A METHOD FOR COMBINED ANALYSIS OF THE DIALLEL CROSSES REPEATED IN SEVERAL ENVIRONMENTS[1]

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ABSTRACT - This paper presents a metodology derived from the model proposed by Gardner & Eberhart for computing combined analysis of variance of diallel crosses tested in several environments, aiming to obtain estimators for the parameters and sums of squares formulae. The following mathematical model was adapted for a combined analysis of the complete diallel crosses:

$$Y_{ijj'} = m + \frac{1}{2}(v_j + v_{j'}) + e_i + \frac{1}{2}(ev_{ij} + ev_{ij'}) + \theta(\bar{h} + e\bar{h}_i + h_j + eh_{ij} + h_{j'} + eh_{ij'} + s_{jj'} + es_{ijj'}) + \bar{\varepsilon}_{ijj'} ,$$

where: $Y_{ijj'}$ is the variety mean if $j = j'$ or the cross mean if $j \neq j'$ in the i^{th} environment; e_i is the environment effects; ev_{ij} and $ev_{ij'}$ are the effects of the interaction environment x variety, $e\bar{h}_i$ is the effect of the interaction environment x average heterosis; eh_{ij} and $eh_{ij'}$ are the effects of the interaction environment x variety heterosis and $es_{ijj'}$ is the interaction environment x specific heterosis. The other parameters of this model are similarly defined in Gardner & Eberhart work. When $j = j'$ then $\theta = 0$ and for $j \neq j'$ then $\theta = 1$. The estimators for the parameters and the sums of squares formulas were determined through the least squared method. Variances of the parameters estimators and the analysis of variance were also determined. An example is presented with its correspondent analysis.

Index terms: parameters, combining ability, environment x effect interaction.

MÉTODO PARA ANÁLISE CONJUNTA DE CRUZAMENTOS DIALÉLICOS REPETIDOS EM VÁRIOS AMBIENTES

RESUMO - O presente trabalho apresenta uma metodologia de análise conjunta da variância de cruzamentos, dialélicos de variedades, a partir do modelo proposto por Gardner & Eberhart (1966), quando estes são repetidos em vários ambientes, com vistas à obtenção de estimadores dos parâmetros e das somas de quadrados. O seguinte modelo matemático foi adaptado de Gardner & Eberhart (1966)

$$Y_{ijj'} = m + \frac{1}{2}(v_j + v_{j'}) + e_i + \frac{1}{2}(ev_{ij} + ev_{ij'}) + \theta(\bar{h} + \bar{h}e_i + h_j + eh_{ij} + h_{j'} + eh_{ij'} + s_{jj'} + es_{ijj'}) + \bar{\varepsilon}_{ijj'} ,$$

onde: $Y_{ijj'}$, é a média da variedade se $j = j'$ e do cruzamento se $j \neq j'$, no i-ésimo ambiente; e_i é o efeito de ambientes; ev_{ij} e $ev_{ij'}$ são os efeitos da interação ambiente x variedades; $\bar{h}e_i$ é o efeito da interação ambiente x heterose média; eh_{ij} e $eh_{ij'}$ são os efeitos da interação ambiente x heterose de variedade, e $es_{ijj'}$ é o efeito da interação ambiente x heterose específica. Os demais parâmetros do modelo são definidos por analogia ao modelo de Gardner & Eberhart. Para $j = j'$ tem-se que $\theta = 0$ e, para $j \neq j'$ $\theta = 1$. Os estimadores dos parâmetros e somas de quadrados foram determinados através do método dos quadrados mínimos. São determinadas, ainda, as variâncias das estimativas dos diferentes parâmetros e a análise da variância. A título de ilustração um exemplo é apresentado com sua correspondente análise.

Termos para indexação: parâmetros, capacidade de combinação, interação efeito x ambiente.

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[1] Accepted for publication on December 12, 1990
Paper presented at the XVI Congresso Nacional de Milho e Sorgo, Belo Horizonte, MG, Brazil, August 4-8, 1986.

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INTRODUCTION

Diallel crosses are important in plant breeding programs because they allow selection of the materials showing good combining ability and can be used to obtain estimatives of genetic parameters.

Several works are reported in literature about the theory and analysis of the diallel cross (Hayman 1954, Griffing 1956, Kempthorne 1956, Gardner 1965, Gardner & Eberhart 1966, Vencovsky 1970, Hallauer & Miranda Filho 1981, and others). The procedure of the diallel analysis of variety crosses proposed by Gardner & Eberhart (1966) have been widely used for the evaluation of genetic potential of varieties in crosses (Miranda Filho & Rissi 1975, Hallauer & Miranda Filho 1981). However, there are no references about estimators for the several parameters and sums of squares for diallel crosses repeated at several environments for this specific kind of experiments.

