2005 Beltwide Cotton Conferences, New Orleans, Louisiana - January 4 - 7, 2005

STABILITY OF YIELD AND FIBER QUALITY IN THE NORTH DELTA: I. EVALUATION OF METHODS

Ron McNew
University of Arkansas
Fayetteville, AR
Owen Gwathmey and Chism Craig
University of Tennessee
Jackson, TN
Bobby Phipps
University of Missouri
Portageville, MO
Fred Bourland
University of Arkansas
Keiser, AR

Abstract

This paper describes different types of stability that were considered for use in stability analysis of variety test data. The types of stability are absolute stability, no-interaction stability and linear-interaction stability. Each type is illustrated using an artificially chosen numerical example of variety-environment values. No-interaction stability was selected for the analysis of the variety test data in order to evaluate variety stability.

Introduction

A tri-state project was initiated in 2002 to pool variety test data from Arkansas, Missouri and Tennessee. The objective was to analyze the stability of cotton varieties in the North Delta, primarily with respect to lint yield. By pooling data, more environments would be included in the analysis, giving better information about stability than could be obtained from only the environments of tests conducted in a single state.

The objective of this paper is to define and illustrate several candidates for stability that we considered for use in our analysis of variety test data. At the end, we will briefly indicate the basis for the type of stability we chose for our analysis.

Models and Measures of Stability

In order to clarify our use of “stability of yield”, we adopted the following definition: A stable variety is one whose yields in a population of environments fit an idealized model of yield consistency. The idealized pattern reflects the meaning of stability of yield. In our application of this definition, the population of environments is the fields of cotton producers in the North Delta in combination with their conditions of climate, management, etc. that affect yield. Thus, the same field in two different years is two different environments. For a variety that is not stable, it is necessary to specify the form of deviations of yields from the idealized pattern this variety would have had if it were stable. These deviations are used to measure the degree of stability of a non-stable variety. The measure is the variance of these deviations. By this measure, a stable variety will be one whose deviations, and thus their variance, are zero. The greater is the variance, the less stable is the variety.

We identified three models for consideration which will be referred to as the absolute stability model, the no-interaction stability model and the linear-interaction stability model. The following gives the details for each type of stability.

Absolute Stability

In the absolute stability model, a stable variety is one whose yields are the same for all environments.

For an unstable variety, its deviations are the differences between its yields and its mean across all environments. That is, the idealized pattern of stability for this variety is one in which all yields are the same as its mean yield. The variance of these deviations across the population of environments is the absolute stability of the variety.

A feature of the absolute stability of a variety is that it is not dependent upon the yields of other varieties under consideration. This feature does not occur for the next two types of stability.

No-Interaction Stability

For the no-interaction stability model, there is a fixed set of varieties under consideration. A stable variety for this model is one whose variety x environment interaction effects is zero for all environments in the population. For this kind of stability, a variety's yields are not constant across environments, but there is an element of constancy. What is constant across environments is the difference between the variety's yield in an environment and the environment mean, i.e., the mean yield of all varieties in that environment. This constant difference is equal to the difference between the variety mean and the mean of all varieties' means.

For an unstable variety, the idealized yield pattern to which it is compared for determining its deviations and its degree of stability is the one for which the yields have the same mean as the variety and differ from their environmental mean by the same amount that the variety mean differs from the mean of all varieties' means. Thus, the deviations of the variety's yields from this pattern are its interaction effects. Therefore, the variance of these deviations is the variance of the variety's interaction effects. This variance is the measure of the no-interaction stability of the variety.

In this approach to stability, the stability of a variety is not an inherent property of the variety but is dependent on the other varieties under consideration. That is, its stability is relative rather than absolute. If a variety were included with a different set of other varieties, then its stability could change.

Linear-Interaction Stability

The linear-interaction stability model is a modification of the no-interaction stability model. In this model, the interaction effects for a stable variety are not required to be zero; instead, they are required to form a straight line when plotted against the environment means. This model makes use of the following: The interaction effects of a variety can be partitioned into two parts. One part is the least squares regression of its interaction effects on the environment means and the other is the residual. If all the interaction effects lie on a straight line when plotted against the environment means, then the residuals are zero and the interaction effect is completely determined by the regression line. Because the mean of the interaction effects of a variety is zero, if the slope of the regression line is zero, then the all of the variety's interaction effects are zero. If the slope of the regression line is not zero, then the variety's interaction effects are not zero. Thus, a variety that is stable by the no-interaction stability model is also stable by the linear-interaction stability model, but not conversely.

A variety that is not stable by the linear-interaction stability model is compared to an idealized pattern of yields having the same mean as the variety and having interaction effects that lie on the least squares regression line as described above. The deviations for this comparison are the residuals from the fitted regression and the variance of these residuals measures the degree of stability of the unstable variety. This variance for an unstable variety cannot be larger than its variance for the no-interaction stability model.

