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Environmental Stability and Adaptation of Several Cotton Cultivars[1]

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ABSTRACT

We studied the stability, adaptation, and yields of several diverse cotton (*Gossypium hirsutum* L.) cultivars that had been grown at several locations in one or more of three, 3-year periods of testing. We used as environmental indexes the mean lint yields of three "standard" cultivars that were common to all tests. The yields of the remaining cultivars were regressed upon these indexes. The regression coefficients (b values) were used as measures of adaptability, and the coefficients of determination (r^2 values) were used as measures of stability. Analyses of variance of lint yields also were computed.

In comparison with the three standards, most of the other cultivars were adapted to all environments (b = 1.0), and all but one were stable. However, there were several significant yield differences among the cultivars within each of the three periods of testing. Thus, yield level was the most divergent parameter measured, adaptation was next, the stability was the least divergent. Because we found significant differences among commercial cultivars in both adaptation and stability, we believe that the use of these two parameters in conjunction with yield would be of significant benefit in breeding material evaluation.

Additional index words: *Gossypium hirsutum L.*, Lint yields, Strain evaluation, Cultivar tests, Regression, Correlation, Genotype-environment interactions.

EVALUATION is an important and necessary step in the development of improved cotton (*Gossypium hirsutum* L.) cultivars. Because of genotype-environment interactions, the evaluation of these breeding strains requires repeated testing in both time and space. The decision to release a strain is usually made on the basis of whether the strain performance was "satisfactory" in comparison to the performance of one or more "standard" cultivars over a period of 2 or more years. Thus, a major problem is deciding whether the performance of the strains was "satisfactory." Often the strain performance may be outstanding at one location in 1 or more years, but be variable, mediocre, or even substandard at other locations.

The breeder will be faced with the task of evaluating a mass of data so that he can decide on the disposition of the strain. In making the decision, there are at least three questions which he should consider: i) how did the strain's overall average yield compare to the overall average yields of the others? ii) is it better adapted to one type of environment than to another? iii) was its yield performance consistent relative to the yield performance of the other strains? That is, the breeder will want to ascertain how his strain compared with other strains or standard cultivars in yield level, adaptation, and stability, respectively.

An analysis of variance that combines years and locations would provide the answer to question (i); a diligent study of the results of the analysis could give a partial answer to question (ii). We believe a complete answer to questions (ii) and (iii) can be more satisfactorily obtained from the regression of a cultivar's respective yields on the respective calculated environmental indexes.

Eberhart and Russell (2) proposed a method of measuring cultivar stability in which the cultivar yields in the respective environments are regressed upon the environmental indexes that are obtained by subtracting the mean yield of all cultivars in all environments from the mean yield of all cultivars in each environment. They defined a stable cultivar as one with a regression coefficient (b) equal to 1.0, and with mean square deviations from regression

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(s^2_d) equal to 0. Apparently, a cultivar that did not meet both these qualifications would be classed as unstable. That is, cultivars with $b \neq 1.0$ and $s^2_d = 0$, or with $b = 1.0$ and $s^2_d \neq 0$, or with $b \neq 1.0$ and $s^2_d \neq 0$ would all be unstable.

Finlay and Wilkinson (3) used regression and analysis of variance in their study of barley yields. However, they used b values as a measure of both stability and adaptation. Cultivars with $b < 1.0$ were considered above average in stability and specially adapted to unfavorable environments; cultivars with b values > 1.0 were considered below average in stability and specially adapted to favorable environments; and cultivars with $b = 1.0$ were described as average in stability and either poorly or well adapted to all environments, depending upon the cultivar mean yield.

In this paper we use the regression coefficient (b) as a measure of adaptation in the sense that Finlay and Wilkinson (3) used it. While we believe this character is important in breeding material evaluation, it should be of particular importance in areas where management, soil or climatic variables cause definable and distinct differences in yield levels. An example is the irrigated and dryland cotton production area in the Texas High Plains. In such areas the breeder will probably prefer to develop separate genotypes for dryland and irrigated conditions. Thus, he would be seeking strains with $b > 1.0$ for irrigated (high-yielding) conditions, and strains with $b < 1.0$ for dryland (low-yielding) conditions when he tests his materials over this broad range of conditions. In this sense, b would be used as an indicator of adaptation rather than as a stability measure (2, 3).

