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Análisis del comportamiento productivo de TUC 95-10 a partir de un modelo mixto multiambiental y multiedad

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RESUMEN

En 2011, el Programa de Mejoramiento Genético de la Estación Experimental Agroindustrial Obispo Colombres (Tucumán, R. Argentina) liberó comercialmente la variedad TUC 95-10. El nuevo cultivar fue evaluado en una serie de ensayos multiambientales a través de diferentes edades de corte para valorar su comportamiento productivo en el área cañera de Tucumán comparando, además, su desempeño con respecto al de LCP 85-384, la principal variedad cultivada en la provincia. Los modelos lineales mixtos (MLM), por su flexibilidad, permiten evaluar el desempeño de variedades a partir de un único modelo multiambiental y multiedad ya que consideran la posible presencia de varianzas residuales heterogéneas entre diferentes ambientes y la posible falta de independencia entre observaciones, i.e. correlaciones temporales entre edades de corte y correlaciones espaciales entre parcelas vecinas. El objetivo de este trabajo es evaluar el comportamiento productivo y la calidad industrial de TUC 95-10 con un MLM multiambiental a través de diferentes edades de corte. Los ensayos fueron conducidos en seis localidades durante tres edades de corte (caña planta, soca 1 y soca 2). Se ajustaron diferentes MLM que contemplaron correlaciones (temporales y/o espaciales) y heterocedasticidades para toneladas de caña por hectárea (TCH), rendimiento fabril (RF%) y toneladas de azúcar por hectárea (TAH) en la estructura de (co)varianzas de los errores. Los MLM ajustados proporcionaron un mejor ajuste de los datos que aquellos obtenidos con un modelo ANOVA con supuestos clásicos de varianzas residuales homogéneas e independencia entre observaciones, proveyendo además, estimaciones más precisas (menor error estándar) para las comparaciones estadísticas de los rendimientos esperados. Los resultados de las comparaciones de medias de los mejores modelos mostraron que TUC 95-10 es una variedad de alto potencial productivo con valores de TCH y TAH significativamente superiores a los de LCP 85-384 a través de localidades y edades de corte.

Palabras clave: caña de azúcar, nueva variedad, LCP 85-384, ensayos multiambientales.

ABSTRACT

TUC 95-10 productive performance analysis by a multienvironment and multi-age mixed model

In 2011, the Sugarcane Breeding Program of Estación Experimental Agroindustrial Obispo Colombres (Tucumán, R. Argentina) released TUC 95-10 variety commercially. The new cultivar was evaluated in a series of multienvironment trials across different crop ages to assess its productive performance in Tucumán sugarcane area and compare it with LCP 85-384, the principal variety in the province. On account of their flexibility, linear mixed models (LMM) allow evaluating the suitability of varieties with a multienvironment and multi-age single model, since they consider the existence of heterogeneous residual variances among different environments and the possible lack of independence among observations, i.e temporal correlations among crop ages and spatial correlation among neighboring plots. This work aimed to evaluate TUC 95-10 productive performance and industrial quality with a multienvironment LMM through different crop ages. The trials were conducted at six locations during three crop ages (plant, first and second ratoon). LMM alternatives contemplated correlations (temporal and/or spatial) and heteroscedasticities for tons of cane per hectare (TCH), sugar content (SC%) and ton of sugar per hectare (TSH) in the structure of (co) variances of errors. The adjusted LMM provided a better fit of the data than that obtained with an ANOVA model with classical assumptions of homogeneity of variances and independence of observations, while providing more precise estimates (lower standard error) for statistical comparisons of expected yields. The results from comparisons of means and standard errors of the best models proved that TUC 95-10 is a variety with high yield potential, with TCH and TSH values significantly superior to those of LCP 85-384 across locations and crop ages.

Key words: sugarcane, new cultivar, LCP 85-384, multienvironment trials.

