Proposal of methodology to assess the representativeness of environments for genotypic discrimination

Devanir Mitsuyuki Murakami[1] **and Cosme Damião Cruz***[2]
[1]Departamento de Fitotecnia, UFV, CEP 36571-000, Viçosa, MG, Brazil; [2]Departamento de Biologia Geral, UFV, CEP 36571-000, Viçosa, MG, Brazil. (* Corresponding Author. E-mail: cdcruz@mail.ufv.br).

ABSTRACT

In this work, a methodology is proposed for evaluating environment representatitivity through genotypic performance (grain productivity, kg/ha) of commercial corn hybrids and the use of the determination coefficient (R^2) as a referential for a likely successful search for representative sites. The methodology is based on the adoption of procedures similar to those adopted in the diallelic analysis, as proposed by Griffing (1956), in which the data evaluated are measurements of dissimilarity between environment pairs. For this, several experiments were assessed during 3 different seasons: a) two in the autumn (alternative) growing season of 1996 and 1997; and, b) one in the summer (normal) growing season of 1996/97. All the experiments were arranged in a randomized block design, with three repetitions. The methodology made possible the identification of that (those) environment(s) presenting greater overall capacity for environmental representativeness and the one which best replaces it (them) during the three seasons. It was concluded that this methodology was effective for the purposes established as well as being easily interpreted and implemented.

KEY WORDS: Maize, environmental representativeness, diallelic analysis.

INTRODUCTION

The study of environments is important to provide information on cultivar response patterns, to learn about location degree of representativeness and to help make decisions about setting up experiments in a determined location when technical problems or lack of resources occur.

Environments are understood to be all the non-genetic variables that can affect the phenotypic expression of a given genotype. The environmental conditions can be predictable (soil fertility, photoperiod, agronomic practices, etc) and unpredictable (rainfall distribution, temperature, pests and diseases).

It is usual in plant breeding programs to assess the genotypic performance in several locations (environments) from which it is possible to obtain knowledge on genotype x environment interaction effects. While analysing genotype x environment interaction, the following situations can occur: a) absence of interaction, with genotypes performing similarly in the various environments or, b) presence of interaction, which then can be classified as of simple or complex type. In the simple type, the genotypes present differentiated performances according to the environmental alterations but their ranks are not generally changed in the different environments. In the complex type, there is an inversion of the genotypic rank in the environments, which makes genotype recommendation difficult for the entire network of experiments.

For cultivar recommendation purposes, the presence of genotype x environment interaction has been treated in the analyses of adaptability and stability or environment stratification. However, for genotype selection in breeding process, the existence of genotype x environment interaction of the complex type constitutes a barrier in determining which environment can be considered the most representative when the need to reduce costs with experiments arises. This problem can be solved with statistical methodology that discriminates the representative capacity among environments. This allows the breeder to safely discard some environments while carrying out his studies, so that the gains from selection are optimised.

This study proposes a methodology to assess the representativeness of environments using the genotypic performance (grain yield) of commercial maize hybrids. Its application, as will be shown, is general and recommended for use in assessments of segregant families in various environments to obtain maximization of the gains from selection. The use of a coefficient of determination R^2 is also proposed as referential of the possibility of success in search of locations with general representative capacity.

METHODOLOGY

In this study, information on a set of genotypes (hybrids, cultivars, families etc.) assessed in several environments (locations) was assumed available. A dissimilarity matrix between environment pairs was obtained from this data considering the performance of the genotypes for a given trait.

It is proposed that the representative capacity of environments be ascertained by adapting the procedures of the diallel analysis of Griffing (1956) method 4 using dissimilarity among environment measurements. Grain yield (kg/ha) was the trait used to obtain the matrix of dissimilarity measurements. The same procedures developed by Griffing and described in Cruz and Regazzi, (1997) for system solution and sum of squares and degrees of freedom calculation were used.

The terms General Representative Capacity (GRC) and Specific Representative Capacity (SRC) were proposed in the statistical model:

$Y_{ij} = \mu + \alpha_i + \alpha_j + \delta_{ij} + \varepsilon_{ij}$, where,

Y_{ij} = value of the dissimilarity measurement among the ith and jth environments (i, j = 1, 2, 3, …, a; i<j);

μ = inherent constant to all observations (general mean of the dissimilarities);

α_i and α_j = general representative capacity (GRC) of the i-th and j-th environment;

δ_{ij} = specific representative capacity (SRC) between environment pairs, where $s_{ij} = s_{ji}$;

ε_{ij} = experimental error.

