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Cotton Variety Testing: Additional Information on Variety X Environment Interactions[1]

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MILLER et al.[3] presented data on the magnitudes of variety × environment interactions observed in cotton variety tests conducted over a 3-year period at 9 locations in North Carolina. A substantial variety × location × year second-order interaction for lint yield was observed in these tests, indicating that the varieties showed differential responses when grown under different environments. The variety × year and variety × location first-order interactions, however, were small and nonsignificant for yield. Apparently neither location nor years had any consistent effect on these differential varietal responses. Furthermore, the lack of a sizeable variety × location interaction in the North Carolina area suggested that it would not be necessary to divide the state into subareas for variety-evaluation purposes.

The above data were obtained from a rather limited number of locations and years, in one specific area, and the question arises as to the general applicability of such observations. During 1935 to 1937, a group of cotton varieties were tested at a series of locations in the cotton belt, from North Carolina to Texas. Analyses of these data should provide additional information, with more general applicability, on the nature and magnitudes of variety × environment interactions in cotton. The objective of the present paper is to report the results of these analyses and to discuss their implications on variety-testing procedures.

MATERIALS AND METHODS

Complete data were available for 16 cotton varieties tested in 8 replicates at the same 11 locations for the 3-year period, 1935–1937. The 16 varieties were chosen because they were representative of the more widely grown varieties in cultivation at the time of initiation of these tests. Sufficient quantities of seed were obtained at the beginning of the study to provide for 3 years' planting at each of the locations.

The 11 test locations were Statesville, N. C.; Florence, S. C.; Knoxville, Tenn.; Jackson, Tenn.; Marianna, Ark. (delta location); Marianna, Ark. (upland location); Stoneville, Miss.; Baton Rouge, La.; College Station, Texas; Greenville, Texas; and Lubbock, Texas. Plantings at each of these locations were made on the same block of land for the 3-year period. Additional tests had also been conducted in Alabama and Georgia, but since the test location within each of these states was not the same for all 3 years, these data were omitted from the present analyses.

Field data were obtained from each location according to a uniform set of instructions. Gin data were obtained at a central location, and the same gin was used for processing the samples sent in from the different test areas. Fiber-length evaluations were likewise made in a central laboratory.

Variance analyses of the combined data and estimation of the variance components were straightforward, following the procedures outlined in detail by Miller et al.[3]

[1] Joint contribution from Departments of Field Crops and Experimental Statistics, North Carolina Agr. Exp. Sta., Raleigh, and Crops Research Division, ARS, USDA. Journal Paper 1046, North Carolina Agr. Exp. Sta. Original data collected under direction of O. A. Pope in cooperation with personnel at the state experiment stations and Federal field stations at which the tests were conducted.

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[3] Miller, P. A., Williams, J. C., and Robinson, H. F. Variety × environment interactions in cotton variety tests and their implications on testing methods. Agron. J. 51:132–134. 1959.

EXPERIMENTAL RESULTS

Estimation of Variance Components

Estimates of the pertinent variance components are presented in Table 1. The relative magnitudes of these components indicate the relative importance of the corresponding sources of variation.

Considering lint yield, it is noted that the variety × location × year interaction was relatively large and statistically significant; this source of variation being slightly larger than the variety component. The first-order interaction of varieties × locations was considerably smaller than that for the second-order interaction, although still statistically significant. The variety × year source of variation was very small and nonsignificant. The large second-order interaction indicates that the varieties showed differential responses when grown in different environments. The presence of a variety × location interaction indicates further that there was at least some consistent location effect on these differential responses. That is, certain varieties tended to rank consistently different in yield at certain locations, in all 3 years of testing, than they did at other locations. The fact that this source of variation was relatively small in magnitude, however, indicates that a rather large portion of the differential varietal responses could not be accounted for by consistent differences in the cotton-growing environments of the different locations. The very small and nonsignificant variety × year interaction indicated that the varieties ranked essentially the same in yield performance in each of the 3 years of testing. Apparently the reactions of the varieties to different types of environments encountered over the 11 locations in any 1 year were similar to those encountered in the other 2 years.

