

**GENOTYPE BY ENVIRONMENT INTERACTION FOR YIELD
IN SUGARCANE PERFORMANCE TRIALS:
A COMPARISON OF FREQUENTLY USED MODELS**

By

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**KEYWORDS: Genotype-Environment Interaction,
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Abstract

THE OBJECTIVE of this paper was to apply different multivariate statistical analysis, (cluster analysis, model of main effects additives and multiplicative interaction (AMMI), regression analysis of sites (GGE) and principal coordinates analysis (PCO)), to compare their utility and efficiency in the study of the genotype-environment interaction (GE) in sugarcane cultivars. Performance data of eighteen cultivars evaluated at four locations, in the south-eastern region of Cuba, was used in this study. The experimental design used in each trial was a randomised complete block. The evaluated variable was tonnes of cane per hectare. Analysis of variance showed that effects of genotype, environment and GE were highly significant. Cluster analysis discriminated between four locations, while the GGE method only generated three groups of environments. The *biplot* indicated that there were similar results between the AMMI and GGE model. The scatter point diagrams obtained from PCO analysis, however, revealed only limited agreement with the results obtained by the AMMI and GGE model. The G+GE captured by AMMI (50.2 %) and GGE (77.0 %) were both more adequate than PCO analysis in quantifying environment and genotype effects.

Introduction

The differential response of a genotype or cultivar for a given trait across environments is defined as the genotype \times environment interaction (GE). If this GE is large, it may result in failure to differentiate performance of genotypes across environments, and it can reduce the precision of the selection across the environments.

Therefore, GE is an important and an essential component of plant breeding programs dedicated to cultivar development. Further, effective statistical analysis of yield trials can help breeders to make faster progress (Gauch, 2006).

The objective of the present study was to compare different multivariate statistical techniques for analysis of multi-environment sugarcane cultivar yield trials.

Materials and methods

Data from a multi-environment trial were analysed. The trial was carried out in the south-eastern region of Cuba at four locations across the sugarcane production zone (Table 1). Eighteen sugarcane cultivars released by the Cuban National Institute for Sugarcane Research (INICA) over the last 10 years were evaluated (Table 2).

Experiments at each location were planted in a randomised block design using three replications. Cane yield (t/ha) for one cropping season was recorded.

Table 1—Information of the four experiment locations of the multi-environment trial.

County	Location		Year planted	Harvested (months)	Soil type	Annual Rainfall (mm)
	Name	Code				
Santiago de Cuba	Paquito Rosales	PR	2006	16	Cambisol Eutrico	1156.7
Santiago de Cuba	Julio A. Mella	ME	2006	16	Acrisol Alúmico	1031.1
Granma	Enidio Días	ED	2006	16	Feozem Calcárico	1130.4
Guantánamo	Manuel Tames	MT	2006	16	Cambisol Eutrico	966.6

Table 2—Clones (genotypes) evaluated in the multi-environment trial.

Code	Clone	Code	Clone	Code	Clone
G1	B7274	G7	C86-531	G13	C90-501
G2	C128-83	G8	C87-632	G14	C90-530
G3	C323-68	G9	C88-380	G15	C90-647
G4	C86-12	G10	C89-250	G16	C91-356
G5	C86-156	G11	C89-559	G17	C92-325
G6	C86-503	G12	C90-317	G18	CP52-43

The 18 experimental cultivars were (G1), (G2), (G3), (G4), (G5), (G6), (G7), (G8), (G9), (G10), (G11), (G12), (G13), (G14), (G15), (G16), (G17) and (G18).

Statistical analysis

Repeated measures analysis of variance (ANOVA) was performed to determine the significance of the main effects of genotype and environment, as random effects, and the effect of genotype-environment interaction. With the residuals of GE, a multivariate statistical analyses for GE and phenotypic stability was carried out.

Multivariate statistical techniques

The analysis used for the study of GE interaction and phenotypic stability in sugarcane cultivars were: cluster analysis (Ghadery *et al.*, 1980), additive and multiplicative interaction (AMMI) (Gauch, 2006), regression analysis of sites (GGE) (Yan *et al.*, 2006), and principal coordinates analysis (PCO) (Westcott, 1987). All statistical analyses were performed using the Statistica system (StatSoft, 2003).

Results and discussion

Analysis of variance

Results of analysis of variance for the yield data are presented in Table 3, which gives an overall picture of the relative magnitudes of the genotype, environment, and GE variance. Locations were the most important source of variation, accounting for 65.2%. GE interaction accounted for 25.8% of total sum of squares.

Table 3—Analysis of variance and variance term estimates for cane yield.