The residuals from the fitted regression for linear-interaction stability are also the residuals from regressing the variety's yields on the environment means. Thus it is not necessary to determine the interaction effects to obtain these residuals and their variance. In terms of this regression, a stable variety by the no-interaction stability model has residuals that are zero and a regression line with a slope of 1.

Illustrations

A numerical example will be used to aid in clarification of each of the stability models and measures described above. In addition to the Tables that accompany the text, the Appendix contains graphics using the numerical example to illustrate features of each type of stability and the measure of the degree of variety stability for each type of stability.

In the example, there are three varieties (V1, V2, V3) under consideration and four environments (E1, E2, E3, E4) in the population of environments. For each variety in each environment there is value which can be thought of as the yield when that variety is grown in that environment (Table 1).

Table 1. Numerical values for use in illustrating stability models and measures, consisting of the true yields of 3 varieties (V1, V2, V3) in 4 environments (E1, E2, E3, E4), the variety means across the population of four environments, the environment means across the three varieties under consideration, and the mean of yields from all varieties in all environments. The color coding of varieties in this table will be used consistently throughout the illustrations, including the graphics in the Appendix.

	E1	E2	E3	E4	Var. mean
V1	10	11	11	12	11
V2	8	10	13	17	12
V3	12	12	12	16	13
Env. mean	10	11	12	15	12

Absolute Stability

In order to be a stable variety by the absolute stability model, the yield for all four environments would have to be the same. Thus, none of the varieties are stable according to this model. To determine a variety's degree of absolute stability, it would be compared to a yield pattern for which the mean is the same as the variety's mean and the yields in the four environments are equal to that mean. The deviations (Table 2) between the true yields and the idealized yields are computed by subtracting the variety mean from the true yields.

Table 2. Deviation of each true yield of a variety from the variety mean and the variance of the deviations for a variety which is the measure of that variety's absolute stability.

	E1	E2	E3	E4	Variance
V1	-1	0	0	1	0.67
V2	-4	-2	1	5	15.33
V3	-1	-1	-1	3	4.00

The variance of these deviations for each variety (Table 2) is the measure of the absolute stability of that variety. **V1** is the most stable of the 3 varieties and **V2** is the least stable or the most unstable. If the variance is converted to a standard deviation by taking the square root, then this number can be roughly interpreted as the average of the magnitudes of the deviations of the true yields of a variety from the idealized yields if it were stable. For example, **V3** has a stability standard deviation of 2 where the individual magnitudes are 1, 1, 1, and 3.

No-Interaction Stability

The calculation of the interaction effect will be illustrated for yield of **V1** in E1: it is (true yield - variety mean - mean for E1+ overall mean) = (10 - 11 - 10 - 12) = 1. In order for a variety to be stable, all of its interaction effects must be zero which means that each of its true yields must equal the variety mean + environment mean - overall mean, the values of which are shown in Table 3.

Table 3. Idealized yields for stable varieties having the same variety means and environment means as occur in Table 1.

	E1	E2	E3	E4	Var. mean
V1	9	10	11	14	11
V2	10	11	12	15	12
V3	11	12	13	16	13
Env. mean	10	11	12	15	12

Another way to compute the interaction effects is to subtract the values for stable varieties given in Table 3 from the true yields of Table 1. The interaction effects that result from doing this are shown in Table 4. Although **V1** and **V3** have some interaction effects that are 0, none of the varieties is stable with respect to the no-interaction stability model. **V1** was most stable in terms of absolute stability but **V3** is most stable with respect to no-interaction stability. **V2** is least stable for both types of stability. A feature of the stability variances for absolute stability and no-interaction stability illustrated in this example is that there is no order relationship – either one can be the larger one. A related feature, but not occurring in the example, is that a variety that is stable according to the absolute stability model cannot be stable by the no-interaction stability model. The converse is also true.

Table 4. Interaction effects and their variances for each variety; the variance measures the degree of no-interaction stability for each variety.

	E1	E2	E3	E4	Variance
V1	1	1	0	-2	2.00
V2	-2	-1	1	2	3.33
V3	1	0	-1	0	0.67

Linear-Interaction Stability

As described previously, the linear-interaction stability measure is the variance of the residuals from regressing the variety yields on the environment means and the residuals are the differences between the variety yields and the yields of the reference stable variety. The reference yields are the predicted yields from the regression. The regression coefficients can be computed by standard formulas for simple linear regression of Y on X. For example, these standard formulas would be applied to the (X,Y) pairs (10,10), (11,11), (11,12), (15,12) to obtain the intercept and slope of the regression for **V1**. The regression coefficients for each variety are given in Table 5.

