Australian Journal of
Crop Science
AJCS

AJCS 11(05):516-521 (2017)
ISSN:1835-2707
doi: 10.21475/ajcs.17.11.05.p304

Correlation among adaptability and stability assessment models in maize cultivars

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Abstract

Abstract - The aim of the current study is to associate four different adaptability and stability analysis models using the Spearman's correlation based on productivity data. Twenty-five (25) hybrid maize cultivars were assessed in 11 environments located in the Brazilian Northeastern region, between 2012 and 2013. The study has followed a complete randomized block design with two repetitions. There was high correlation between the methods by Cruz et al. and Eberhart and Russel. Both methods have shown mean correlation with the method by Verma et al. With respect to favorable environments, the methodology by Lin and Binns has shown high correlation with the methods by de Cruz et al. and Eberhart and Russel, as well as negative correlation with the method by Verma et al. The methods by Lin and Binns and Verma et al. should not be used together, since there was no correlation between them. The combined use of the methods by de Cruz et al. and Eberhart and Russel has provided the best genotype selection results, since these methods associated productivity data with the cultivars' stability and adaptability. Therefore, these methods were the most adequate for this type of analysis.

Keywords: Adaptability; interaction between genotype and environment; predictability; stability; *Zea mays*.
Abbreviations: DR:_ dark red; E_Early; HD_Double-cross hybrid; HMS_ Modified single-cross hybrid; HS_Single-cross hybrid; HT_Three-way cross hybrid; O_Orangish; R_Reddish; SE_Super early; SMDENT_Semi-dent; SMHARD_Semi-hard; Y_Yellow; YE_ Yellowish.

Introduction

Maize is one of the most important products in the agricultural sector. It has great economic importance due to its versatility of use and nutritional composition. This cereal is used both in human/animal diets and in the high-technology industry (Ai and Jane, 2016).

Maize is grown under different environmental conditions in the Brazilian Northeastern region, fact that enables genotypes to interact with the environments and results in the differentiated genotype performances. According to IBGE (2016), the maize productivity has increased by approximately 2,500 thousand tons in the Northeastern region, from 2010 to 2014. This increase is directly related to crop management and to the use of superior cultivars selected according to the assessment of the relative behavior of genotypes in a large number of environments. There are several methods to estimate the genotypes' adaptability and stability based on different principles. Among them, the methods based on simple linear regression (Eberhart and Russel, 1966; Cruz et al., 1989) and on segmented linear regression (Verma et al., 1978), as well as the non-parametric methods (Lin and Binns, 1988), stand out.

Aspects such as the ease of analysis and the interpretation of results should be taken into consideration at the time to select the methods to be used. In addition, it is necessary assuring improved safety in the indication of cultivars to producers (Cruz and Regazzi, 1997; Borges et al., 2000). It is also worth taking into consideration that some methods are alternative, whereas others are complementary and can be used together (Cruz et al., 2012). Cargnelutti Filho et al. (2007) have recommended using the method by Eberhart and Russel (1966) to assess maize crops. Silva Filho et al. (2008) have recommended using the method by Lin and Binns (1988), as well as the AMMI method, to assess cotton crops. According to Vasconcelos et al. (2015), the methods by Eberhart and Russell (1966) and Lin and Binns (1988) have shown consistency in the assessment of peanut cultivars.

According to the method by Eberhart and Russell (1966), the adaptability - or linear response to the environments - is found through the estimation of the parameter β_{1i} and through the mean productivity β_{0i}, whereas the stability is found through the regression deviations δ_{ij}, according to the model:

$Y_{ij}= \beta_{0i} I_j+\delta_{ij}+\epsilon_{ij}$, wherein: Y_{ij} is the mean grain yield (kg ha^{-1}) of the genotype i in the environment j; β_{0i} is the general mean; β_{1i} is the linear regression coefficient; δ_{ij} is the regression deviation; ϵ_{ij} is the mean experimental error; and I_j is the coded environmental index.

