the MP (i.e., F_1 - MP, F_2 - MP); and two, as a percent deviation {[(F_1 - MP)/MP] X 100, [(F_2 - MP)/MP] X 100}. HP heterosis was calculated only for the F_1 using the same two methods as for MP heterosis, except that the HP value was substituted for the MP value in the formula. The HP of each parental combination was determined by averaging the parental data over all environments (years and locations) using all information available in the experiments. Once the HP of a parental combination had been determined, HP heterosis was calculated using only the data from the whole plots containing the F_1. Values were calculated within each whole plot, then averaged over replications for each experiment, then averaged over all experiments.

Analyses of variance were used to determine whether heterosis was significant over environments (years and locations); and if so, for which crosses, by how much, and in which direction. Mean and percent heterosis over all test environments were reported for F_1 MP, F_1 HP, and F_2 MP heterosis to indicate such information for each trait. Variance component analyses by crosses were also used to determine the consistency of heterosis over locations, years, and locations by years. Griffing's (3) Method 4, Model I was used to determine general (GCA) and specific combining ability (SCA) effects on heterosis for each trait as well as the consistency of such estimates over environments.

RESULTS AND DISCUSSION

Heterosis

Statistical analyses of parental means averaged over locations and years (Table 1) indicated significant differences among those parents for lint yield, pulled lint percent, two measures of fiber length, uniformity index, micronaire, and 1/8-inch gauge stelometer, but not for picked lint percent. Parental means can be used with the data in Tables 2 through 9 to identify the best cross combinations.

In the F_1, heterosis for lint yield (Table 2), relative to the MP, was significant in nine of 10 crosses. Mean heterosis ranged from 64 to 173 kg/ha, an 11.5 to 34.0% increase over the MP. Mean F_1 HP heterosis was significant for seven crosses and ranged from 70 to 145 kg/ha, a 12.6 to 26.6% increase over the HP. In the F_2, seven of 10 crosses displayed significant MP heterosis. The lowest heterotic cross increased mean lint yield by 40 kg/ha, a 7.3% increase, while the highest cross increased yield by 102 kg/ha, an 18.6% increase. HP heterosis was not calculated in the F_2 for this or any of the other traits studied. All three estimates (F_1 MP, F_1 HP, and F_2 MP) were positive and significant for crosses 1 X 3, 1 X 4, 1 X 5, 3 X 4, and 3 X 5. In addition, crosses 2 X 4 and 4 X 5 displayed significant HP heterosis.

Picked lint percent MP heterosis (Table 3) was significant for three crosses in both the F_1 and F_2. Mean heterosis was negative in one cross and positive in two others in each generation. Mean F_1 HP heterosis was significant for only one cross with an increase of 0.8% (2.2% heterosis). Cross 1 X 3 was positive and significant in all three estimates.

Pulled lint percent (Table 4) showed considerably more response than picked lint percent. Six of 10 F_1s exhibited significant F_1 mean MP heterosis that ranged from 0.7 to 1.5% (a 2.7 to 6.1% increase over the MP). Mean F_1 HP heterosis was significant for four crosses and ranged from 0.8 to 0.9%, an increase of 3.1 to 3.5% compared to the HP. Only two crosses in the F_2 were significant for mean MP heterosis which ranged from 0.7 to 1.3% (2.8 to 5.2% heterosis). All three estimates were positive and significant for crosses 1 X 3 and 3 X 5. In addition, crosses 1 X 4 and 4 X 5 showed significant HP heterosis.

In the F_1, mean MP heterosis for 2.5% SL (Table 5) was significant for nine crosses. Heterosis varied from 0.33 to 0.86 mm (1.2 to 3.2% heterosis). Mean F_1 HP heterosis was significant for three combinations and ranged from a low of 0.47 mm (1.7% heterosis) to a high of 0.86 mm (3.2% heterosis). In the F_2, mean MP heterosis was significant for four of 10 crosses; one was negative, and three were positive. Cross 1 X 2 was positive and significant for all three estimates. In addition, crosses 1 X 3 and 1 X 5 exhibited significant HP heterosis.

Mean MP heterosis for 50% SL (Table 6) resulted in six of 10 F_1s that displayed significant heterotic effects. The smallest significant increase over the MP was 0.25 mm (2.0% heterosis), and the largest was 0.38 mm (3.1% heterosis). One cross exhibited significant mean F_1 HP heterosis with an increase of 0.43 mm (3.3% heterosis). In the F_2, mean MP heterosis was significant for only one cross with an increase of 0.20 mm (1.5% heterosis). No crosses were positive and significant in all three estimates. Cross 1 X 5 was the only one to show significant HP heterosis.

F_1 mean MP heterosis for uniformity index (Table 7) was nonsignificant for all crosses. The mean F_1 HP heterotic effect for cross 1 X 2 was a decrease of -0.8% in uniformity (-1.6% heterosis). No other significant differences were detected for F_1 HP comparisons. F_2 mean MP heterosis was significant for three crosses; one was positive in direction, two were negative. No cross was significant in more than one estimate, and only one of the four that was significant was positive in direction. Heterosis for uniformity index was largely nonexistent.

Fiber fineness (i.e., micronaire) mean MP heterosis (Table 8) was significant for only one of 10 crosses in the F_1, and it decreased micronaire -0.2 units (-4.8% heterosis). A significant negative heterotic effect was also exhibited for mean F_1 HP heterosis in four of 10 crosses ranging from -0.1 to -0.4 units, a decrease of -3.2 to -9.4% heterosis. In the F_2, mean MP heterosis was significant for three crosses; one was negative in direction, two were positive. No cross was significant in all three estimates. Crosses displaying significant HP heterosis were 1 X 5, 2 X 4, 3 X 4, and 4 X 5; but all were in the negative direction toward more fineness. In another environment, that tendency might be advantageous; but in a short-season environment on the northern edge of the Cotton Belt, it is not.

