

Relative Performance of F_1 and F_2 Hybrids from Doubled Haploids and Their Parent Varieties in Upland Cotton, *Gossypium hirsutum* L.¹

William R. Meredith, Jr., R. R. Bridge, and J. F. Chism²

ABSTRACT

Three doubled haploids were compared to their parent varieties in their ability to produce F_1 and F_2 hybrids, their interaction with locations, and the type of gene action involved. Doubled haploids were similar to their parent varieties in productivity of their crosses, interaction with locations, and type of gene action. Both F_1 and F_2 hybrids tended to give more consistent performances over all four locations than their parents. For lint yield, F_1 hybrids were no better than the highest yielding parents. However, the F_1 hybrids produced better combinations of yield and fiber properties. Lint yield and its components showed considerable dominance effects while fiber properties tended to be inherited in an additive manner. For the six crosses and nine characteristics studied, only one case of significant epistasis was detected.

The minimum within-variety variability makes doubled haploids a useful tool in many genetic experiments. However, there is no indication that, in a cotton breeding program, doubled haploids differ from other varieties of similar genetic background.

Additional key word: Gene action.

DOUBLED haploids are of interest to research workers because they afford an easy way of obtaining genetically pure lines. The production of large numbers of doubled haploids is now possible by the use of the semigamy phenomenon as developed and reported by Turcotte and Feaster (13). Chase (2) has postulated that doubled haploids may also have special breeding value as parents in producing hybrids. He stated that selection against deleterious genes or combinations of genes on haploids should result in establishing lines probably better than unselected lines from the same population. Harlan (4) discussed their use in the production of synthetic varieties.

Meyer (6) discussed the properties of doubled haploids in cotton and strongly urged that they be used more in breeding programs, especially in the production of hybrids. In the few experiments in which the breeding value of both doubled haploids and other cultivars were studied, the results were not conclusive. Miller and Lee (7) in a series of topcrosses found that the doubled haploid 'M8' combined well with the recurrent variety 'Coker 100A.' In the same study another doubled haploid 'Z106' was below average in combining ability. Our primary objective of this study was to compare the ability of doubled haploids with their parent varieties in the production of F_1 and F_2 hybrids.

A second objective was to investigate the interaction effect with locations by doubled haploids, parent

varieties, and F_1 and F_2 hybrids. According to Dobzhansky and Wallace (3) heterozygosity in cross-pollinated species gives greater adaptation and stability over varying environments than homozygosity. If this is the case in predominantly self-pollinated crops, like cotton, we would expect the F_1 and F_2 hybrids to be more stable and have smaller interaction mean squares than their parents. Kohel (5), working with individual cotton plants studied F_1 hybrids from eight doubled haploids and one pure line. He found that hybrids were not less variable than parents. He concluded that heterozygosity in cotton probably does not condition greater adaptability. A second factor that conditions greater stability, according to these authors (3), is polymorphism. A population that is genetically heterogeneous would be expected to be more stable than one completely homozygous such as doubled haploids.

A third objective was to study and compare the nature of gene action of doubled haploids and their parent varieties. Bridge (1) and Miller (10) have investigated the genetic and environmental variances of cotton varieties. In general, they found the genotype by environment component of variance was largest for yield and its components. While the interaction of genotypes and environments for fiber properties was frequently significant, the variety component was of much greater magnitude.

Several workers (6, 8, and 14) found that the major portion of genetic variability for lint yield and its components is due to additive effects. For yield and its components, the nonadditive portion has been explainable mostly on a dominance model. However, Miller and Marani (8), Ramey (12), and Marani (10,11) reported significant epistasis in some crosses. The size and frequency of epistatic effects has usually been small. Fiber properties had very small nonadditive components of genetic variance.

"How do doubled haploids differ in behavior from their parents on a population basis?" formed the major objective of this report.

MATERIALS AND METHODS

We used three doubled haploids, M-71, 63-3, and M-73, and their parent varieties, 'Stoneville 213,' 'Acala 1517D,' and 'PD-246,' respectively. The plants of M-71 and M-73 used in this study were three generations away from the original haploid. The other doubled haploid, 63-3, was obtained from the Arizona breeding program and is assumed to be several generations from the original haploid plant. We used two groups of parents and crosses. One group consisted of the three doubled haploids, their three F_1 hybrids, and their three F_2 hybrids. The other corresponding group consisted of three parental varieties, three F_1 hybrids, and three F_2 hybrids. Seed of the parental varieties were obtained from the breeder producing them. The 18 treatments were grown at four locations in the Mississippi Delta in 1968. Planting dates varied from April 17 to May 8. Each plot consisted of 2 rows, 1 m apart and 16 m long. The experimental design was a randomized complete block with four replications. All plots were harvested twice by a mechanical picker modified to handle small plots.