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INTRODUCTION

The development of new varieties is a key process that contributes not only to productivity increase, but also to varietal diversification in sugarcane growing regions. Currently, LCP 85-384 is the principal variety in Tucumán (R. Argentina) (Ostengo *et al*., 2012). Its high cane production and sugar content levels turn this variety into a commercial control difficult to supersede by clones that have been evaluated in the Sugarcane Breeding Program (SCBP) of the Estación Experimental Agroindustrial Obispo Colombres (EEAOC) in recent years. In 2011, the SCBP released TUC 95-10 variety commercially, after evaluating its productive performance in a series of multienvironment trials (METs) across different crop ages and locations in Tucumán sugarcane area, while comparing it with LCP 85-384. In these trials, information is taken advantage of when analyzing all available data simultaneously. Mixed linear models (MLM) enable the global analysis of information obtained in a series multienvironment and multi-age trials, because they consider the presence of heterogeneous residual variances among locations and the possible lack of independence among observations (Schabenberger and Pierce, 2002). For the latter, at least two types of correlations are expected in each trial: temporal correlation among yield data from the same plot across different crop ages, as there are consecutive harvests per genotype, and spatial correlations among data from neighboring plots. Correlated data and the heteroscedasticity condition can be approached with MLM by modelling the variance and covariance structure of errors. The high flexibility of these models allow avoiding classical assumptions of the analysis of variance (ANOVA), i.e. independence among observations and homogeneous residual variances. The correct modelling of the covariance structure of observations enables a better estimation of standard errors used in genotype means comparison, and it is expected to increase experiment efficiency (Keselman *et al*., 1998). To consider temporal correlations among observations recorded at different crop ages, various models are used to define the variance and covariance matrix structure of errors (Núñez-Antón and Zimmerman, 2001). Among these, the first order autoregressive (AR1) and compound symmetry (CS) models are often used, as well as their analogue versions, which provide heterogeneous residual variances among crop ages (AR1H and SCH). Models AR1 and AR1 (H) are based on the assumption that the correlations between pairs of observations decrease exponentially with distance increase over time, while for CS and CSH models, correlation is the same, regardless of the time that elapses among observations. To model spatial correlation among observations from neighboring plots, the anisotropic first order autoregressive model (AR1XAR1) is recommended (Gilmour *et al*., 1997). This model assumes that spatial dependence between two plots decreases exponentially with distance between them, depending on the orientation in which these distances are calculated.

This work aimed to evaluate TUC 95-10 productive performance at different locations in Tucumán sugarcane area along different crop ages, by a multienvironment and multi-age MLM.

MATERIALS AND METHODS

Data

METs were conducted at six sites representing contrasting environments typical of the sugarcane plantation area in Tucumán, R. Argentina. Trials were planted in 2006 according to a randomized complete block design with three replications. Plots of three 10-meter-long rows were taken as the experimental units. TUC 95-10, LCP 85-384 and other 18 genotypes selected were assessed at three crop ages (plant cane, first and second ratoon), taking into account: tons of cane per ha (TCH), sucrose content at the beginning of harvest (SC%) and tons of sugar per ha (TSH) (estimated with TCH and SC% product).

Fitted models

Mixed models with different spatial and temporal correlation structures were compared separately, in order to determine the most suitable structure for each situation and variable in this dataset. Order one autoregressive structure was the most appropriate to consider temporal correlation for both variables (TCH and SC%). In the case of spatial correlation, the anisotropic autoregressive models of order 1 (AR1XAR1) was the best only for TCH, i.e. independent observations are frequent among neighbouring plots for SC% (Ostengo, 2010). On this basis, different multienvironment and multi-age mixed models for TCH, SC% and TSH were adjusted: i) null model: independence among data and homogeneous residual variances among locations are considered, i.e. a classical linear model; ii) heteroscedastic null model: spatial and temporal independence was considered as in the null model, but heterogeneous residual variances among locations were taken into account; iii) spatial model: spatial correlation was included only, using anisotropic autoregressive of order one models (AR1XAR1); iv) temporal model: temporal correlation among data obtained from the same plot along crop ages was included only, using a first order autoregressive heterogeneous model (AR1H); v) three-dimensional model: temporal and spatial correlations were modelled for variance and covariance structure of residuals with a first order autoregressive model in three dimensions, where dimensions as determined by rows and columns to position the plot were associated with spatial correlation, while crop age dimension was associated with temporal correlation. In the last three models, the possible heterogeneity of residual variances among locations was also contemplated. For all models, the effects of variety, crop age and their interaction were taken to be fixed, whereas the effects of location, block within location and genotype per location, location per crop age, and genotype per location per crop age interactions were considered as random.