Diallel analysis repeated over environments is referred by Matzinger et al. (1959); using the model developed by Griffing (1956), they made a study of a diallel cross with ten inbred lines selected at random from a sample of a synthetic population of maize. These crosses were tested at three locations during three years. The objective was to determine the relative importance of general and specific combining ability and of their interactions with locations and years.

Miranda Filho & Rissi (1975) presented an individual and combined analysis for two years of diallel crosses in maize for the following measured: grain yield, plant height and ear height. The sums of squares of the analysis of variance and the estimates of the genetic parameters of the means relative for the two years and combined were calculated through the means of the characters using Gardner (1967) formulas. Hence, they could not obtain the interaction effects (parameters) x years.

The sums of squares of the interactions of effects (parameters) by years were calculated as: $S_{py} = r_1 S_{p1} + r_2 S_{p2} - (r_1 + r_2) S_{p12}$, where S_{py} is the sum of squares of the effect (v_j, $h_{jj'}$, $\bar{h}$, h_j, $s_{jj'}$) by year interaction at a total (over replications) level; r_1 and r_2 are the number of replications in the two years; S_{p1} and S_{p2} are the sums of squares of the effects in the first and second year, respectively, calculated through the varieties and crosses means, and S_{p12} is the sum of squares relative to the effect involved, calculated through the means of both years weighted by the replications.

Gama et al. (1984) made a study of heterosis using 19 populations of maize at three locations using the Gardner & Eberhart (1966) diallel model. For the combined analysis over locations, they considered the location means but did not consider the interactions for estimating effects x locations.

Hence, the objective of this work was the development of a method of analysis for diallel crosses, adapted from the Gardner & Eberhart (1966) for experiments conducted over several environments. The mathematic expressions for the analysis of variance and estimation of parameters are given.

METHOD

The model for diallel crosses (Gardner & Eberhart 1966) among a fixed set of varieties was adapted to analysis of the diallel crosses experiments conducted at several environments. The adapted model is:

$$Y_{ijj'} = m_v + \frac{1}{2}(v_j + v_{j'}) + e_i + \frac{1}{2}(ev_{ij} + ev_{ij'}) + \theta(h_{jj'} + eh_{ijj'}) + \bar{\varepsilon}_{ijj'}$$

where: $Y_{ijj'}$ is the mean of a quantitative trait for the cross between varieties j and j' in i^{th} environment; m_v is the mean parental varieties; v_j is the effect of j^{th} variety ($j = 1, 2, \ldots, n$); e_i is the effect of i^{th} environment ($i = 1, 2, \ldots, a$); ev_{ij} is the interaction effect of i^{th} environment with a j^{th} variety; $h_{jj'}$ is the heterosis effect when a variety j is crossed with a variety j'; $eh_{ijj'}$ is the interaction effect of i^{th} environment with a cross jj'; $\bar{\varepsilon}_{ijj'}$ is the experimental error associated with the mean $Y_{ijj'}$; θ is a conditional coefficient when $j = j'$ then $\theta = 0$ (varieties) and when $j \neq j'$ then $\theta = 1$ (crosses).

The effect of heterosis can be decomposed as follows:

$$h_{jj'} = \bar{h} + h_j + h_{j'} + s_{jj'}$$

where, $\bar{h}$ is the average heterosis: h_j is the variety heterosis confered by the variety j to its crosses (same for $h_{j'}$); $s_{jj'}$ is the specific heterosis from the varieties cross j and j'.

In the same way, the effect of the interaction environment x heterosis can be partitioned as:

$$eh_{ijj'} = e\bar{h}_i + eh_{ij} + eh_{ij'} + es_{ijj'} ,$$

where: $e\bar{h}_i$ is the interaction effect of i^{th} environment with the average heterosis; eh_{ij} is the interaction effect of i^{th} environment wih the heterosis of j^{th} variety (same for $eh_{ij'}$); $es_{ijj'}$ is the interaction effect of i^{th} environment with the varieties cross j and j';

The estimators of parameters and sums of squares were obtained through the least square method. The following restrictions were placed on the model:

$$\sum_j v_j = \sum_i e_i = \sum_i ev_{ij} = \sum_j ev_{ij} = 0; \ \sum_j h_j = \sum_j s_{jj'} = \sum_{j'} s_{jj'} = 0; \ \sum_j eh_{ij} = \sum_{j'} eh_{ij'}$$

$$= \sum_j es_{ijj'} = \sum_{j'} es_{ijj'} = \sum_i e\bar{h}_i = 0$$

The matematic model used can be presented as a matrix form:

