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Yield and technological performance of sugarcane cultivars grown under Af climate conditions

Desempenho produtivo e características tecnológicas de cana-de-açúcar plantadas em condições climáticas Af

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Abstract

Sugarcane crops are grown in almost all regions of Brazil, in various types of soil and under the influence of different climate conditions, which results in diverse production environments as climate factors directly influence the yield and technological quality of a sugarcane crop. The present study evaluated the agronomic and technological characteristics of sugarcane cultivars grown in Af climate conditions. The agronomic traits (natural matter production and the number, length, and diameter of stalks) and technological attributes (Brix, purity, Pol, reducing sugars, total reducing sugars, moisture, and fiber content) of three sugarcane cultivars, IACSP93-6006, RB83-5486, and SP79-1011, were determined in a three-year experiment with a randomized block design using four blocks and two repetitions per block. The cultivars IACSP93-6006 and SP79-1011 exhibited superior agronomic traits compared to RB83-5486, showing better adaptation to the soil and climate conditions of the study area. However, the technological attributes, which were below the minimum standard levels required by the sugar and ethanol industry, were not statistically different among the studied cultivars. The abundant rainfall and high temperatures, characteristics of an Af climate, were not favorable for sucrose accumulation in the IACSP93-6006, RB83-5486, and SP79-1011 cultivars. Therefore, despite the high yield, sugarcane intended for industrial purposes should not be grown under Af climate conditions, owing to the insufficient technological parameters.
Key words: Maturation. Precipitation. *Saccharum officinarum*.

Resumo

A cana-de-açúcar é cultivada em quase todas as regiões do Brasil, em vários tipos de solo e sob a influência de diferentes condições climáticas, resultando em diversos ambientes de produção, sendo que fatores climáticos influenciam diretamente na produtividade e na qualidade tecnológica da cana-de-açúcar. Objetivou-se avaliar as características agronômicas e tecnológicas de cultivares de cana-de-açúcar cultivadas em condições climáticas tipo Af. Foram utilizadas três cultivares de cana-de-açúcar: IACSP93-6006, RB83-5486 e SP79-1011. O experimento foi realizado em delineamento em blocos casualizados, com quatro blocos e duas repetições por bloco. Na avaliação agronômica foram determinados a produção de matéria natural, número de colmos, comprimento do colmo e o diâmetro

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do colmo. Quanto aos atributos tecnológicos foram determinados Brix, pureza, Pol, açúcares redutores, açúcares redutores totais, umidade e fibra. Houve diferença para as características agronômicas, produção de matéria natural, número de colmos, comprimento do colmo e diâmetro do colmo, com destaque para as cultivares IACSP93-6006 e SP79-1011, que demonstraram adaptação às condições edafoclimáticas da região. Não houve diferença para os atributos tecnológicos, Pol, Brix, açúcares redutores, pureza, açúcares redutores totais, fibra e umidade, cujos valores ficaram abaixo do padrão mínimo exigido pela indústria de produção de açúcar e álcool, evidenciando que as condições climáticas não foram favoráveis ao acúmulo de sacarose, pois no clima tipo Af a precipitação pluviométrica e temperatura são elevadas. As cultivares apresentaram altas produções por hectare, no entanto, os parâmetros tecnológicos foram insuficientes para serem usados na indústria sucroalcooleira.
Palavras-chave: Maturação. Precipitação. *Saccharum officinarum*.

Introduction

Sugarcane cultivation is experiencing rapid growth throughout Brazil. The planted area has substantially increased to meet the ethanol demand of large economies that are interested in renewable fuels (Brinkman et al., 2018). In recent years, plant breeding programs have contributed to the development of the sugarcane crop in Brazil, by developing new cultivars that have an improved yield and quality (Dal-Bianco et al., 2012).

