Crop Breeding and Applied Biotechnology 4:472-476, 2004
Brazilian Society of Plant Breeding. Printed in Brazil

Influence of the environmental index on the estimation of stability parameters of Eberhart and Russell

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Received 5 February 2004

Accepted 19 September 2004

ABSTRACT - *The objective of this study was to verify the influence of the environmental index on the analysis and estimates of adaptability and stability parameters, using environmental indices obtained from four genotype groups (A, B, C, and QPM). Data of preliminary maize cultivars trials of Embrapa Maize and Sorghum, were used obtained in the 2000/2001 harvest season in nine environments of the southeast and central-western regions. The interchange of environmental indices did not affect the parameter estimates and the genotype classification of the four groups equally in relation to their stabilities of yield and response to environments. The cause of this variation is probably more linked to the experimental errors and the differences in the interaction of the genotypes of each group with the environments than to the covariance of the genotype means with their respective environmental indices.*

Key words: genotype x environment interaction, maize.

INTRODUCTION

As the name suggests, the genotype x environment interaction is proper of the genotypes and the evaluated environments and must always be evaluated when alterations in any of these factors occur. This is routine in breeding programs because breeders are interested in the performance of genotypes across different sites and years.

Eberhart and Russell (1966)'s methodology for the study of the adaptability and stability of cultivars is still broadly used by different researchers due to its efficiency and simplicity. It consists basically of a simple linear regression analysis for each genotype, of a dependent variable, in our case the yield in each environment, in relation to the environmental index obtained by the mean of all genotypes in the environment.

The use of the environmental index deviation in relation to the general mean of all environments, whose sum is zero, has the interesting characteristic of making the constant of regression equal to the general mean of the genotype. Besides, it permits the classification of the environments in favorable or unfavorable in function of a higher or lower mean than the general mean. The ease of interpretation also led to the use of the environmental index deviation in other methodologies for studies on adaptability and stability such as those of Verma et al. (1978), Silva and Barreto (1985) and Cruz et al. (1989).

However, in spite of this and other advantages, the main

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statistical restriction of the environmental index deviation is the fact that it is not independent of the observation Y_{ij}, since the genotype means contribute to the calculation of the index, which can seriously affect the results of linear regression (Lin et al. 1986, Westcott 1986, Becker and Léon 1988, Crossa 1990, Silva 1995).

The objective of this study was to verify the influence of the environmental index in the analysis and the estimates of adaptability and stability parameters of Eberhart and Russell (1966) by means of the interchange of the environmental indices obtained from four genotype groups evaluated in a same series of environments.

MATERIAL AND METHODS

Data of preliminary trials with maize cultivars of Embrapa Maize and Sorghum obtained during the harvest 2000/2001, in nine environments in the Southeastern and Central-western regions of Brazil were used: (Anhembi-São Paulo, Birigui-São Paulo, Goiânia-Goiás, Goianésia-Goiás, Janaúba-Minas Gerais, Paracatu-Minas Gerais, Sete Lagoas-Minas Gerais-fertile soil, Sete Lagoas-Minas Gerais-acid soil, and Londrina-Paraná). Four groups of 25 genotypes with 23 distinct genotypes (A, B, C, and QPM) and two common commercial controls of the four groups were evaluated in a 5 x 5 simple lattice in plots of two 5 m long rows spaced 0.8 m apart. After the individual analyses, the trials where the ratio of the greatest/smallest effective error was up to seven between and within each group of genotypes were selected to obtain the largest possible number of common environments. Thereafter, the analyses of adaptability and stability were performed according to the methodology of Eberhart and Russell (1966) described by Cruz and Regazzi (1994), using Genes (Cruz 1997). With this software, it is possible to do the analyses by choosing the proper environmental index or the environmental indices provided during the analysis. Four analyses for each genotype group were done: one with its the proper environmental index (EI), and the three others with the environmental indices of the other three groups. Additionally, an analysis of environmental stratification was carried out for each genotype group by the algorithm of Lin (1982), described by Cruz and Regazzi (1994).