$\underset{\sim}{Y} = X\underset{\sim}{\beta} + \underset{\sim}{\epsilon}$, where $\underset{\sim}{Y}$ is the vector of observed means; X is the matrix of parameter coefficients; $\underset{\sim}{\beta}$ is the vector of parameters, and $\underset{\sim}{\epsilon}$ is the vector of experimental errors (where $\underset{\sim}{\epsilon} \sim N(\phi, \sigma^2 I)$. The system of normal equations is given by $X'X\underset{\sim}{\beta} = X'\underset{\sim}{Y}$ and the parameters are estimated by $\hat{\underset{\sim}{\beta}} = (X'X + A)^{-1} X'Y$, being A a matrix where $A\underset{\sim}{\beta} = \phi$ based upon the restrictions formerly imposed.

For better comprehension of calculation the following notation is considered:

$Y_{ijj'}$ = variety mean when j = j', and hybrid mean when j ≠ j' in i^{th} environment; $Y_{iv} = \sum_j Y_{ijj}$ = sum of variety means in the i^{th} environment; $Y_{iH} = \sum_{j<j'} Y_{ijj'}$ = sum of hybrid means in the i^{th} environment; $Y_{i..} = Y_{iv} + Y_{iH} = \sum_{j\leq j'} Y_{ijj'}$ = sum of population means (varieties and hybrids) in the i^{th} environment; $Y_{ij.} = \sum_{j'=1}^{n} Y_{ijj'}$ = sum of the means of j^{th} variety and their crosses in the i^{th} environment (a variety + its crosses); $Y^*_{ij.} = \sum_{j\neq j'} Y_{ijj'}$ = sum of the means of all crosses of the j^{th} variety in the i^{th} environment; $Y_{.v} = \sum_i Y_{iv}$ = sum of the variety means at all environments; $Y_{.H} = \sum_i Y_{iH}$ = sum of the hybrid means at all environments; $Y_{...} = Y_{.v} + Y_{.H} = \sum_{ij\neq j'} Y_{ijj'}$ = sum total (varieties and hybrids); $Y^*_{.j.} = \sum_{ij'} Y_{ijj'}$ = sum of the hybrid means which is included in the j^{th} variety at all environments.

The sum of squares of each effect adjusted for the precedent effects were obtained by sequentially fitting of the following reduced models:

$$Y_{ijj'} = m + \frac{1}{2}(v_j + v_{j'})$$

$$Y_{ijj'} = m + \frac{1}{2}(v_j + v_{j'}) + e_i$$

$$Y_{ijj'} = m + \frac{1}{2}(v_j + v_{j'}) + e_i + \frac{1}{2}(ev_{ij} + ev_{ij'})$$

$$Y_{ijj'} = m + \frac{1}{2}(v_j + v_{j'}) + e_i + \frac{1}{2}(ev_{ij} + ev_{ij'}) + \theta\bar{h}$$

$$Y_{ijj'} = m + \frac{1}{2}(vj + vj') + e_i + \frac{1}{2}(ev_{ij} + ev_{ij'}) + \Theta\bar{h} + \Theta e\bar{h}_i$$

$$Y_{ijj'} = m + \frac{1}{2}(v_j + v_{j'}) + e_i + \frac{1}{2}(ev_{ij} + ev_{ij'}) + \Theta(\bar{h}+e\bar{h}_i+h_j+h_{j'})$$

$$Y_{ijj'} = m + \frac{1}{2}(v_j + v_{j'}) + e_i + \frac{1}{2}(ev_{ij} + ev_{ij'}) + \Theta(\bar{h} + e\bar{h}_i + h_j + h_{j'} + eh_{ij} + eh_{ij'})$$

$$Y_{ijj'} = m + \frac{1}{2}(v_j + v_{j'}) + e_i + \frac{1}{2}(ev_{ij} + ev_{ij'}) + \Theta(\bar{h} + e\bar{h}_i + h_j + h_{j'} + eh_{ij} + eh_{ij'} + s_{jj'})$$

$$Y_{ijj'} = m + \frac{1}{2}(v_j + v_{j'}) + e_i + \frac{1}{2}(ev_{ij} + ev_{ij'}) + \Theta(\bar{h} + e\bar{h}_i + h_j + h_{j'} + eh_{ij} + eh_{ij'} + s_{jj'} + es_{ijj'})$$

where (in these models), $\Theta = 0$ if $j = j'$ and $\Theta = 1$ if $j \neq j'$.

RESULTS

The estimators for the different parameters are presented in Table 1. Ought to be remembered that these estimators were obtained considering the imposed restrictions, in matrix A, to solve the equations system; in case other restrictions were adopted, other expressions would be obtained.