Sugarcane crops are grown in all regions of Brazil, in various types of soil and under the influence of different climate conditions, which results in diverse production environments (Salgado, Carlucci, Bonacim, Novi, & Pacagnella, 2014). Climate factors directly influence the yield and technological quality of a sugarcane crop (Cardozo & Sentelhas, 2013; Silva, Borges, & Albuquerque, 2014), primarily due to the edaphic-climatic conditions, crop management, and selected variety. Different sugarcane cultivars may have distinct yields and technological attributes, depending upon the production environment (Inman-Bamber, Bonnett, Spillman, Hewitt, & Xu, 2009; Oliveira et al., 2014). Therefore, the crop must be studied in different development/production environments, to decipher the best cultivar and management strategy for each production environment.

Studies concerning the yield and technological attributes of sugarcane have been conducted in different climates, including As (Abreu, Silva, Teodoro, Holanda, & Sampaio, 2013), Aw (Cruz et al., 2010; Rhein et al., 2016), Awi (Caione et al., 2011), Cfa (Schwerz et al., 2017), and Cwa (Macêdo et al., 2012). However, information regarding the behavior of the sugarcane plant under Af climate conditions, which is characterized by abundant rainfall throughout the year and no dry season, is still required.

This study evaluated the agronomic traits and technological attributes of three sugarcane cultivars grown under Af climate conditions.

Materials and Methods

Experimental site

The study was performed at the Animal Reproduction Biotechnology Center (Central de Biotecnologia de Reprodução Animal - CEBRAN), located in the city of Castanhal (65 m altitude; 01°18′S and 47°55′W), state of Pará, Brazil, which has an Af climate, according to the Köppen-Geiger climate classification (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2014). During the experimental period (June 2010 to October 2013), the annual climatological averages were: 3044.2 mm of rainfall, mean temperature of 26.8º, mean minimum temperature of 22.2º, mean maximum temperature of 34.1º, and 80% relative humidity (Figure 1, Table 1).

The sugarcane cultivars studied, IACSP93-6006, RB83-5486, and SP79-101, were donated by the Federal Institute of Education, Science, and Technology of the state of Pará (Instituto Federal de Educação, Ciência e Tecnologia do Pará), campus of Castanhal. These cultivars were chosen for the study as they are commonly grown in the study region.

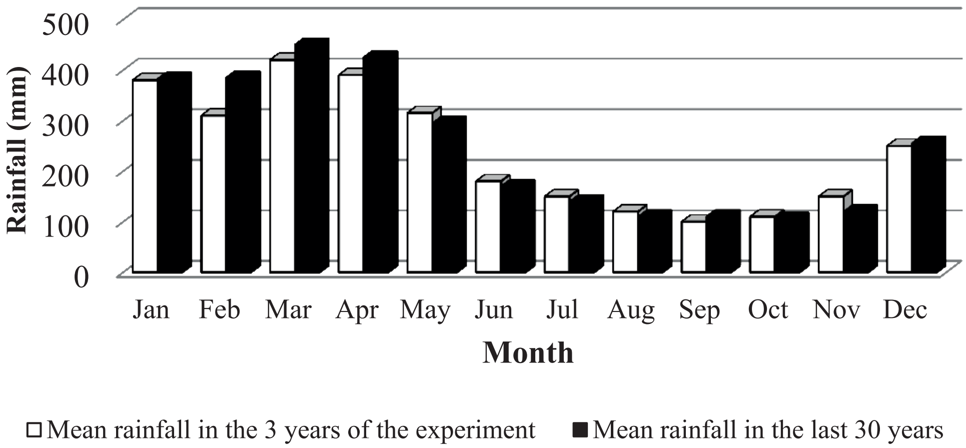

Figure 1. Average rainfall of the last 30 years and during the experimental period (average of three years) in the study area. Source: data provided by the automatic weather station of the National Institute of Meteorology (Instituto Nacional de Meteorologia - INMET), Belém, state of Pará (2014).

