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Energy traits in three sugarcane cultivars in Tucumán, Argentina

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ABSTRACT

Bagasse (stalk fibre) and agricultural harvest residues (AHR) obtained from sugarcane are considered energy sources that can contribute to reduce the use of non-renewable fuels. The purpose of this work was to characterize the main sugarcane cultivars grown in Tucumán according to the yield of fibre and AHR and their energetic quality components for use as fuel in steam boilers. Three sugarcane cultivars (Tuc 95-10, TucCP 77-42 and LCP 85-384) were evaluated in four trials distributed throughout the sugarcane growing area of Tucumán. The trials were planted in a randomised complete-block design with three repetitions. Samples of 15 stalks with tops and leaves were taken from each plot to determine fibre content of the stalks (%) and the AHR proportion (%) in order to estimate the yields of AHR per hectare (TAHR) and fibre (TFH). Energy parameters that determine the AHR quality were analysed separately for tops and leaves and included ash (As%), fixed carbon (FC%), volatile solids (VS%) and higher calorific value (HCV). For TAHR, there were no significant differences among cultivars. However, Tuc 95-10 and TucCP 77-42 showed significantly higher values of TFH than LCP 85-384. Of the energy parameters of AHR, there were statistically significant differences among varieties in As% (leaves and tops), HCV (top) and FC% (leaves). Tuc 95-10 showed the lowest values of As% and highest values of FC% and HCV, which implies a higher AHR quality than the other cultivars. The results of this study show the importance of characterizing sugarcane clones for different traits in an energy crop context.

Key words: Agricultural harvest residue, bagasse, varieties, calorific value, cogeneration.

RESUMEN

EVALUACIÓN DE COMPONENTES ENERGÉTICOS EN TRES VARIEDADES DE CAÑA DE AZÚCAR EN TUCUMÁN, ARGENTINA

El bagazo (fibra del tallo) y el residuo agrícola de cosecha (RAC) obtenidos de la caña de azúcar son considerados fuentes de energía que pueden contribuir a disminuir el uso de combustibles no renovables. El propósito de este trabajo fue caracterizar las principales variedades de caña de azúcar cultivadas en Tucumán de acuerdo al rendimiento en fibra (bagazo) y RAC y a la calidad de este último para ser utilizadas como combustible en calderas de vapor. Tres variedades de caña de azúcar (Tuc 95-10, TucCP 77-42 y LCP 85-384) se evaluaron en ensayos realizados en cuatro localidades de Tucumán. Se tomaron muestras de 15 tallos con hojas y despuntes de cada parcela para determinar el contenido de fibra (%) del tallo y la proporción de RAC (%) para estimar las toneladas por hectárea de RAC (TRACH) y fibra (TFH). Los parámetros de eficiencia energética que determinan la calidad del RAC se analizaron por separado para despuntes y hojas. Se realizaron las siguientes determinaciones: ceniza (%), carbono fijo (%), sólidos volátiles (%) y poder calorífico superior (PCS). Para TRACH, no hubo diferencias significativas entre las variedades. Sin embargo, Tuc 95-10 y TucCP 77-42 mostraron valores más altos de TFH que LCP 85-384 con diferencias estadísticamente significativas. Con respecto a los parámetros de eficiencia energética del RAC, se registraron diferencias estadísticamente significativas entre las variedades en cenizas (hojas y despuntes), PCS (despuntes) y carbono fijo (hojas). En estos parámetros, Tuc 95-10 mostró los valores más bajos de ceniza y los valores más altos de carbono fijo y PCR, lo que implica una mayor calidad de RAC que las otras variedades. Los resultados de este estudio muestran la importancia de caracterizar los genotipos de caña de azúcar con respecto a características asociadas a la calidad energética, en un contexto actual en el que la caña de azúcar se considera un cultivo energético.

Palabras clave: Residuo agrícola de cosecha (RAC), poder calorífico, variedades, bagazo, fibra.

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INTRODUCTION

Sugarcane is becoming an increasingly important energy crop in many areas of the world. The agricultural harvest residue (AHR) left after green-cane harvesting and the bagasse (stalk fibre) resulting from the milling can contribute to reductions in the use of non-renewable fuels since they can be used as fuels in steam boilers (Ripoli *et al*. 2000). AHR comprises dry leaves, green leaves, immature upper internodes and other elements (soil, roots and sand). Differences in chemical composition were found between dry leaves and the top (immature internodes and green leaves) (Franco *et al.* 2013). For this reason, it is recommendable to analyse them separately. The production of AHR is influenced by several factors including cultivar, production levels, crop age, management and harvesting systems and operation (Días Paes and Olivera 2005).