Cruz et al. (1989) have performed the bi-segmented regression analysis and used the mean (β_0), the linear response to unfavorable environments (β1) and the linear response to favorable environments ($\beta_1+\beta_2$) as adaptability parameters to individually assess the genotypes' behavior in each environment.

The stability of the cultivars is assessed through the regression coefficients (R^2) and regression deviations (δ_d^2) of each material, according to the environmental variations. This method adopts the following model:

$Y_{ij}= \beta_{0i}+\beta_{1i}I_j+\beta_{2i}T(I_j)+\delta_{ij}+\epsilon_{ij}$, wherein: Y_{ij}, β_{0i}, I_j and ϵ_{ij} are the previously defined variables; $T(I_j)=0$, if $I_j <0$ or $T(I_j)=I_j- I_+$, if $I_j >0$, wherein I_+ is the mean of the positive indices I_j .

Verma et al. (1978) have identified the ideal genotype based on a double linear regression analysis. Each analysis used a model similar to that by Finlay and Wilkinson (1963) or Eberhart and Russell (1966) in order to measure the genotypes' response to two environment types characterized as unfavorable or favorable (Cruz et al., 2012). The regressions were calculated according to the methodology by Eberhart and Russell (1966). According to Verma et al. (1978), the ideal genotype presents high productive capacity, as well as values such as β1i <1 and β1i >1 for unfavorable and favorable environments, respectively.

Lin and Binns (1988), modified by Carneiro (1998), used a non-parametric adaptability and stability analysis to detail information for favorable and unfavorable environments, as well as to find the maximum-performance genotype for most environments. The first modification lied on the decomposition of P_i in the parts concerning favorable and unfavorable environments. This first modification was treated according to Lin and Binns (1988) in the present study. The P_i estimate was given through:

$P_i= \frac{\sum_{j=1}^{a} (Y_{ij}-M_j)^2}{2a}$, wherein: P_i is the estimation of the i^{th} genotype stability parameter; Y_{ij} is the productivity of the i^{th} genotype in the j^{th} environment; M_j is the maximum response observed among all genotypes in the j^{th} environment; and *a* is the number of environments.

The *Embrapa Tabuleiros Costeiros* assesses maize cultivars through partnerships with national experimentation networks in order to select and indicate the genotypes presenting better adaptability and stability to the producers, as well as to increase the crop productivity in these regions. The number of cultivars and methods assessed in the current study presents desirable features and valuable information to explore to the maximum the beneficial effects of the G x E interaction in breeding programs.

The aim of the current study is to compare the methods for the analysis of maize genotypes' adaptability and stability, through the adoption of the models by Eberhart and Russell (1966), Cruz et al. (1989), Verma et al. (1978) and Lin and Binns (1988) based on productivity data.

Results and Discussion

Analysis of variance and agronomic performance

All variables have shown significant difference in all factors (Table 3). The interactions have shown different cultivar responses in different environments and years, as well as edaphoclimatic differences in the environments during the two experimental years. Similar results were found by Carvalho et al. (2011), who observed significant differences in these variation sources when they studied the adaptability and stability of maize hybrids in the Brazilian Northeastern region. These interactions have affected the hybrids' productivity and showed the need of performing stability analysis in order to predict, in detail, the behavior of each maize cultivar according to environmental variations between and within years.

The cultivars 30A68HX, 2B707HX, 30A16HX, 2B587HX, 2B710HX, 2B604HX, 30A37HX, 30A95HX, 2B433HX, P4285H, 20A55HX, 30F53HR, AG8041YG, 2B688HX and 20A78HX have shown the highest yields and exceeded the overall mean (Table 4).