Table 1
Mean, maximum, and minimum temperatures over the last 30 years and during the experimental period (average of the three years) in the study area

Months	Mean temperature (º) over the last 30 years			Mean temperature (º) of the experimental period		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Jan.	26.0	31.0	22.7	26.2	34.1	21.8
Feb.	25.8	30.7	22.8	26.1	33.9	22.2
Mar.	25.9	30.7	23.0	26.3	34.3	22.4
Apr.	26.2	31.1	23.1	26.4	33.7	22.2
May	26.5	31.8	23.1	26.7	33.8	22.7
June	26.5	31.9	22.8	26.7	33.7	22.1
July	26.3	32.0	22.4	26.7	33.4	22.2
Aug.	26.7	32.5	22.5	27.1	34.3	22.2
Sept.	26.8	32.7	22.5	27.3	34.8	22.2
Oct.	27.0	32.6	22.4	27.3	34.6	22.0
Nov.	27.1	32.6	22.7	27.4	34.5	22.1
Dec.	26.7	32.1	22.8	27.0	34.1	21.8

Source: data provided by the automatic weather station of the National Institute of Meteorology (Instituto Nacional de Meteorologia - INMET), Belém, state of Pará (2014).

Treatments and design

The treatments consisted of three sugarcane cultivars (IACSP93-6006, RB83-5486, and SP79-101) in an experiment conducted over three years in a completely randomized design with two blocks (spatial and temporal) and eight replicates per treatment (four blocks and two repetitions per block), totaling 24 experimental plots.

The experimental plots consisted of four rows (4 m in length), with 1 m spacings between the rows. The marginal rows and a 1 m length at the ends of the central rows were not considered in the crop evaluation, so only two linear meters of the two central rows from each plot were considered as the usable area. Soil chemical analyses were performed before the beginning of the experiment and after each harvest (Table 2).

Table 2
Analysis of the soil of the experimental area during the three years of study

Year	pH	OM	P	$H^+ + Al^{+3}$	Al^{+3}	Ca^{+2}	Mg^{+2}	K^+	SB	CEC	V
		g/kg	mg/dm³	---------------------mmolc/dm³-------------------------							%
Year I	5.1	35.0	18.0	4.1	0.0	1.2	0.4	0.6	1.7	5.7	29.0
Year II	6.0	19.5	25.0	3.5	0.1	3.0	0.8	2.9	3.9	7.3	53.2
Year III	6.7	24.0	26.0	3.6	0.1	2.2	0.5	3.1	2.8	6.4	43.0

pH - hydrogen potential; OM - organic matter; P - phosphorus; $H^+ + Al^{+3}$ - potential acidity; Al^{+3} - aluminum; Ca^{+2} - calcium; Mg^{+2} - magnesium; K^+ - potassium; SB - sum of bases; CEC - cation exchange capacity; and V% - percentage of base saturation.

Dolomitic limestone (2 t ha^{-1}) was applied 60 days before planting. During the tillage two harrowings were performed, the first using a disc harrow followed by a leveling harrow. Subsequently, furrows were opened 1 m apart, at a depth of 25 cm. In June 2010, the stalks were manually planted and distributed in the furrows, such that the basal portion of a seedling was in contact with the apical portion of the subsequent one, at a density of 15-18 buds per linear meter and subsequently sectioned.

The amount of fertilizer used during planting, for the first and second ratoons, was calculated from the results of the soil analyses. To achieve a yield of 100 t ha^{-1}, 50, 120, and 120 kg ha^{-1} of N; 140, 70, and 40 kg ha^{-1} of P_2O_5; and 140, 150, and 160 kg ha^{-1} of K_2O were directly applied in the furrows at the time of planting, and by broadcasting in the other years. Dolomitic limestone (1 t ha^{-1}; PRNT 90%) was applied during the second ratoon crop.

Weed control was accomplished through herbicide applications. For pre-emergence, the 3-(3,4-dichlorophenyl)-1,1-dimethylurea (500 g L^{-1}) herbicide was applied at 3 L ha^{-1} after planting and at each harvest. Sixty days after planting, the 3-chloro-5-(4,6-dimethoxypyrimidin-2-ylcarbamoylsulfamoyl)-1-methylpyrazole-4 carboxylic acid (750 g kg^{-1}) herbicide was applied to control the purple nutsedge (*Cyperus rotundus*), at a dose of 17.1 g ha^{-1}. After 90 days, the N-(phosphonomethyl) glycine (480 g L^{-1}) herbicide was applied at a dose of 3.2 L ha^{-1}, whilst the rows were protected with tarpaulin to avoid herbicide contact with the sugarcane plants. The herbicides were manually applied using a backpack sprayer, and the operator was properly dressed in personal protective equipment. The crops were manually harvested during all crop cycles, when the plants were approximately 13 months old.