Fifty-boll samples were taken from each plot prior to first harvest. The samples from the first two replications were bulked

¹ Cooperative investigation, Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture, and the Delta Branch of the Mississippi Agricultural Experiment Station, Stoneville, Miss. Published as Journal Paper 1766 of the Mississippi Agr. Exp. Sta. Received Aug. 23, 1969.

² Research Geneticist, Crops Research Division, ARS, USDA, Stoneville, Miss.; Plant Breeder, Delta Branch Experiment Station, Mississippi Agr. Exp. Sta., Stoneville, Miss.; and Research Associate, Delta Branch Experiment Station, Stoneville, Miss.

to form a composite and the last two replications bulked to form another. Lint percent was determined from saw-ginned composite samples. The average treatment lint percent for a given location was multiplied by its seed cotton yield per plot to obtain the lint yield per plot. To estimate boll size, the average weight in grams per boll of the composite samples was used. The weight of 200 seeds from each composite sample was used to obtain seed index estimates.

Fiber length was measured as 50% and 2.5% span length on a Digital Fibrograph. Strength (T_1) expressed as grams per tex and elongation (E_1) were measured with the $\frac{1}{8}$ -inch gauge Stelometer. Fiber fineness is expressed in micronaire units. Fiber determinations were made by the U.S. Cotton Fiber Laboratory of the Crops Research Division, ARS, USDA, at Knoxville, Tenn.

The statistical evaluation was made in the usual manner for one involving 18 treatments and 4 locations, except that the treatment and treatment by location components were further partitioned. The 17 degrees of freedom for treatments were partitioned into 1 for doubled haploid versus parental varieties, 8 within the variety group, and 8 within the doubled haploid group. The latter two components were each further partitioned into 2 for generations (parents, F_1 , and F_2), 2 for variation among parents of crosses, 2 for variation among F_1 hybrids, and 2 for variation among F_2 hybrids. We also used the same approach (Table 2) of partitioning into orthogonal comparisons the 51 degrees of freedom associated with the treatment by location interaction component.

Table 3 presents differences in interaction components between parents and their F_1 and F_2 hybrids. The interaction mean squares for the three doubled haploid parents and the three variety parents is combined from Table 2, to give the interaction component for parents. Also the interaction mean squares among all hybrid populations are combined to give the hybrid \times location interaction component as given in Table 3. We used the hybrid populations interaction mean square as the lower variance for an F test with the parents by locations interactions mean square. We assumed that F_1 hybrids would interact with locations to no greater degree than their parents. The "t" test was used to test for significance of gene effects or for the difference in gene effects.

Heterosis was expressed as percent deviation of the F_1 hybrids from the average of the parents, $100 \times (F_1 - MP)/MP$ where MP is the average of the parents. A significant deviation of the mean of F_1 and MP from the F_2 expressed as percent of the MP, $100 \times [F_2 - \frac{1}{2}(F_1 + MP)]/MP$ was used as an indication of the presence of epistatic effects.

RESULTS

Comparisons of Doubled Haploid and Parent Varieties

The comparisons of doubled haploids with their parent varieties and their respective F_1 and F_2 hybrids are given in Table 1. Significant differences

between doubled haploids and their three parent varieties were detected at least once for every characteristic except lint yield. M-71 differed from Stoneville 213 only in lint percentage. M-73 differed from PD-246 in four fiber properties. Doubled haploid 63-3 differed from Acala 1517D in six of the nine characters measured. The hybrids from doubled haploids and parent varieties also exhibited some differences. For the hybrid comparisons only one significant difference in yield was detected. This was the F_1 comparison between Acala 1517D \times PD-246 and 63-3 \times M-73. The differences in lint percentage, boll size, and fiber properties between 63-3 and Acala 1517D are also evident in their hybrids.

Interaction with Locations

We partitioned the 51 degrees of freedom associated with interaction mean square estimates (Table 2). Although significant interactions were detected for most characteristics, the interaction effects are relatively small as compared to the main effects. The three degrees of freedom comparison for variety and doubled haploid interactions with locations was not significant for any characteristic. The two 24 degrees of freedom comparisons involving variation among variety-derived populations and variation among doubled haploid-derived population produced mean squares of similar magnitude. Further partitioning into six degrees of freedom comparisons indicated no trends between variety or doubled haploid derived populations. However, the data suggest that parents tend to have larger interaction mean squares than their F_1 and F_2 hybrid populations.