Fiber strength (i.e., 1/8-inch gauge stelometer, T_1) displayed few significant heterotic effects for MP or HP heterosis in either the F_1 or the F_2 (Table 9). Mean MP heterosis was significant for two crosses in the F_1; one was in the negative direction, the other in the positive. Only one cross exhibited significant mean F_1 HP heterosis with a decrease of -7.5 kN m kg^{-1} (-4.1% heterosis). In the F_2, mean MP heterosis was significant for two of 10 crosses; one was in the negative direction, the other in the positive. No cross was significant in all three estimates. The only cross, 2 X 4, displaying a significant HP heterosis was toward reduced fiber strength.

Overall, lint yield exhibited the most crosses (23 of 30 comparisons) with heterotic effects relative to the F_1 MP, F_1 HP, and F_2 MP (Table 10). Pulled lint percent, 2.5% SL, and 50% SL MP heterosis were frequently expressed in the F_1, but were much less apparent in the F_1 HP and F_2 MP. Few significant MP heterotic effects were displayed by crosses in the F_1 for picked lint percent, fiber fineness, and fiber strength while none were observed for uniformity index. Other than for lint yield in the F_1, few crosses exhibited significant HP heterotic effects in other traits, particularly picked lint percent, 50% SL, uniformity index, and T_1.

Each cross-trait combination indicated in Table 10 by one or more asterisks displayed from a genetic standpoint significant heterosis, i.e., dominance and/or epistatic gene action. From a practical standpoint, those results for overall mean F_1 HP heterosis are more informative. Crosses 2 X 3 and 2 X 5 can be eliminated from consideration for hybrid production because neither displayed significant HP heterosis for any trait. Considering the economic importance of lint yield, cross 1 X 2 can probably be eliminated. Also, its heterosis for uniformity index was in an undesirable direction, i.e., toward less uniformity. If used for hybrids, crosses 1 X 5, 2 X 4, 3 X 4, and 4 X 5 would have heterosis in an undesirable direction for fiber fineness and/or strength. Considering their positive results and lack of negatives, crosses 1 X 3, 1 X 4, and 3 X 5 appear to be the most promising in this group.

Combining Ability

GCA effects of MP heterosis were significant in the F_1 for lint yield and pulled lint percent, but not for the other traits (Table 11). No significant SCA effects of heterosis were found for any trait. Lint yield, 2.5% SL, and T_1 displayed no significant GCA or SCA interactions with environments. One or more GCA by environment interactions were noted for the lint percents, 50% SL, uniformity index, and micronaire. One or more SCA by environment interactions were detected for the lint percents, uniformity index, and micronaire. The reduced number of replications (two or three present/location) in the F_1 analyses in conjunction with the significant GE interactions present, may have obscured the expression of GCA and SCA main effects. Even with interactions, an increased number of replications probably would have been instrumental in the identification of GCA and SCA main effects. This supposition appears substantiated by the data which follows for the F_2.

In the F_2, all four replications/location were available for analysis to determine GCA and SCA effects of MP heterosis (Table 12). Significant GCA effects of heterosis were observed for all traits except 50% SL and micronaire while significant SCA effects of heterosis were observed for all traits except lint yield, 50% SL, and T_1. The GCA effects were approximately twice the size of the SCA effects for picked and pulled lint percents, about 50% larger for uniformity index, and nearly the same size for 2.5% SL. The only trait in the F_2 MP not exhibiting significant GCA or SCA effects of heterosis was 50% SL. No significant GE interactions were observed that could help explain the lack of expression in 50% SL. One or more GCA of heterosis by environment interactions were detected for lint yield, the lint percents, 2.5% SL, and micronaire. One or more SCA of heterosis by environment interactions were noted for lint yield, the lint percents, 2.5% SL, and uniformity index.

Consistency of Response

Except for combination 1 X 2, all crosses displayed significant F_1 MP heterosis for lint yield (Table 2). Three of the nine remaining hybrids showed some inconsistency of heterosis over environments (Table 13). Two crosses, 2 X 3 and 2 X 5, showed significant variation in heterosis among years; and one, 3 X 4, exhibited significant locations by years (LY) effects. Crosses not showing significant F_1 HP heterosis for yield were 1 X 2, 2 X 3, and 2 X 5 (Table 2). Of the remaining seven hybrids, two exhibited significant variations among environments for heterosis (Table 13). Cross 2 X 4 was significant for heterosis differences among locations and among LY while 4 X 5 was for LY. In the F_2, crosses 2 X 4, 2 X 5, and 4 X 5 did not show significant MP heterosis (Table 2). Two of the seven remaining crosses exhibited significant inconsistencies among environments (Table 13). Both 1 X 3 and 2 X 3 displayed significant variations among years while 1 X 3 also showed significant LY effects. Of the 23 combinations exhibiting significant overall heterosis, 16 were stable over environments; seven were not.

Crosses 1 X 2, 1 X 3, and 3 X 5 showed significant F_1

MP heterosis for picked lint percent (Table 3). Cross 1 X 2 was significant for LY while 3 X 5 was for years (Table 14). Only cross 1 X 3 exhibited significant F_1 HP heterosis for picked lint percent (Table 3), and it was consistent across environments (Table 14). In the F_2, three crosses, 1 X 3, 3 X 4, and 3 X 5, were significant for MP heterosis (Table 3); only 1 X 3 displayed a significant LY effect (Table 14). Three of seven heterotic combinations were inconsistent in expression across environments.

In the F_1 MP comparisons for pulled lint percent, six of 10 crosses had significant heterosis (Table 4). Four crosses (i.e., 1 X 5, 3 X 4, 3 X 5, and 4 X 5) had significant inconsistencies over years while cross 1 X 5 also had a significant LY effect (Table 15). Four crosses (i.e., 1 X 3, 1 X 4, 3 X 5, and 4 X 5) had significant F_1 HP heterosis (Table 4). Cross 1 X 4 varied significantly among locations while crosses 3 X 5 and 4 X 5 were significant for years (Table 15). Crosses 1 X 3 and 3 X 5 were significant for F_2 MP heterosis (Table 4), but only 1 X 3 was significant for an environmental variation, LY (Table 15). Eight of 12 heterotic combinations displayed inconsistent heterosis over environments.