Measurements

The agronomic traits were evaluated following the methods described by Miranda et al. (2015). The natural matter production (NMP), in t ha^{-1}, was measured after the harvesting and weighing of all plants from the usable area of the sugarcane bed (4 linear meters). To quantify the NMP, the whole plant was used. The number of stalks per linear meter (NStalk) was determined by counting all the stalks in the sugarcane bed of the usable area and dividing that number by the total length of the planting line. The stalk length (StalkL) was calculated considering the distance (m) from the base to the upper end of the plant.

A caliper was used to measure the diameter of the central internode (Stalk diameter - StalkD in cm). The StalkL and StalkD were both determined considering the same 20 stalks that were randomly selected among those harvested from the sugarcane bed of the usable area.

The technological parameters were analyzed at the Technology Laboratory of the Pará Pastoril e Agrícola S.A. - PAGRISA mill, located in the city of Ulianópolis, state of Pará. The Brix, purity, Pol, reducing sugars (RS), total reducing sugars (TRS), moisture, and fiber content were determined.

Statistical Analyses

The means were analyzed using an analysis of variance and compared with the Tukey's test at a 5% probability. To determine whether there were differences in the climate data during the experimental period, a non-parametric Kolmogorov-Smirnov test was performed at the 5% probability level.

Results and Discussion

Owing to the similar topography and soil of the experimental area, which was only 600 m^2, and the fact that there were no differences in the rainfall or minimum temperatures during the experimental period, the results are discussed considering only the treatment effect (cultivars). Therefore, the blocks in the design were only considered to decrease the variance of the treatments and thus render the test more sensitive. The agronomical traits were statistically different among the cultivars ($p < 0.05$), whilst the technological attributes were not.

All the cultivars presented a high NMP under the studied climate conditions; and the cultivars IACSP93-6006 and SP79-1011 were superior to RB83-5486. The NMP values found in this study were higher than those reported in studies performed under other climate conditions. The NMP of sugarcane crops grown under the Aw and Am climate conditions ranged from 58.8 to 136.9 t ha^{-1} and 116.79 to 192.91 t ha^{-1}, respectively (Capone, Lui, Silva, Dias, & Melo, 2011; Oliveira et al., 2011). Macêdo et al. (2012) evaluated two sugarcane cultivars in a Cwa climate under irrigated and rainfed conditions during the drought period, where the highest NMP (103.0 t ha^{-1}) was observed in the irrigated cultivation. In the same study, the RB83-5486 cultivar had an NMP of 84.0 t ha^{-1} under irrigated conditions (Macêdo et al., 2012), while in the present study, its NMP was 250.16 t ha^{-1}.

In this study, the cultivar SP79-1011 had the highest NStalk among those evaluated (Table 3). The NStalk is positively correlated with the yield of sugarcane fields, meaning that a high Nstalk is an important agronomic trait. The NStalk is influenced by high temperatures (25º to 30º) and solar radiation, which favor tillering and tiller senescence (Waclawovsky, Sato, Lembke, Moore, & Souza, 2010). Thus, sugarcane crops grown under the environmental conditions evaluated in the present study tend to have a high NStalk, due to the high solar radiation and high mean temperature (26.8º) found in the low-latitude region (01°18′S). The NStalk values observed in the present study were similar to those reported by Oliveira et al. (2011), who found 13 stalks per linear meter for sugarcane cultivars grown in an Aw climate.