Table 5. Regression coefficients, predicted yields and residuals for the regression of the variety yields on the environment means. Each predicted yield (PRED) is the sum of the intercept coefficient (INT) and the product of the slope coefficient (SLOPE) and the environment mean. Each residual (RES) results from subtracting the predicted yield from the variety yield. The variance of the residuals is the measure of the linear-interaction stability of the variety. [All calculated values except the final variance are expressed as fractions to give exact values free of rounding errors.]

			----- E1 -----		----- E2 -----		----- E3 -----		----- E4 -----		
Variety	INT	SLOPE	PRED	RES	PRED	RES	PRED	RES	PRED	RES	Variance
V1	47/7	5/14	144/14	-4/14	149/14	5/14	154/14	0	169/14	-1/14	0.071
V2	-66/7	25/14	118/14	-6/14	143/14	-3/14	168/14	1	243/14	-5/14	0.452
V3	19/7	12/14	158/14	10/14	170/14	-2/14	182/14	-1	218/14	6/14	0.571

Because not all of the residuals are zero for any variety, none of the varieties are stable according to the linear-interaction model.

A feature of the regression slopes is that their average is 1. A variety that is stable according to the no interaction model has a slope coefficient of 1 and has residuals that are zero. A variety that is stable according to the linear-interaction model but is not stable according to the no interaction model has zero residuals but a slope coefficient that is different from 1.

The large differences between the no-interaction stability and linear-interaction stability measures for **V1** and **V2** indicate that the instability in them reflected in their interaction effects can be explained by their having a linear yield response to the environment but that this response does not parallel the average yield response of all varieties. On the other hand, the similarity of these two stability measures for **V3**, which is a result of its slope being near one, indicates that its interaction effects have little linear response to the environment.

Selecting a Stability Measure

One approach in investigating variety stability is not to use just one measure but to use all three measures and possibly others that we did not consider. Each measure of stability gives an indication of a different type of stability so that together we gain a better overall picture of a variety's stability than is provided by only one measure. We wanted to have a single measure in order to have a concise result about each variety's stability. The following explains our reasons for selecting no-interaction stability.

When identifying candidates for variety stability at the outset of our project, we included absolute stability mostly because it was simple conceptually. However, we did not use it because it did not seem of practical value. We would expect most varieties to respond to the environment; that is, we would expect them to do well in a good environment but not do well in a poor environment. Thus, we did not think that "stability" should mean constancy of yield. A desirable feature of absolute stability would seem to be that it does not depend on the other varieties being considered. On the other hand, usually the set of varieties being considered in variety tests are those from which producers will be selecting the one they will plant. Therefore, having a stability measure that is relative to such a set actually seems like a positive feature rather than a negative.

The choice of no-interaction stability over linear-interaction stability was not so clear. We primarily chose it because a variety that has no-interaction stability will have consistent performance in relation to the set of varieties considered, regardless of the environment. Thus, if a variety is stable with respect to the no-interaction model and if it has a mean lint yield that exceeds the mean of all currently used varieties by 200 pounds per acre, then we can count on it having a yield advantage of 200 pounds per acre regardless of the environment.

Note About Data Analysis of Stability

Although analyzing data in a stability study was not relevant to this paper, a note about such an analysis will be added here for those who may not be familiar with the approach. Piepho (1999) describes the statistical models for analyzing stability models, including the three stability models described in our paper. The statistical software used in his paper is the MIXED procedure in SAS which allows all the flexibility that is needed in fitting stability models.

References

Piepho, Hans-Peter. 1999. Stability Analysis Using the SAS System. Agron. J. 91:154-160.

Appendix

Each of Figures A1, A2 A3 displays the features of the indicated type of stability. The true yields (Table 1) are represented by the numeric symbols in the plot. The color coding of varieties used in the Tables is continued in these Figures. The dotted lines join the values of the idealized pattern corresponding to each variety for the respective type of stability. The variance of a variety's deviations of its true yields from the respective line is the stability measure for that variety.

