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# AN ALTERNATIVE APPROACH TO THE STABILITY ANALYSIS PROPOSED BY SILVA AND BARRETO

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## ABSTRACT

A modification of the stability analysis proposed by Silva and Barreto (Simpósio de Experimentação Agrícola, 1, Piracicaba. Fundação Cargill, Campinas, pp. 49-50, 1985) is presented and discussed. The original and modified analysis are applied for comparison, to yield data of corn trials, with 17 cultivars tested in 12 locations, during 1982/83. It could be shown that the alternative approach has fundamental properties, not inherent in the original one, namely: the computation of parameter estimates and sums of squares is much simplified; the standard errors of these estimates are smaller; the residual correlations, between stability parameter estimates of more interest are eliminated. The latter property permits a better evaluation of the genetic correlation eventually present between stability patterns, for a given trait.

Expressions are given to calculate estimates of parameters, their variances and of sums of squares, for the modified model.

## INTRODUCTION

Several methods for the analysis of cultivar stability and adaptability have been adopted by breeders to identify the extent of cultivar x location interaction and to recommend cultivars for regions with specific variations.

The study of stability by variance or sums of squares estimates associated

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with interaction of the genotype x environment type has been commonly used. This type of study has some disadvantages since the estimates obtained are of low precision and do not contain detailed information on the performance of each cultivar. Thus, methodologies based on, or complemented with, regression analyses have been preferred.

In 1966, Eberhart and Russell presented a methodology in which stability parameters were identified as 1) the regression coefficient ($b_1$) obtained by linear regression of mean cultivar yield at each location as a function of an environmental index expressed by the mean yield of all cultivars for each environment, coded for the overall mean for the trials, and 2) the estimator of the variance component of deviations from linear regression ($S^2_{di}$). According to the interpretations most commonly used, this analysis permits the identification of predictable (stable) behavior when $S^2_{di} = 0$, or of unpredictable (unstable) behavior when $S^2_{di} \neq 0$, and of wide (or general) adaptability when $b = 1$, of specific adaptability to favorable environments when $b > 1$, or of specific adaptability to unfavorable environments when $b < 1$.

Verma *et al.* (1978) defined an ideal cultivar as one that presents high productivity associated with high stability in unfavorable environments and capable of responding satisfactorily to favorable environmental conditions. Since the identification of such a cultivar is not possible by the method of Eberhart and Russell (1966), they proposed to perform the analysis using two regression equations, the first involving only locations with negative indices and the second, locations with positive indices (the least negative environmental index should also be included in the latter as an absolute value for line continuity) so that the response of a cultivar may be tested using two line segments.

One of the drawbacks of the methodology proposed by Verma *et al.* (1978) appears when a relatively small number of locations is analyzed in any subgroup, so that the analysis may become impracticable or the statistical tests questionable. An alternative for avoiding this problem is the use of the model proposed by Silva and Barreto (1985), in which the fit is obtained by a single equation consisting of two line segments.

The objective of the present paper is to present a modification of the methodology proposed by Silva and Barreto (1985) and to discuss its advantages in relation to the original method.

## MATERIAL AND METHODS

### *Methodology*

Stability and adaptability analysis is used to study the differential behavior of a group of cultivars tested in a set of locations. The analysis is performed in two steps: in the first, joint analysis of variance is performed to obtain information on the existence and extent of significance of cultivar x location interaction and on the partitioning of locations/ cultivar sums of squares. During the second stage, regression analysis of mean cultivar performance is performed for each cultivar as a function of an environmental index, thus obtaining estimates that measure the predictability and adaptability of each material tested.

The following model was proposed by Silva and Barreto (1985) to evaluate stability and adaptability:

$$Y_{ij} = \beta_{0i} + \beta_{1i} X_j + \beta_{2i} T(X_j) + \delta_{ij} + \bar{e}_{ij} \quad (1)$$

where:

$Y_{ij}$ = mean for cultivar *i* (i = 1, 2, . . . , m) at location *j* (j = 1, 2, . . ., n) resulting from *r* trial replications.