In the F_1 MP for 2.5% SL, nine of 10 crosses had significant heterosis (Table 5). Crosses 1 X 3, 1 X 4, 1 X 5, 3 X 5, and 4 X 5 showed no environmental effects (Table 16). Crosses 1 X 2, 2 X 3, and 2 X 5 were significant among years while 3 X 4 was for locations. F_1 HP heterosis for

2.5% SL was significant only for 1 X 2, 1 X 3, and 1 X 5 (Table 5). Only 1 X 2 varied significantly among years (Table 16). Crosses 1 X 2, 2 X 3, 2 X 4, and 3 X 4 had earlier demonstrated F_2 MP heterosis (Table 5). Only 2 X 3 displayed inconsistencies of heterosis over years (Table 16). Of 16 heterotic combinations for 2.5% SL. six were inconsistent over environments.

Six of 10 F_1s had exhibited significant MP heterosis for 50% SL (Table 6). Crosses 1 X 2, 1 X 5, 2 X 3, and 2 X 5 displayed no significant inconsistencies over environments; whereas, a year effect was significant for 3 X 5 and 4 X 5 (Table 17). Only one F_1, 1 X 5, displayed significant HP heterosis (Table 6), and it was not sensitive to environment (Table 17). The same was true in the F_2 MP analyses for cross 2 X 3 (Tables 6 and 17). Only two of eight heterotic combinations were inconsistent over environments.

No crosses displayed significant F_1 MP heterosis for uniformity index (Table 7). Cross 1 X 2 was significant for F_1 HP heterosis (Table 7), but displayed no significant environmental effects (Table 18). Three crosses (i.e., 1 X 5, 2 X 4, and 4 X 5) showed significant F_2 MP heterosis (Table 7), but no environmental effects (Table 18). The four heterotic combinations were all consistent across environments.

Micronaire in the F_1 MP comparisons exhibited significant heterosis only in cross 4 X 5 (Table 8); but no significant environmental effects were detected (Table 19). F_1 HP heterosis for micronaire was significant in crosses 1 X 5, 2 X 4, 3 X 4, and 4 X 5 (Table 8); heterosis inconsistencies were significant only in 2 X 4 for LY and in 4 X 5 for years (Table 19). In the F_2 MP comparisons, crosses 1 X 4, 1 X 5, and 2 X 5 gave significant heterosis (Table 8); but only the heterosis for 1 X 4 differed significantly over years (Table 19). Five of eight heterotic combinations were consistent over environments for micronaire.

Only crosses 2 X 3 and 2 X 4 had significant F_1 MP heterosis for T_1 (Table 9), but neither were significantly influenced by environment (Table 20). For F_1 HP heterosis, only cross 2 X 4 was heterotic (Table 9); and again it displayed no environmental influences (Table 20). For F_2 MP heterosis, crosses 1 X 2 and 4 X 5 were heterotic (Table 9), but no environmental influences were evident (Table 20). All five crosses displaying heterosis were consistent over environments.

Consistency of heterosis is summarized by cross for all traits in crosses previously displaying mean heterosis (Table 21). From the earlier discussion on mean heterosis, crosses 1 X 3, 1 X 4, and 3 X 5 were identified as highly promising for hybrid production while three crosses were eliminated and four others had demonstrated heterosis in an undesirable direction for one or more traits. Consistency of HP heterosis was displayed by all three crosses for lint yield. Crosses 1 X 4 and 3 X 5 exhibited inconsistency of heterosis for pulled lint percent over locations and years, respectively. The percentage of inconsistent heterosis (23.6 and 26.2%, respectively, for the two crosses) and the trait involved would likely not detract from their use in hybrid production.

While significant environmental effects occurred for the heterosis of almost all traits, the generally small magnitude of heterosis for the fiber properties probably would not justify evaluating them over a large number of locations and/or years. In most cases, the fiber properties of F_1 hybrids were intermediate between their parents; this is consistent with results reported by other researchers. Selection of parents with good fiber properties should provide adequate fiber properties in the resulting hybrids.

Lint yield is probably the single most important criterion in determining the potential economic value of a hybrid; therefore, those cross combinations which exhibit the greatest overall HP heterosis for yield and which do not exhibit significant and large environmental influences on that heterosis have the highest potential for commercial production. The cross combinations which displayed significant and large environmental effects, especially for lint yield, have questionable value since their performance is likely to be erratic.

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Table 1. Parental means for lint yield, lint percents, and fiber properties over three locations and 3 years.

Parent	Lint yield	Picked lint percent	Pulled lint percent	2.5% span length	50% span length	Uniformity index	Micronaire	1/8-inch gauge stel.
	$kg\ ha^{-1}$	------ % -------		------ mm ------		%	units	$kN\ m\ kg^{-1}$
Lockett 77	585 a*	34.8 a	25.5 a	27.10 b	12.90 b	47.7 a	3.8 c	176.6 a
Tamcot SP21	532 b	35.0 a	25.5 a	27.71 a	13.08 a	47.2 b	3.8 c	181.2 a
Paymaster 303	505 b	34.1 a	24.8 b	27.05 b	12.62 c	46.6 c	3.9 b	174.6 b
Tamcot SP37	532 b	34.4 a	25.3 ab	27.71 a	12.95 ab	46.8 c	3.6 d	174.2 b
Westburn M	550 ab	34.5 a	25.8 a	27.28 b	12.93 b	47.3 ab	4.1 a	183.4 a

* Means within a column followed by the same letter are not significantly different at the 0.05 probability level (protected LSD test).

Table 2. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP mean and percent heterosis averaged over locations and years for lint yield.