The sum of the squares of the GRC and SRC effects can be estimated by the following expression, as described in Cruz and Regazzi (1997):

$$SS_{(GRC)} = \sum \hat{\alpha}_i Y_{i.} = \frac{1}{(p-2)}\sum Y_{i.}^2 - \frac{4}{p(p-2)}Y_{..}^2 ,$$

(p=number of environments)

$$SS_{(SRC)} = \sum_i \sum_{<j} Y_{ij}^2 - \frac{1}{(p-2)}\sum_i Y_{i.}^2 + \frac{2}{(p-1)(p-2)}Y_{..}^2$$

The estimates of the effects for the adopted model are obtained using the formulas

$$\hat{m} = \frac{2}{p(p-1)}Y_{..}$$

$$\hat{\alpha}_i = \frac{1}{(p-2)}\left[Y_{i.} - (p-1)\hat{m}\right] = \frac{1}{(p-2)}\left[Y_{i.} - \frac{2}{p}Y_{..}\right] = \frac{1}{p(p-2)}\left[pY_{i.} - 2Y_{..}\right]$$

$$\hat{\delta}_{ij} = Y_{ij} - (\hat{m} + \hat{\alpha}_i + \hat{\alpha}_j) = Y_{ij} - \frac{1}{(p-2)}\left(Y_{i.} + Y_{.j}\right) + \frac{2}{(p-1)(p-2)}Y_{..}$$

The genotype dissimilarity measures among environment pairs used as Y_{ij} values were obtained using three statistics, as can be observed in Cruz (1997):

1. G x A_{ij} mean square ($MSGA_{jj'}$),

2. Square of the Mean Euclidian distance based on the G x $A_{jj'}$, interaction (SMEDGA),

3. Square of the Mean Euclidian distance based on the Original Data (SMEDO).

The determination coefficient (R^2) given by the ratio between the effect sum of squares and the total sum of squares (T.S.S.), where T.S.S.= $SS_{(GRC)} + SS_{(SRC)}$ was adopted to analyse the relative importance of the GRC and SRC effects. When there is a greater proportion of GRC than SRC the chances success in finding a representative environment improve. Otherwise, the search for a more representative environment is not justified as it will not be promising.

Table 1 shows the analysis of the environment representativeness capacity using the dissimilarity means and double entry analysis.

In this methodology proposal, locations were considered random and representative of the studied region and, therefore, the α'_s indicate how much a given environment represents the other (GRC). As dissimilarity means are used, positive and negative signs indicate smaller or greater environmental representativeness, respectively. Values of $\alpha'_s = 0$, indicate average environment representativeness. Representative environments should have negative sign and the lowest α'_s value. The δ_{ij} indicate which of the environments would have greater SRC when a given environment is taken as representative. They are indicators of the levels of similarity among the environment pairs and their sign has the same importance already quoted for the α'_s. In practical terms, the δ_{ij} values are important indicators of the environments with capacity to substitute the environment taken as most representative.

Several experiments were set up in Southern Mato

Grosso state in three growing seasons: a) two in the autumn (alternative) growing season of 1996 and 1997; and, b) one in the summer (normal) growing season of 1996/97. Grain yield (kg/ha) was assessed using a randomised complete block design with three replications. Each plot consisted of four 5.20m long rows spaced at 0.90m and 0.20m between plants. Only the two central lines were used for data collection.

RESULTS AND DISCUSSION

There was perfect correlation (r = 1.00) between the dissimilarity means estimated by MSGAjj' and SMEDGA in all the experiments. However, between SMEDO and MSGAjj' the correlations were negative, r = -0.57, r = -0.40 and r = -0.19 for the 1996 and 1997 autumn (alternative) growing season and 1996/97 summer (normal) growing season, respectively. Similar results were also found between SMEDO and SMEDGA. Given these results, the analysis of the representative environment capacity was carried out considering dissimilarity means obtained by the square of the mean Euclidian distance based on the G x A_{jj} (SMEDGA) interaction.

