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Environment and genotype-environment interaction in maize breeding in Paraná, Brazil

Francisco Terasawa Jr.[1*], Roland Vencovsky[2], and Henrique Koehler[3]

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ABSTRACT - *The objectives of this study were: to quantify environmental variation and genotype-environment effects in maize hybrids, within and between two macro-environments in the state of Paraná; and to group the environments according to the hybrid performance and determine the most adequate locations for selection in the state in the main crop season. The trials were carried out in the 2003/2004 growing season at six locations: Campo Largo (CL), Ponta Grossa (PG), Fazenda Rio Grande (FZ), Londrina (LD), Centenário do Sul (CS) and Palotina (PL). The effects of location (L), macro-environments (ME), locations within macro-environments (WME), hybrids (H), and the interactions (H x L), (H x ME), (H x WME) were significant (at 0.1 % probability). Two clusters were formed, contrasting with the macro-environment zoning: (CL, FZ) and (PG, CS, LD). PL was excluded from both. Under the average conditions of the state, environments appropriate for high yields were most suitable for selection as well.*

Key-words: dissimilarity, genotype-interaction, selection, zoning

INTRODUCTION

Located in a subtropical area, Parana is the leading Brazilian maize producer. The environmental heterogeneity in the state is considerable, given by the geographical conditions and technological practices and a planting period of nine months of the year (Caramori 2003). Seed companies have divided the state into two macro-environments (ME) to recommend region-specific hybrids, based on the climatic characteristics and crop eco-physiology (Andrade et al. 1996). The south, southwest and center of the state, characterized by altitudes of over 650m asl, represent a warm climatic area (ME1) where high yields are obtained. The region in the north and northeast of the state (ME2) is even warmer. Most studies of environmental zoning were based on climatic data and geographic information that affect the crop (Pollak and Corbett 1993, Hartkamp et al. 2000, Caramori 2003). In several breeding programs, environments were classified based on cultivar performance and evaluated in a broad range of environments, focusing on the effects of genotype environment interaction (GEI) (Bernardo 2002, Löffler et al. 2005). Environments were hierarchically grouped, based on dissimilarity measures (Ouyang et al. 1995, Setimela et al. 2005). Complex and significant GEI have been detected in regional trials across Paraná (Gerage et al. 2005). It is known that the effectiveness of evaluations depends on the magnitude of the experimental location and the target environment

[1] Semília Genética e Melhoramento, Rua Conselheiro Laurindo, 809, sala 408, 80.060-100, Curitiba, PR, Brasil. *E-mail: fterasawa@semilia.com.br
[2] Departamento de Genética, ESALQ/USP, C.P. 83, 13.400-970, Piracicaba, SP, Brasil
[3] Departamento de Fitotecnia e Fitossanitarismo, Universidade Federal do Paraná (UFP), C.P. 19061, 80.035-050, Curitiba, PR, Brasil

(Comstock 1977). The efficiency of indirect selection (IS) is also determined by the magnitude of the genetic and environmental components of variation, by the genotypic repeatability coefficient at each location and by the genotypic performances (Falconer 1987). The effectiveness of IS in stressful (SE) and non-stressful environments (NSE) differs (Byrne et al. 1995, Atlin et al. 2000, Hohls 2001, Bänzinger and Cooper 2001, Guillen-Portal et al. 2004). Highest estimates of repeatability coefficient (r) and genetic variability (V_G) were obtained in NSE, followed by intermediate and highly stressful environments (SE). Guillen–Portal et al. (2004) obtained a high estimate of $r_{jj'}$ between NSE and SE, suggesting the possibility of concentrating selection on optimal conditions. Other results, however, indicated that genetic correlations between NSE and SE tended to decrease as the level of stress increases (Hohls 2001).