$X_j$ = environmental index defined by:

$$X_j = \frac{Y_{\cdot j}}{m} - \frac{Y_{\cdot\cdot}}{mn}, \text{ where } \sum_{j=1}^{n} X_j = 0$$

The term $T(X_j)$ was originally defined by:

$$T(X_j) = 0 \text{ if } X_j \leqslant 0$$
$$T(X_j) = 1 \text{ if } X_j > 0.$$

In the present paper we will consider that:

$$T(X_j) = 0 \text{ if } X_j \leqslant 0$$
$$T(X_j) = X_j - \bar{X}_p \text{ if } X_j > 0,$$

where:

$\bar{X}_p$ = mean of positive $X_j$ indices;

thus:

$$\sum_{j=1}^{n} T(X_j) = \sum_{j=1}^{n_1} T(X_j) = \sum_{j=n_1+1}^{n} T(X_j) = 0$$

where:

$n_1$ = number of unfavorable locations (negative $X_j$ index)
$n - n_1$ = number of favorable locations (positive $X_j$ index)
$\beta_{0i}$ = intercept of the regression equation,
$\beta_{1i}$ = linear regression coefficient associated with the $X_j$ variable,
$\beta_{2i}$ = linear regression coefficient associated with the $T(X_j)$ variable,
$\bar{e}_{ij}$ = mean experimental error associated with the $Y_{ij}$ observation.

On the basis of the new model proposed, algebraic expressions of the estimates of the parameters, of their respective variances and of the residual covariances among them were obtained by the least squares method. Analysis of variance appropriate for the model was elaborated and the expected mean squares of highest interest were deduced. The determination coefficient $R^2$, was used to test the fit of the model to the experimental data. The parameter used to evaluate deviation from regression, which quantifies the predictability of the behavior of each cultivar tested, was also emphasized.

*Experimental material*

To compare the results obtained by the original method of Silva and Barreto (1985) with those obtained using the proposed alteration, analysis of ear weight stability (kg/ha) was performed for 17 maize (*Zea mays* L.) cultivars tested at 12 locations: São Gabriel D' Oeste (MS), Bandeirantes (PR), Biriguí (SP), Dourados (MS), Barretos (SP), Campinas (SP), Lavras (MG), Capinópolis (MG), Sete Lagoas (MG), Inhumas (GO), Santa Helena de Goiás (GO), and Jacarezinho (PR), in 1982/83.

The data used in the present study refer to means adjusted for intrablock errors of cultivars of the National Corn Trial (CNPMS/EMBRAPA), according to Torres (1988, Tables 45 and 46). Joint location analysis was performed with mean and cultivar effects considered as fixed and the remaining effects considered as random.

## RESULTS AND DISCUSSION

Estimators and variances and covariances of regression coefficients, as well as regression sums of squares and deviation from regression were obtained by the least squares method taking into consideration the modification proposed to obtain the $T(X_j)$ index described in model (1).

*Estimators and variances of the regression coefficients*

Using a matrix notation, the equations defined in model (1) may be represented by $Y = X\beta + \Delta$, where:

$Y$ = n x 1 vector of the means for cultivar *i* at the various locations;
$X$ = n x 3 matrix of fixed quantities, whose first column is formed by ones, the second by $X_j$ values, and the third by $T(X_j)$ values;
$\beta$ = 3 x 1 vector of the stability parameters;
$\Delta$ = n x 1 vector of the deviations associated with $Y_{ij}$ for each i in relation to values expected through the regression equation.