In Table 3 the interaction mean squares for parents and doubled haploids are pooled and compared with the pooled interaction mean squares for hybrids. For every characteristic the hybrids have lower interaction mean squares than the parents of the hybrids. Using the hybrid interaction mean square as the lower variance, F test indicated these differences were significant for five of the nine characteristics measured.

Gene Action

The significant variation among generations, parents, and F_1 and F_2 hybrids, as indicated in Table 2 for lint yield, boll size, 2.5% span length, and micro-

Table 1. Mean performance from four locations of doubled haploid and variety populations for lint yield, yield components, and fiber properties.

Parental types	Lint yield, kg/ha	Yield components			Fiber properties				
		Lint %	Boll size	Seed index	.50	2.5%	T_1	E_1	Micro-naire
St. 213	1,271	40.0	5.82	10.6	.54	1.12	19.1	6.8	4.9
M-71	1,343	40.6*	5.84	10.5	.53	1.11	18.6	6.9	4.9
Acala 1517D	917	36.1**	6.35	13.0	.59	1.18	24.0	6.3	4.3
63-3	865	32.0	6.74**	14.1**	.62**	1.20	25.9**	5.7**	4.2
PD-246	950	37.0	6.63	12.5	.57	1.14	22.4*	5.5	4.4
M-73	959	36.9	6.63	12.4	.57	1.18**	21.6	5.8*	4.2**
F_1 St. 213 \times Acala	1,325	38.5**	6.57	12.0	.58	1.16	21.0	6.5**	4.6
F_1 M-71 \times 63-3	1,278	37.1	7.00**	12.6	.60	1.19**	22.0**	6.0	4.6
F_2 St. 213 \times Acala	1,130	38.5**	6.28	11.5	.58	1.15	21.0	6.4*	4.7
F_2 M-71 \times 63-3	1,195	36.6	6.76**	12.7	.58	1.17	21.7*	6.1	4.7
F_1 St. 213 \times PD-246	1,280	38.0	6.52	11.6	.56	1.18	20.8*	6.2	4.3
F_1 M-71 \times M-73	1,301	37.9	7.08**	11.5	.56	1.18	20.0	6.3	4.3
F_2 St. 213 \times PD-246	1,135	38.5	6.23	11.3	.56	1.16	21.0*	5.9	4.4
F_2 M-71 \times M-73	1,211	38.3	6.34	11.5	.57	1.17	20.4	6.3**	4.4
F_1 Acala \times PD-246	1,129*	37.1**	6.85	12.7	.60	1.23**	23.1	5.9	4.2
F_1 63-3 \times M-73	1,034	35.8	7.48**	13.1	.59	1.20	23.0	5.8	4.4
F_2 Acala \times PD-246	1,014	36.3	6.87	12.8	.59	1.20	23.5	5.7	4.3
F_2 63-3 \times M-73	979	35.8	6.87	13.0	.58	1.19	23.0	5.8	4.3
CV%	10.7	1.7	4.4	3.5	3.5	2.0	2.9	4.6	3.1

* and ** indicates statistical significantly better at the .05 and .01 level, respectively, than its comparable variety or doubled haploid population.

Table 2. Mean square estimates for lint yield, yield components, and fiber properties from doubled haploids and their parental variety populations.