According to the parameters estimated through the method by Eberhart and Russel (1966), the cultivars 2B707HX, 30A16HX, 2B587HX, 2B604HX, 30A95HX, 30A91HX and 2B688HX have shown yield above the general mean and presented β_{1i} values significantly above the unit, thus showing adaptation to favorable environments. All genotypes indicated for favorable environments, except for the 30A91HX one, have shown $\delta^2 d$ significantly different from zero, i.e., their performance was unstable. However, according to Cruz et al. (1989), materials presenting estimates such as $R^2 > 80$ should not have their predictability degrees impaired.

The hybrids P 4285 H, AG 8041 YG and 30 F 53 HR have shown β_{1i} values statistically lower than the unit and they were recommended for unfavorable environments. The genotypes 30 A 68 HX and 2 B 710 HX were considered highly adaptable since they presented β_{1i} values close to 1. However, just the hybrid 2 B 710 HX has shown high R^2 values ($R^2 > 80$) among these hybrids.

According to the method by Cruz et al. (1989), the genotypes 2 B 707 HX, 30 A 16 HX, 2 B 587 HX, 2 B 604 HX, 30 A 91 HX and 2 B 688 HX have shown β_{1i} and ($\beta_{1i} + \beta_{2i}$) higher than 1 and mean above the general mean; thus, they were indicated for favorable environments. On the other hand, the genotypes 30 F 53 HR and AG 8041 YG were indicated for unfavorable environments (β_{1i} and $\beta_{1i} + \beta_{2i} <1$). The hybrids 30 A 16 HX, 2 B 587 HX, 2 B 710 HX, 2 B 604 HX, 30 A 37 HX, 2 B 433 HX, 30 A 91 HX and 2 B 688 HX have shown good stability.

According to Cruz et al. (1989), the ideal hybrid shows high production capacity, as well as $\beta_1<1$, $(\beta_1 + \beta_2) >1$ and regression deviation variance close or equal to zero. No cultivar has met this condition. Similar results were found by Oliveira et al. (2006b) and Albrecht et al. (2007), who have studied beans and wheat, respectively, and did not find a genotype with ideal features.

According to the methodology by Lin and Binns (1988), the genotypes 2 B 707 HX, 30 A 16 HX and 2 B 587 HX have shown the lowest P_i estimates for favorable environments. The genotypes 2 B 604 HX, 30 A 37 HX, P 4285 H and AG 8041 YG stood out in unfavorable environments. It is worth highlighting that the hybrids 30 F 53 HR, 2 B 688 HX and 20 A 78 HX were considered low-stability genotypes because they presented the highest P_i estimates in all environments.

With respect to the method by Verma et al. (1978), the genotypes 30 A 95 HX, 30 A 91 HX, 2 B 688 HX and 20 A 78 HX were indicated for favorable environments ($\beta_{1i}>1$), whereas the genotypes 30 A 16 HX, 2 B 587 HX, 30 A 37 HX, 2 B 433 HX, P 4285 H and 30 F 53 HR were indicated for unfavorable environments (β1i<1). Among them, just the hybrids 30 A 95 HX, 20 A 55 HX, AG 8041 YG, 2 B 688 HX, 20 A 78 HX and 20 A 55 HX have shown good stability. According to Verma et al. (1978), the ideal genotype presents high production capacity, as well as $\beta_{1i}<1$ value for unfavorable environments and $\beta_{1i}>1$, for favorable environments. The genotypes 20 A 55 HX and AG 8041 YG have shown such features in the current study.

Table 1. Joint analysis of the mean grain production of 25 hybrid maize cultivars tested in eleven localities of North-Eastern Brazil, 2012 and 2013

Source of variation		DF	MS
Repetition (Environment (Year))		20	2008048.22**
Environments		10	89808806.92**
Years		1	1.15**
Cultivars		24	11854182.24**
Environments*Years		10	46658161.92**
Cultivars*Environments		240	2156901.94**
Cultivars*Years		24	6519353.39**
Cultivars*Environments*Years		240	1414978.16**
Error		530	737275.21
CV(%)	9.86		
Mean (kg*ha^{-1})	8711.12		

* and ** indicate significance at 5% and 1%, respectively.