Three of the 11 locations were in Texas, at the very western edge of the testing region. It is generally considered that the cotton-growing environments of this Texas area are rather different from those encountered in the remainder of the region under study. Consequently the yield data were reanalyzed, with these 3 locations omitted. The resulting variance components are presented in column 3 of Table 1. Comparing these components with those from the analysis of the 11 locations, it is noted that the variety × location interaction source of variance was decreased in size, and was no longer statistically significant. This suggests that a major portion of the original variety × location interaction may have been due to the effects of the Texas locations. The second-order interaction, however, was large and highly significant indicating that the varieties were still showing substantial differential responses to the

Table 1—Variance component estimates from combined analysis of 16 varieties grown at 11 locations for 3 years.

Variance source	Lint yield, lb./plot		Lint percent	Wt. of 100 bolls, lb.	Staple length, 1/32 in.
	11 locs.	8 locs.†			
Varieties (σ^2_v)	1.346	1.933	26.83	0.0487	16.405
Vars. × yrs. (σ^2_{vy})	0.010	0.013	0.05*	0.0002**	0.048**
Vars. × locs. (σ^2_{vp})	0.295**	0.060	0.27**	0.0014**	0.041
Vars. × yrs. × locs. (σ^2_{vpy})	1.373**	1.575**	0.94**	0.0020**	0.394**
Plot error (σ^2_e)	3.399	4.325	0.69	0.0038	0.806

* Interaction mean square significant at 1% level of probability. ** Interaction mean square significant at 5% level of probability. † From analysis omitting 3 Texas locations (see text).

different environments encountered over the remaining 8 locations. The variety × year interaction remained very small and nonsignificant.

In regard to lint percentage, boll size, and staple length, it is noted that in all cases the second-order interactions were highly significant and substantially larger than either of the first-order interactions. Even these second-order interactions, however, were very small in magnitude relative to the variety components. Variety × environment interactions were present, of course, but may be considered as being of rather minor importance in view of the much larger sources of variation attributable to the differences among the varieties. For this reason it did not appear worthwhile to reanalyze these data omitting the Texas locations.

Comparison With Results From North Carolina Tests

As indicated earlier, Miller et al.[3] have presented data on the magnitudes of variety × environment interactions observed in cotton variety tests conducted over a 3-year period at 9 locations in North Carolina. A comparison of the relative magnitudes of the different sources of variation from the regional tests with those from the North Carolina tests are presented in Table 2. Since the units of measurement for each of the corresponding traits differed between the two sets of tests, the values presented are the ratio of the pertinent variance component to the error variance component for that trait.

Considering the 3 interaction sources of variance, it is noted that for all 4 traits the second-order interactions are substantially larger than either of the first-order interactions. In regard to lint yield, the variance component ratios from the 2 sets of tests are fairly similar in magnitude. For the other 3 traits, there is a certain amount of fluctuation between the values from the 2 sets of data. In these cases, however, the 3 interaction sources of variance are all very small relative to the variety source of variance, and thus are of relatively less concern to the breeder. It is of interest to note that for lint percent, boll weight, and fiber length, there was substantially more variation among the 16 varieties evaluated in the regional tests than among the 15 varieties included in the North Carolina tests.

DISCUSSION

The discussion herein concerning variety × environment interactions in cotton and their implications on testing procedures is based on the data obtained from the series of tests just described. Consequently, the conclusions are of general applicability only to the extent that these original data reflect a true picture of the variability likely to be encountered in the cotton-growing environments of this region. It is recognized that 11 locations and 3 years are a rather limited sample in this respect.

The 16 varieties included were chosen because they were the more widely grown ones in cultivation in 1935. Thus they represented a rather highly selected group that had previously survived testing and selection throughout the region. Such varieties might be expected to be more widely adapted and show less variety × environment interactions than previously untested material.