Estimators of regression coefficients can be calculated by the normal equations $X'X\hat{\beta} = X'Y$, from which we obtain:

$$\hat{\beta}_{0i} = \overline{Y}_{i\cdot}$$

$$\hat{\beta}_{1i} = \frac{\sum_{j=1}^{n} Y_{ij} X_j - \sum_{j=1}^{n} Y_{ij} T(X_j)}{\sum_{j=1}^{n} X_j^2 - \sum_{j=1}^{n} T^2(X_j)}$$

$$\hat{\beta}_{2i} = \frac{\sum_{j=1}^{n} X_j^2 \sum_{j=1}^{n} Y_{ij} T(X_j) - \sum_{j=1}^{n} T^2(X_j) \sum_{j=1}^{n} Y_{ij} X_j}{\sum_{j=1}^{n} T^2(X_j) \left[ \sum_{j=1}^{n} X_j^2 - \sum_{j=1}^{n} T^2(X_j) \right]}$$

$$\hat{\beta}_{1i} + \hat{\beta}_{2i} = \frac{\sum_{j=1}^{n} Y_{ij} T(X_j)}{\sum_{j=1}^{n} T^2(X_j)}$$

The estimators have the following variances:

$$\hat{V}(\hat{\beta}_{0i}) = \frac{1}{n} \hat{\sigma}^2$$

$$\hat{V}(\hat{\beta}_{1i}) = \frac{1}{\sum_{j=1}^{n} X_j^2 - \sum_{j=1}^{n} T^2(X_j)} \hat{\sigma}^2$$

$$\hat{V}(\hat{\beta}_{2i}) = \frac{\sum_{j=1}^{n} X_j^2}{\sum_{j=1}^{n} T^2(X_j) \left[ \sum_{j=1}^{n} X_j^2 - \sum_{j=1}^{n} T^2(X_j) \right]} \hat{\sigma}^2$$

$$\hat{V}(\hat{\beta}_{1i} + \hat{\beta}_{2i}) = \frac{1}{\sum_{j=1}^{n} T^2(X_j)} \hat{\sigma}^2$$

It can also be seen that:

$$\hat{Cov}(\hat{\beta}_{0i}, \hat{\beta}_{1i}) = \hat{Cov}(\hat{\beta}_{0i}, \hat{\beta}_{2i}) = \hat{Cov}(\hat{\beta}_{0i}, \hat{\beta}_{1i} + \hat{\beta}_{2i}) = 0$$

$$\hat{Cov}(\hat{\beta}_{1i}, \hat{\beta}_{2i}) = -\hat{V}(\hat{\beta}_{1i})$$

$$\hat{Cov}(\hat{\beta}_{1i}, \hat{\beta}_{1i} + \hat{\beta}_{2i}) = 0$$

*Regression sums of squares and deviation from regression*

The proposed modification permits the orthogonal partition of locations/ cultivar $i$ sums of squares. Thus, the new method will not evade the traditional stability parameters related to the mean squares and their components and will also permit the identification of the statistical tests that best fit the hypotheses formulated. It can then be seen that:

SS (locations/cultivar $i$) = SS (regression) + SS (deviations), for each $i$:

or:

$$Y'Y - C = (\hat{\beta}'X'Y - C) + (Y'Y - \hat{\beta}'X'Y)$$

where:

C = correction for the mean;

$$SS\ (regression) = \frac{[\sum_{j=1}^{n} Y_{ij} X_j - \sum_{j=1}^{n} Y_{ij} T(X_j)]^2}{\sum_{j=1}^{n} X_j^2 - \sum_{j=1}^{n} T^2(X_j)} + \frac{[\sum_{j=1}^{n} Y_{ij} T(X_j)]^2}{\sum_{j=1}^{n} T^2(X_j)}$$

$$R^2 = \frac{SS\ (regression)}{SS\ (total)} \times 100$$

$R^2$ = Determination coefficient of the model.

The expected mean squares associated with regression and deviations from regression are shown in Table I. The environmental indices were considered as fixed amounts. These expectations are of great value in the evaluation of the significance of $\sigma^2_{di}$, which is the predictability measurement for the material tested.