The objectives of this study were: i) to quantify the environmental variation and GEI effects within and among ME1 and ME2; ii) to obtain the dissimilarity pattern of six locations in ME1 and ME2 based on the genotypic performance; iii) to identify the suitability of different environments for indirect selection in a maize breeding program, for the main growing season in the state of Paraná.

MATERIAL AND METHODS

Two sets of maize hybrids (S1 and S2) were evaluated in the 2003/2004 growing season in six and five environments across the state of Parana, respectively. Both of the two macro-environments (ME1, ME2) were sampled. Each set consisted of 22 experimental hybrids and 3 commercial checks, totaling 25 treatments per set. Seeds were supplied by the seed company Sementes Boa Safra and the Instituto Agronômico do Paraná (IAPAR). The commercial hybrids AG 9020, P30K75, P30F33 were used as controls. The trials of ME1 were carried out in Ponta Grossa (FT Pesquisa e Sementes), Fazenda Rio Grande (PUC/PR) and Campo Largo (local farmer), and those of ME2 in Londrina (IAPAR), Centenário do Sul (Milenia Genética e Biotecnologia) and Palotina (COODETEC).

The environments differed in the geo-climatic characteristics, crop rotation schedule and the applied technology. Planting location and date were determined according to regional standards (Caramori 2003). Sampling covered the considerable environmental heterogeneity (Table 1). The most ideal environment was Ponta Grossa (PG), with a highly fertile soil, large daily thermal amplitude, regular rainfall during the growing season, and timely planting. Campo Largo (CL) was the most stressful environment of ME1, due to successive maize cultivation without adequate crop rotation, intermediate soil fertility with presence of aluminum, and expected occurrence of stalk and leaf diseases. Fazenda Rio Grande (FZ) represented a high-yield environment, with highly fertile soil and suitable growing technology. The late planting date was however unfavorable. Only the first set (S1) was evaluated at FZ. Londrina (LD) represented the most favorable condition within ME2, at 570m asl, (Table 1). Centenário do Sul (CS) represented an intermediate condition, at low altitude (360m asl) provided with supplementary irrigation. Palotina (PL), at 350 m asl, represented the most stressful environment.

Additional effects were obtained in the analysis of variance, including factors such as locations within macro-environments (WME), locations among macro-environments (ME) and their respective GEI effects: hybrids x WME and hybrids x ME. An environmental dissimilarity study and cluster analysis were performed (Ouyang et al. 1995), where:

$D_{jj'} = 2(1 - 1/n)(1 - r_{jj'})$:

($D_{jj'}$): distance between environment j and j'.

($r_{jj'}$): correlation coefficient between locations j and j'

n: number of genotypes

The groups were formed by single linkage clustering. Indirect selection (IS) effects were estimated for each pair of environments, by assessing the selection of the best five genotypes (i = 20%). The efficiency of indirect selection was compared to local selection by the estimates $\Delta_{j/j'}$ and $\Delta_{j/j'}(\%)$, and confirmed by the t test:

$\Delta_{j/j'} = Y_{j/j} - Y_{j/j'}$

$\Delta_{j/j'}(\%) = 100.\ \Delta_{jj'} / Y_{j/j}$

$Y_{j/j}$: Mean yield in environment j of the locally selected elite genotypes

$Y_{j/j'}$: Mean yield in environment j' of the elite genotypes selected indirectly in j

Table 1. Characterization of six environments of maize cultivation: Campo Largo (CL), Ponta Grossa (PG), Fazenda Rio Grande (FZ), Londrina (LD), Centenário do Sul (CS) and Palotina (PL) in the main growing season of 2003/2004

Location	Macro-environment	Altitude (m asl)	Planting date	Pl ha^{-1}	Previous crop
CL	1	895	09/25	75,000	Maize
PG	1	860	09/23	65,000	Nabo
FZ	1	900	11/20	62,500	Oat
LD	2	570	10/01	62.500	Oat
CS	2	360	10/04	65,000	Oat.
PL	2	350	09/24	60,000	Oat