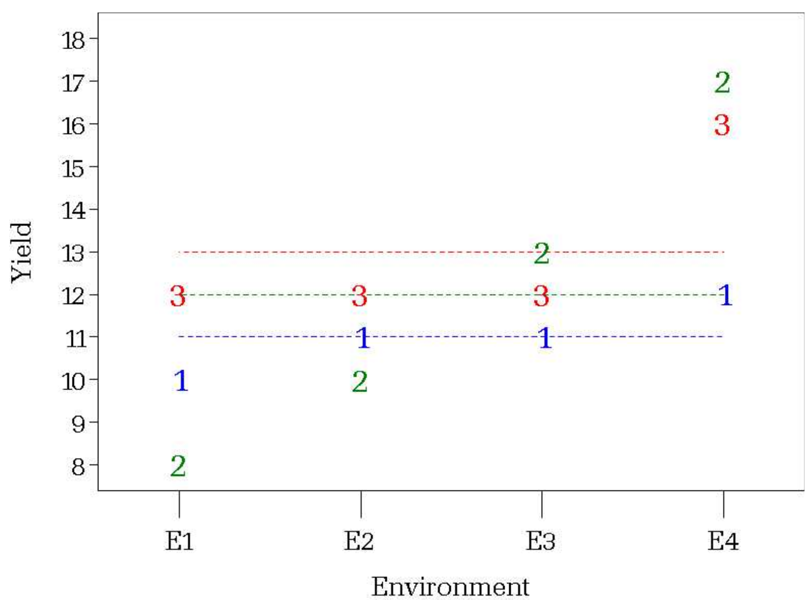

Figure A1. Graphic displaying features of the absolute stability model and the measure of absolute stability for each variety. See text for interpretations of the features.

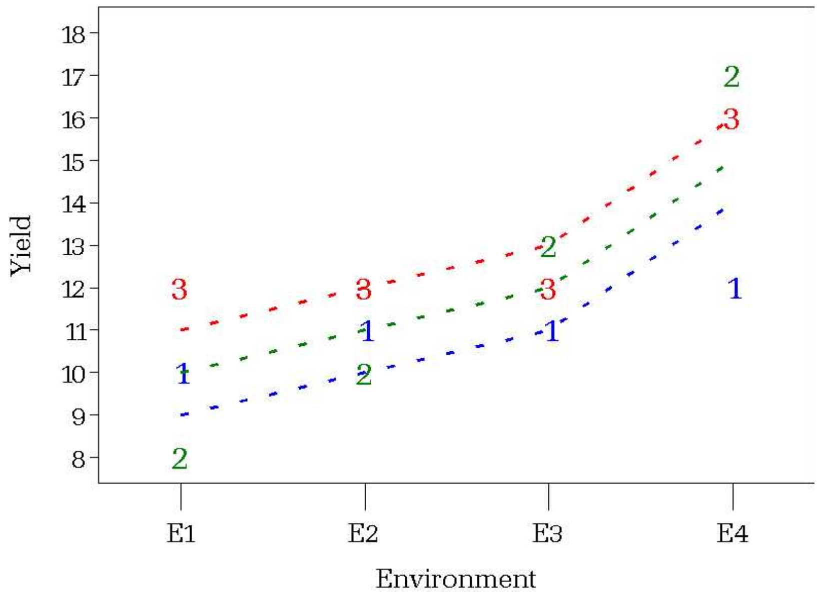

Figure A2. Graphic displaying features of the no-interaction stability model and the measure of no-interaction stability for each variety. See text for interpretations of the features.

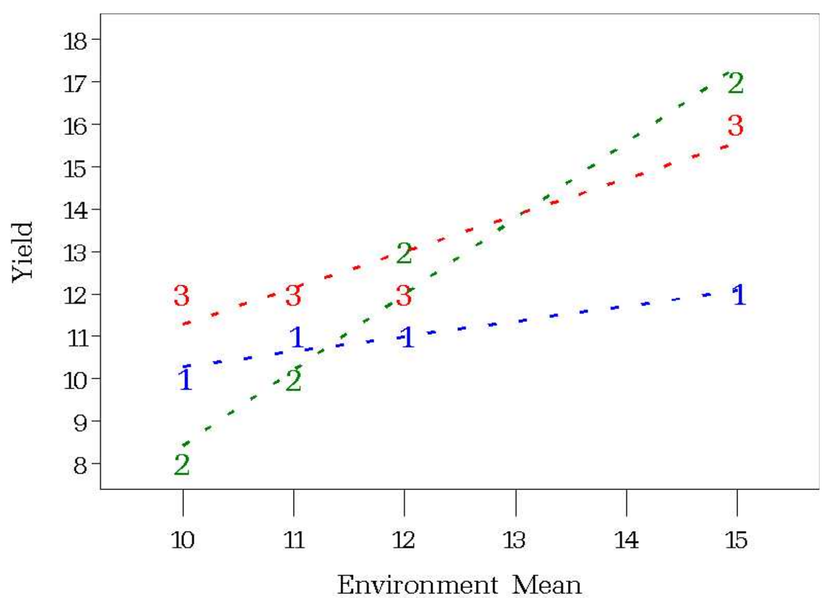

Figure A3. Graphic displaying features of the linear-interaction stability model and the measure of linear-interaction stability for each variety. See text for interpretations of the features.