The results of joint analysis of variance are presented in Table II. The significance of cultivars x locations interaction mean square suggests the existence of a differential cultivar behavior which can be studied by stability analysis.

A comparison of the methods employed is presented next, with emphasis on the advantages obtained with the proposed alteration.

*Stability parameters*

The original and modified methods present three stability parameters whose estimates are presented in Table III. In both methods, $\hat{\beta}_{1i}$ represents the linear response of cultivar $i$ to variation in unfavorable environments (locations with negative indices), and $\hat{\beta}_{1i} + \hat{\beta}_{2i}$ represents the linear response to variation in favorable environments (locations with positive indices).

Table I - Joint analysis of variance with partition of location/cultivar sums of squares in regression and deviations from regression.

| Source of variation | d.f. | MS/r | F | E(MS) |
|---|---|---|---|---|
| Cultivars (C) | m - 1 | | | |
| Locations (L) | n - 1 | | | |
| C x L interaction | (n - 1) (m - 1) | | | |
| Locations/cultivars | m (n - 1) | | | |
| Locations/cultivars 1 | n - 1 | | | |
| Regression/cultivar 1 | (2) | $MR_1$ | $MR_1/MD_1$ | $\sigma^2 + \sigma^2_{d1} + (\frac{1}{2}) \sum_{j=1}^{n} [\beta_{11} X_j + \beta_{21} T(X_j)]^2$ |
| Deviation/cultivar 1 | (n - 3) | $MD_1$ | $MD_1/MRes$ | $\sigma^2 + \sigma^2_{d1}$ |
| ⋮ | | | | |
| Locations/cultivars m | n - 1 | | | |
| Regression/cultivars m | (2) | $MR_m$ | $MR_m/MD_m$ | $\sigma^2 + \sigma^2_{dm} + (\frac{1}{2}) \sum_{j=1}^{n} [\beta_{1m} X_j + \beta_{2m} T(X_j)]^2$ |
| Deviation/cultivar m | (n - 3) | $MD_m$ | $MD_m/MRes$ | $\sigma^2 + \sigma^2_{dm}$ |
| Residual | | MRes | | $\sigma^2$ |

$\bar{\sigma}^2 = \bar{\sigma}^2_e / r$

$\bar{\sigma}^2_e$ = MS (residual) of the analysis with individual data.

Table II - Summary of joint analysis of variance of ear yield for 17 maize cultivars tested at 12 locations (1982/83).

| Source of variation | d.f. | MS x $10^{-3}$ |
|---|---|---|
| Replications/location | 12 | 1,437.9** |
| Locations (L) | 11 | 122,356.5** |
| Cultivars (C) | 16 | 7,163.2** |
| L x C interaction | 176 | 763.0** |
| Residual | 192 | 270.7** |
| Mean (kg/ha) | 6,927 | |
| CV (%) | 7.5 | |

**Significant at the 1% level of probability (F test).

The first advantage of the proposed modification is related to the fact that in this case the estimate of $\hat{\beta}_{0i}$ coincides with the overall mean for cultivar *i* in relation to all the locations where it was tested. Despite the existence of interactions, the overall cultivar mean is a basic parameter for genotype discrimination and its inclusion in the regression equation, representing the intercept of the line on the Y axis (mean yield axis) greatly facilitates the interpretation of cultivar behavior and comparative superiority.

Table III shows that, among the most productive cultivars (cultivars *6, 13* and *14*), the most stable in unfavorable locations was cultivar *6* as calculated by both methods, and the most responsive in favorable locations was cultivar *13,* as calculated by the modified method, and cultivar *14,* as calculated by the original method.

*Estimate precision*

The standard deviations associated with the estimates of the stability coefficients are presented in Table III. It can be seen that the standard deviations estimated by the modified method were smaller, indicating greater precision of this method as compared to the original one.