Cross		F_1 1†		2		3		4		5	
		kg ha^{-1}	% Het	kg ha^{-1}	% Het	kg ha^{-1}	% Het	kg ha^{-1}	% Het	kg ha^{-1}	% Het
	1 MP			55	10.0	131**	25.3**	64*	11.5*	126**	22.6**
	HP			32	5.2	110**	18.9**	70*	12.6*	103**	17.6**
	2 MP	48*	8.4*			83**	16.3**	120**	24.0**	68*	12.1*
	HP	---	---			49	8.9	104**	19.5**	34	5.7
F_2	3 MP	102**	18.6**	94**	17.9**			149**	29.2**	173**	34.0**
	HP	---	---	---	---			126**	23.8**	145**	26.6**
	4 MP	40*	7.3*	-3	-0.6	44*	8.4*			89**	17.0**
	HP	---	---	---	---	---	---			103**	18.7**
	5 MP	58**	10.4**	7	1.2	64**	12.1**	25	4.7		
	HP	---	---	---	---	---	---	---	---		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

Table 3. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP mean and percent heterosis averaged over locations and years for picked lint percent.

			F_1									
Cross			1†		2		3		4		5	
			%	% Het	%	% Het	%	% Het	%	% Het	%	% Het
	1	MP			-0.6*	-1.8*	0.8**	2.5**	0.3	0.9	0.1	0.3
		HP			-0.6	-1.6	0.8*	2.2*	0.4	1.0	0.0	0.0
	2	MP	-0.5	-1.3			0.3	0.9	0.4	1.3	0.2	0.5
		HP	---	---			-0.2	-0.7	0.2	0.7	-0.3	-0.9
F_2	3	MP	0.7**	2.1**	0.5	1.3			0.0	0.0	0.9**	2.7**
		HP	---	---	---	---			-0.2	-0.6	0.7	2.1
	4	MP	-0.2	-0.6	-0.3	-1.0	-0.7**	-2.0**			0.1	0.2
		HP	---	---	---	---	---	---			0.2	0.6
	5	MP	-0.1	-0.4	0.1	0.3	1.3**	3.8**	-0.1	-0.4		
		HP	---	---	---	---	---	---	---	---		

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

† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

Table 4. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP mean and percent heterosis averaged over locations and years for pulled lint percent.

Cross		F_1: 1†		2		3		4		5	
		%	% Het	%	% Het	%	% Het	%	% Het	%	% Het
	1 MP			-0.5	-2.1	0.9**	3.8**	0.7**	2.9**	0.8**	3.0**
	HP			-0.7	-2.5	0.9**	3.5**	0.8*	3.1*	0.4	1.5
	2 MP	0.0	0.0			0.1	0.3	0.5	1.9	0.2	0.9
	HP	---	---			-0.5	-2.1	0.7	2.6	0.1	0.3
F_2	3 MP	0.7**	2.8**	0.3	1.1			0.7**	3.0**	1.5**	6.1**
	HP	---	---	---	---			0.3	1.4	0.9**	3.4**
	4 MP	0.1	0.5	0.0	0.0	0.1	0.3			0.7*	2.7*
	HP	---	---	---	---	---	---			0.8*	3.2*
	5 MP	0.0	0.0	0.1	0.2	1.3**	5.2**	0.2	0.8		
	HP	---	---	---	---	---	---	---	---		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

Table 5. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP mean and percent heterosis averaged over locations and years for 2.5% span length.

Cross		F_1 1†		2		3		4		5	
		mm	% Het	mm	% Het	mm	% Het	mm	% Het	mm	% Het
	1 MP			0.84**	3.0**	0.61**	2.3**	0.38*	1.4*	0.86**	3.2**
	HP			0.47*	1.7*	0.76**	2.8**	0.16	0.6	0.86**	3.2**
	2 MP	0.25*	0.9*			0.61**	2.3**	0.20	0.7	0.41**	1.5**
	HP	---	---			0.18	0.6	0.28	1.0	0.22	0.8
F_2	3 MP	0.25	0.9	0.36**	1.3**			0.41*	1.5*	0.33*	1.2*
	HP	---	---	---	---			0.14	0.5	0.25	0.9
	4 MP	-0.03	-0.1	0.36**	1.3**	-0.30*	-1.0*			0.58**	2.2**
	HP	---	---	---	---	---	---			0.38	1.4
	5 MP	-0.23	-0.8	0.00	0.0	-0.03	-0.1	0.18	0.6		
	HP	---	---	---	---	---	---	---	---		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

Table 6. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP mean and percent heterosis averaged over locations and years for 50% span length.

			F_1									
Cross			1†		2		3		4		5	
			mm	% Het	mm	% Het	mm	% Het	mm	% Het	mm	% Het
	1	MP			0.28*	2.2*	0.20	1.5	0.18	1.5	0.38**	2.9**
		HP			0.23	1.8	0.25	2.0	0.21	1.6	0.43**	3.3**
	2	MP	-0.03	-0.2			0.38**	3.1**	0.05	0.5	0.28*	2.2*
		HP	---	---			0.06	0.5	-0.01	-0.0	0.22	1.7
F_2	3	MP	0.18	1.3	0.20*	1.5*			0.10	0.9	0.25*	2.0*
		HP	---	---	---	---			0.00	0.0	0.09	0.7
	4	MP	-0.03	-0.1	0.00	0.0	-0.15	-1.3			0.25*	2.0*
		HP	---	---	---	---	---	---			0.24	1.8
	5	MP	-0.05	-0.4	0.08	0.7	0.03	0.1	-0.15	-1.2		
		HP	---	---	---	---	---	---	---	---		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

Table 7. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP mean and percent heterosis averaged over locations and years for uniformity index.

		F_1									
Cross		1†		2		3		4		5	
		%	% Het	%	% Het	%	% Het	%	% Het	%	% Het
	1 MP			-0.3	-0.7	-0.3	-0.7	0.0	0.0	-0.1	-0.3
	HP			-0.8*	-1.6*	-0.4	-0.8	-0.4	-0.9	-0.3	-0.7
	2 MP	-0.5	-1.0			0.4	0.9	-0.1	-0.3	0.3	0.6
	HP	---	---			0.0	0.0	-0.5	-1.1	0.2	0.4
F_2	3 MP	0.2	0.5	0.1	0.2			-0.3	-0.6	0.4	0.8
	HP	---	---	---	---			-0.2	-0.5	-0.1	-0.2
	4 MP	0.0	0.0	-0.6*	-1.3*	-0.1	-0.1			-0.1	-0.2
	HP	---	---	---	---	---	---			-0.4	-0.8
	5 MP	0.6*	1.3*	0.3	0.6	0.1	0.3	-0.8**	-1.8**		
	HP	---	---	---	---	---	---	---	---		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

Table 8. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP mean and percent heterosis averaged over locations and years for micronaire.