The sum of squares are calculated from the following expressions:

Correction factor:

$$C = \frac{2}{an(n+1)} Y^2_{...}, \text{ where } Y_{...} = \sum_{ij\leq j'} Y_{ijj'}$$

Total sum of squares adjusted by the mean:

$$SS_T = \sum_{ij\leq j'} Y^2_{ijj'} - C$$

Population sum of squares adjusted by the mean:

$$SS_P = \frac{1}{a}\sum_{j\leq j'} Y^2_{.jj'} - C$$

Varieties sum of squares adjusted by the mean (m):

$$SS_V = \frac{4}{a(n+2)} \sum_j (Y_{.jj} + \frac{1}{2}\overset{*}{Y}_{.j.})^2 - \frac{4}{an(n+2)} Y^2_{...}$$

Environment sum of squares adjusted for mean (m) and varieties (v_j):

$$SS_E = \frac{2}{n(n+1)}\sum_i Y^2_{i..} - C$$

TABLE 1. Expressions for estimating for the different parameters.

Parameter	Formulae for estimating
Parent mean	$\hat{m} = \frac{1}{n\,a} Y_{.v}$
Variety effect	$\hat{v}_j = \frac{1}{a} Y_{.jj} - \frac{1}{na} Y_{.v}$
Environment effect	$\hat{e}_i = \frac{1}{n} Y_{iv} - \frac{1}{na} Y_{.v}$
Environment x Variety interaction	$\hat{ev}_{ih} = Y_{ijj} - \frac{1}{a} Y_{.jj} - \frac{1}{n} Y_{iv} + \frac{1}{na} Y_{.v}$
Heterosis effects	$\hat{h}_{jj'} = \frac{1}{a} Y_{.jj'} - \frac{1}{2a}(Y_{.jj} + Y_{.j'j'})$
Average heterosis effect	$\hat{\bar{h}} = \frac{2}{an(n-1)} Y_{.H} - \frac{1}{na} Y_{.v}$
Variety heterosis	$\hat{h}_j = \frac{1}{a(n-2)} Y^*_{.j'} - \frac{1}{2a} Y_{.jj} - \frac{2}{an(n-2)} Y_{.H} + \frac{1}{2na} Y_{.v}$
Specific heterosis	$\hat{s}_{jj'} = \frac{1}{a} Y_{.jj'} - \frac{1}{a(n-2)}(Y^*_{.j.} + Y^*_{.j'.}) + \frac{2}{a(n-1)(n-2)} Y_{.H}$
Environment x Heterosis interaction	$\hat{eh}_{ijj'} = Y_{ijj'} - \frac{1}{2}(Y_{ijj} + Y_{ij'j'}) - \frac{1}{a}[Y_{.jj'} - \frac{1}{2}(Y_{.jj} + Y_{.j'j'})]$
Environment x Average heterosis	$\hat{e\bar{h}}_i = \frac{2}{n(n-1)} Y_{iH} - \frac{1}{n} Y_{iv} - \frac{2}{an(n-1)} Y_{.H} + \frac{1}{na} Y_{.v}$
Environment x Variety heterosis	$\hat{eh}_{ij} = \frac{2}{n-2} Y^*_{ij.} - \frac{1}{2} Y_{ijj} - \frac{2}{n(n-2)} Y_{iH} + \frac{1}{2n} Y_{iv} - \frac{1}{a(n-2)} Y^*_{.j.} + \frac{1}{2a} Y_{.jj} + \frac{2}{an(n-2)} Y_{.H} - \frac{1}{2na} Y_{.v}$
Environment x Specific heterosis	$\hat{es}_{ijj'} = Y_{ijj'} - \frac{1}{n-2}(Y^*_{ij'.}) + \frac{2}{(n-1)(n-2)} Y_{iH} - \frac{1}{a} Y_{.jj'} + \frac{1}{a(n-2)}(Y^*_{.j.} + Y^*_{.j'.}) - \frac{2}{a(n-1)(n-2)} Y_{.H}$

Environments x populations interaction sum of squares:

$$SS_{EP} = SS_T - SS_P - SS_E + C$$

Environments x varieties interaction sum of squares adjusted for mean (m) varieties (v_j) and environments (e_i):

$$SS_{EV} = \frac{4}{n+2}\Sigma_{ij}(Y_{ijj} + \frac{1}{2}\overset{*}{Y}_{ij.})^2 - \frac{4}{n(n+2)}\sum_i Y^2_{i..} - SS_V$$