Estimates of correlation coefficients

The Spearman's correlation coefficients range from -1.00 to 1.00 and it indicates, respectively, the total disagreement and total agreement of the classificatory positions between two variables. These values may be considered low ($0.10 \leq r \leq 0.29$), medium ($0.30 \leq r \leq 0.49$) or high ($0.50 \leq r \leq 1$). However, the values -1.00 and 1.00 in the current study did not indicate that the two estimates of the different methods fully disagreed or agreed with the classificatory positions between two variables. Thus, it is necessary interpreting the values of each estimate pair. The correlation between adaptability or stability estimates and the use of different methods may help better predicting the behavior of the assessed genotypes (Oliveira et al., 2006a).

By considering the four methodologies analyzed in the current study, it was found that the method by Eberhart and Russel (1966) presented high correlation with the method by Cruz et al. (1989), thus showing agreement of information (Table 5). The similarity between these two methods was also reported by Domingues et al. (2013) and Pereira et al. (2009), who explained that this redundancy may be attributed to the non-identification of an optimal-performance genotype, according to the method by Cruz et al. (1989).

The β_{1i} in the method by Eberhart and Russel (1966) has shown mean correlation with the β_{2i} in the method by Verma et al. (1978), as well as high correlation with the β_{1i} and (β_{1i} + β_2) in the method by Cruz et al. (1989). According to Miranda et al. (1998), these results have indicated that the cultivars selected due to high productivity and β_{1i}>1 in the method by Eberhart and Russell (1966) would also have been indicated for favorable environments, according to the method by Verma et al. (1978).

The method by Lin and Binns (1988) has shown negative correlation with the methods by Eberhart and Russel (1966) and Cruz et al. (1989) for unfavorable environments. It has indicated that the methods disagreed on the indicated genotypes. However, these methods have shown high correlation in favorable environments. These results are consistent with those reported by Franceschi et al. (2010). According to Cargnelutti Filho et al. (2007), it indicates that cultivars presenting the lowest P_i values in the general classification and in favorable environments also present the highest β_1 scores. Nonetheless, according to Silva and Duarte (2006), Polizel et al. (2013) and Cavalcante et al. (2014), these methods were complementary.

The method by Verma et al. (1978) has shown no significant correlation with the method by Lin and Binns (1988). Thus, there was no similarity in the information found between these methods. This result reinforces the idea that using more than one method to estimate genetic parameters provides greater data interpretation reliability at the time to recommend cultivars for a given region (Vaconcelos et al., 2015). Verma et al. (1978) and Lin and Binns (1988) have shown negative and no correlation, respectively, with mean yield, thus suggesting that the genotypes indicated through these methods did not present the highest mean yields. Such results disagree with those found by Cargnelutti Filho et al. (2009) and Josias et al. (2015) in studies conducted with maize and soybean, respectively.

Materials and Methods

Location and genotypes used in this study

Twenty-five (25) maize hybrids from public and private companies (Table 1) were assessed in Maranhão (Balsas, Brejo, Colinas and São Raimundo das Mangabeiras), Piauí (Nova Santa Rosa, Teresina and Uruçuí) and Sergipe states (Nossa Senhora das Dores, Frei Paulo and Umbaúba) from 2012 to 2013. The assessments comprised 11 environments, since the maize breeding experimental area in Nossa Senhora das Dores was divided in two environments, which were featured according to different fertilizations (Table 2).

The high-fertilization range experiments conducted in Nossa Senhora das Dores County comprised 180.00 kg ha^{-1} N, 149.80 kg ha^{-1} P_2O_5 and 85.60 kg ha^{-1} K_2O. The low-fertilization range experiments comprised 45.00 kg ha^{-1} N, 37.80 kg ha^{-1} P_2O_5 and 21.60 kg ha^{-1} K_2O in the form of 535 and 135 kg ha^{-1} of 8-28-16 + Zn, at sowing. Twenty-one (21) days after emergence of plants, the experiments received topdressing nitrogen in the form of urea.