We believe a more logical parameter for stability would be one which measures dispersion around the regression line and would, therefore, be related to the predictability and repeatability of performance within environments. The use of s^2_d as a criterion for stability is appropriate, but we are suggesting that the coefficient of determination can be used for this purpose also. This parameter is well suited for this purpose. It not only provides a measure of variation (6), but it is easily calculated, independent of units of measure, easily interpreted, and differences between r^2 values can be statistically tested.

Stability and adaptation studies have been reported for several crops, but the divergence and magnitude of these parameters in Upland cotton cultivars have not been adequately explored. Therefore, we are reporting the results of a study in which we evaluated the yield performance, stability, and adaptation of several diverse cotton cultivars. We are also presenting a critique of the use of these parameters for advanced strain evaluations.

MATERIALS AND METHODS

To have sufficient data from a wide range of environments, we used the yields reported for the "Plains Regional Cotton Variety Tests" for the years 1960 through 1968 as given in the annual publication "Regional Cotton Variety Tests" (1). The test sites were located in southwestern Oklahoma, the High and Rolling Plains of Texas, and north-central Texas. Entries in the tests were constant within each of three, 3-year periods, 1960-62 (12 entries), 1963-65 (10 entries), and 1966-68 (12 entries). The environments (total tests within each 3-year period were 23, 21, and 22, respectively. Four cultivars were common to all tests, and three of them, 'Blightmaster A5,' 'Gregg 35,' and 'Lankart Sel. 57,' were used as "standards." The arithmetic average of their respective lint yields for a given location for a given year was considered as the "environmental index" for that location in that year. The fourth cultivar common to all tests, 'Paymaster 101A,' was not used in the calculation of the environmental indexes because we wanted to see how its performance would compare to the standards in each of the three separate test periods.

Because the published data (1) did not give individual replication data, the analysis of variance of lint yields for each of the three periods had to be calculated on the reported mean yield values. Therefore, the only sources of variation were environments, cultivars, and the environment $\times$ cultivar interaction. (And with only these sources of variation available, the environment $\times$ cultivar interaction mean squares could not be tested, and s^2_d values could not be calculated.) The cultivar average yields were separated into nonoverlapping groups by the Scott and Knott method (4).

Regression analyses were used to ascertain the "stability" and "adaptation" of the cultivars within each of the three, 3-year periods. The environmental index was used as the independent variable, and the individual cultivar yield was used as the dependent variable. The data were plotted, and a linear regression line and 0.05 probability level confidence belts for estimated individual yields ($\hat{Y}$) were drawn. The regression coefficients (b values) were tested to ascertain if they differed significantly from 1.0. The square root of the coefficient of determination (r^2) of each cultivar was tested to see if it differed significantly from that of the standard cultivar that had the largest coefficient of determination (i.e., the most stable of the three standard

Table I. Statistical and adaptation characteristics of certain cotton cultivars.

Period	Cultivar	Regr. (b)	Coef. of Det. r^2	Lint yield, kg/ha*	Adaptation†
1	Acala 4-42	0.870	0.872	631 d	A
(1960-62)	Austin	1.096	0.891	811 a	A
	Blightmaster A5	1.048	0.958	758 b	A
	Coker 100A	0.965	0.897	738 b	A
	Deltapine 15	1.024	0.914	749 b	A
	Gregg 35	0.941	0.929	775 b	A
	Lankart Sel. 57	1.010	0.922	760 b	A
	Lockett 88A	1.103	0.914	799 a	A
	Northern Star 4-11	1.007	0.906	694 c	A
	Paymaster 54B	1.054	0.872	817 a	A
	Paymaster 101A	1.166	0.958	843 a	H
	Western Stormproof	1.036	0.916	738 b	A
	Avg.			759	
2	Auburn 56	1.149	0.945	693 a	H
(1963-65)	Blightmaster A5	1.106	0.974	635 b	H
	Deltapine SL	1.231	0.927	677 a	H
	Gregg 35	0.906	0.958	597 b	L
	Lankart Sel. 57	0.990	0.966	633 b	A
	Lockett 4789	1.021	0.980	627 b	A
	Northern Star 5	1.084	0.887	610 b	A
	Parrott	0.957	0.931	609 b	A
	Paymaster 101A	1.151	0.968	649 b	H
	Stoneville 7A	1.227	0.949	693 a	H
	Avg.			642	
3	Acala 1517D	0.940	0.803	401 c	A
(1966-68)	Blightmaster A5	1.002	0.753	485 b	A
	Coker 201	1.152	0.857	540 a	A
	Gregg 35	1.052	0.885	544 a	A
	Lankart Sel. 57	0.946	0.850	550 a	A
	Lockett 4789	1.030	0.867	519 a	A
	Northern Star 5	0.865	0.750	504 a	A
	Paymaster 54B	1.090	0.848	542 a	A
	Paymaster 101A	1.120	0.922	550 a	A
	Paymaster 111	0.936	0.823	495 b	A
	Stoneville 7A	1.070	0.769	548 a	A
	Western Stormproof	0.955	0.740	470 b	A
	Avg.			512	