Heterosis sum of squares adjusted for mean (m), varieties (v_j), environments (e_i) and environments x varieties interaction (ev_{ij}):

$$SS_H = \frac{1}{a}\sum_{j\leq j'} Y^2_{.jj'} - \frac{4}{a(n+2)}\sum_j(Y_{.jj} + \frac{1}{2}\overset{*}{Y}_{.j.})^2 + \frac{2}{a(n+1)(n+2)}Y^2_{...}$$

The heterosis sum os squares can be partitioned into:

$$SS_H = SS_{\bar{H}} + SS_{VH} + SS_{SH}.$$

The average heterosis sum of squares adjusted for mean (m), varieties (v_j), environments (e_i) and environment x varieties interaction (ev_{ij}):

$$SS_{\bar{H}} = \frac{2}{an(n-1)}Y^2_{.H} + \frac{1}{na}Y^2_{.V} - \frac{2}{an(n+1)}Y^2_{...}$$

The varieties heterosis sum of squares adjusted for mean (m), varieties (v_j), environments (e_i), environment x varieties interaction (ev_{ij}) and average heterosis ($\bar{h}$):

$$SS_{VH} = \frac{1}{a(n-2)}\sum_j \overset{*}{Y}^2_{.j} - \frac{4}{an(n-2)}Y^2_{.H} + \frac{1}{a}\sum_j Y^2_{.jj} - \frac{1}{na}Y^2_{.V} - SS_V$$

The specific heterosis sum of squares adjusted for mean (m), varieties (v_j), environments (e_i) environments x varieties interaction (ev_{ij}), average heterosis ($\bar{h}$):

$$SS_{SH} = \frac{1}{a}\sum_{j<j'} Y^2_{.jj'} - \frac{1}{a(n-2)}\sum_j \overset{*}{Y}^2_{.j.} + \frac{2}{a(n-1)(n-2)}Y^2_{.H}$$

The sum of squares for environments x heterosis interaction adjusted for mean (m), varieties (v_j), environments (e_i), environments x varieties interaction (ev_{ij}) and heterosis ($h_{jj'}$):

$$SS_{EH} = \sum_{i,j<j'} Y^2_{ijj'} - \frac{4}{n+2}\Sigma_{ij}(Y_{ijj} + \frac{1}{2}\overset{*}{Y}_{ij.})^2 + \frac{2}{(n+1)(n+2)}\sum_i Y^2_{i..} - SS_H$$

The sum of squares for environments x heterosis interaction can be partitioned into:

$$SS_{EH} = SS_{EVH} + SS_{ESH}$$

The sum of squares of the environments x average heterosis interaction adjusted for mean (m), varieties (v_j), environments (e_i), environments x varieties interaction (ev_{ij}) and average heterosis ($\bar{h}$):

$$SS_{E\bar{H}} = \frac{1}{n(n-1)}\sum_i Y^2_{iH} + \frac{1}{n}Y^2_{iv} - \frac{2}{an(n-1)}Y^2_{.H} - \frac{1}{na}Y^2_{.v} - SS_E$$

The sum of squares of the environments x heterosis interaction for varieties adjusted for mean (m), varieties (v_j), environments (e_i) environments x varieties interaction (ev_{ij}), average heterosis ($\bar{h}$), environments x average heterosis interaction ($e\bar{h}_i$) and varieties heterosis (h_j):

$$SS_{EVH} = \sum_{ij} Y_{ijj}^2 + \frac{1}{n-2}\sum_{ij} Y_{ij.}^{*2} - \frac{4}{n+2}\sum_{ij}(Y_{ijj} + \frac{1}{2}Y_{ij.}^{*2})^2 + \frac{4}{n(n+2)}\sum_i Y_{i..}^2 - \frac{4}{n(n-2)}\sum_i Y_{iH}^2 - \frac{1}{ni}\sum Y_{iv}^2$$

The sum of squares of the environments x specific heterosis interaction adjusted for mean (m), varieties (v_j), environments (e_i), environments x varieties interaction (ev_{ii}), average heterosis ($\bar{h}$), environments x average heterosis interaction ($\bar{h}_{ei}$), varieties heterosis (h_j), environments x varieties heterosis interaction (eh_{ij}) and specific heterosis ($s_{ijj'}$):

$$SS_{ESH} = \sum_{ij<j'} Y_{ijj'}^2 - \frac{1}{n-2}\sum_{ij} Y_{ij.}^{*2} + \frac{2}{(n-1)(n-2)}\sum_i Y_{iH}^2 \text{ à } SS_{SH}$$

These sums of squares are estimated as follows:

$$SS_P = SS_V + SS_H \; ; \; SS_H = SS_{\bar{H}} + SS_{VH} + SS_{SH}$$

$$SS_{EP} = SS_{EV} + SS_{EH} \; ; \; SS_{EH} = SS_{E\bar{H}} + SS_{EVH} + SS_{ESH}$$

Before partitioning the sums of squares in accordance with Table 2, the experimental data is submitted to a common analysis of variance including observations from all replications for each environment. The residual mean square of the combined analysis is obtained through the following expression:

$$MS_M = [\sum_{i=1}^{a} g_i (MS_i / r_i)] / (\sum_{i=1}^{a} g_i)$$

where: MS_i is residual mean square of the individual analysis in the i^{th} environment; g_i are the degrees of freedom associated to this residual, and r_i is the number of replications. The other mean squares were obtained in the usual manner.