		F_1									
Cross		1†		2		3		4		5	
		units	% Het	units	% Het	units	% Het	units	% Het	units	% Het
1	MP			0.0	0.0	0.1	1.7	0.0	0.0	-0.1	-1.9
	HP			0.0	0.0	0.0	0.0	-0.1	-2.1	-0.2**	-5.2**
2	MP	-0.1	-2.3			0.0	0.0	0.0	0.0	0.0	0.0
	HP	---	---			-0.1	-2.8	-0.1*	-3.2*	-0.1	-2.5
F_2 3	MP	0.0	0.0	0.0	0.0			-0.1	-2.2	0.0	0.0
	HP	---	---	---	---			-0.2**	-5.0**	0.0	0.0
4	MP	0.1*	2.4*	-0.1	-1.4	0.0	0.0			-0.2**	-4.8**
	HP	---	---	---	---	---	---			-0.4**	-9.4**
5	MP	-0.1*	-2.4*	0.1**	3.5**	0.0	0.0	-0.1	-1.8		
	HP	---	---	---	---	---	---	---	---		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

Table 9. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP mean and percent heterosis averaged over locations and years for 1/8-inch gauge stelometer.

Cross		F_1 1†		2		3		4		5	
		kN m kg^{-1}	% Het	kN m kg^{-1}	% Het	kN m kg^{-1}	% Het	kN m kg^{-1}	% Het	kN m kg^{-1}	% Het
	1 MP			1.2	0.7	-0.2	-0.1	2.2	1.3	2.4	1.3
	HP			-0.2	-0.1	-0.2	-0.1	0.5	0.3	-0.1	-0.0
	2 MP	3.9*	2.2*			4.5*	2.5*	-4.4*	-2.4*	2.4	1.3
	HP	---	---			1.8	1.0	-7.5**	-4.1**	-0.2	-0.1
F_2	3 MP	2.9	1.7	0.5	0.3			0.1	0.1	0.6	0.3
	HP	---	---	---	---			-0.5	-0.3	-3.4	-1.8
	4 MP	-0.9	-0.5	-3.3	-1.8	-1.5	-0.8			1.4	0.8
	HP	---	---	---	---	---	---			-3.8	-2.1
	5 MP	1.1	0.6	-1.3	-0.7	-1.4	-0.8	-4.0*	-2.2*		
	HP	---	---	---	---	---	---	---	---		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

Table 10. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP heterosis effects summarized by cross for all traits.

Cross	Lint yield	Picked lint percent	Pulled lint percent	2.5% span length	50% span length	Uniformity index	Micronaire	1/8-in. gauge stel.
				F_1 MP Heterosis				
1 X 2†	--	*	--	**	*	--	--	--
1 X 3	**	**	**	**	--	--	--	--
1 X 4	*	--	**	*	--	--	--	--
1 X 5	**	--	**	**	**	--	--	--
2 X 3	**	--	--	**	**	--	--	*
2 X 4	**	--	--	--	--	--	--	*
2 X 5	*	--	--	**	*	--	--	--
3 X 4	**	--	**	*	--	--	--	--
3 X 5	**	**	**	*	*	--	--	--
4 X 5	**	--	*	**	*	--	**	--
				F_1 HP Heterosis				
1 X 2	--	--	--	*	--	*	--	--
1 X 3	**	*	**	**	--	--	--	--
1 X 4	*	--	*	--	--	--	--	--
1 X 5	**	--	--	**	**	--	**	--
2 X 3	--	--	--	--	--	--	--	--
2 X 4	**	--	--	--	--	--	*	**
2 X 5	--	--	--	--	--	--	--	--
3 X 4	**	--	--	--	--	--	**	--
3 X 5	**	--	**	--	--	--	--	--
4 X 5	**	--	*	--	--	--	**	--
				F_2 MP Heterosis				
1 X 2	*	--	--	*	--	--	--	*
1 X 3	**	**	**	--	--	--	--	--
1 X 4	*	--	--	--	--	--	*	--
1 X 5	**	--	--	--	--	*	*	--
2 X 3	**	--	--	**	*	--	--	--
2 X 4	--	--	--	**	--	*	--	--
2 X 5	--	--	--	--	--	--	**	--
3 X 4	*	**	--	*	--	--	--	--
3 X 5	**	**	**	--	--	--	--	--
4 X 5	--	--	--	--	--	**	--	*

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

† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

Table 11. Mean squares for general (GCA) and specific combining ability (SCA) effects for heterosis and interactions with locations, years, and locations by years for F_1 midparent heterosis.

	Mean squares†								
Trait	GCA	SCA	GCA X loc	SCA X loc	GCA X year	SCA X year	GCA X loc X year	SCA X loc X year	Error
Lint yield	33262*	17453	5638	15219	11448	7895	13873	15538	12168
Picked lint percent	3.07	4.15	4.34*	2.36	3.24	4.66*	2.61	5.27**	1.91
Pulled lint percent	10.17**	2.53	3.07*	1.26	3.47*	3.94**	3.88**	3.00*	1.45
2.5% span length‡	1.605	1.219	0.941	1.060	0.889	0.754	0.533	0.685	0.741
50% span length‡	0.416	0.254	0.498	0.685	0.973*	0.239	0.319	0.544	0.369
Uniformity index	1.78	1.54	1.07	2.64	6.65**	1.84	2.06	3.50**	1.72
Micronaire	0.10	0.10	0.08	0.02	0.15**	0.02	0.04	0.08*	0.05
1/8-inch gauge stelometer	0.55	1.53	1.25	1.23	1.38	0.48	0.70	1.10	0.89

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Degrees of freedom for GCA, SCA,..., Error were 4, 5, 8, 10, 8, 10, 16, 20, and 99, respectively.
‡ Mean squares should be multiplied by 10^{-3}.