Source	DF.	Mean squares		Percent of total sum of squares
Location (L)	3	30345.6	**	59.1
Rep. (within L)	8	89.1		0.5
Genotype (G)	17	813.9	**	9
GxL	51	780.6	**	25.8
Error	136	64,3		5.7

** indicate significant differences at $p < 0.01$

Statistical analysis to study GE interaction effects and phenotypic stability

a) Cluster analysis

Mella was detected as the major contributing location to the GE interaction (Figure 1). This location is characterised by a different soil than at the others locations (Table 1). Removal of Mella from the analysis resulted in a single cluster, containing all other locations, with significance for GE interaction.

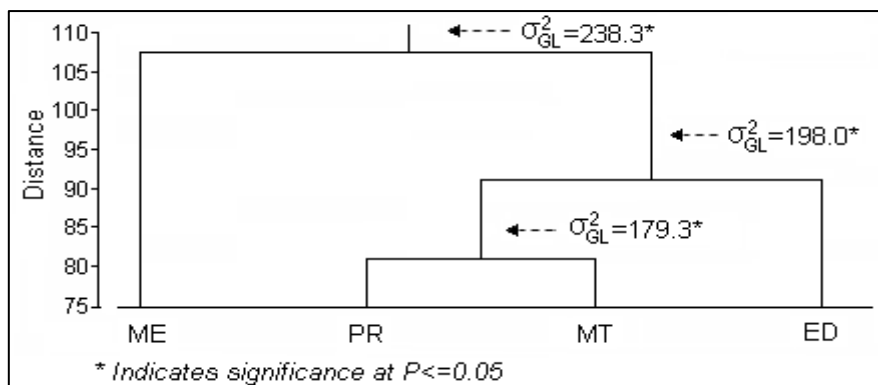


Fig. 1—Cluster dendrogram showing the relationships among locations and their GE interaction effects for cane yield. Cluster analysis using Ward's method algorithm.

b) AMMI and GGE models analysis

AMMI analysis indicated that the first multiplicative components explained 50.2% of the GE interaction (Figure 2). Enidio Díaz was detected as the location with the highest yield, with genotype G14 performing best at this location. On the other hand, Paquito Rosales showed the lowest average yield. The G5, G9 and G4 cultivars performed well over all locations.

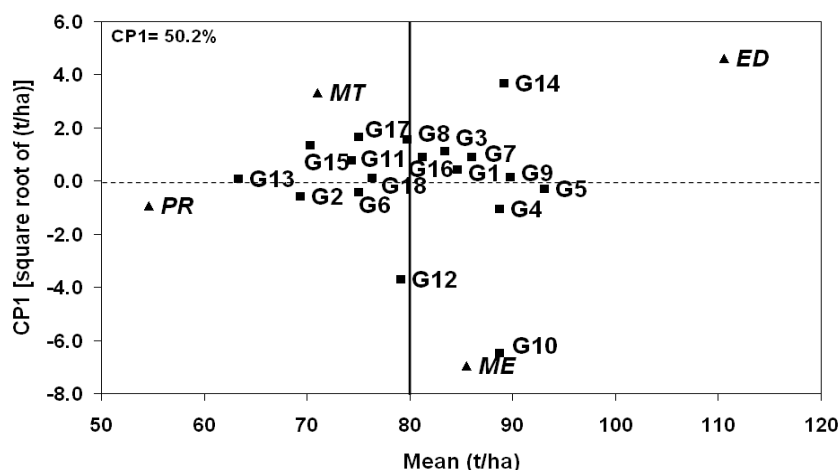


Fig. 2—AMMI₁ Biplot: The genotype and environment means are shown on the abscissa, with a vertical line at grand mean. The principal component (PC) 1 scores are shown on ordinate.

The GGE model (Figure 3a) explained 77% of the variance of genotypes and GE interaction. The locations were grouped into three for the region in study: (i) Enidio Díaz, (ii) Mella and Paquito Rosales, and (iii) Manuel Tames. This result is different to the cluster analysis, which revealed significant differences between Mella and Paquito Rosales locations. Vertex genotypes for each location are the most responsive genotypes (Yan *et al.*, 2006) and include G14 in Enidio Díaz; G10 and G5 in Mella and Paquito Rosales; and G17 in Manuel Tames.