RESULTS AND DISCUSSION

A simple classification of the environmental indices (EI) in decreasing order (Table 1) showed that the environments (E) of Londrina and Janaúba were the most favorable ones while the environment of Sete Lagoas-acid soil was the most unfavorable for all four groups. Some environments, as Birigui, for example, varied between favorable and unfavorable depending on the genotype (G) group, indicating that the complex part of the G x E interaction can vary with the genotype group, which may cause difficulties in studies of environmental stratification.

An interesting point to observe is the symmetry between the favorable and unfavorable environments from one environment to another and also the interval of total variation within each environmental index. The variation of the EIs shows that the QPM genotypes had a better performance in the most unfavorable environment, Sete Lagoas-acid soil than the genotypes of the other three groups, and the second worst performance in the most favorable environment. Despite the EI of the group QPM presented great symmetry regarding the extremes, it presented a greater concentration of favorable environments, two of which with low variation (Janaúba and Sete Lagoas-fertile).

The variation of the EI of group B was balanced between the environments but was the most asymmetric considering the extreme environments. The environmental indices A and C were very similar in symmetry, though they presented disagreement in relation to the quality of the environments, as the others. Silva (1995) mentions that the lack of representativity of the environments, which can be observed when the EI presents

Table 1. Environmental indices and variation of the nine evaluated environments (Env) based on the means of 25 treatments in preliminary trials with A, B, C and QPM maize

Env	Index QPM	Variation	Env	Index A	Variation	Env	Index B	Variation	Env	Index C	Variation
9	1888.08	1422.68	9	2472.46	1546.44	9	1592.43	177.44	9	2885.42	1874.84
3	465.40	148.84	5	926.02	459.20	5	1414.99	609.76	5	1010.58	553.72
2	316.56	35.76	2	466.82	102.24	3	805.23	374.64	2	456.86	349.16
5	280.80	20.84	6	364.58	151.12	1	430.59	272.64	4	107.70	51.24
7	259.96	206.12	1	213.46	217.96	6	157.95	182.52	7	56.46	109.20
1	53.84	631.68	7	-4.50	127.76	4	-24.57	228.60	1	-52.74	430.32
4	-577.84	235.68	3	-132.26	569.84	7	-253.17	442.08	6	-483.06	82.76
6	-813.52	1059.80	4	-702.10	2902.40	2	-695.25	2732.96	3	-565.82	2849.56
8	-1873.32		8	-3604.50		8	-3428.21		8	-3415.38	

Environments: 1-Anhembi (SP); 2-Birigui (SP); 3-Goiânia (GO); 4-Goianésia (GO); 5-Janaúba (MG); 6-Paracatu (MG); 7-Sete Lagoas fertile (MG); 8-Sete Lagoas acid soils (MG) and 9-Londrina (PR) irregular distribution, concentrating values in some subintervals or presenting extreme isolated values may be a serious problem since it will exert a strong influence on the estimates of the regression parameters, leading to wrong results.

The correlation coefficients (r) varying from r = 0.96 between A and C to r = 0.80 between B and QPM indicated that the four EIs were strongly correlated (Table 2).

Table 2. Correlation coefficients among the environmental indices of the preliminary trials A, B, C, and QPM

	QPM	A	B	C
QPM	1.000	0.891	0.799	0.906
A		1.000	0.902	0.957
B			1.000	0.858
C				1.000

The environmental stratification by the algorithm of Lin (1982) showed great similarity between some environments for the four genotype groups, especially Anhembi, Goianésia, Janaúba, and Sete Lagoas-acid soils (Table 3). The environments Sete Lagoas-fertile, only included in the environmental series analyses realized for the genotype groups B and QPM, and Londrina, included in environmental series analyses for the genotype groups C and QPM were outstanding, since in results obtained with other genotype groups these sites were classified as similar. The trials of Birigui, Goiânia (under weed stress), and Paracatu (under leaf disease stress) were considered specific environments for groups A and B, or grouped together with one or another environment of the aforementioned environmental series.