*Correlation between stability parameter estimates*

Table IV shows the correlation coefficients between the stability parameter estimates obtained by the original and the modified methods. We estimated residual correlations, *i.e.* correlations inherent in the methodology, which are obtained by the elements of the dispersal matrix $(X'X)^{-1}\hat{\sigma}^2$, and the phenotypic correlations, which

Table III - Estimates and standard deviations of stability parameters. Ear yield of 17 maize cultivars (kg/ha).

| Cultivar | Methodology | | | | | | |
|---|---|---|---|---|---|---|---|
| | Original | | | Modified | | | |
| | $\hat{\beta}_0$ | $\hat{\beta}_1$ | $\hat{\beta}_1 + \hat{\beta}_2$ | $\hat{\beta}_0$ | $\hat{\beta}_1$ | $\hat{\beta}_2$ | $\hat{\beta}_1 + \hat{\beta}_2$ |
| 1 | 6158.4 | 0.79 | 1.15 | 6440.7 | 0.96 | 0.21 | 1.17 |
| 2 | 6178.2 | 0.74 | 1.21 | 6547.7 | 0.95 | 0.30* | 1.25 |
| 3 | 6735.2 | 0.67 | 1.26 | 7198.8 | 0.93 | 0.38* | 1.31 |
| 4 | 7230.6 | 1.00 | 1.02 | 7244.2 | 1.02 | -0.02 | 1.00 |
| 5 | 6456.3 | 0.73 | 0.73 | 6455.5 | 0.72 | 0.06 | 0.78 |
| 6 | 7185.4 | 0.39 | 1.08 | 7730.4 | 0.75 | 0.16 | 0.91 |
| 7 | 7565.4 | 1.30 | 0.83 | 7197.4 | 1.07 | -0.15 | 0.92 |
| 8 | 7435.6 | 1.46 | 0.81 | 6927.9 | 1.16 | -0.33* | 0.83 |
| 9 | 7092.3 | 1.15 | 0.96 | 6951.8 | 1.07 | -0.14 | 0.93 |
| 10 | 6780.1 | 1.05 | 0.99 | 6732.3 | 1.01 | 0.03 | 1.04 |
| 11 | 6016.1 | 1.06 | 0.85 | 6754.5 | 0.94 | 0.00 | 0.94 |
| 12 | 6781.3 | 1.53 | 0.85 | 6254.4 | 1.21 | -0.33* | 0.88 |
| 13 | 8184.8 | 1.39 | 1.01 | 7890.8 | 1.19 | -0.08 | 1.11 |
| 14 | 7801.0 | 0.94 | 1.13 | 7950.8 | 1.05 | -0.02 | 1.03 |
| 15 | 6528.6 | 1.16 | 0.75 | 6209.1 | 0.95 | -0.11 | 0.84 |
| 16 | 6936.0 | 0.69 | 1.28 | 6856.1 | 0.98 | 0.21 | 1.19 |
| 17 | 6331.7 | 0.94 | 1.05 | 6451.5 | 1.04 | -0.18 | 0.86 |
| SD | 215.0 | 0.15 | 0.24 | 106.2 | 0.06 | 0.15 | 0.15 |

*Significantly different from zero at the 5% level of probability (t test).

are obtained from the estimates of the coefficients associated with the 17 cultivars tested.

The existence of residual correlations between stability measurements in the original method is the main reason for the modification proposed in the present paper, since such modification permits the calculation of phenotypic correlations free from methodological errors and consequently representing more correctly the genetic nature of the associations studied.