Models were adjusted using PROC MIXED, SAS, 9.1. Version (SAS Institute, 2003). Model comparison was based on Akaike information criterion (AIC). Models with lower AIC values were superior regarding adjustment. Additionally, the residual maximum likelihood ratio test (LRT) was used for evaluation.

A Fisher's LSD test (significance level of 5%) was performed with the mean values and standard errors adjusted for the best model for each variable (TCH, SC% and TSH), in order to compare TUC 95-10 and LCP 85 - 384 performances across locations and crop ages for each crop age separately, as well as crop age performance for each variety.

RESULTS

Model comparison

Table 1 displays AIC and (-2 Log) likelihood values used in the residual maximum likelihood ratio test (LRT) to evaluate the different models adjusted to analyze multienvironment and multi-age sugarcane data. According to these values, the model which considered temporal and spatial correlations by means of a first order autoregressive model in three dimensions, as well as heterogeneous residual variances among locations (three-dimensional model) showed the best adjustment for TCH and TSH analysis. Concerning SC%, the model which only includes temporal correlation with a heterogeneous first order autoregressive model, and which also considers heteroscedasticity in residual variances among locations, was the best.

The purpose of using a better fit model is to reduce experimental error for yield estimation and comparison. In the adjusted models, the best fit is also reflected by the decrease in standard errors of the difference between means, used when comparing varieties through ages, varieties for each age, and ages for each variety with respect to the null model for the three variables analyzed (Table 2). This implies that the trial can be conducted more efficiently with the selected models.

Productive performance analysis

Mean comparison results obtained with a multienvironment and multi-age mixed model showed that TUC 95-10 was superior to LCP 85-384 in TCH and TSH, with statistically significant differences across locations and crop ages. With respect to sugar content (SC%), TUC 95-10 yielded less than LCP 85-384. However, the difference recorded across locations and crop ages between these two cultivars was not statistically significant (Table 3). Table 4 shows the comparison between TUC 95-10 and LCP 85-384 in relation to TCH, SC% and TSH values, and the statistical significance for each crop age (plant cane and first and second ratoon). As for TCH and TSH, TUC 95-10 was superior than LCP 85-384 at all crop ages. In the case of TCH, differences were statistically significant in all cases,

Table 1. Akaike criteria (AIC) and (-2 log) likelihood values (-2L) of five multienvironment and multi-age mixed models adjusted for tons of cane per hectare (TCH), sugar content (SC%) and tons of sugar per hectare (TSH) in sugarcane variety trials.

Model†	*P* ††	TCH		SC%		TSH	
		AIC	-2 *L*	AIC	-2 *L*	AIC	-2 *L*
Null model	6	8065.1	8053.1	2746.9	2736.9	3631.8	3619.8
Heteroscedastic null model	11	8036.1	8014.1	2738.4	2718.4	3598.0	3576.0
Spatial model	23	7930.0	7884.0	2736.0	2692.0	3570.8	3524.8
Temporal model	29	7942.0	7884.0	<u>2722.7</u>	2668.7*	3567.3	3509.3
Three-dimensional model	29	<u>7905.4</u>	7847.4*	2728.7	2680.7	<u>3554.3</u>	3496.3*

† Multienvironment and multi-age mixed models.
†† P = number of model parameters.
Underlined values indicate minimum AIC (best model).
**Better adjustments according to the LRT, at a 5% significance level.*

Table 2. Standard error average values of the difference between two means of: (1) varieties through crop ages, (2) varieties for each crop age and (3) crop ages for each variety, obtained from two mixed models for TCH, SC% and TSH.