Different parameters determine the energy quality of AHR, for example ash (As%), fixed carbon (FC%), volatile solids (VS%) and higher calorific value (HCV) (Zamora *et al*. 2016). Ash, FC% and VS% influence biomass energy and contribute to the speed of reaction (Mistretta *et al.* 2014). In the case of ash, this has a negative impact on the combustion processes in bagasse boilers (Magasiner and de Kock 1987), whereas the HCV value represents the amount of heat released by complete combustion (Hugot 1964).

In Tucumán (Argentina), about 94% of the sugarcane area is mechanically harvested as green cane (Ostengo et al. 2018). Romero *et al.* (2007) reported production between 7 and 16 t/ha of AHR (dry) in this province across different cultivars. Therefore, the use of AHR is an alternative source to be considered for renewable energy in the steam boilers of mills.

The sugarcane breeding program of Estación Experimental Agroindustrial Obispo Colombres (SCBP-EEAOC) recently released several new cultivars that are being planted in the sugarcane production area in Tucumán (Ostengo *et al.* 2018). Energetic characterization of AHR have been carried out on the main sugarcane cultivar (LCP 85-384) cultivated in Tucumán (Zamora *et al*. 2016; Golato *et al.* 2017), but industry is interested in characterization of the new cultivars released by SCBP-EEAOC.

Here, we characterize the yield of stalk fibre and AHR and their energetic quality components of the main sugarcane cultivars grown in Tucumán for application as renewable fuel sources in steam boilers

MATERIALS AND METHODS

Sugarcane cultivars LCP 85-384, TucCP 77-42 and Tuc 95-10 were evaluated in multi-environment trials planted in four locations in the sugarcane-growing areas of Tucumán (Table 1). Tuc 95-10 was released in 2011 by SCBP-EEAOC (Cuenya *et al.* 2011). Trials in each environment were planted in randomized complete-block designs with three replicates. The plots were three rows each 10 m long.

In the first ratoon, a sample of 15 stalks (with its dry leaves and tops) was taken at random from each plot at the end of the harvest season (September). Samples of leaves and tops were dried separately in an oven (105°C) until constant weight was achieved. The following energy quality parameters were determined on the leaf and top samples: moisture (H%), ash percentage on a dry basis (As%), fixed carbon percentage on a dry basis (FC%), volatile solids percentage on a dry basis (VS%), and higher calorific value on a dry basis (HCV). All the analytical determinations were

Table 1. Location and environmental characteristics of the multi-environment trials.

Location		Average annual rainfall (mm)*	Soil characteristics		
			Texture	Organic material	Drainage
Cevil Pozo	26º51’05”S 65º07’00”W	931	Loamy Franco	Medium to high	Good
Los Quemados	27º13’51”S 65º11’36”W	850	Sandy loam	Medium to low	Kept
Ingas	27º26'47"S 65º21'22"W	650	Sandy loam	Medium to low	Kept
Santa Ana	27º28’36”S 65º40’34”W	1194	Sandy loam	High	Good

*Average data recorded over 1961-1990.

performed according to procedures described in Zamora Rueda *et al.* (2015). In addition, stalk samples, cleaned and correctly topped, were processed in the laboratory to determine cane fibre% according to the methodology described by Diez *et al*. (2000). The AHR dry weight was calculated from the sum of leaves and top dry weights in order to estimate the percentage of AHR (AHR%) considering the weight of the stalk sample.

The experimental plots were manually harvested and weighed to estimate cane yield (t/ha). The AHR yield per hectare (t/ha) was estimated from cane yield and AHR%. Similarly, fibre yield (t/ha) was estimated from cane yield (t/ha) and fibre%.

For each variable a multi-environmental mixed model was adjusted using the Infostat program in interface with the statistical software R, where the cultivar effect was considered as fixed. In this model, possible heterogeneity of the residual variances among locations was also considered. Comparison of means among cultivars was performed across locations using Fisher's LSD test (5%).

RESULTS

Table 2 results show that the values of AHR yield and fibre yield ranged from 9 to 10 t/ha. In the case of AHR, yield (t/ha) no statistically significant differences ($p<0.05$) were detected among cultivars. For fibre yield (t/ha), Tuc 95-10 showed the highest values with statistically significant differences only with LCP 85-384. These results are determined by the high fibre % value of Tuc 95-10. For this variable, the differences seen between Tuc 95-10 and the other two cultivars were statistically significant.