The scheme of the analysis of variance in Table 2 is a nonorthogonal partition of the sums of square, and the expressions to obtain the estimates of variances of estimates of the different parameters is provided in Table 3.

NUMERICAL EXAMPLE

The procedure of this method will be illustrated using data from an experiment of a diallel cross of five maize varieties and the crosses among them, 20 treatments with three replications, conducted at two kinds of soils (acid and nonacid). The mean values for grain yield in ton/ha ($Y_{ijj'}$), the sums of each variety ($Y_{.jj}$) and of each cross ($Y_{.jj'}$), and the sums of varieties (Y_{iv}), crosses (Y_{iH}) at each soil, the sums of each soil ($Y_{i..}$), and the sums of varieties ($Y_{.v}$), crosses ($Y_{.H}$) and total ($Y_{...}$) are presented in Table 4.

The results of the combined analysis of variance are presented in Table 5. Also, this Table provides information on the coefficient of variation, estimates of general average, means of the varieties and their crosses and average heterosis.

TABLE 2. Scheme for combined analysis of variance of a diallel cross considering n parental varieties and their crosses at a environments.

Source of variation	d.f.	Sum of squares	Mean squares
Total	$a\frac{n(n+1)}{2} - 1$	SS_T	...
Environments	$a-1$	SS_E	MS_E
Populations	$\frac{n(n+1)}{2} - 1$	SS_P	...
Varieties	$n-1$	SS_V	MS_V
Heterosis	$\frac{n(n-1)}{2}$	SS_H	MS_H
Mean heterosis	1	$SS_{\bar{H}}$	$MS_{\bar{H}}$
Variety heterosis	$n-1$	SS_{VH}	MS_{VH}
Specific heterosis	$\frac{n(n-3)}{2}$	SS_{SH}	MS_{SH}
Environments x Populations	$(a-1)[\frac{n(n+1)}{2} - 1]$	SS_{EP}	MS_{EP}
Environments x Varieties	$(a-1)(n-1)$	SS_{EV}	MS_{EV}
Environments x Heterosis	$(a-1)[\frac{n(n-1)}{2}]$	SS_{EH}	MS_{EH}
Environment x Mean heterosis	$a-1$	$SS_{E\bar{H}}$	$MS_{E\bar{H}}$
Environment x Varieties heterosis	$(a-1)(n-1)$	SS_{EVH}	MS_{EVH}
Environments x Specific heterosis	$(a-1)[\frac{n(n-3)}{2}]$	SS_{ESH}	MS_{ESH}
Mean pooled error	$[\frac{n(n+1)}{2} - 1]\sum_{i=1}^{a}(r_i - 1)$	...	MS_M

r_i = number replications of treatments in the i^{th} environment.

TABLE 3. Expressions for estimating the variances of parameters, for a diallel cross involving n parental varieties and their crosses at a environments.

Estimates of parameters	Estimates of variance
Mean ($\hat{m}$)	$\frac{1}{na} s^2$
Varieties ($\hat{v}_j$)	$\frac{n-1}{na} s^2$
Environments ($\hat{e}_i$)	$\frac{a-1}{na} s^2$
Environments x Varieties ($\hat{ev}_{ij}$)	$\frac{(a-1)(n-1)}{na} s^2$
Heterosis ($\hat{h}_{jj'}$)	$\frac{3}{2a} s^2$
Mean heterosis ($\hat{\bar{h}}$)	$\frac{n+1}{an(n-1)} s^2$
Varieties heterosis ($\hat{h}_j$)	$\frac{(n-1)(n+2)}{4an(n-2)} s^2$
Specific heterosis ($\hat{s}_{jj'}$)	$\frac{n-3}{a(n-1)} s^2$
Environments x Heterosis ($\hat{eh}_{ijj'}$)	$\frac{3(a-1)}{2a} s^2$
Environments x Mean heterosis ($\hat{e\bar{h}}_i$)	$\frac{(a-1)(n+1)}{an(n-1)}$
Environments x Varieties heterosis ($\hat{eh}_{ij}$)	$\frac{(a-1)(n-1)(n+2)}{4an(n-2)} s^2$
Environments x Specific heterosis ($\hat{es}_{ijj'}$)	$\frac{(a-1)(n-3)}{a(n-1)} s^2$

$s^2 = MS_M$ = Mean pooled error.