CL = Campo Largo; PG = Ponta Grossa; FZ = Fazenda Rio Grande; LD = Londrina; CS = Centenário do Sul; PL = Palotina

RESULTS AND DISCUSSION

The mean yield in ME1 exceeded that of ME2 by 1.9 t ha^{-1}, in both S1 and S2 (Table 2). High-yield environments were PG and FZ, in ME1, and LD in ME2, as expected. Lowest yields were obtained in CL and PL, in ME1 and ME2, respectively. The performance of the hybrids confirmed the large environmental variations within and among ME. The following effects were significant at 0.1 % of probability: H, ME, WME, (H X L), (H x ME), (H x WME) (Table 3).

The estimates of environmental dissimilarity ($D_{jj'}$) were lowest for CL and FZ ($D_{CL,FZ} = 0.21$). This result had been expected, considering the geo-climatic similarity of these locations. In ME2, the estimate for LD and CS ($D_{LD,CS} = 0.33$) was lowest. The largest distance was observed between PL and CL ($D_{PL,CL} = 0.8$) (Table 4).

The similarity for (PG, CS) and (PG, LD) was surprising, with estimates of around 0.3. PL was the most distant environment, on average ($D_{PL(\bar{X})} = 0.65$), followed by CL ($D_{CL(\bar{X})} = 0.52$). The mean distances were lowest for CS, PG and LD (Table 5). The environmental diversity identified by the estimates was not extreme in the six locations, given that the maximum limit of $D_{jj'}$ is equal to four, for $r_{jj'}=-1$ (Ouyang et al. 1995).

Table 2. Average yields of the two sets (S1, S2) ($Y_{\bar{x}}$) (t ha^{-1}) in macro-environments ME1 and ME2, in maize, in the main growing season of 2003/2004

	PG	FZ	CL	MA1$_{\bar{x}}$	LD	CS	PL	MA2$_{\bar{x}}$
$Y_{\bar{x}(S1)}$	14.29	11.53	9.01	11.61	10.05	9.40	9.59	9.68
$Y_{\bar{x}(S2)}$	14.27	-	9.27	11.77	10.49	10.17	8.93	9.86
$Y_{\bar{x}G}$	14.28	11.53	9.14	11.65	10.27	9.79	9.26	9.77

PG = Ponta Grossa; FZ = Fazenda Rio Grande; LD = Londrina; CS = Centenário do Sul; PL = Palotina; CL = Campo Largo; S1 = set 1; S2 = set 2

Table 3. Estimates of MS by the combined analysis of locations in the two sets (S1, S2) in maize, in the main growing season of 2003/2004

	S1		S2	
	df	MS	df	MS
B / L	12	1.06	10	1.08
L	5	297.01 ***	4	341.18***
ME	1	422.66 ***	1	327.33***
WME	4	265.60 ***	3	345.80***
H	24	35.46 ***	24	24.63***
H x L	120	2.06 ***	96	2.31***
H x ME	24	3.44 ***	24	2.96***
H x WME	96	1.72 ***	72	2.09***
Error	288	0.51	240	0.54
Total	449		374	
CV	6.70%		6.90%	

S1 = Set 1; S2 = Set 2

Table 4. Estimates of environmental distance ($D_{jj'}$) among CL, PG, FZ, LD, CS, and PL in maize, in the main growing season of 2003/2004

		ME1			ME2		
	$D_{jj'}$	CL	PG	FZ	LD	CS	PL
	CL	-	0.56	0.21	0.45	0.55	0.81
ME1	PG		-	0.43	0.34	0.25	0.58
	FZ			-	0.49	0.51	0.81
	LD				-	0.33	0.57
ME2	CS					-	0.46
	PL						-
	Average	0.52	0.43	0.49	0.44	0.42	0.65

CL = Campo Largo; PG = Ponta Grossa; FZ = Fazenda Rio Grande; LD = Londrina; CS = Centenário do Sul; PL = Palotina; ME1 = macro-environment 1; ME2 = macro-environment 2

Two groups of environments were formed by the cluster analysis (Figure 1): (CL, FZ) and (PG, LD, CS). Interestingly, cluster (PG, LD, CS) was not consistent with the geo-climatic zoning. PL represented a distinct location, excluded from either group.