In operational terms, obtaining either MSGAjj' or SMEDGA estimates is equally easy and would give the same results. In this study the option was to use only the SMEDGA values. The inconveniences of using SMEDO are: a) it varies according to the number of genotypes in the experiment; b) it does not take into consideration the correlation among the genotypes; and, c) it presents negative correlation with the other methods.

In the autumn 1996 growing season experiment, 12 commercial maize hybrids were assessed in four locations: 1: Lagoa Funda farm, Campo Verde county (previous crop: maize); 2: Lagoa Funda farm (previous crop: soybean); 3: Juriti farm, Primavera do Leste county (previous crop: maize) and 4: Girasol farm located in the Petrovina High Lands (previous crop: maize). The results of the environmental representativeness capacity analyses presented R^2 of 88.88% for GRC and 11.12% for SRC, indicating possible success in the search for a more representative environment (Table 2). According to the proposed methodology, location four showed the largest GRC ($\alpha_{(4)}$ = -101,420.41)) followed by locations 2, 1 and 3. Location three had the smallest GRC and could be discarded if necessary. On the other hand, if there were a shortage of resources or difficulties of any kind, so that only a single experiment could be set up, location four would be the most recommended. This result was similar to that obtained by the traditional environmental stratification analysis based on the non-significance of the genotype x environment interaction (Table 3), proving the efficiency of the proposed method to determine the most representative environment. The advantage is its easy interpretation and execution.

Table 1. Analysis of environment representativeness using dissimilarity measures and double entry analysis.

S.V.	Df	S.S.	M.S.	R^2
GRC	p-1	G.S.S.	M.S.G.	G.S.S. / T.S.S.
SRC	p(p-3)/2	S.S.S.	M.S.S.	S.S.S. / T.S.S.
Total	p(p-1)/2	T.S.S.		

The environment with the best substitution capacity for location four was location one because it presented the best SRC with $\delta_{(1, 4)}$= -37,516.42. The 1 and 4 environment pair presented the lowest dissimilarity value of the MSGAjj' and SMEDGA methods (Table 4), indicating coherent results and functioning of the proposed method. It is pointed out that the SRC, which is easy to analyse and interpret, presents values

Table 2. Summary of the representativeness analysis carried out by the double entry procedure adapted to the diallel method. The analysis used dissimilarity measures among environment pairs, estimated from the grain yield (kg/ha) data of the 1996 autumn growing season experiments, in the south of Mato Grosso state, by the square of the Mean Euclidian distance based on the GxA_{jj} (SMEDGA) interaction.

S.V.	df	S.S.	R^2 (%)
Treatment	5	268,073,263,106.05	
G.R.C.	3	238,252,452,562.87	88.88
S.R.C.	2	29,820,810,543.18	11.12
GRC effect - Yield (kg/ha)			
	$\alpha_{(1)}$	20,017.63	
	$\alpha_{(2)}$	-72,675.71	
	$\alpha_{(3)}$	154,078.48	
	$\alpha_{(4)}$	-101,420.41	
S.R.C. effect - Yield (kg/ha)			
	$\delta_{(1,2)}$	-19,049.94	
	$\delta_{(1,3)}$	56,566.36	
	$\delta_{(1,4)}$	-37,516.42	
	$\delta_{(2,3)}$	-37,516.42	
	$\delta_{(2,4)}$	56,566.36	
	$\delta_{(3,4)}$	-19,049.94	

that are linked to the GRC results. Such relationship does not occur with the MSGAjj’ and SMEDGA values that do not have direct relation with the GRC.

In the analysis of representativeness of the experiments in the 1996/97 summer growing season, 16 commercial maize hybrids were assessed in six locations: 1: Lagoa Funda farm, Campo Verde county (previous crop: maize); 2: Juriti farm, Primavera do Leste county (previous crop: soybean); 3: Juriti farm (previous crop: maize); 4: São Roque farm, Primavera do Leste county (previous crop: soybean); 5: São Carlos farm, Rondonópolis county (previous crop: maize) and 6: UFMT/FAMEV farm, Santo Antonio do Leverger county (previous crop: vegetables), where R^2s of 85.30% and 14.70% were obtained for GRC and SRC, respectively, indicating the possibility of success in the search for an environment with a general representative capacity (Table 5). Environment four presented greater general representative capacity with $\alpha_{(4)}$ = -110,350.74 and environment three also showed a good GRC, $\alpha_{(3)}$: -106,282.15 Taking environment four as the most representative, the analysis showed environment one as the best substitute in case of some technical problem (including shortages of resources, labour, seeds, etc.), because of its best SRC, $\delta_{(1,4)}$= -49,498.49. This result does not exactly match that from the most similar environment pair, but was the second most similar environment pair (Table 4).