Looking at Tables 5 and 6, the individual and combined analysis of variance for the main effects of the diallel can be attained with ease thru Gardner (1967) methodology. The interactions can easily be obtained thru the methodology used by Miranda Filho & Rissi (1975) for it has a simplicity for calculations besides to preconize the number of different replications; therefore it envolves a great number of calculi since it needs the individual analysis of variance of each envolved environment and some algebra, which will bring more work and erros. It is important, therefore, when there are only two environments.

Thus, this work presents statistic details allowing to obtain the estimates of the parameters effects and it is of more simple use because it envolves less calculi, mainly when there are a great number of environments.

The estimates of the parameters for heterosis ($\hat{h}_{jj'}$), specific heterosis ($\hat{s}_{jj'}$) varieties heterosis ($\hat{h}_j$), varieties ($\hat{v}_j$) and their respective standard error are given in Table 7. The esti-

TABLE 4. Mean grain yield (ton/ha) of five maize varieties and the ten respective crosses over in the two soils (acid and nonacid).

Entries	Soils: Acid	Soils: Nonacid	Total($Y_{.jj'}$)	Mean($\bar{Y}_{.jj'}$)
1	2.80	7.70	10.50	5.25
2	5.00	6.50	11.50	5.75
3	3.43	6.80	10.23	5.12
4	2.17	7.50	9.67	4.84
5	3.00	6.27	9.27	4.64
1 x 2	3.63	8.40	12.03	6.02
1 x 3	3.93	7.07	11.00	5.50
1 x 4	2.27	7.23	9.50	4.75
1 x 5	2.83	7.80	10.63	5.32
2 x 3	3.93	6.70	10.63	5.32
2 x 4	3.87	7.30	11.17	5.59
2 x 5	4.00	6.17	10.17	5.09
3 x 4	3.57	7.47	11.04	5.52
3 x 5	3.53	8.23	11.76	5.88
4 x 5	2.60	7.53	10.13	5.07
Total var.(Y_{iv})	16.40	34.77	51.17=$Y_{.v}$	
Total cros.(Y_{iH})	34.16	73.90	108.06=$Y_{.H}$	
Total($Y_{i..}$)	50.56	108.67	159.23=$Y_{...}$	

From: Gama et al. (1987).

TABLE 5. Combined analysis of variance for grain yield (ton/ha) for five parental varieties of maize and their ten possible crosses tested over two types of soils.

Source of variation	DF	Sum of squares	Mean squars	F value
Soils	1	112.519	112.5199	560.79**
Entries	14	4.6507	0.3322	1.66
Varieties	4	1.7889	0.4472	2.23
Heterosis	10	2.8618	0.2862	1.43
Mean heterosis	1	0.5479	0.5479	2.73
Variety heterosis	4	0.3885	0.0971	0.48
Specific heterosis	5	1.9254	0.3851	1.92
Soils x Entries	14	9.6595	0.6899	3.44**
Soils x Varieties	4	6.8263	1.7066	8.51**
Soils x Heterosis	10	2.8332	0.2833	1.41
Soils x Mean het.	1	0.1504	0.1504	0.75
Soils x Variety het.	4	0.4437	0.1109	0.55
Soils x Specific het.	5	2.2392	0.4478	2.23
Mean pooled error	76	...	0.2006	
C.V. (%)		14,62		
General mean		5.31		
Parents mean ($\hat{m}_V$)		5.12	$s(\hat{m}_v) = 0.14$	
Crosses mean ($\hat{m}_H$)		5.40		
Mean heterosis ($\hat{\bar{h}}$)		0.28	$s(\hat{\bar{h}}) = 0.17$	

*, ** Significant at the 5% and 1% levels, respectively.

TABLE 6. Analysis of variance in accordance with Miranda Filho & Rissi methodology.

Source	DF	Sum of squares (SS): Soil (1)	Sum of squares (SS): Soil (2)	Combined SS: A	Combined SS: B	Interactions: With soils (C)
Entries	14	8.0641	6.2068	4.6507	2.3184	9.6595
Varieties	4	6.8397	1.7483	1.7889	0.8917	6.8263
Heterosis	10	1.2244	4.4580	2.8618	1.4267	2.8332
Mean het.	1	0.0616	0.6336	0.5479	0.2726	0.1504
Var. het.	4	0.3938	0.4378	0.3885	0.1936	0.4437
Spec. het.	5	0.7688	3.3865	1.9254	0.9604	2.2392
Error	-	-	-	-	-	-

A - Analysis with totals of soils means, as usual (Table 5).