Differences among cluster analysis by genotypic performances and geo-climatic zoning have been described in several species, including maize (Setimela et al. 2005) and have been ascribed to GEI effects. In fact, complex GEI effects were observed in comparison with local selection (Table 5). Although the dissimilarity analysis included the complete set of genotypes, the response to indirect selection (IS) focused on the superior hybrids only. The deviation due to indirect selection ($\Delta_{j/j'}$) ranged from zero to -1.05 t ha^{-1} (Table 5). A mean progress ($G_{j/j}$) of about 2.0 t ha^{-1} was obtained for LS (Table 5). No IS effect was observed for the pairs $Y_{PG/FZ}$, $Y_{FZ/PG}$, $Y_{PG/\bar{x}}$, $Y_{FZ/\bar{x}}$, given that the same group of genotypes was selected (i = 20 %). FZ and PG were the most appropriate environments for indirect selection, with the lowest $\Delta_{(\bar{x})}$ estimates. Significant IS effects were only reported for the target-environments PL and CL (Table 5), suggesting the need of local selection at these locations. The highest negative IS effects were obtained by selection in CL and PL, with mean Δ and Δ% of -0.6 t ha^{-1} and -4%, respectively. In addition, the highest reduction was observed between PL and CL ($\Delta_{PL/CL}$= -9.3 %; $\Delta_{CL/PL}$= -7.4%) (Table 4). Highly significant deviations were detected for the target-environment PL ($Y_{PL/j'}$), in all cases (Table 4). Selection in stressful environments should be conditioned to specific strategies of adaptability to those conditions (Hohls 2001). All analysis confirmed the superiority of high-yield environments over stressful environments with respect to the average performance in the main growing season of Paraná.

CONCLUSIONS

Large environmental variation and significant genotype-environment interaction were observed among locations, within and between the two macro-environments of Parana State.

Two clusters, distinct from the geo-climatic zoning, were obtained by the dissimilarity analysis: (CL, FZ) and (PG, LD, CS), while PL represented a separate location, excluded from the groups.

High-yield environments were more appropriate than stressful locations for indirect selection in maize breeding programs, for the main growing season in Paraná State.

Local selection was more efficient than indirect selection, for stressful target-environments.

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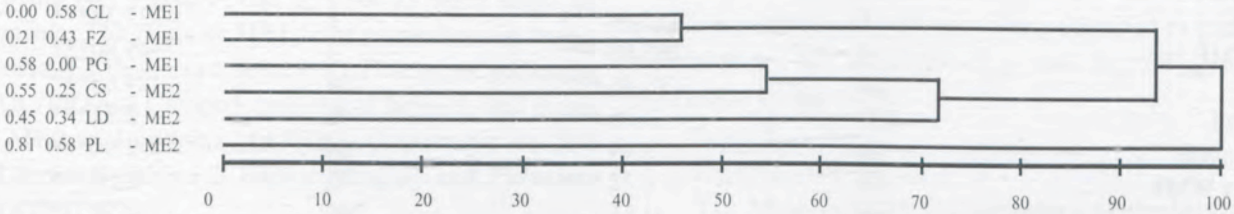

S1 = Set 1; S2 = Set 2; CL = Campo Largo; FZ = Fazenda Rio Grande; PG = Ponta Grossa; CS = Centenário do Sul; LD = Londrina; PL = Palotina. ME1 = macro-environment 1; ME2 = macro-environment 2

Figure 1. Clusters and mean distances ($D_{jj'}$) of S1 and S2 between CL, FZ, PG, CS, LD, and PL