In the autumn 1997 experiments, 15 commercial maize hybrids were assessed in eight locations: 1: Lagoa Funda farm, Campo Verde county (previous crop: soybean); 2: Juriti farm, Primavera do Leste county (previous crop: maize); 3: Juriti farm, Primavera do Leste county (previous crop: soybean); 4: São Roque farm, Primavera do Leste county (previous crop: maize); 5: São Roque farm (previous crop: soybean); 6: Cuiabana farm, Primavera do Leste county (previous crop: soybean); 7: Santa Maria farm, Rondonopolis county (previous crop: soybean) and 8: Ponte de Pedra farm, Rondonopolis county (previous crop: soybean). In these experiments, the GRC and SRC effects

Table 3. Mean square G x A interaction value divided by number of replications (MSI/r), calculated F (Fcal), tabled F (Ftab) at the 5% level of probability and location grouping (LG) according the traditional stratification method, based on the discrimination of maize cultivar yield (kg/ha) in the 1996 autumn growing season in Southern Mato Grosso state.

MSI/r	Fcal	Ftab(5%)	LG
87,823.74	0.93	1.89	1 4
96,660.21	1.02	1.65	1 4 2
171,020.46	1.81	1.89	3 4
176,626.76	1.87	1.89	2 3

Table 4. Dissimilarity among pairs of locations obtained from the G x $A_{jj'}$ mean square ($MSGA_{jj'}$), square of the mean Euclidian distance based on the G x $A_{jj'}$ interaction (SMEDGA) and square of the mean Euclidian distance based on the original data (SMEDO), using maize grain yield (kg/ha) in the 1996 autumn growing season, 1996/97 summer growing season and 1997 autumn season in Southern Mato Grosso state.

Experiments	Pairs of Environments	MSGAjj'	SMEDGA	SMEDO
Autumn season (1996)	1 x 2	113,575.29	208,221.37	855,053.32
	1 x 3	278,504.65	510,591.86	518,022.29
	1 x 4	87,823.74	161,010.19	5,056,079.04
	2 x 3	176,626.76	323,815.73	1,116,732.20
	2 x 4	88,581.61	162,399.62	9,263,113.13
	3 x 4	171,020.46	313,537.52	4,834,605.49
summer growing season (1996/97)	1 x 2	155,368.70	291,316.31	7,955,031.93
	1 x 3	132,090.17	247,669.08	12,197,853.39
	1 x 4	98,235.89	184,192.30	6,940,716.38
	1 x 5	330,248.46	619,215.86	5,229,665.42
	1 x 6	205,860.99	385,989.35	4,355,946.78
	2 x 3	126,047.77	236,339.56	710,457.45
	2 x 4	145,549.50	272,905.31	301,469.76
	2 x 5	220,034.40	412,564.50	798,386.77
	2 x 6	212,213.67	397,900.64	999,869.42
	3 x 4	79,171.57	148,446.70	883,877.12
	3 x 5	171,708.64	321,953.71	2,037,289.06
	3 x 6	203,491.28	381,546.15	2,526,097.45
	4 x 5	195,788.43	367,103.31	571,530.02
	4 x 6	185,084.39	347,033.23	715,307.76
	5 x 6	356,840.23	669,075.44	693,013.88
Autumn season (1997)	1 x 2	234,947.34	438,568.38	985,034.98
	1 x 3	234,773.36	438,243.62	4,259,525.70
	1 x 4	158,153.97	295,220.75	14,129,760.27
	1 x 5	211,739.03	395,246.18	1,700,060.35
	1 x 6	214,259.22	399,950.54	5,375,253.65
	1 x 7	245,001.44	457,336.03	3,018,962.21
	1 x 8	221,181.91	412,872.90	6,275,881.26
	2 x 3	376,964.85	703,667.73	2,181,293.21
	2 x 4	127,814.22	238,586.55	9,120,460.46
	2 x 5	231,994.76	433,056.89	595,506.86
	2 x 6	248,068.84	463,061.84	2,687,052.31
	2 x 7	131,360.46	245,206.18	986,999.61
	2 x 8	361,277.99	674,385.58	3,503,950.91
	3 x 4	314,548.61	587,157.41	3,701,221.48
	3 x 5	307,298.21	573,623.32	1,233,820.78
	3 x 6	329,419.14	614,915.73	690,942.08
	3 x 7	341,426.18	637,328.86	762,858.69
	3 x 8	231,821.51	432,733.49	650,407.05
	4 x 5	108,805.31	203,103.24	6,845,044.80
	4 x 6	159,375.77	297,501.44	2,514,450.71
	4 x 7	66,461.31	124,061.12	4,614,107.62
	4 x 8	220,698.32	411,970.20	2,097,075.62
	5 x 6	341,660.62	637,766.48	1,822,063.51
	5 x 7	161,952.25	302,310.86	512,279.61
	5 x 8	288,798.09	539,089.77	2,175,136.31
	6 x 7	145,810.37	272,179.36	669,117.98
	6 x 8	348,147.54	649,875.40	686,290.05
	7 x 8	362,841.95	677,304.97	1,351,110.98