* Any two means followed by the same letter are not significantly different at the 0.05 probability level according to the Scott-Knott test. † A, H, L, adapted to all, high-yielding, and low-yielding environments, respectively.

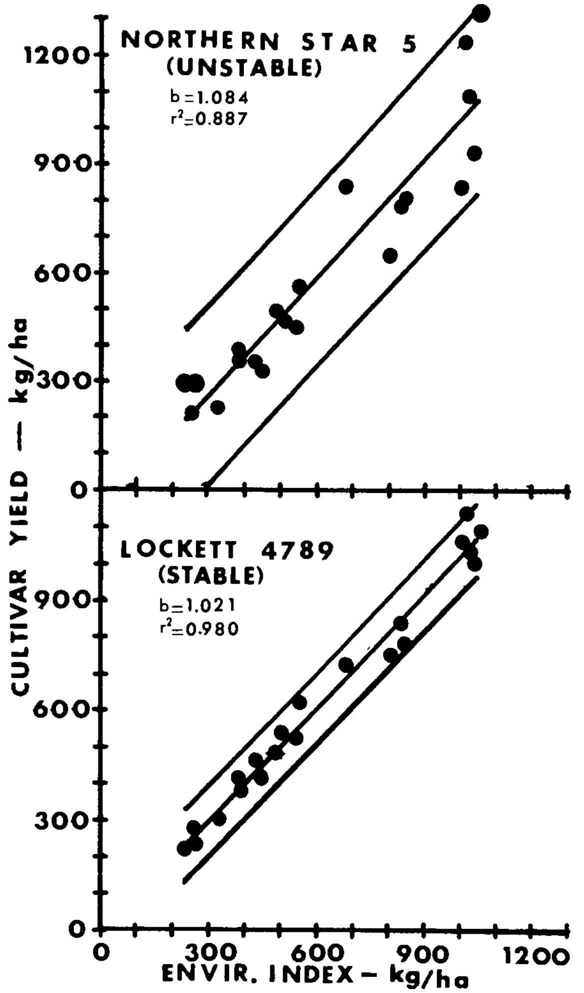

Fig. 1. Regression lines and confidence belts (P = 0.05) for an unstable and stable cultivar, 1963 to 1965 period.

cultivars). Statistical analyses were conducted according to procedures outlined by Snedecor (5).

Based upon the results of the analyses, the cultivars were classified as follows:

Adaptation. If b was not significantly different from 1.0, the cultivar was considered adapted to all environments; if b was significantly larger than 1.0, the cultivar was considered better adapted to high yielding environments; if b was significantly smaller than 1.0, the cultivar was considered better adapted to lower yielding environments.

Stability. A cultivar was considered stable unless its r^2 value was significantly smaller than that of the standard cultivar that had the largest r^2 value of the three standard cultivars.

RESULTS AND DISCUSSION

Ideally, a cultivar would be adapted to all environments, stable, and above average in yielding ability, particularly for a given production area. In the 1960-62 test period, the four cultivars (Table 1) whose yield values are followed by the letter "a" met these criteria. (The average yield, 759 kg/ha, would be included in the group of means followed by the letter "b.") A fifth cultivar, Paymaster 101A, was high-yielding and stable, but was better adapted to high-yielding environments than to low-yielding environments ($b > 1.0$).

For cultivars adapted to high-yielding environments, it is a simple matter to determine the environmental index (yield level) above which the cultivar could be expected to yield more than the average of the standards. This environmental index will be the one which, when substituted as X into the linear regression equation of the test cultivar, will equal calculated $\hat{Y}$. For example, the equation for Paymaster 101A for the 1960-62 period was $\hat{Y} = 1.166X - 48.209$ where $\hat{Y}$ = the calculated yield, and X = the environmental index. In this equation, setting $X = \hat{Y}$ will give a value of 290 kg/ha. That is, when X = 290 kg/ha, $\hat{Y}$ = 290 kg/ha. Thus, in any environment in which the average yield of the three standards (i.e., the environmental index) is above 290 kg/ha, the yield of Paymaster 101A should exceed the average yield of the three standards. For example, when the environmental index = 1,000 kg/ha, Paymaster 101A should yield 1,118 kg/ha. For $b < 1.0$, the environmental index level below which the cultivar will exceed the yield of the standards can be determined in a similar manner.