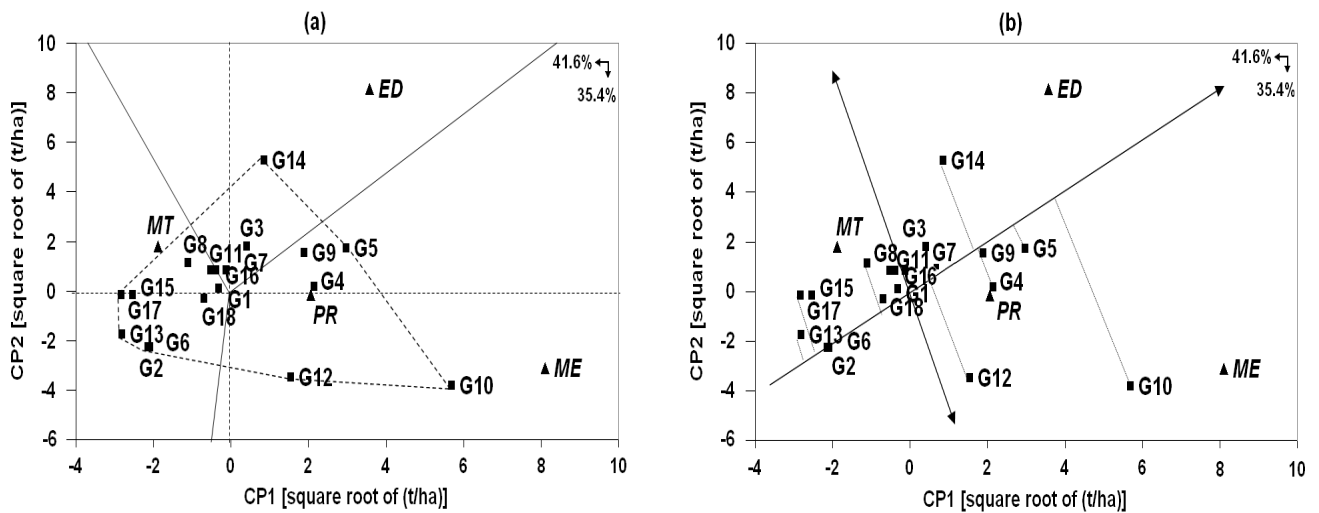


Fig. 3—Biplot GGE: (a) best performance genotypes for each environment, (b) mean performance for genotypes and its stability.

Figure 3b shows the mean performance of genotypes (the line that passes through the *biplot* origin and the environment) and genotype stability (the line that passes through the *biplot* origin and the genotype), obtaining results similar to AMMI1 (Figure 2).

Principal coordinates analysis

In the low cycle (Figure 4a) and for the four locations in the study, the genotypes more distant to the centre of the diagram are G5, G9 and G4, and are regarded as the most stable cultivars. Also, genotypes G7, G1 and G10 are further from the centre, for the first three cycles of low yield. Nevertheless, G7 was more repeatable across all cycles, showing stability for discriminating environments and low yield.

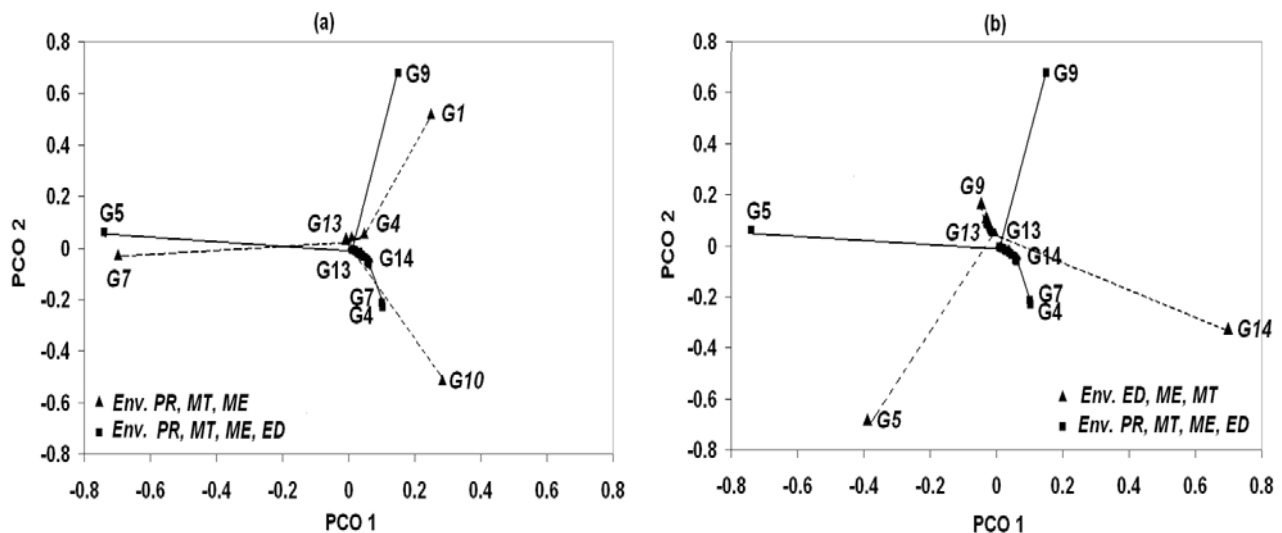


Fig. 4—Plot of the first two principal coordinates (PCO1 and PCO2 axes) obtained from principal coordinate analysis in two last cycles (a) low yield and (b) high yield.