Almost none of these 1935 varieties, as such, are in cultivation today. The majority of our current varieties, however, originated from selection, within, or crosses between, this original material. Thus the current germplasm may be somewhat comparable with that sampled in these tests. On this point, a comparison of the variety variance component ratios (Table 2) indicates that the range of varietal differences in yielding ability was about the same for these original 16 varieties as it was for the more current group of 15 varieties evaluated in the North Carolina tests. The original group of strains, however, did show considerably greater varietal variation in lint percentage, boll weight, and fiber length. Since these traits are generally considered to be more highly heritable than lint yield,[4] this narrowing of the range of variability may well reflect the effectiveness of consistent selection for these traits over the intervening years.

Table 2—Comparison of relative magnitudes of different sources of variation from regional tests (11 locations, 3 years) with those from the North Carolina tests (9 locations, 3 years). Values presented are the ratios of the pertinent variance components to the error variance for that trait.

Variance source	Lint yield		Lint %		Boll wt.		Fiber length	
	Region	N.C.	Region	N.C.	Region	N.C.	Region	N.C.
Varieties	0.40	0.44	38.88	1.34	12.82	1.43	20.35	1.02
Vars. × yrs.	0.00	0.01	0.07	0.06	0.05	0.03	0.06	0.13
Vars. × locs.	0.09	0.04	0.39	0.09	0.37	0.05	0.05	-0.06
Vars. × locs. × yrs.	0.40	0.26	1.36	0.15	0.53	0.09	0.49	0.26
Plot error	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Regardless of the similarity in results from the two different kinds of germplasm discussed earlier, it is not intended that generalizations can be made from the 1935 varieties and conditions encountered in those early tests to unselected strains and variety tests of today. However, the general agreement in magnitude of genotype-environmental interactions encountered in the regional tests compared with the later North Carolina tests is not considered a chance occurrence. Further comparisons with other samples of genetic materials tested under different environmental conditions are necessary if generalizations are to be made.

Importance of Testing Varieties Over a Range of Environments

The present regional data substantiate the observations from the North Carolina tests that cotton varieties show sizeable differential responses when grown under different environments. The variety × location × year interaction for lint yield was of approximately the same magnitude as the variety source of variation. If a group of varieties are evaluated under only one environment, the observed differences among the varieties are confounded with the differences due to the effects of the variety × environment interactions. In the present case, on the average, about one-half of the variation observed among the varieties in a single test was due to the interaction of the varieties with that particular test environment. Such interaction effects provide little or no information as to how the varieties would perform under different environments. Thus, in order to make variety recommendations, it is essential that varieties be evaluated over an adequate sample of the environments likely to be encountered over the breeding area in future years.

Division of Region into Subareas For Breeding Purposes

If a large variety × location interaction is observed in a study such as the present one, it would indicate that the

[4] Miller, P. A., Williams, J. C., Robinson, H. F., and Comstock, R. E. Estimates of genotypic and environmental variances and covariances in Upland cotton and their implications in selection. Agron. J. 50:126–131. 1958.

region concerned should be subdivided into smaller breeding areas. In the present case, this first-order interaction over the 11 locations was relatively small; being about 1/4 the magnitude of the variety source of variation. Elimination of the 3 Texas locations from the analysis further decreased this interaction to only about 1/30 of the variety component. Thus, on the basis of the present data, it would not appear necessary to divide this area east of Texas into subareas for breeding purposes.

It appears rather naive to suggest that all the cotton belt states east of Texas could be considered as being in one breeding area. On the other hand, about 85% of the cotton acreage in this area is being planted to only 3 varieties, with at least some acreage of two of the varieties occurring in all the states. Although various factors, some of which may not be related to actual performance, enter into the grower's choice of a cotton variety, this observation does suggest that some varieties are reasonably well adapted over this wide area.