Table 12. Mean squares for general (GCA) and specific combining ability (SCA) effects for heterosis and interactions with locations, years, and locations by years for F_2 midparent heterosis.

	Mean squares†								
Trait	GCA	SCA	GCA X loc	SCA X loc	GCA X year	SCA X year	GCA X loc X year	SCA X loc X year	Error
Lint yield	55034**	7040	14449	12402	34970**	26697**	17287	20374**	10240
Picked lint percent	15.94**	7.93**	2.23	3.30	2.57	6.19**	4.80**	4.88**	2.02
Pulled lint percent	7.27**	4.20*	1.46	1.88	2.79	6.22**	4.73**	3.66**	1.46
2.5% span length‡	2.471*	2.780**	0.776	1.165	2.327**	2.097**	0.565	1.117	0.757
50% span length‡	0.953	0.434	0.352	0.658	0.841	0.530	0.397	0.632	0.458
Uniformity index	7.46*	5.31*	2.04	1.87	2.25	4.43*	1.22	1.79	2.23
Micronaire	0.02	0.31**	0.06	0.04	0.16*	0.10	0.09	0.05	0.06
1/8-inch gauge stelometer	4.41**	0.22	1.44	0.60	1.17	1.37	1.40	0.77	1.01

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Degrees of freedom for GCA, SCA,..., Error were 4, 5, 8, 10, 8, 10, 16, 20, and 216, respectively.
‡ Mean squares should be multiplied by 10^{-3}.

Table 13. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP heterosis percentages of total variance due to the inconsistency of heterosis over locations, years, and locations by years for lint yield.

		F_1									
Cross	Source	1†		2		3		4		5	
		MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
	Locations (L)			42.0**	55.5**	0.0	0.0	0.0	0.0	0.0	0.0
1	Years (Y)			0.0‡	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	L X Y			19.9	1.5	0.0	0.0	7.0	41.3	19.4	34.0
	Locations	0.0	---			0.0	2.6	0.0	12.6*	10.0	30.7**
2	Years	3.1	---			33.1*	1.6	0.0	0.0	35.4*	35.5**
	L X Y	0.0	---			0.0	0.0	35.5	44.0*	2.4	0.0
	Locations	0.0	---	0.0	---			0.0	0.0	0.0	0.0
F_2 3	Years	18.5**	---	19.7*	---			0.0	0.0	4.3	21.1
	L X Y	43.0**	---	15.9	---			62.4*	25.7	0.0	0.0
	Locations	0.0	---	7.6	---	0.0	---			0.0	0.0
4	Years	0.0	---	9.0	---	0.0	---			0.0	0.0
	L X Y	8.7	---	0.0	---	0.1	---			31.9	64.2**
	Locations	5.0	---	0.0	---	0.0	---	0.0	---		
5	Years	0.0	---	17.8*	---	0.0	---	2.6	---		
	L X Y	5.2	---	16.9	---	0.0	---	0.0	---		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.
‡ Most zeroes denote negative variance components for which zero is the most reasonable value.

Table 14. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP heterosis percentages of total variance due to the inconsistency of heterosis over locations, years, and locations by years for picked lint percent.

		F_1									
Cross	Source	1†		2		3		4		5	
		MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
	Locations (L)			0.0‡	0.0	0.0	0.0	52.2**	41.6**	0.0	0.0
1	Years (Y)			0.0	0.0	0.0	0.0	0.0	0.0	7.2	19.3
	L X Y			67.3**	64.0**	0.0	0.0	0.0	14.3	20.4	5.2
	Locations	0.0	---			0.0	0.0	0.0	0.0	0.0	0.0
2	Years	4.8	---			7.6	26.5	31.4*	19.4	5.8	6.3
	L X Y	3.4	---			0.0	0.0	0.0	0.0	16.0	34.0
	Locations	0.0	---	28.6*	---			7.4*	0.0	0.0	1.4
F_2 3	Years	0.0	---	2.2	---			32.6**	49.6**	21.8*	11.8*
	L X Y	71.2**	---	0.0	---			35.4*	0.1	23.8	35.8
	Locations	0.0	---	2.8	---	14.6	---			0.0	0.0
4	Years	0.0	---	3.7	---	0.0	---			9.8	0.0
	L X Y	13.1	---	0.0	---	3.7	---			9.3	23.2
	Locations	0.0	---	0.0	---	0.0	---	5.7	---		
5	Years	14.3*	---	12.2**	---	4.4	---	0.0	---		
	L X Y	20.3	---	36.2*	---	0.0	---	0.0	---		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.
‡ Most zeroes denote negative variance components for which zero is the most reasonable value.

Table 15. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP heterosis percentages of total variance due to the inconsistency of heterosis over locations, years, and locations by years for pulled lint percent.

	Cross	Source	F_1									
			1†		2		3		4		5	
			MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
F_2	1	Locations (L)			0.0‡	0.0	0.0	0.0	13.6	23.6*	0.0	0.0
		Years (Y)			0.0	0.0	0.0	0.0	9.2	0.0	12.2*	0.0
		L X Y			59.2*	64.1**	0.0	0.0	7.9	20.6	43.1*	37.8
	2	Locations	0.0	---			0.0	0.0	0.0	0.0	0.0	24.9*
		Years	5.5	---			0.0	20.6	14.8	0.0	0.0	0.0
		L X Y	10.6	---			0.0	0.0	27.6	10.5	35.8	19.8
	3	Locations	0.0	---	7.4	---			0.0	0.0	0.0	0.0
		Years	0.0	---	0.0	---			27.1*	39.0*	32.9*	26.2*
		L X Y	68.2**	---	0.0	---			21.9	13.7	10.8	17.7
	4	Locations	0.0	---	9.6	---	15.7	---			0.0	0.0
		Years	0.0	---	12.6	---	0.0	---			42.0*	24.4*
		L X Y	22.5	---	0.0	---	0.0	---			7.4	23.1
	5	Locations	0.0	---	0.0	---	0.0	---	3.0	---		
		Years	26.8*	---	0.0	---	2.2	---	4.5	---		
		L X Y	2.9	---	63.0**	---	0.0	---	21.8	---		

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

† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

‡ Most zeroes denote negative variance components for which zero is the most reasonable value.