Design used

The experiments were implemented at the time recommended for each region and followed a complete randomized block design with two repetitions. The plots were composed of four 5.0 m-long rows, and spaced 0.70 m between rows and 0.20 m between holes within the rows. The fertilization was done according to the results of the soil analyses conducted in each experimental area. The irrigation was not carried out, whereas weed and pest controls were performed according to the crop need in each region.

Statistical analysis

The productivity data were subjected to analysis of variance. The joint analysis of variance was performed through the F-max test by Hartley (1950), after the homogeneity of the

Table 2. Mean production (Kg ha^{-1}) of 25 hybrid maize cultivars, estimate of coefficients (β_0, β_{1i} e β_{2i}), of the regression deviations (δ^2d), determination coefficients (R^2), Pis (general, favorable, unfavorable) of the genotypes of hybrid maize.

Genotype	Mean	Eberhard and Russell (1966)			Cruz et al. (1989)			Lin and Binns (1988)			Verma et al. (1978)		
		β_{1i}	δ^2_d (x10^4)	R²	β_{1i}	$\beta_{1i}+\beta_{2i}$	R²	General(x10^5)	Favorable(x10^5)	Unfavorable (x10^5)	β_{1i}	β_{2i}	R^2
30 A 68 HX	9402a	1.03^{ns}	85.04**	70	0.91^{ns}	1.58**	74	14.35	17.64	19.60	1.34	0.95	37
2 B 707 HX	9301a	1.20*	85.04**	78	1.22*	1.11^{ns}	79	17.79	13.53	23.94	1.58	1.08	59
30 A 16 HX	9287a	1.49**	68.47**	86	1.40**	1.91**	87	17.09	11.26	25.50	0.16	0.85	53
2 B 587 HX	9192a	1.29**	59.77**	87	1.31**	1.19^{ns}	87	18.50	14.40	24.42	0.99	0.85	51
2 B 710 HX	9150a	1.02^{ns}	31.44**	85	1.10^{ns}	0.63^{ns}	88	18.58	16.90	21.01	1.08	0.80	47
2 B 604 HX	9146a	1.19*	49.58**	81	1.10*	1.63**	84	19.79	20.87	18.22	1.03	-0.18	17
30 A 37 HX	9124a	1.13^{ns}	10.34**	85	1.18^{ns}	0.89^{ns}	85	17.47	17.81	16.97	0.63	0.81	44
30 A 95 HX	8992a	1.21*	25.58^{ns}	77	1.18*	1.34^{ns}	77	19.99	16.06	25.65	1.90	1.51	80
2 B 433 HX	8932b	1.06^{ns}	78.68**	90	1.08^{ns}	0.96^{ns}	90	20.63	21.43	19.48	0.57	0.30	10
P 4285 H	8907b	0.70**	-27.02*	61	0.64**	1.03^{ns}	63	23.97	31.49	13.12	0.74	0.74	23
20 A 55 HX	8853b	1.13^{ns}	48.48**	87	1.22^{ns}	0.68^{ns}	90	22.06	19.45	25.83	0.68	1.50	89
30 F 53 HR	8833b	0.80*	11.92^{ns}	50	0.89*	0.32**	54	29.23	35.71	19.89	0.32	0.28	5
AG 8041YG	8743b	0.82*	13.19**	69	0.84*	0.74^{ns}	69	22.06	33.53	17.55	0.88	1.54	94
30 A 91 HX	8737b	1.18*	44.43*	88	1.14*	1.37^{ns}	89	25.00	22.94	27.96	1.38	1.44	68
2 B 688 HX	8736b	1.20*	13.13^{ns}	79	1.15*	1.43*	80	29.00	31.16	25.88	1.19	1.76	85
20 A 78 HX	8730b	1.11^{ns}	64.92*	76	1.14^{ns}	0.98^{ns}	76	30.94	32.62	28.50	0.96	1.85	94
DKB 370	8640b	0.88ns	52.17**	70	0.94ns	0.57*	72	29.70	32.13	26.17	1.73	0.85	51
30 K 73 H	8591b	1.00ns	39.47**	78	0.97**	1.10ns	78	27.04	31.69	20.33	0.65	0.17	3
DKB 330 YG	8579b	1.00^{ns}	39.47**	72	1.00^{ns}	0.99^{ns}	72	29.41	32.31	25.21	0.56	1.03	31
AS 1596 R2	8401c	0.92^{ns}	66.93**	69	0.89^{ns}	1.09^{ns}	69	31.60	36.79	24.10	0.37	0.01	0
Statusvip	8345c	0.77**	65.81**	61	0.81**	0.56*	62	31.27	39.00	21.00	1.11	0.68	24
BM 820	8275c	0.80*	64.97**	64	0.94*	0.16**	72	38.18	44.70	28.76	0.98	1.78	75
AS 1555 YG	8098c	0.95^{ns}	61.19**	74	0.79^{ns}	1.73**	84	39.67	48.31	27.21	1.63	1.58	84
BRS 2022	7428d	0.65**	46.70**	57	0.65**	0.65^{ns}	57	58.79	74.13	36.62	1.10	1.21	58
BRS 2020	7354d	0.47**	50.08**	35	0.49**	0.37**	35	66.56	86.91	37.16	1.43	1.57	83
General mean	8711.12												