The present data do not in anyway preclude the possibility of breeding varieties for specific environments. The only requirement for such an objective is that the important environmental factors are under some degree of control or are at least predictable at planting time. Such factors as local disease problems, response to irrigation, adaptation to local harvesting methods, etc., may require the breeding of varieties to meet the specialized requirements of a small area.

Sampling of Environments Within a Breeding Area

Once the breeding area has been defined, the question arises as to what comprises an adequate sample of the environments likely to be encountered within that area. The relatively small variety × location and variety × year interactions observed from these tests indicate that neither locations nor years were substantially related, in a consistent manner, with the environmental factors causing differential varietal responses. Obviously such a factor as soil type, which was consistently different from location to location over the 3-year period, had only minor effects on the observed variety interactions. Although it is not clear as to which environmental factors were important, they apparently were ones which were not consistently associated with locations and years in these tests. It follows, therefore, that a reasonably adequate sample of environments might be obtained by growing the material at *(1)* a series of locations in one year, *(2)* a series of years at one location, or *(3)* any combination of years and locations involving a fairly large number of tests.

It is realized that alternatives *(1)* and *(2)* are not in accord with normal procedures followed by the plant breeder in strain evaluation. The adequacy of such testing methods and reliability of the data for selection purposes will depend upon the range of environments encountered over a series of locations or years compared to those experienced in both years and locations. The specific results of this study provide no basis for discriminating against the choice of the first two alternatives.

In regard to number of tests, calculations were made from the present data on lint yield to obtain information on the relationship between number of testing environments and the precision of variety evaluation. The data from the 8 locations east of Texas were used for these calculations, since as has already been discussed, it may be reasonable to consider this as one breeding area.

The expected variance of a variety mean ($V_{\bar{x}}$) from a series of replicated tests over several locations and years may be expressed as follows:

$$V_{\bar{x}} = \frac{\sigma^2_e}{rpy} + \frac{\sigma^2_{vpy}}{py} + \frac{\sigma^2_{vp}}{p} + \frac{\sigma^2_{vy}}{y},$$

where the variance components in the numerator are as defined in Table 1, and r, p, and y are the number of replicates, locations, and years; respectively, in which the varieties are to be tested. Thus by substituting the observed values for the variance components in the above formula, the variance of a variety mean may be predicted for any particular combination of replicates, locations, and years that might be considered. The smaller the variance of a variety mean; the more precise are the estimates of variety performance.

Substituting the variance components estimated from the present data, the expected variance of a variety mean for lint yield becomes:

$V_{\bar{x}} = 4.325/rpy + 1.575/py + 0.060/p + 0.013/y.$

It is obvious that the last two terms of the right hand side of this equation, involving the variety × location and variety × year components, will have very little effect on the magnitude of the variance of a treatment mean. The second-order interaction component (1.575) and the error term (4.325), however, will have considerable effect. This indicates, as has already been discussed, that while it is essential to test varieties over a number of different environments, it apparently makes little difference as to how these environments are distributed over locations and years. For the purpose of making some rather approximate calculations as to the number of testing environments needed to sample this region, the last two terms in the above equation were ignored. Various values for "r" and "py" were then substituted in the denominators of the appropriate terms in this equation, and calculations made as to the expected values for $V_{\bar{x}}$. It should be noted that "p" and "y" were not varied separately, but that only their product was considered.