Table 16. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP heterosis percentages of total variance due to the inconsistency of heterosis over locations, years, and locations by years for 2.5% span length.

Cross	Source	F_1									
		1†		2		3		4		5	
		MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
F_2 1	Locations (L)			0.0‡	0.0	0.0	0.0	20.8	0.0	0.0	0.0
	Years (Y)			20.2*	20.6*	0.0	0.0	0.0	0.0	0.0	0.0
	L X Y			24.4	33.9	0.0	7.6	0.0	0.0	10.1	0.0
2	Locations	0.0	---			0.0	0.0	0.0	0.0	11.0	0.0
	Years	0.0	---			53.5**	23.8	0.0	29.4**	26.6*	29.4*
	L X Y	0.0	---			0.0	0.0	65.3**	49.9**	0.0	0.0
3	Locations	9.5	---	1.0	---			44.4*	12.4**	0.0	0.0
	Years	27.8*	---	29.3*	---			0.0	0.0	9.6	8.8
	L X Y	5.0	---	0.0	---			2.1	56.4*	0.0	0.0
4	Locations	0.0	---	2.2	---	0.0	---			0.0	0.0
	Years	5.0	---	4.8	---	8.5	---			16.4	6.5
	L X Y	0.0	---	8.8	---	6.8	---			0.0	0.0
5	Locations	22.4**	---	0.0	---	0.0	---	0.0	---		
	Years	30.7**	---	4.8	---	0.0	---	6.3	---		
	L X Y	0.0	---	8.4	---	16.6	---	0.0	---		

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

† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

‡ Most zeroes denote negative variance components for which zero is the most reasonable value.

Table 17. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP heterosis percentages of total variance due to the inconsistency of heterosis over locations, years, and locations by years for 50% span length.

Cross		Source	F_1									
			1†		2		3		4		5	
			MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
	1	Locations (L)			0.0‡	0.0	0.0	0.0	2.9	1.4	0.0	0.0
		Years (Y)			0.0	0.0	0.0	0.0	0.0	12.9	0.0	0.0
		L X Y			0.0	0.0	0.0	0.0	0.0	0.0	6.1	0.0
	2	Locations	0.0	---			1.9	0.0	17.8*	24.5*	0.0	0.0
		Years	8.5	---			2.8	0.0	40.7**	41.1**	7.7	29.9*
		L X Y	15.5	---			0.0	0.0	2.0	0.0	21.8	6.6
	3	Locations	0.0	---	0.0	---			20.9**	0.0	0.0	0.0
F_2		Years	5.5*	---	12.4	---			0.0	0.0	18.5*	29.0*
		L X Y	29.5*	---	0.0	---			47.3*	81.8**	28.8	7.1
	4	Locations	0.0	---	0.0	---	0.0	---			11.2	11.1*
		Years	0.0	---	0.0	---	15.4	---			53.9**	24.2**
		L X Y	0.0	---	8.2	---	0.0	---			0.0	33.5
	5	Locations	12.4	---	0.0	---	0.0	---	0.0	---		
		Years	0.0	---	0.0	---	0.0	---	0.0	---		
		L X Y	2.9	---	30.0*	---	0.0	---	0.2	---		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.
‡ Most zeroes denote negative variance components for which zero is the most reasonable value.

Table 18. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP heterosis percentages of total variance due to the inconsistency of heterosis over locations, years, and locations by years for uniformity index.

	Cross	Source	F_1 1†		2		3		4		5	
			MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
		Locations (L)			0.0‡	0.0	0.0	0.0	0.0	0.0	18.2	19.4
	1	Years (Y)			0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6
		L X Y			0.0	0.0	23.4	13.8	0.0	5.4	0.0	0.0
		Locations	0.0	---			14.5	0.0	0.0	0.0	0.0	0.0
	2	Years	12.0	---			5.1	0.0	38.1*	13.2	0.0	0.0
		L X Y	0.0	---			0.0	0.0	13.0	27.4	35.4	34.7
		Locations	0.0	---	6.5	---			0.0	0.0	0.0	0.0
F_2	3	Years	0.0	---	0.0	---			0.0	0.0	26.1*	22.1
		L X Y	4.9	---	0.0	---			62.5*	65.5**	17.5	13.0
		Locations	0.0	---	0.0	---	0.0	---			20.9*	0.0
	4	Years	0.0	---	0.0	---	5.4	---			35.3*	32.0*
		L X Y	0.0	---	0.0	---	0.0	---			0.0	0.0
		Locations	0.0	---	0.0	---	5.4	---	0.0	---		
	5	Years	11.2	---	24.6**	---	8.3	---	0.0	---		
		L X Y	0.0	---	19.2	---	0.0	---	0.0	---		

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

† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

‡ Most zeroes denote negative variance components for which zero is the most reasonable value.

Table 19. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP heterosis percentages of total variance due to the inconsistency of heterosis over locations, years, and locations by years for micronaire.

			F_1									
	Cross	Source	1†		2		3		4		5	
			MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
		Locations (L)			0.0‡	0.0	8.9	0.0	0.0	0.0	0.0	0.0
	1	Years (Y)			0.0	0.0	0.0	0.0	35.2*	20.2	0.0	0.0
		L X Y			0.0	0.0	37.5	39.3	1.8	0.0	12.5	37.1
		Locations	0.4	---			0.0	0.0	0.0	0.0	0.0	23.4
	2	Years	26.1*	---			0.0	0.0	0.0	0.0	0.0	0.0
		L X Y	0.0	---			0.0	0.0	61.2*	53.7*	12.5	0.0
		Locations	0.0	---	0.0	---			6.3	1.8	9.4	20.8
F_2	3	Years	0.0	---	0.0	---			36.5*	23.6	0.0	0.0
		L X Y	0.0	---	0.0	---			0.0	0.0	0.0	0.0
		Locations	0.0	---	0.0	---	12.0	---			0.0	0.0
	4	Years	37.1**	---	0.0	---	3.7	---			28.0	12.4*
		L X Y	11.4	---	0.0	---	0.0	---			0.0	37.4
		Locations	0.0	---	0.0	---	0.0	---	0.0	---		
	5	Years	0.0	---	0.0	---	20.0*	---	0.0	---		
		L X Y	0.0	---	0.0	---	0.0	---	16.4	---		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.
‡ Most zeroes denote negative variance components for which zero is the most reasonable value.