For the high cycle (Figure 4b), the genotypes (G5 and G9) more distant to the centre in the last cycle, are the same as for the previous cycle. G14 was a winning genotype for the first three cycles, showing stability for high-yielding environments. AMMI and PCO analyses were very

similar for identifying G5, G9 and G4 cultivars, as the more stable cultivars. For G14, AMMI and GGE results partially do not agree with PCO. This genotype is mainly associated with high-yielding environments (Enidio Díaz).

The multivariate analyses AMMI and the regression analysis for sites (GGE) were similar to show genotype performance across environments, with differences in the contribution explained in terms of GE interaction variance ($GGE > AMMI1$). Both these models were better than PCO analysis in quantifying environment and genotype effects for cane yield and can be equivalent for gaining accuracy. Other models, like cluster analysis, did not show a clear tendency to group, and they are a poorer fit to the data observed. In our point of view, GGE and AMMI are ideal models for visualising patterns in yield-trial data.

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INTERACTIONS GÉNOTYPE-ENVIRONNEMENT POUR LE RENDEMENT CANNE DANS LES ESSAIS DE CANNE À SUCRE: UNE COMPARAISON DES MODÈLES FRÉQUEMMENT UTILISÉS

Par

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MOTS-CLÉS: Interactions Génotype-Environnement,
Canne à Sucre, Analyses Statistiques, AMMI.

Résumé

L'OBJECTIF de cette étude était d'évaluer les différentes analyses multivariées (analyse des conglomerats, modélisation additive et multiplicative de l'interaction (Modèle AMMI), analyse de régression des environnements (GGE) et analyse des coordonnées principales (PCO)), afin de comparer leurs utilités et leurs efficacité dans l'étude des interactions génotype-environnement (GE) des cultivars de canne à sucre. Les données de rendement en canne de dix-huit cultivars évalués dans quatre sites dans la région Sud-Est de Cuba, étaient utilisées pour cette étude. Le dispositif expérimental adopté pour chaque essai était un bloc randomisé. L'analyse de variance a démontré que les effets génotype, environnement et GE étaient hautement significatifs. L'analyse des conglomerats a distingué les quatre sites, alors que la méthode GGE en a distingué trois. Le

biplot a indiqué que les résultats pour les modèles AMMI et GGE étaient similaires. Un graphique d'éparpillement des points obtenu de l'analyse PCO, a toutefois révélé un accord limité entre les résultats obtenus par les modèles AMMI et ceux du GGE. Les G+GE obtenus par AMMI (50.2 %) et GGE (77.0 %) étaient tout deux plus précis que l'analyse PCO pour quantifier les effets environnement et génotype.

COMPARACIÓN DE MÉTODOS ESTADÍSTICO MULTIVARIADOS EN EL ESTUDIO DE LA INTERACCIÓN GENOTIPO AMBIENTE Y LA ESTABILIDAD FENOTÍPICA EN CAÑA DE AZÚCAR

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PALABRAS CLAVES: Caña de Azúcar,
Análisis Estadístico, AMMI.

Resumen

EL OBJETIVO del presente trabajo fue aplicar diferentes métodos estadísticos multivariados como el análisis de cluster, análisis de coordenadas principales (PCO), modelo de efectos principales aditivos e interacción multiplicativa (AMMI) y análisis de regresión de sitios (GGE), para comparar su utilidad y eficiencia en el estudio de la interacción genotipo-ambiente (IGA) y la estabilidad fenotípica en caña de azúcar. Los datos analizados corresponden a cuatro estudios multiambientales conducidos en la región sur oriental de Cuba, con 15 cultivares, sobre la variable tonelada de caña/ha. Se encontró predominio del efecto ambiental en la varianza total (65.2 %), seguido de la IGA (25.8 %). El análisis de cluster sugirió agrupamiento de las localidades, diferenciándose unas de otras, sin embargo, la agrupación realizada por el modelo GGE generó tres ambientes. Resultados similares mostraron los modelos AMMI y GGE en la descripción del patrón de comportamiento de la IGA y la estabilidad fenotípica de los cultivares, correspondiendo la mayor extracción de la varianza al *biplot* GGE₂ (77.0 %), seguido del *biplot* AMMI₁ (50.2 %). Al comparar los resultados de estos dos modelos con el análisis de PCO, no se encontró total coincidencia en sus resultados, por lo que los dos primeros resultaron más adecuados.