The analysis of the 1963 to 1965 period indicated that none of the cultivars met all three criteria for an ideal cultivar (Table 1). Five cultivars were better adapted to high-yielding environments ($b > 1.0$) and three of them were above average in yield. One cultivar was better adapted to low-yielding environments ($b < 1.0$). The contrast in variation in an unstable (Northern Star 5, $r^2 = 0.887$) and stable (Lockett 4789, $r^2 = 0.980$) cultivar is illustrated in Figure 1 by the width of the 0.05 probability level confidence belts for the regression line for predicting individual yields. (The belts appear straight to the eye because of the very small residual sum of squares in these fitted regression lines.) Northern Star 5 was the only unstable cultivar in any of the tests.

All cultivars in the 1966-68 period were adapted to all environments, but none were significantly higher than average in yield (i.e., the average yield, 512 kg/ha would be in the group of means followed by the letter "a"). This indicates that the environmental conditions of this period were not conducive to the expression of the genetic yield potentials of the various cultivars.

A study of the b values of the four cultivars common to all tests and years indicates that cultivar performance was not consistent over all three periods of testing. The type of adaptation exhibited by Blightmaster, Gregg, and Paymaster was not constant throughout the three periods (i.e., there was a significant change in b values). This might be considered a manifestation of "instability"; however, it should be noted that the average yield levels of the three periods were different. That is, if the environmental conditions had been the same in each of the three periods, maybe the adaptations (b values) of the standards would have been the same in each of the three periods. (We assume there were no significant changes in the genetic make-up of the standards over the years of testing.) On the other hand, perhaps there are genotypes which will maintain a constant type of adaptation even though the mean yields of the standards to which they are being compared fluctuate from environment to environment. In this particular study, Lankart did exhibit this type of performance; this characteristic may be partially responsible for the widespread and continued use of this cultivar. But as discussed below, there is some bias in our measures when the cultivar being evaluated is also one of the standards.

It should be pointed out that the measure of "stability" we have used here is a measure of dispersion of yields around a regression line; and the slope of the regression line is a measure of adaptation. Therefore, the more consistent the cultivar yield is in relation to the average yield of the three standards, the nearer the regression coefficient and the coefficient of determination approach 1.0, and the broader the adaptation and the more "stable" the cultivar may be considered. However, the chief disadvantage of this measure of stability is that the standard cultivars are used in the determination of the environmental indexes and are then individually tested against these same indexes. Therefore, there must be some bias in the comparisons among the standards; the fewer the number of standards used, the greater the bias will be. On the other hand, there must be some "reference point" for comparison of performances which will not be changed when a new strain or cultivar is brought into the evaluation program. From a practical standpoint, a breeder should want to compare his material against the cultivars he believes to be the best available or most widely produced in the area. If this is the case, the adaptation and stability of the standards are secondary in importance because the breeder is interested primarily in how his materials performed in comparison with the standards, and not in how the standards performed relative to each other.

Because the standards should be updated as the breeding materials are improved, we propose the following technique for consideration. In the first 2- or 3-year cycle of testing all materials would be evaluated for yield, stability, and adaptation using three to five standards, and the techniques given above. Then the three to five entries that performed best in the first cycle of testing would become the standards for the second cycle of testing. As the program is continued, new cultivars and breeding lines superior to the standards should be discovered; these would be used as standards for a third cycle of testing. Thus, the standards would get successively "better" and the quality of the breeding materials would always be tested against an ever-improved set of standards. This should lead to the development of additional superior cultivars.

In summary, we found that commercial cultivars differ significantly in adaptation, stability and yield potential. Therefore, we believe that the use of the two additional parameters, adaptation and stability, in conjunction with yield would be of significant benefit in the evaluation and characterization of advanced-strain breeding materials. It is also our opinion that a group of standards should be used for the calculation of environmental indexes, and this group should be updated as new, improved cultivars or strains are detected by the testing procedures. Finally, we believe that these techniques also could be used very effectively for characters other than yield.

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