Exchanges of the environmental index (EI) altered the estimates of the adaptability and stability parameters of Eberhart and Russell (1966) and the mean squares (MS) of linear environment, of the interaction genotypes x linear environments, and of the combined deviation, as can be verified for each trial group, when using the proper EI and the EIs of the other groups (Table 4). The existence of variability between the genotypes within the four groups was verified. The groups C and QPM, in spite of the greater variability between the genotypes, presented smaller genotype x environment interaction, in contrast to the greater MS of the error, resulting in smaller yet still significant F statistics, in comparison with groups A and B. The significance of the MS of linear environment indicates the existence of significant variations in the environments, leading to variations of the genotype means.

Table 3. Environment groups that result in a non-significant genotype x environment interaction for the four groups of preliminary maize trials

Groups	QPM	A	B	C
i	4 7 2 5 1 9	1 5 4 8	4 7 5 8 1	1 4 5 9 8
ii	3 4	4 7	4 9	4 7
iii	1 8	1 7	8 9	1 3
iv	5 8	2	2	7 9
v	3 5	3	3	2 9
vi	3 5 6	6	6	1 6
vii	3 7			2 3
viii	8 9			
ix	6 9			
x	7 8			
xi	1 6			

Environments: 1-Anhembi (SP); 2-Birigui (SP); 3-Goiânia (GO); 4-Goianésia (GO); 5-Janaúba (MG); 6-Paracatu (MG); 7-Sete Lagoas fertile (MG); 8-Sete Lagoas acid soil (MG) and 9-Londrina (PR)

In turn, the G x E linear interaction is an indicator of significant differences between the coefficients of regression of the evaluated genotypes and, consequently, of their environmental response. However, a significant F was found only for group A, and when using the EIs of C and QPM. Comparing the values of F to G x linear E within a same line of Table 4, one notes a strong tendency of the values in bold to be lower than the other values, indicating that the use of the proper EI tended to underestimate these MS in relation to the MS estimated with the EIs of the other groups, especially for the QPM group. Nevertheless, the lowest F values were not obtained with the EI of the proper group but with the EI of group A in the other groups.

It is interesting to observe the fact that the sum of EI, per construction, was equal to zero and the mean of B1 equal to the unit. By the exchange of EI, the B1s were influenced by the EIs, resulting in B1 means below 1.0 when using EIs of other groups (Table 4). In view of the greater symmetry and correlation between the EIs of A and C, it can be inferred that the distance from the unit, as seen for the EIs B and QPM, is an indicator for the dissimilarity between the EIs. In other words, the nearer to 1.0, the more similar are the EIs and the smaller must be the effects of shifting from one to the other. The EI of the QPM group, opposite to the EIs of the other groups, resulted in B1 means above 1.0 when used in the other groups, without exception.

When the MS of the combined deviations are significant, they indicate that the genotypes differ among each other in relation to the predictability of performance in view of the environmental variation, where some are more stable or predictable than others. The use of the proper EIs within each group as recommended by the analysis of Eberhart and Russell (1966) generally obtained much smaller F values than the use of the EIs of the other groups of cultivars. This influenced the genotype classification in relation to the yield predictability directly. The EI of group B was the one that affected the classification of the other groups most, reducing the number of predictable to less than 20% of the evaluated genotypes. Besides, the comparison between EIs within genotypes for each genotype group showed that the use of the EI of group B led to the greatest disagreement of genotype classification in relation to the other groups; 8 genotypes were identified as predictable by the EI of B against three classifications as unpredictable, or vice-versa, by the other three EIs. The EI of C produced six errors while the EIs of A and QPM presented the best results, by which only two genotypes were misclassified compared to the conventional analysis based on the proper environmental indices.

Finally, it is noted that, despite the conduction of the trials in contiguous areas with two common controls, it is likely that the differences, caused by the change of the environmental indices in the adaptability and stability parameters contained among their causes a much more accentuated influence of the lack of the indices' representativity than the covariance between the genotype means and their respective environmental indices. The lack of the indices' representativity can be caused by the experimental errors and the variations in the genotype x environment interaction inherent to the different groups.

Table 4. Analyses of adaptability and stability of Eberhart and Russell (1966) for yield in 25 treatments of preliminary trials of A, B, C and QPM maize, evaluated in nine environments in 2000/2001, with proper (in bold) and exchanged Environmental Index (E.I.)