Ns: not significant, ** and * Significant at 1% and 5% of probability. respectively. according to the Student's T test for β , ** and * Significant at 1% and 5% of probability. respectively. according to the F test for S^2d. Means followed by the same letter are not significantly different according to the Scott-Knott test at 5% probability.

Table 3. Estimate of the Spearman correlation coefficients for adaptability and stability for each couple of methods and means (Kg/ha) obtained for the 25 tested cultivars.

	Mean	E&R	Cruz	L&B
E&R$^{(1)}$	0.69**	-	-	-
Cruz$^{(2)}$	0.69**	0.95**	-	-
L&B$^{(3)}$	-0.90**	-0.73**	-0.72**	-
Verma$^{(4)}$	-0.29^{ns}	-0.09^{ns}	-0.14^{ns}	0.18^{ns}

(1) Eberhard e Russell (1966). (2) Cruz et al. (1989). (3) Lin e Binns (1988). (4) Verma et al. (1978) using the mean values as a parameter of stability. ** significant at 1% probability according to the Student's T test.

Table 4. Relation between the hybrid maize used in the experiments and their respective origin, type, cycles, colors, textures of the grains and responsive firm.

Cultivar	Transgenic/conventional	Type	Cycle	Grain color	Grain texture	Company
30 A 95 HX	Transgenic	HT	P	O	SMHARD	MORGAN
30 A 68 HX	Transgenic	HS	SE	O	SMHARD	MORGAN
BM 820	Conventional	HS	E	R	HARD	BIOMATRIX
DKB 330 YG	Conventional	HS	SE	Y/O	SMDENT	DEKALB
AS 1596 R2	Transgenic	HS	E	Y	SMDENT	AGROESTE
P 4285 H	Transgenic	HS	E	Y/O	HARD	DU PONT
2 B 710 HX	Transgenic	HS	E	Y/O	SMHARD	DOW
30 A 16 HX	Transgenic	HS	E	O	SMHARD	MORGAN
DKB 370	Conventional	HMS	E	Y/O	SMHARD	DEKALB
AG 8041 YG	Transgenic	HS	E	Y/O	SMHARD	SEMENTES
20 A 55 HX	Transgenic	HT	E	O	SMHARD	MORGAN
30 F 53 HR	Transgenic	HS	E	O	SMHARD	DU PONT
30 A 37 HX	Transgenic	HS	SE	Y/O	SMHARD	MORGAN
30 A 91 HX	Transgenic	HMS	E	Y/O	SMHARD	MORGAN
2 B 587 HX	Transgenic	HS	E	Y/O	SMDENT	DOW
2 B 433 HX	Transgenic	HT	SE	Y/O	SMDENT	DOW
AS 1555 YG	Transgenic	HS	E	O	SMHARD	AGROESTE
BRS 2022	Conventional	HD	E	O	SMDENT	EMBRAPA
STATUSVIP	Transgenic	HS	E	O	HARD	SYNGENTA
BRS 2020	Conventional	HD	E	O	SMHARD	EMBRAPA
2 B 707 HX	Transgenic	HS	E	O	SMHARD	DOW
20 A 78 HX	Transgenic	HS	E	O	SMHARD	DOW
2 B 604 HX	Transgenic	HMS	E	O	SMHARD	DOW
30 K 73 H	Transgenic	HS	E	Y/O	SMHARD	DU PONT
2 B 688 HX	Transgenic	HT	E	O	SMHARD	DOW