B - Analysis with means of soils.

C - Sum of squares calculated by $S_{pe} = S_{p(1)} + S_{p(2)} - 2S_{p(12)}$, where $S_{p(1)}$, $S_{p(2)}$ and $S_{p(12)}$ are the sums of squares for soils (1) and (2) and in the combined analysis as in B. S_{pxe} is adapted to means (over r replications) level as in this paper (Table 5).

TABLE 7. Estimates of the effects for heterosis ($\hat{h}_{jj'}$) (above the diagonal) especific heterosis ($\hat{s}_{jj'}$) (below the diagonal), varieties heterosis ($\hat{h}_j$), varieties ($\hat{v}_j$) and respective standard error, in ton/ha*.

Parental varieties	Parental varieties 1	2	3	4	5	Variety heterosis ($\hat{h}_j$)
1	...	516.7	316.7	-291.7	375.0	-76.7
2	494.4	...	-116.7	291.7	-108.3	-187.8
3	-94.4	-416.7	...	541.7	1008.3	201.1
4	-411.1	283.3	144.4	...	333.3	-90.6
5	11.1	-361.1	366.7	-16.7	...	153.9

$s(\hat{h}_{jj'}) = 387.92$, $s(\hat{s}_{jj'}) = 223.96$, $s(\hat{h}_j) = 216,37$ and $s(\hat{v}_j) = 283.30$. * The values are multiplied by 10^3.

TABLE 8. Estimates of the effects for soils x varieties interaction ($\hat{e}v_{ij}$), soils ($\hat{e}_i$) and of soils x mean heterosis interaction ($\hat{e}\bar{h}_i$) and respective standard errors, in ton/ha*.

Soils	Parental varieties 1	2	3	4	5	Soils ($\hat{e}_i$)	Soils x Mean het. ($\hat{e}\bar{h}_i$)
Acid	-613.3	1086.7	153.3	-830.3	-203.3	-1836.7	-149.9
Nonacid	613.3	-1086.7	-153.3	830.3	203.3	1836.7	149.9

$s(\hat{e}v_{ij}) = 283.30$, $s(\hat{e}_i) = 141.65$ and $s(\hat{e}\bar{h}_i) = 173.48$. * The values are multiplied by 10^3.

TABLE 9. Estimates of the effects for the interactions soils x heterosis ($\hat{e}h_{ijj'}$) (above the diagonal), soils x specific heterosis ($\hat{e}s_{ijj'}$) (below the diagonal), soils x variety heterosis ($\hat{e}h_{ij}$) and respective standard errors, in ton/ha*.

Soil	Parental varieties	Parental varieties 1	2	3	4	5	Soils x Variety heterosis ($\hat{e}h_{ij}$)
	1	...	-783.3	500.0	75.0	-441.7	-16.7
	2	-533.3	...	-166.7	-8.3	108.3	-83.3
Acid	3	511.1	88.9	...	-225.0	-691.7	155.6
	4	50.0	33.0	27.8	...	-316.7	191.7
	5	-27.8	588.9	-450.0	-111.1	...	-247.2
	1	...	783.3	-500.0	-75.0	441.7	16.7
	2	533.3	...	166.7	8.3	-108.3	83.3
Nonacid	3	-511.1	88.9	...	-225.0	691.7	-155.6
	4	-50.0	-33.3	-27.8	...	316.7	-191.7
	5	27.8	-588.9	450.0	111.1	...	247.2

$s(\hat{e}h_{ijj'}) = 387.92$, $s(\hat{e}s_{ijj'}) = 223.97$ and $s(\hat{e}h_{ij}) = 216.37$. * The values are multiplied by 10^3.

mates effects for soils (e_i), soils x varieties interaction ($\hat{e}v_{ij}$) and soils x average heterosis ($\hat{e}\bar{h}_i$) as well as their respective standard errors are given in Table 8. Finally, in Table 9 the estimates effects of the interaction soils x heterosis ($\hat{e}h_{ijj'}$), soils x specific heterosis ($\hat{e}s_{ijj'}$) and soils x variety heterosis ($\hat{e}h_{ij}$) and their respective standard errors are shown.

It is worthwhile to point out that this work did not involve a study of interpretations of genetic parameters; therefore, these interpretations can be found in Gardner (1965), Gardner & Eberhart (1966) and Vencovsky (1970), among others, then we must take in consideration the development of the method much more than the determinations found.

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