contributed with 57.13% and 42.87%, respectively, ensuring success in the search for a representative environment (Table 6). The representativeness analysis showed that environment four was the most representative of all, presenting $\alpha_{(4)}$: -163,580.08. The environment with greatest substitution capacity for environment four (best SRC) was environment seven with $\delta_{(4,7)}$: -90,240.00. These two environments presented the least dissimilarity value in the MSGAjj' and SMEDGA methods (Table 4), which are consistent results. These same results were obtained in the environment stratification analyses by the traditional process (Table 7), confirming the efficiency of the method proposed to analyse the representative capacity of the environments (locations).

Table 5. Summary of the analysis of representativeness carried out by the double entry analysis adapted to a diallel using dissimilarity measures among environment pairs estimated by the mean Euclidian distance based on the $GxA_{jj'}$ interaction (SMEDGA). Data was grain yield (kg/ha) obtained in the experiments in the summer 1996/97 growing season, in Southern Mato Grosso state.

S.V.	df.	S.S.	R^2 (%)
Treatment	14	854,079,917,730.06	
G.R.C.	5	728,528,147,257.72	85.30
S.R.C.	9	125,551,770,472.34	14.70
GRC effect - Yield (kg/ha)			
$\alpha_{(1)}$		-8,175.23	
$\alpha_{(2)}$		-37,514.37	
$\alpha_{(3)}$		-106,282.15	
$\alpha_{(4)}$		-110,350.74	
$\alpha_{(5)}$		157,207.25	
$\alpha_{(6)}$		105,115.25	
SRC effect – Yield (kg/ha)			
$\delta_{(1,2)}$		-15,210.85	
$\delta_{(1,3)}$		9,909.70	
$\delta_{(1,4)}$		-49,498.49	
$\delta_{(1,5)}$		117,967.08	
$\delta_{(1,6)}$		-63,167.43	
$\delta_{(2,3)}$		27,919.33	
$\delta_{(2,4)}$		68,553.66	
$\delta_{(2,5)}$		-59,345.14	
$\delta_{(2,6)}$		-21,916.99	
$\delta_{(3,4)}$		12,862.83	
$\delta_{(3,5)}$		-81,188.15	
$\delta_{(3,6)}$		30,496.29	
$\delta_{(4,5)}$		-31,969.96	
$\delta_{(4,6)}$		51.96	
$\delta_{(5,6)}$		54,536.18	

Table 6. Summary of the representativeness analysis carried out by double entry analysis adapted to a diallel using dissimilarity measures between environment pairs estimated by the square of the Mean Euclidian Distance based on the $GxA_{jj'}$ interaction (SMEDGA). Data was grain yield (kg/ha) obtained in the autumn 1997 growing season, in Southern Mato Grosso state.