For the energy quality the parameters of AHR (Table 3), there were statistically significant differences among cultivars in both top and leaves for the ash content (ash %). Tuc 95-10 had the lowest ash% value in the AHR components. The differences between the other two cultivars were statistically significant in leaves. In the tops, statistically significant differences were only detected in TucCP 77-42 compared to Tuc 95-10. For FC%, Tuc 95-10 recorded the highest averages values in leaves and tops, with significant differences among cultivars only in leaves. For HCV, Tuc 95-10 was superior to LCP 85-384 and TucCP 77-42 for both components (top and leaves), with a statistically significant difference in tops between Tuc 95-10 and TucCP 77-42. No statistically significant differences ($p<0.05$) were detected among cultivars for VS% and H% in the harvest residues.

DISCUSSION AND CONCLUSIONS

We grew three cultivars of sugarcane in Tucumán and evaluated them in a multi-environmental trial with respect to characteristics associated to the production of

Table 2. Means of three cultivars across locations in Tucuman (Argentina) for variables associated with energy production. Statistical significance according to Fisher's LSD test.

Cultivar	Cane yield (t/ha)	AHR%	Fibre%	Yield of AHR (t/ha)	Yield of fibre (t/ha)
TucCP 77-42	95.9 a	10.60 b	10.42 b	10.2 a	9.99 ab
Tuc 95-10	90.1 ab	10.01 b	11.28 a	9.0 a	10.16 a
LCP 85-384	85.8 b	11.60 a	10.43 b	9.9 a	8.95 b

AHR: agricultural harvest residue. Different letters indicate statistically significant differences ($p<0.05$)

Table 3. Means of three cultivars across locations in Tucuman (Argentina) for variables associated with energy quality in tops and leaves. Statistical significance according to Fisher's LSD test.

Cultivar	Ash (% dry basis)	Fixed carbon % dry basis	Higher calorific value kJ/kg	Volatile solids % dry basis	Moisture %
Tops					
Tuc 95-10	7.98 b	18.74 a	17,496 a	73.28 a	38.65 a
TucCP 77-42	8.83 a	18.49 a	17,280 b	72.70 a	39.73 a
LCP 85-384	8.45 ab	18.65 a	17,407 a	72.91 a	35.87 a
Leaves					
Tuc 95-10	11.34 a	16.96 a	16,705 a	71.66 a	8.57 a
TucCP 77-42	12.16 b	16.70 b	16,578 a	71.39 a	8.33 a
LCP 85-384	11.95 b	16.41 c	16,661 a	71.76 a	8.41 a

Different letters within a column indicate statistically significant differences ($p<0.05$).

energy (AHR yield and fibre yield) and to the energy quality of the AHR (As%, FC%, VS% and HCV). LCP 85-384 is the main cultivar grown in Tucumán, while Tuc 95-10 is a new cultivar released by the SCBP-EEAOC in 2011. For this reason, it is of interest to characterize and compare these cultivars according to different energy traits within the context where sugarcane is considered an important energetic crop. Tuc 95-10 had a higher fibre yield per hectare than LCP 85-384. However, no differences were detected among cultivars for AHR yield whose values ranged from 9 to 10 (t/ha). These values were similar to those obtained by Romero *et al*. (2007).

With regards to energy parameters of AHR, differences among cultivars were found in As% (leaves and tops), HCV (top) and FC% (leaves). In these parameters Tuc 95-10 showed the lowest values of AS% and the highest values of FC% and HCV. These results suggest that the AHR of Tuc 95-10 would have better energy quality than the other cultivars (Magasiner and de Kock 1987). Subsequent studies could confirm the AHR quality of Tuc 95-10.

Other research has been carried out in Tucumán related to the quality of the AHR (Zamora *et al.* 2016; Golato *et al.* 2017). However, those studies were conducted on a single cultivar (LCP 85-384), in a single environment and applying a different AHR sampling methodology (sample taken from the soil after harvesting). In our study, the energy quality was compared among different cultivars (including a new cultivar) in multi-environmental trials where the parameters were assessed separately for leaves and tops.

The results reported here are the first stage of a more extensive analysis, which will include the study of the environmental influence on these energy traits and any genotype-by-environment interaction.

The characterization of cultivars with respect to the level of energy production and energy quality of their AHR components could be a useful tool for a more efficient and sustainable management of the sugarcane industry.

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