Table 5. Effects of indirect selection (Δ), observed yield (Y) and genetic progress (G) in environment j with local selection (j/j) and of indirect selection in environment j' (j/j') in maize, in the main growing season of 2003/2004

	J						
	CL	**PG**	**LD**	**PL**	**CS**	**FZ**	**Average**
$Y_{Average}$	9.14	14.28	10.27	9.26	9.78	11.53	10.63
$Y_{j/j}$	11.10	16.67	11.82	11.40	11.61	13.79	12.64
$G_{j/j}$	1.96	2.40	1.56	2.14	1.83	2.26	2.00
$Y_{j/j'(CL)}$	11.10	15.89	11.22	10.35	11.09	13.24	12.05
$G_{j/j'(CL)}$	1.96	1.61	0.95	1.09	1.31	1.70	1.41
Δ_S	-	-0.78*	-0.60*	-1.05**	-0.53*	-0.55	-0.59
$\Delta_S(\%)$	-	-4.70	-5.10	-9.30	-4.50	-4.00	-4.70
$Y_{j/j'(PG)}$	10.88	16.67	11.54	10.82	11.49	13.79	12.42
$G_{j/j'(PG)}$	1.74	2.40	1.28	1.56	1.71	2.26	1.79
Δ_S	-0.21*	-	-0.28	-0.58*	-0.12	0.00	-0.22
$\Delta_S(\%)$	-1.90	-	-2.30	-5.10	-1.10	0.00	-1.90
0$Y_{j/j'(LD)}$	10.61	16.19	11.82	10.48	11.27	13.59	12.21
$G_{j/j'(LD)}$	1.47	1.91	1.56	1.22	1.49	2.06	1.58
Δ_S	-0.49*	-0.48**	-	-0.92**	-0.34*	-0.20*	-0.42
$\Delta_S(\%)$	-4.40	-2.90	-	-8.00	-2.90	-1.40	-3.40
$Y_{j/j'(PL)}$	10.28	15.88	11.18	11.40	11.23	12.96	12.08
$G_{j/j'(PL)}$	1.14	1.60	0.92	2.14	1.45	1.43	1.45
Δ_S	-0.82**	-0.80**	-0.64**	-	-0.38*	-0.83*	-0.56
$\Delta_S(\%)$	-7.40	-4.80	-5.40	-	-3.30	-6.00	-4.30
$Y_{j/j'(CS)}$	10.41	15.98	11.23	10.92	11.61	13.40	12.15
$G_{j/j'(CS)}$	1.28	1.70	0.96	1.65	1.83	1.87	1.52
Δ_S	-0.68**	-0.70*	-0.60*	-0.49*	-	-0.39	-0.48
$\Delta_S(\%)$	-6.10	-4.20	-5.00	-4.10	-	-2.90	-3.80
$Y_{j/j'(FZ)}$	10.82	16.76	11.40	11.31	11.34	13.79	12.57
$G_{j/j'(FZ)}$	1.82	2.48	1.36	1.72	1.95	2.26	1.93
Δ_S	-0.16	0.00	-0.04	-0.69*	-0.06	-	-0.16
$\Delta_S(\%)$	-1.40	0.00	0.40	-5.70	-	-0.50	-1.30

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Ambiente e interação genótipo-ambiente no melhoramento de milho no estado do Paraná

RESUMO - *Os objetivos deste trabalho foram: quantificar a variação ambiental e as interações genótipo-ambiente em híbridos de milho, entre e dentro de dois macro-ambientes do Estado do Paraná; associar os ambientes pelo desempenho de genótipos, estabelecendo os locais mais representativos e adequados à seleção na primeira safra da cultura, no Estado. Os experimentos foram conduzidos na safra 2003/2004 em seis locais: Campos Largo (CL), Ponta Grossa (PG), Fazenda Rio Grande (FZ), Londrina (LD), Centenário do Sul (CS) e Palotina (PL). Os efeitos de locais (L), macro-ambientes (MA), locais dentro de macro-ambientes (DMA), híbridos (H), e as interações (H x L), (H X MA), (H x DMA) foram significativos a 0,1% de probabilidade. Obtiveram-se dois agrupamentos, não coincidentes com o zoneamento por macro-ambientes: (CL, FZ) e*

(PG, CS, LD). PL foi excluído de ambos. Os ambientes aptos a altas produtividades foram mais adequados à seleção para as condições médias do Estado.