S.V.	df	S.S.	R^2 (%)
Treatment	27	2,129,113,126,850.39	
G.R.C.	7	1,216,449,883,141.95	57.13
S.R.C.	20	912,663,243,708.44	42.87
GRC effect - Yield (kg/ha)			
$\alpha_{(1)}$		-50,273.80	
$\alpha_{(2)}$		9,575.32	
$\alpha_{(3)}$		141,431.49	
$\alpha_{(4)}$		-163,580.08	
$\alpha_{(5)}$		-9,147.41	
$\alpha_{(6)}$		32,694.93	
$\alpha_{(7)}$		-70,558.97	
$\alpha_{(8)}$		109,858.52	
SRC effect - Yield (kg/ha)			
$\delta_{(1,2)}$		30,826.68	
$\delta_{(1,3)}$		-101,354.25	
$\delta_{(1,4)}$		60,634.46	
$\delta_{(1,5)}$		6,227.22	
$\delta_{(1,6)}$		-30,910.76	
$\delta_{(1,7)}$		129,728.63	
$\delta_{(1,8)}$		-95,151.99	
$\delta_{(2,3)}$		104,220.74	
$\delta_{(2,4)}$		-55,848.86	
$\delta_{(2,5)}$		-15,811.20	
$\delta_{(2,6)}$		-27,648.59	
$\delta_{(2,7)}$		-142,250.34	
$\delta_{(2,8)}$		106,511.57	
$\delta_{(3,4)}$		160,865.82	
$\delta_{(3,5)}$		-7,100.93	
$\delta_{(3,6)}$		-7,650.86	
$\delta_{(3,7)}$		118,016.17	
$\delta_{(3,8)}$		-266,996.69	
$\delta_{(4,5)}$		-72,609.43	
$\delta_{(4,6)}$		-20,053.58	
$\delta_{(4,7)}$		-90,240.00	
$\delta_{(4,8)}$		17,251.59	
$\delta_{(5,6)}$		165,778.79	
$\delta_{(5,7)}$		-66,422.93	
$\delta_{(5,8)}$		-10,061.51	
$\delta_{(6,7)}$		-138,396.77	
$\delta_{(6,8)}$		58,881.78	
$\delta_{(7,8)}$		189,565.25	

Table 7. Mean squares G x A interaction values divided by the number of replications (MSI/r), calculated F (Fcal), tabled F (Ftab) at the 5% level of probability and location grouping (LG), according to the traditional stratification method. Data was maize cultivar yield (kg/ha) obtained in the autumn 1997 growing season in Southern Mato Grosso state.

MSI/r	Fcal	Ftab(5%)	LG
66,461.31	0.50	1.73	4 7
108,545.33	0.81	1.52	4 7 2
138,064.72	1.03	1.43	4 7 2 5
167,823.01	1.26	1.38	4 7 2 5 1
145,810.37	1.09	1.73	6 7
159,375.77	1.19	1.73	4 6
214,259.22	1.61	1.73	1 6
220,698.32	1.65	1.73	4 8
221,181.91	1.66	1.73	1 8

CONCLUSION

The proposed methodology to assess the representativeness of environments based on their genotypic discrimination capacities was efficient in the three studies carried out on maize hybrids in several locations. The method has the further advantage of easy interpretation and execution.

RESUMO

Proposta de metodologia para avaliação da representatividade de ambientes para discriminação genotípica

Neste trabalho foi proposta metodologia para avaliação da representatividade de ambientes através da performance genotípica (produtividade de grãos, kg/ha) de híbridos comerciais de milho e a utilização do coeficiente de determinação (R^2) como referencial da possibilidade de sucesso na busca de locais representativos. A metodologia baseia-se na adoção de procedimentos análogos ao adotados em análise dialélica, proposta por Griffing (1956) em que os dados avaliados são medidas de dissimilaridade entre pares de ambientes. Para tanto, vários experimentos foram avaliados em três épocas, sendo, dois de safrinha (safrinha/96 e safrinha/97) e um de safra normal 1996/97. Todos os experimentos foram instalados sob o delineamento em blocos casualizados com três repetições. Com a metodologia proposta foi possível identificar aquele(s) ambiente(s) com maior capacidade geral de representatividade ambiental e aquele que melhor o substitui, nas três épocas. Deste modo, conclui-se que a metodologia foi eficiente para os propósitos estabelecidos com a vantagem de ser de fácil interpretação e execução.

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