HS: Single-cross hybrid; HD: Double-cross hybrid; HT: Three-way cross hybrid; HMS: Modified single-cross hybrid,Cycle: SE: Super early; E: Early, Grain color: O: Orangish; R: Reddish; Y: Yellowish
Texture of the grain: SMDENT: Semi-dent; SMHARD: Semi-hard;

Table 5. Geographic coordinates of the municipalities of the North-Eastern region of Brazil where the experiments were performed, 2012 and 2013.

Municipality	Latitude(S)	Longitude(W)	Altitude(m)	Soil type	Rainfall (mm) 2012	Rainfall (mm) 2013	Mean temperature (^{o}C)
Colinas/MA	06^{0}01’	44^{0}14’	141	Ultisol DR	569.9	503.9	27
São R. das Mangabeiras/MA	07^{0}22’	45^{0}36’	225	Ultisol. Y	865.8	865.8	26
Brejo/MA	03^{0}41’	42^{0}45’	55	Latosol Y	889.8	889.8	27
Balsas/MA	07^{0}32’	46^{0}02’	247	Ultisol Y	896.5	896.5	29
Uruçuí/PI	03^{0}11’	41^{0}37’	70	Ultisol Y	571.0	689.0	25
Teresina/PI	05^{0}05’	42^{0}49’	72	Ultisol Y	748.8	909.1	28
Nova Santa Rosa/PI	08^{0}24’	45^{0}55’	469	Latosol Y	658.0	705.0	23
Frei Paulo/SE	10^{0}55’	37^{0}53’	272	Cambisol	830.5	746.3	26
Nossa Sra das Dores/SE	10^{0}30’	37^{0}13’	200	Latosol Y	834.0	741.2	25
Umbaúba/SE	12^{0}22’	37^{0}40’	109	Ultisol Y	821.9	1343.6	24

Soil type: DR: dark red; Y: Yellow

residual variances was found. The methods by Eberhart and Russell (1966), Cruz et al. (1989), Lin and Binns (1988) and Verma et al. (1978) were used to estimate adaptability and stability. The adaptability and stability analyses were performed in the GENES software (Cruz, 2006).

Finally, the Spearman's correlation coefficients between the adaptability and stability analysis methods were calculated in the SAS 9.3 software package (SAS Institute Inc., 2011).

Conclusions

The selection of the hybrids to be indicated depends on the adopted adaptability and stability analysis method.

It is recommended using the methods by Lin and Binns (1988) and Verma et al. (1978) together in order to study adaptability and stability.

The methods by Eberhart and Russel (1966) and Cruz et al. (1989) have shown high correlation to study the adaptability and stability of hybrid maize cultivars because they took stability, adaptability and productivity into consideration, simultaneously.

Acknowledgments

To CAPES for the grant provided and to EMBRAPA for infrastructures and resources necessary for the realization of this study.

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