Source	d.f.	Lint yield	Yield components			Fiber properties				
			Lint %	Boll size	Seed index	50%	2.5%	T ₁	E ₁	Micro-naire
Var. vs DH	1	1	36.40**	3.52**	5.14**	.00033	.00001	0.05	0.117	0.002
Var. Pop.	8	2,465**	12.51**	5.91**	5.05**	.00247**	.00851**	19.77**	1.367**	0.444**
Gen.	2	3,717**	0.23	0.88**	0.35	.00133	.00458**	0.46	0.237	0.135**
Par.	2	4,390**	32.41**	1.36**	12.40**	.00429**	.01245**	48.31**	3.150**	0.751**
F ₁	2	1,209**	4.26**	0.25	2.29*	.00252	.01085**	13.01**	0.877**	0.457**
F ₂	2	542**	13.13**	0.47*	5.18**	.00174	.00615**	17.28**	1.206**	0.435**
DH Pop.	8	3,462**	43.00**	13.90**	9.24**	.00436**	.00608**	34.72**	1.101**	0.463**
Gen.	2	1,918**	1.22	3.85**	0.05	.00018	.00482**	0.98	0.111	0.012
DH	2	7,370**	147.45**	1.94**	26.11**	.01365**	.01787**	106.13**	3.180**	1.232**
F ₁	2	2,535**	8.97**	0.52*	5.52**	.00302*	.00052	17.91**	0.582**	0.245**
F ₂	2	1,940**	13.35**	0.63**	5.28**	.00058	.00114**	13.85**	0.532**	0.364**
Var. vs DH × Loc.	3	30	0.86	0.07	0.09	.00011	.00092	0.82	0.089	0.022
Var. Pop × Loc.	24	155	0.64*	0.09	0.48	.00105**	.00153**	0.65*	0.074	0.027
Gen. × Loc.	6	240*	0.44	0.07	0.17	.00152**	.00203**	0.34	0.077	0.029
Par. × Loc.	6	176	1.17*	0.13	1.17	.00135**	.00227**	1.29**	0.121	0.036
F ₁ × Loc.	6	98	0.42	0.11	0.31	.00112**	.00146**	0.40	0.029	0.007
F ₂ × Loc.	6	104	0.53	0.05	0.26	.00022	.00035	0.57	0.071	0.034
DH Pop. × Loc.	24	147	0.92**	0.18*	0.64	.00070*	.00096*	0.72*	0.107	0.032*
Gen. × Loc.	6	31	1.00*	0.30**	0.22	.00072	.00086	0.28	0.032	0.014
DH × Loc.	6	157	0.63	0.26**	1.41*	.00135**	.00173*	1.35**	0.174	0.068**
F ₁ × Loc.	6	125	1.89**	0.12	0.61	.00036	.00083	0.32	0.080	0.015
F ₂ × Loc.	6	273*	0.62	0.05	0.31	.00036	.00043	0.92	0.143	0.032
Error	204†	104	0.40	0.08	0.53	.00040	.00057	0.40	0.079	0.019

*, **, indicates statistical significance at the .05 and .01 levels, respectively. † Error degrees of freedom is 204 for lint yield and 68 for all other characteristics.

Table 3. Pooled interaction mean square estimates for doubled haploids and their parental varieties and pooled mean square estimates of all F₁ and F₂ hybrid interaction mean squares.†

Source	df	Lint yield	Yield components			Fiber properties				
			Lint %	Boll size	Seed index	50%	25%	T ₁	E ₁	Micro-naire
Parents × Loc.	12	166	.899	.196	1.29**	.00135*	.00200*	1.32*	.147	.052*
Hybrids × Loc.	24	151	.858	.094	0.38	.00052	.00077	0.55	.081	.022

*, **, indicates statistical significance at the .05 and .01 levels, respectively. † F test made by using Hybrid × Location mean square as denominator.

naire is an indication that nonadditive gene action exists in these populations. Nonsignificance does not necessarily indicate the absence of nonadditive effects. The presence of significant heterosis in Table 4 gives further evidence of nonadditive gene effects. Heterosis for lint yield occurred in every cross. Highly significant heterosis for lint percent, boll size, 2.5% span length, and fineness was also detected. Differences in amount of heterosis, from populations derived from doubled haploid and their parental varieties, were detected in only three cases. Two of these involved boll size and the other micronaire. The heterosis observed is the result of either dominance, epistasis, or their combined effects. If dominance is the only cause of the heterosis observed, the F₂ mean should equal the mean of the F₁ and MP.

In Table 5, these comparisons expressed as a percentage of the MP are given. Nonsignificance does not rule out the possibility of epistasis operating in these populations. From Table 5, there is little evidence suggesting epistasis was a large factor in the heterosis observed. For the six crosses and nine characteristics measured, only in one case was a deviation from the additive and dominance model large enough to be considered significant. The difference in size of epistatic effects was large enough to be significant in two cases. The apparent discrepancies in presence of epistasis and in the size of epistatic effects are due to the differences in positive and negative effects for comparable crosses.

DISCUSSION

Doubled Haploids and Parent Varieties

Small but significant differences between doubled haploid populations and their variety counterparts were detected. There was no consistent trend for

Table 4. Percent heterosis from crosses among doubled haploids and among their parental varieties and percent difference in heterosis between doubled haploids and their respective parent variety crosses.