The use of the original method leads to the derivation of phenotypic correlations among $\hat{\beta}_0$, $\hat{\beta}_1$ and $\hat{\beta}_1 + \hat{\beta}_2$ which reflect the residual nature of the associations

Table IV - Correlations between the stability coefficients obtained by the original and modified method of Silva and Barreto (1985).

| Coefficients | Residual | | Phenotypic | |
|---|---|---|---|---|
| | Original | Modified | Original | Modified |
| $\hat{\beta}_0$ and $\hat{\beta}_1$ | 0.80 | 0.00 | 0.45 | 0.08 |
| $\hat{\beta}_0$ and $\hat{\beta}_1 + \hat{\beta}_2$ | -0.76 | 0.00 | -0.19 | 0.23 |
| $\hat{\beta}_1$ and $\hat{\beta}_1 + \hat{\beta}_2$ | -0.60 | 0.00 | -0.59 | 0.02 |

and consequently are devoid of any practical breeding usefulness. These correlations, when estimated by the modified method, may show a magnitude or sign quite different from those obtained by the original method (Table IV). Table IV shows that the phenotypic correlation between $\hat{\beta}_1$ and $\hat{\beta}_1 + \hat{\beta}_2$ is practically zero instead of high and negative as obtained by the original method. Thus, on the basis of the estimates obtained by the modified method, it is clear that cultivar behavior in terms of response to favorable and unfavorable locations is independent. This means that it is possible to identify stable treatments in unfavorable locations and responsive treatments in favorable locations, as well as any other response combination of interest to the breeder.

Table V shows estimates of the correlations between the stability parameters obtained by the original method and those obtained by the modified method. It can be seen that the correlations are high (above 0.80). However, as discussed previously the modified method induces changes that are relevant for plant breeding even though it does not alter drastically the magnitude of the estimates.

Table V - Correlations between the stability coefficients estimated by the original method and those estimated by the modified method.

| Coefficient (original and modified) | Estimate |
|---|---|
| Between $\hat{\beta}_0$'s | 0.82 |
| Between $\hat{\beta}_1$'s | 0.84 |
| Between $(\hat{\beta}_1 + \hat{\beta}_2)$'s | 0.86 |

*Determination coefficient*

Table VI presents the determination coefficient for both methods. The coefficient measures the degree of fit of the proposed models to the experimental data. For the modified method we additionally present the variance component associated with the deviations from regression which describes the predictability of the cultivar in terms of linear response to an improved environment.

Table VI - Estimates of determination coefficients and of the component of deviation from regression. Ear yield of 17 maize cultivars (1982/83).

| Cultivar | Modified methodology | | Original methodology |
|---|---|---|---|
| | $\hat{\sigma}^2_{di}$ | $R^2$ (%) | $R^2$ (%) |
| 1 | 155,806.4* | 93.8 | 93.9 |
| 2 | 1,473.9 | 97.1 | 97.0 |
| 3 | - 66,294.9 | 98.5 | 98.4 |
| 4 | 120,677.5 | 94.6 | 94.6 |
| 5 | 263,841.9** | 85.5 | 85.5 |
| 6 | 1,262,843.1** | 65.9 | 68.6 |
| 7 | 96,314.8 | 95.3 | 96.2 |
| 8 | 246,473.0** | 93.3 | 93.9 |
| 9 | 301,413.5** | 91.7 | 91.6 |
| 10 | - 24,154.5 | 97.6 | 97.6 |
| 11 | 203,486.3* | 92.0 | 92.3 |
| 12 | 32,186.8 | 97.2 | 98.0 |
| 13 | 681,175.4** | 88.2 | 88.7 |
| 14 | 40,777.0 | 96.5 | 96.6 |
| 15 | 77,761.9 | 94.7 | 95.6 |
| 16 | 172,638.4* | 93.7 | 95.0 |
| 17 | 274,814.3** | 91.6 | 91.1 |

Significant at the *5% and **1% levels of probability (F test).

As can be seen, the fit of the modified method was practically identical to that of the original method. In this respect, one method is not superior to the other.

In addition to the comparisons reported above, other important aspects should be emphasized with respect to the modified method. When the results obtained by the modified method are compared to those obtained by the method of Eberhart and Russell (1966) (Table VII), it can be seen that the $\hat{\beta}_1$ coefficient of Eberhart and Russell (1966) shows intermediate estimates between $\hat{\beta}_1$ and $\hat{\beta}_1 + \hat{\beta}_2$ and that their determination coefficient is slightly lower.