Results of these calculations are presented graphically in Figure 1, where the expected variance of a variety mean

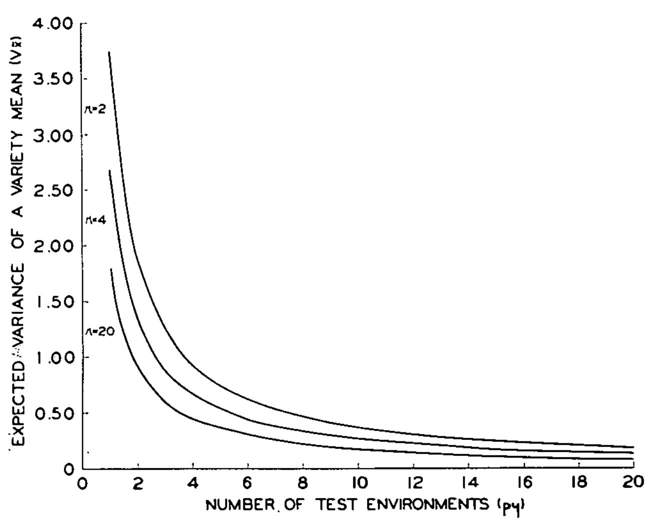

Figure 1—Expected variance of a variety mean ($V_{\bar{x}}$) for various assumed numbers of replicates per test (r) and test environments (py).

(V_x) is plotted for an assumed number of testing environments (py) ranging from 1 to 20. Three values for "r" (number of replicates) were assumed for illustrative purposes. The 3 lines in the graph, therefore, represent the relationship between the expected variance of a variety mean and number of test environments for 2, 4, and 20 replicates, respectively.

Several features are worthy of note. For each of the assumed number of replicates, the expected variance of a variety mean decreases as the number of testing environments is increased; but in decreasing increments with each additional test environment. A point is thus reached beyond which an increase in the number of test environments results in only very small amounts of increased precision. It is not possible to pinpoint any particular number of testing environments as being adequate for variety evaluation. Possibly about 10 might be sufficient in the present case. This graph, however, is presented only as an indication of expected trends.

In regard to number of replications, it is evident that if the tests are conducted at only one or two environments, an increase in the number of replications results in rather sizeable decreases in the expected variance of a variety mean. If the varieties are evaluated at several environments, however, the expected variance of a variety mean is decreased only slightly by increasing the number of replications. Over-all, it is important to note that increasing the number of environments is much more effective in decreasing the expected variance of a variety mean than is any increase in number of replications. This is in agreement with the data reported by Sprague and Federer[5] for corn.

SUMMARY

Sixteen varieties of cotton were evaluated at the same 11 locations in the North Carolina-to-Texas cotton-growing region for a 3-year period. Analyses of these data provided information on the nature and magnitude of variety × environment interactions in cotton.

In regard to yield, the presence of a large variety × location × year second-order interaction indicated that the varieties showed differential responses when grown in different environments. The variety × location first-order interaction, although statistically significant, was considerably smaller than this second-order interaction. This still indicated, however, that at least some of the varieties tended to rank consistently different in yield at certain locations than they did at others. A re-examination of the data indicated that the major portion of this variety × location interaction was due to the 3 Texas locations. After omission of these locations from the analysis, this interaction was very small and no longer statistically significant. The variety × year first-order interaction was of minor importance and nonsignificant in both analyses (all 11 locations or the 8 locations east of Texas).

Most of the 3 interaction sources of variance were statistically significant for lint percentage, boll size, and fiber length. In all cases, however, the magnitudes of these interactions were very small as compared with the varietal sources of variation, and are thus of less concern to the breeder.

In regard to cotton breeding and testing procedures, the above results indicate that it is essential to test varieties over an adequate sample of the environments likely to be encountered in the breeding area. The relatively small variety × location (particularly in the area east of Texas) and variety × year interactions indicated that neither location nor years, per se, were having consistent effects on differential varietal responses. Thus it apparently makes little difference how this sample of environments is distributed over years and locations. This particular set of data suggested that approximately 10 to 12 test environments would be required to obtain a reasonably precise estimate of varietal performance within the breeding area east of Texas. Increasing the number of testing environments would appear to be much more effective in increasing the precision of variety evaluation than would increasing number of replicates per test.

[5] Sprague, G. F., and Federer, W. T. A comparison of variance components in corn yield trials; II. Error, year × variety, location × variety, and variety components. Agron. J. 43:535–541. 1951.