		E.I. QPM		**E.I. A**		**E.I. B**		**E.I. C**	
Sources of variation		**MS**	**F**	**MS**	**F**	**MS**	**F**	**MS**	**F**
Environment (E)	QPM	**53349948**							
	A			**130436192**					
	B					**110609216**			
	C							**136197184**	
Genotype (G)	QPM	**7541230**	**4.76****						
	A			**5949108**	**2.84****				
	B					**5680555**	**2.84****		
	C							**11386149**	**6.93****
G x E	QPM	**1583573**	**1.51****						
	A			**2095824**	**2.62****				
	B					**1997960**	**2.30****		
	C							**1643065**	**1.79****
E/G	QPM	**3654228**							
	A			**7229439**					
	B					**6342410**			
	C							**7025230**	
Linear E	QPM	**426801024**	**406****	338486496	322**	272659648	259**	350165120	333**
	A	827570944	1033**	**1043492160**	**1302****	849619008	1060**	955381952	1192**
	B	565296832	649**	720470336	828**	**884872896**	**1016****	651005888	748**
	C	893932800	976**	997574272	1089**	801606592	875**	**1089576704**	**1189****
G x E Linear	QPM	**1171613**	**1.11**	1546859	1.47	1559504	1.48	1428092	1.36
	A	1591181	1.99**	**1225677**	**1.53**	1203384	1.50	1405845	1.75*
	B	1024683	1.18	838851	0.96	**849789**	**0.98**	1233115	1.42
	C	1340323	1.46	1100021	1.20	1313843	1.43	**1248085**	**1.36**
Combined deviation	QPM	**1576710**	**1.50****	2029903	1.93**	2404322	2.29**	1979456	1.88**
	A	3315013	4.14**	**2131303**	**2.66****	3242206	4.05**	2610081	3.26**
	B	3877721	4.46**	3016500	3.47**	**2075557**	**2.39****	3359369	3.86**
	C	2736764	2.99**	2177483	2.38**	3267974	3.57**	**1631449**	**1.78****
Effective error	QPM	**1050915**							
	A			**801104**					
	B					**870115**			
	C							**915754**	
Mean	QPM	**7601**							
	A			**8332**					
	B					**8242**			
	C							**7627**	
CV (%)	QPM	**13.49**							
	A			**10.74**					
	B					**11.32**			
	C							**12.55**	
Mean of B1	QPM	**1.00**		0.57		0.55		0.57	
	A	1.39		**1.00**		0.98		0.94	
	B	1.15		0.83		**1.00**		0.77	
	C	1.45		0.98		0.95		**1.00**	

** $P < 0.01$

CONCLUSIONS

1) The differences in performance among the genotype groups in the nine environments slightly affected the formation of homogeneous environment groups in the studies of environmental stratification;

2) the interchange of environmental indices did not affect the parameter estimates and the genotype classification of the four groups linearly in relation to their yield stabilities and responses to the environment stimuli;

3) the errors induced by the originally proposed environmental index were important for two of the four genotype groups and irrelevant for the other two;

4) the causes of these errors were probably stronger linked to the experimental errors and the differences in the interaction between the genotypes of each group with the environments than to the covariance of the genotype means with their respective environmental indices.

Influência do índice ambiental na estimação de parâmetros de estabilidade de Eberhart e Russell

RESUMO - *Esse trabalho teve por objetivo verificar a influência do índice ambiental na análise e nas estimativas de parâmetros de adaptabilidade e estabilidade, utilizando-se índices ambientais obtidos de quatro grupos de genótipos (A, B, C e QPM). Foram utilizados dados dos ensaios preliminares de cultivares de milho da Embrapa Milho e Sorgo, obtidos na safra 2000/2001 em nove ambientes nas regiões Sudeste e Centro-oeste. O intercâmbio de índices ambientais não afetou, da mesma forma, as estimativas dos parâmetros e a classificação dos genótipos dos quatro grupos quanto às suas estabilidades de produção e respostas aos estímulos dos ambientes. As causas dessa variação provavelmente estão ligadas mais fortemente aos erros experimentais e às diferenças na interação entre os genótipos de cada grupo com os ambientes do que à covariância das médias dos genótipos com os seus respectivos índices ambientais.*

Palavras-chave: interação genótipos x ambientes, milho.

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