Cross	Lint yield	Yield components			Fiber properties				
		Lint %	Boll size	Seed index	50%	2.5	T ₁	E ₁	Micro-naire
Doubled haploids									
M-71 × 63-3	15.8**	2.2**	11.4**	2.6	3.5	3.5**	-1.1	-5.0	1.8
M-71 × M-73	13.5**	-2.0**	13.5**	0.4	0.9	3.3**	-0.4	-0.8	-5.1**
63-3 × M-73	13.4**	3.8**	11.9**	-1.1	-1.5	0.6	-3.2*	-0.2	4.0**
Varieties									
Stv. 213 × Acala	21.1**	1.2	8.0*	1.5	1.9	0.8	-2.8	0.3	1.1
Stv. 213 × PD	15.3**	-1.1	4.7	-1.4	1.9	2.3	0.0	0.4	-6.6**
Acala × PD	20.9**	1.5	5.4*	-0.6	3.9	3.7**	-0.5	-0.4	-4.3**
Difference									
1-4	-5.3	1.0	3.4	1.1	1.6	2.7	1.7	-5.3	0.7
2-5	-1.8	-0.9	8.8**	1.8	1.0	1.0	-0.4	-1.2	1.5
3-6	-7.5	2.3	6.5*	-0.5	-5.4	-3.1	-2.7	0.2	8.3**

*, **, indicates statistical significance at the .05 and .01 levels, respectively.

Table 5. Percent epistasis and percent difference in epistasis for doubled haploids and their respective parent variety crosses.

Cross	Lint yield	Yield components			Fiber properties				
		Lint %	Boll size	Seed index	50%	2.5	T ₁	E ₁	Micro-naire
Doubled haploids									
M-71 × 63-3	0.4	-0.4	1.9	2.0	-1.1	-0.3	-1.9	-1.1	2.7
M-71 × M-73	-1.5	-0.1	-5.1	0.3	2.0	0.5	1.4	-0.8	-1.1
63-3 × M-73	0.7	1.9	-3.2	-1.0	-1.2	-0.2	-1.5	-0.1	0.9
Varieties									
Stv. 213 × Acala	-7.3*	0.5	-0.9	-3.5	1.4	-0.5	1.3	-1.2	2.8
Stv. 213 × PD-246	-5.5	0.6	-2.3	-2.4	0.1	-0.6	1.2	-4.0	-2.0
Acala × PD-246	-1.9	-1.5	0.0	0.6	0.0	-0.6	1.8	-3.3	0.9
Difference									
1-4	7.7	-0.9	2.8	5.5**	-2.5	0.2	-3.2	0.1	-0.1
2-5	4.0	-0.7	-2.8	2.7	1.9	1.1	0.2	3.2	0.9
3-6	-2.6	3.4**	-3.2	-1.6	-1.2	0.4	-3.3	3.2	0.0

*, **, indicates statistical significance at the .05 and .01 levels, respectively.

the superiority of doubled haploids or their varieties. For lint yield there was only one case of a significant difference between a doubled haploid population and its parent variety cross counterpart. The lint yield of the doubled haploid 63-3 × M-73 was lower than

that of the F_1 hybrid of Acala 1517D \times PD-246. This was primarily due to the lower lint percent of the former. Differences among hybrids for yield components and fiber properties were usually related to the differences among their parents.

The usefulness of doubled haploids in a breeding program depends upon their ability to transmit desirable characteristics to their offspring. This study indicates no consistent advantage or disadvantage of doubled haploids compared to their parent varieties. Similar results were obtained by Miller and Lee (7) in their topcross studies with two doubled haploids. The varietal identity of the particular parents used to produce an F_1 or F_2 hybrid was more important than whether the parent was a doubled haploid or not.

Interaction with Locations

According to Dobzhansky and Wallace (3) cross fertilizing populations that are homozygous and have no within genetic variability tend to be less stable than similar populations that are more heterozygous or have some within genetic variability. Since doubled haploids are completely homozygous and have no within population genetic variability, they might be expected to perform less consistently than their parent varieties. The parent varieties, even if the component individuals are homozygous probably consist of a mixture of genotypes. The significant differences observed between doubled haploids and their parent varieties is strong evidence that each variety is not homogeneous. However, for all characteristics, environmental interactions were similar for doubled haploid and their parents. No significant differences were detected, nor were there any trends evident.