Model†	TCH			SC%			TSH		
	1	2	3	1	2	3	1	2	3
Null model	3.62	4.74	7.06	0.194	0.324	0.584	0.367	0.523	0.750
Temporal model				0.182	0.301	0.570			
Three-dimensional model	3.27	4.32	6.75				0.344	0.495	0.725

† Multienvironment and multi-age mixed models.

while in the case of TSH, this only applied to plant cane and second ratoon. Concerning SC%, TUC 95-10 was only superior at plant cane age, but the differences between these genotypes were not statistically significant at any crop age. Mean comparisons among crop ages for each variety are displayed in Table 5. It is observed that for TUC 95-10 the highest TCH and TSH values were recorded at first ratoon, and the lowest at plant cane. As regards TCH, statistically significant differences were registered among all crop ages, while TSH differences were statistically significant between plant cane and ratoon ages. Sugar content (SC%) showed no significant differences among crop ages.

CONCLUSIONS

Mixed linear models enable the adjustment of multi-environment and multi-age models with temporal and spatial correlations. Better fits and more efficient analyses are thus attained with respect to classical models. For TCH and TSH, the best alternative was the adjustment of the three-dimensional autoregressive model of order 1, with spatial correlations at row and column levels of plot arrangement, temporal correlation among data from successive harvests, and heteroscedasticity through locations. For SC%, the best alternative was the heteroscedastic autoregressive model of order 1, which accounts for temporal correlations only. These models offered more precise estimates (lower standard errors) of expected yield.

The results from comparisons of means and standard errors of the best models proved that TUC 95-10 is a variety with high yield potential, with TCH and TSH values significantly superior to those of LCP 85-384 across locations and crop ages.

Table 3. TUC 95-10 and LCP 85-384 mean comparisons across locations and crop ages for TCH, SC% and TSH. Statistical significance according to Fisher's LSD test (5%)†.

TCH			SC%			TSH		
TUC 95-10	91.0	a	LCP 85-384	10.75	a	TUC 95-10	9.69	a
LCP 85-384	78.8	b	TUC 95-10	10.64	a	LCP 85-384	8.48	b

Different letters indicate statistically significant differences (p<0.05).
† Test performed with mean and standard error values obtained from the best fit model as selected for each variable.

Table 4. TUC 95-10 and LCP 85-384 mean comparisons across locations for each crop age for TCH, SC% and TSH values. Statistical significance according to Fisher's LSD test (5%)†.

	Plant cane			First ratoon			Second ratoon		
TCH	TUC 95-10	74.5	a	TUC 95-10	107.3	a	TUC 95-10	91.2	a
	LCP 85-384	62.5	b	LCP 85-384	96.9	b	LCP 85-384	77.1	b
SC%	TUC 95-10	10.61	a	LCP 85-384	10.59	a	LCP 85-384	11.26	a
	LCP 85-384	10.39	a	TUC 95-10	10.32	a	TUC 95-10	10.99	a
TSH	TUC 95-10	7.91	a	TUC 95-10	11.16	a	TUC 95-10	9.99	a
	LCP 85-384	6.54	b	LCP 85-384	10.40	a	LCP 85-384	8.50	b

Different letters indicate statistically significant differences (p<0.05).
† Test performed with mean and standard error values obtained from the best fit model as selected for each variable.

Table 5. Crop age mean comparisons across locations for each variety (TUC 95-10 and LCP 85-384) for TCH, SC% and TSH. Statistical significance according to Fisher's LSD test (5%)†.

	TCH			SC%			TSH		
TUC 95-10	First ratoon	107.3	a	Second ratoon	10.99	a	First ratoon	11.16	a
	Second ratoon	91.2	b	Plant cane	10.61	a	Second ratoon	9.99	a
	Plant cane	74.5	c	First ratonn	10.32	a	Plant cane	7.91	b
LCP 85-384	First ratoon	96.9	a	Second ratoon	11.26	a	First ratoon	10.40	a
	Second ratoon	77.1	b	First ratoon	10.59	a	Second ratoon	8.50	a
	Plant cane	62.5	c	Plant cane	10.39	a	Plant cane	6.54	b

Different letters indicate statistically significant differences (p<0.05).
† Test performed with mean and standard error values obtained from the best fit model as selected for each variable.

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