Table 20. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP heterosis percentages of total variance due to the inconsistency of heterosis over locations, years, and locations by years for 1/8-inch gauge stelometer.

			F_1								
Cross	Source	1†		2		3		4		5	
		MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
	1 Locations (L)			0.0‡	0.0	9.0	16.5	24.1*	40.1**	0.0	0.0
	1 Years (Y)			10.9	10.5	0.0	4.3	40.4**	15.3	0.0	0.0
	1 L X Y			17.9	3.3	0.0	0.0	0.0	0.0	0.0	0.0
	2 Locations	10.6	---			5.4	11.2	8.1	0.0	17.0	0.0
	2 Years	0.0	---			0.0	0.0	0.0	0.0	0.0	0.0
	2 L X Y	0.0	---			0.0	2.9	15.7	0.0	0.0	0.0
F_2	3 Locations	0.0	---	1.0	---			0.0	0.0	0.0	0.0
	3 Years	0.0	---	11.5	---			0.0	0.0	0.0	0.0
	3 L X Y	3.0	---	0.0	---			15.2	13.1	0.0	0.0
	4 Locations	0.0	---	0.0	---	0.0	---			6.5	0.0
	4 Years	0.0	---	0.0	---	0.0	---			0.0	0.0
	4 L X Y	0.0	---	0.0	---	0.0	---			0.0	0.0
	5 Locations	0.6	---	0.0	---	0.0	---	10.1	---		
	5 Years	14.5	---	10.8	---	0.0	---	0.0	---		
	5 L X Y	3.0	---	0.0	---	9.6	---	0.0	---		

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

† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

‡ Most zeroes denote negative variance components for which zero is the most reasonable value.

Table 21. F_1 midparent (MP), F_1 high parent (HP), and F_2 MP heterosis percentages of total variance due to the inconsistency of heterosis over locations, years, and locations by years summarized by cross for all traits in crosses displaying mean heterosis.

Cross	Lint yield	Picked lint percent	Pulled lint percent	2.5% span length	50% span length	Uniformity index	Micronaire	1/8-in. gauge stel.
				F_1 MP Heterosis				
1 X 2†	0‡	-,-,**	0	-,*,-	-,-,-	0	0	0
1 X 3	-,-,-§	-,-,-	-,-,-	-,-,-	0	0	0	0
1 X 4	-,-,-	0	-,-,-	-,-,-	0	0	0	0
1 X 5	-,-,-	0	-,*,*	-,-,-	-,-,-	0	0	0
2 X 3	-,*,-	0	0	-,**,-	-,-,-	0	0	-,-,-
2 X 4	-,-,-	0	0	0	0	0	0	-,-,-
2 X 5	-,*,-	0	0	-,*,-	-,-,-	0	0	0
3 X 4	-,-,*	0	-,*,-	*,-,-	0	0	0	0
3 X 5	-,-,-	-,*,-	-,*,-	-,-,-	-,*,-	0	0	0
4 X 5	-,-,-	0	-,*,-	-,-,-	-,**,-	0	-,-,-	0
				F_1 HP Heterosis				
1 X 2	0	0	0	-,*,-	0	-,-,-	0	0
1 X 3	-,-,-	-,-,-	-,-,-	-,-,-	0	0	0	0
1 X 4	-,-,-	0	*,-,-	0	0	0	0	0
1 X 5	-,-,-	0	0	-,-,-	-,-,-	0	-,-,-	0
2 X 3	0	0	0	0	0	0	0	0
2 X 4	*,-,*	0	0	0	0	0	-,-,*	-,-,-
2 X 5	0	0	0	0	0	0	0	0
3 X 4	-,-,-	0	0	0	0	0	-,-,-	0
3 X 5	-,-,-	0	-,*,-	0	0	0	0	0
4 X 5	-,-,**	0	-,*,-	0	0	0	-,*,-	0
				F_2 MP Heterosis				
1 X 2	-,-,-	0	0	-,-,-	0	0	0	-,-,-
1 X 3	-,**,**	-,-,**	-,-,**	0	0	0	0	0
1 X 4	-,-,-	0	0	0	0	0	-,**,-	0
1 X 5	-,-,-	0	0	0	0	-,-,-	-,-,-	0
2 X 3	-,*,-	0	0	-,*,-	-,-,-	0	0	0
2 X 4	0	0	0	-,-,-	0	-,-,-	0	0
2 X 5	0	0	0	0	0	0	-,-,-	0
3 X 4	-,-,-	-,-,-	0	-,-,-	0	0	0	0
3 X 5	-,-,-	-,-,-	-,-,-	0	0	0	0	0
4 X 5	0	0	0	0	0	-,-,-	0	-,-,-

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

† Parents 1 through 5 are 'Lockett 77', 'Tamcot SP21', 'Paymaster 303', 'Tamcot SP37', and 'Westburn M', respectively.

‡ Cross combination did not exhibit mean heterosis.

§ Location, year, and location by year, respectively.

VITA 2

Bruce Eldon Greenhagen

Candidate for the Degree of

Master of Science

Thesis: MAGNITUDE AND CONSISTENCY OF HETEROSIS IN CROSSES AMONG PLAINS-TYPE COTTON CULTIVARS

Major Field: Agronomy

Biographical:

Personal Data: Born June 6, 1954, in Newkirk, Oklahoma, the son of Eldon K. and Betty J. Greenhagen. Married Bobbie S. Timmons on March 23, 1974.

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