The hybrids by location interactions in Table 3 appear to be lower than corresponding interactions involving their parents. This, together with their mean performance, suggests that F_1 and F_2 hybrids of cotton may be more stable over environments than their parents. Both F_1 and F_2 hybrids tended to have similar interaction mean squares, indicating that both heterozygosity within and genetic variability among individuals might contribute to the greater stability of these populations. The genetic composition of a population aside from its degree of homozygosity and heterogeneity would also have a great influence on stability. Kohel (5) found no evidence that F_1 plants were more adaptable than their parents. The different results between the two studies probably is that one concerns populations and the other individual plants. Other factors that might also contribute to the differences are the different genetic material used, different environments, and small number of environments and genetic material sampled in both studies. Consistency of performance over varying environments may be conditioned by heterozygosity, such as in F_1 hybrids, or by heterogeneity such as multilines, synthetics, or mixtures. While the genetic mechanisms conditioning stability are probably less evident in cotton than in more highly cross-fertilized species, it is perhaps too early to generalize on their practical uses in cotton breeding.

Gene Action

Heterosis, as measured by the difference between F_1 hybrids and their parental averages, was evident

for lint yield in all crosses. The highest yielding hybrid involved the highest yielding parents, Stoneville 213 or M-71. No hybrid had lint yield superior to these two parents. However, the F_1 hybrids did contain better combinations of yield and fiber properties than any of the parents. Heterosis was more evident for lint yield, lint percent, and boll size than for seed index and fiber properties. It would appear that additive effects are the major type gene action involved for seed index and most fiber properties. Heterosis of doubled haploids and their parent population crosses was in general very similar. Exceptions to this were two cases involving boll size and one for micronaire.

The only case of epistasis was detected for lint yield in one cross. This does not rule out the possibility of cancelling plus and minus epistatic effects. It would appear however that additive and dominance effects are more important. As with heterosis, the size of epistatic effects was in general very similar for both doubled haploid and their parent varieties. Several exceptions occurred. In general no trends were indicated for different types of gene action involved between doubled haploids and their parent populations.

The data are also useful in comparing inbreeding depressions between F_1 and F_2 hybrids. As Table 5 indicates, F_2 populations mean performance were as expected on the basis of an additive and dominance model. This implies that F_2 hybrids of cotton can be expected to have approximately one half the heterosis effect of F_1 hybrids.

LITERATURE CITED

1. Bridge, R. R., W. R. Meredith, Jr., and J. F. Chism. 1969. Variety environment interactions in cotton variety tests in the Delta of Mississippi. *Crop Sci.* 9:837-838.
2. Chase, S. A. 1952. Production of homozygous diploids of maize from monoloids. *Agron. J.* 44:263-267.
3. Dobzhansky, T., and B. Wallace. 1953. The genetics of homeostasis in *Drosophila*. *Proc. Nat. Acad. Sci.* 39:162-171.
4. Harland, S. C. 1955. The use of haploids in cotton breeding. *Indian J. Genet. and Pl. Breed.* 15:16-17.
5. Kohel, R. J. 1969. Phenotypic stability of homozygous parents and their F_1 hybrids in Upland cotton, *Gossypium hirsutum* L. *Crop Sci.* 9:85-87.
6. Meyer, Jr. R., and N. Justus. 1961. Properties of doubled haploids of cotton. *Crop Sci.* 1:462-464.
7. Miller, P. A., and J. A. Lee. 1964. Heterosis and combining ability in varietal top crosses of Upland cotton, *Gossypium hirsutum* L. *Crop Sci.* 4:646-649.
8. ——— and A. Marani. 1963. Heterosis and combining ability in diallel crosses of Upland cotton. *Crop Sci.* 3:441-444.
9. ———, H. F. Robinson and O. A. Pope. 1962. Cotton variety testing: Additional information on variety \times environment interaction. *Crop Sci.* 2:349-352.
10. Marani, A. 1968. Heterosis and inheritance of quantitative characters in interspecific crosses of cotton. *Crop Sci.* 8:299-303.
11. ———. 1968. Inheritance of lint quality characteristics in interspecific crosses of cotton. *Crop Sci.* 8:653-657.
12. Ramey, H. H. 1963. Gene action in inheritance of lint index in Upland cotton. *Crop Sci.* 3:32-33.
13. Turcotte, E. L., and C. V. Feaster. 1969. Semigametic production of haploids in Pima cotton. *Crop Sci.* 9:653-655.
14. White, T. G. 1966. Analyses of quantitatively inherited characters in *Gossypium hirsutum* L. *Crop Sci.* 6:253-255.