Table VII - Estimates of stability parameters by the method of Eberhart and Russell (1966).

| Cultivar | $b_i$ | $S^2_{di}$ | $R^2$ |
|---|---|---|---|
| 1 | 1.00 | 154,755.9* | 93,2 |
| 2 | 1.01 | 42,645.1 | 95.7 |
| 3 | 1.00 | 14,799.6 | 96.4 |
| 4 | 1.00 | 95,227.6 | 94.6 |
| 5 | 0.73 | 225,745.2** | 85.5 |
| 6 | 0.78 | 1.139,791.0** | 65.5 |
| 7 | 1.04 | 86,465.9 | 95.1 |
| 8 | 1.09 | 275,190.4** | 92.0 |
| 9 | 1.04 | 270,815.5** | 91.4 |
| 10 | 1.02 | - 34,817.7 | 97.6 |
| 11 | 0.94 | 169,611.5* | 92.0 |
| 12 | 1.14 | 82,188.4 | 96.0 |
| 13 | 1.18 | 603,318.4** | 86.2 |
| 14 | 1.04 | 23,249.6 | 96.5 |
| 15 | 0.93 | 64,441.9 | 94.5 |
| 16 | 1.02 | 169,714.4* | 93.1 |
| 17 | 1.00 | 254,378.0** | 91.1 |
| SD | 0.06 | | |

Significant at the *5% and **1% levels of probability by the F test.

The viability of the use of the method proposed by Eberhart and Russell (1966) can be evaluated by rejecting or not the hypothesis $H_0$: $\beta_{2i} = 0$ for each $i$. The non-rejection of this hypothesis indicates that the behavior of the cultivar can be predicted by a single line and in this case the method of Eberhart and Russell is to be preferred. In the present study, the $H_0$ hypothesis was rejected for some cultivars (Table III), demonstrating that, under these circumstances, the use of the original or modified method proposed by Silva and Barreto (1985) is appropriate.

Despite the advantages described, it should be pointed out that the modification of the method of Silva and Barreto (1985) has some drawbacks. Among them is the fact that the equation of the model does not describe a continuous bisegmented line, since it presents a gap at point $X_j$ equal to zero, because it coverges to the left for $\hat{\beta}_0$ and to the right for $\hat{\beta}_0 - \hat{\beta}_2\overline{X}_p$. Because of this feature, the modified method resembles that proposed by Verma *et al.* (1978) with the $\hat{\beta}_1 + \hat{\beta}_2$ estimator identical to the regression coefficient estimated by the latter method for favorable locations (positive indices).

Another questionable aspect both of the original and the modified method is the point of change in slope that coincides with $X_j$ equal to zero. Several investigators have emphasized the need for a methodology that will permit a fluctuating point for the change in slope, a fact that does not occur in the methods discussed here.

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## RESUMO

O trabalho teve por objetivo apresentar uma modificação na metodologia de estudo da estabilidade, proposta por Silva e Barreto (1985), bem como tecer considerações pertinentes. O processo original e sua modificação foram comparados utilizando-se dados de produtividade de espigas de 17 cultivares de milho, avaliados em 12 locais, no ano agrícola de 1982/83. Pôde-se concluir que a alteração proposta tem propriedades fundamentais, não inerentes à metodologia original, pois proporciona considerável simplificação na obtenção das estimativas dos parâmetros e das somas de quadrados; provê estimativas com desvios-padrão menores; elimina a correlação residual existente entre os parâmetros de estabilidade mais importantes. A última propriedade permite uma avaliação mais exata da correlação genética que pode existir entre os padrões de estabilidade, para um dado caráter. São apresentadas as expressões necessárias para a obtenção das estimativas dos parâmetros, de suas variâncias e das somas de quadrados, decorrentes do modelo modificado.

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