Palavras-chave: dissimilaridade, interação genótipo-ambiente, seleção, zoneamento

REFERENCES

Andrade F, Cirilo A, Uhart S and Otegui M (1996) **Ecofisiologia del cultivo de maíz**. Ed. La Barrosa, Buenos Aires. 292p.

Atlin GN, Baker RJ, McRae KB and Lu X (2000) Selection response in subdivided target regions. **Crop Science 40**: 7-13.

Bänziger M and Cooper M (2001) Breeding for low input conditions and consequences for participatory plant breeding: examples from tropical maize and wheat. **Euphytica 122**: 503-519.

Bernardo R (2002) **Breeding for quantitative traits in plants**. Stemma Press, Woodbury. 369p.

Byrne PF, Bolaños J, Edmeades GO and Eaton DL (1995) Gains for selection under drought vs. multilocation testing in related tropical maize populations. **Crop Science 35**: 63-69.

Caramori PH (2003) **Zoneamento agrícola do estado do Paraná**. IAPAR, Curitiba. 76p.

Comstock RE (1977) Quantitative genetics and the design of breeding programs. In: Pollak et al. (ed.) **Proceedings of International Conference on Quantitative Genetics**, Ames, Iowa. 16-21 Aug. Iowa State University Press. Ames IA. p. 705-718.

Falconer DS (1987) **Introdução à genética quantitativa**. UFV Imprensa Universitária, Viçosa. 279p.

Gerage AC, Shioga PS and Araújo PM (2005) **Avaliação estadual de cultivares de milho safra 2004/2005**. Informe da Pesquisa IAPAR. Londrina, (Informe de Pesquisa, 146).

Guillen-Portal FR, Russel WK, Eskridge KM, Baltensperger DD, Nelson LA, D'Croz-Mason NE and Johnson BE (2004) Selection environments for maize in the U.S. western high plains. **Crop Science 44**: 1519-1526.

Hartkamp AD, White JW, Rodriguez Aguilar A, Bänzinger M, Srinivasan G, Granados G and Crossa J (2000) **Maize Production Environments Revisited: A GIS-based Approach** [Online]. Available at http://www.cimmyt.org/Research/NRG/map/researchresultingpaper/GISmaprod/MaProdcont.htm. Accessed in April, 2005.

Hohls T (2001) Conditions under which selection for mean productivity, tolerance to environmental stress, or stability should be used to improve yield across a range of contrasting environments. **Euphytica 120**: 235-245.

Löffler CM, Wei J, Fast T, Gogerty J, Langton S, Bergman M, Merrill B and Cooper M (2005) Classification of maize environments using crop simulation and geographic information systems. **Crop Science 45**: 1708-1716.

Ouyang Z, Mowers RP, Jensen A, Wang S and Zheng S (1995) Cluster analysis for genotype x environment interaction with unbalanced data. **Crop Science 35**: 1300-1305.

Pollak LM and Corbett JD (1993) Using GIS datasets to classify maize-growing regions in Mexico and Central America. **Agronomy Journal 85**: 1133-1139.

Robertson A (1959) The sampling variance of the genetic correlation coefficient. **Biometrics 15**: 469-485.

Setimela P, Chitalu Z, Jonazi J, Mambo A, Hodson D and Bänziger M (2005) Environmental classification of maize-testing sites in the SADC region and its implication for collaborative maize breeding strategies in the subcontinent. **Euphytica 14**: 123-132.