Table 3
Agronomic traits of sugarcane cultivars grown in an Af climate, average of three cuts

Variables	IACSP93-6006	RB83-5486	SP79-1011	SEM
NMP (tMN ha^{-1})	339.02a	250.16b	321.52a	22.47
NStalk (number linear m^{-1})	13.29a	12.05a	15.28b	0.47
StalkL (m)	3.77a	3.73a	3.49b	0.05
StalkD (cm)	2.47a	2.28b	2.35b	0.02

NMP - natural matter production; NStalk - number of stalks; StalkL - stalk length; StalkD - stalk diameter; and SEM - standard error of mean.

The cultivars IACSP93-6006 and RB83-5486 had a higher StalkL than SP79-1011 ($p < 0.05$). Shigaki et al. (2004) evaluated different sugarcane cultivars under drought conditions and found that a high humidity in the soil is the main factor responsible for greater elongation between internodes, which explains the high StalkL values observed in the present study. Capone et al. (2011) reported a StalkL ranging from 3.13 to 4.13 m in sugarcane grown under Am climate conditions, which are similar to those observed in the present study. However, the values reported by Capone et al. (2011) were observed after irrigation during the drought period. The cultivar IACSP93-6006 had a higher StalkD than the other cultivars.

According to Ferreira et al. (2017), morphological characteristics can be used to evaluate the development and adaptation of a crop to a certain environment. Considering the results previously described, we can state that all three cultivars evaluated in this study are adapted to Af climate conditions.

Although the agronomic traits were positively affected by the climate conditions, the technological attributes (Table 4) were negatively affected, i.e., the sucrose accumulation was inadequate compared to that described in other studies conducted in different climate conditions (Oliveira et al., 2012; Macêdo et al., 2012).

Table 4
Technological attributes of sugarcane cultivars grown in an Af climate, presented as the average of three cuts

Variables	IACSP93-6006	RB83-5486	SP79-1011	Standard*	SEM
Brix (% juice)	15.08	14.91	14.78	>18	0.11
Pol (% juice)	11.61	11.11	11.29	>14	0.13
Purity (% juice)	76.96	74.82	76.56	>85	0.74
RS (% juice)	1.68	1.64	1.65	<0.8	0.03
TRS (% juice)	14.54	14.43	14.31	>15	0.12
Moisture (% sugarcane)	71.72	71.19	71.80	<70	0.23
Fiber (% sugarcane)	13.18	13.65	13.52	11 - 13	0.21

Brix - content of soluble solids of sugarcane juice; Pol - sucrose content of sugarcane juice; RS - reducing sugars; TRS - total reducing sugars; *According to Ripoli and Ripoli (2004); and SEM - standard error of mean.

The technological attributes determine the quality of the raw material for the sugar and ethanol industry and will define the sugar and ethanol yields. Comparing the technological attributes observed in the three cultivars evaluated in this study with the standard values for sugarcane processing in the sugar and ethanol industry, we verified that the sucrose accumulation in plants grown under Af climate conditions was inadequate. Thus, sugarcane cultivation in an Af climate for use in the sugar and ethanol industry is not recommended, which shows that climate factors directly affect the behavior of the crop.

The large volume of rainfall during the growing season prolonged the vegetative period, slowing the maturation and, consequently, reduced the sucrose concentration in the stalk. During the entire experimental period, the average total rainfall was 3044.18 mm, with September the month with the lowest rainfall (106.6 mm), demonstrating that the cultivars did not suffer from water stress at any time during the experiment.

Two environmental factors act independently during sugarcane maturation, low temperatures, and water deficit. If the plant does not experience these stress conditions, it will vegetate and not accumulate sucrose (Hoffmann, 2010). A reduced temperature has a direct effect on the nutrient absorption, reducing the vegetative growth, causing the majority of the produced sugars to be stored (Scarpari & Beauclair, 2009). Another factor that stimulates the accumulation of sucrose in sugarcane is the stress caused by water deficit, which reduces the soil humidity and, consequently, decreases the water content in the plant tissues (dehydration forces the conversion of the reducing sugars in sucrose). Cardozo, Sentelhas, Panosso and Ferraudo (2014) verified that the water content in the sugarcane stalk is inversely proportional to the sucrose content, and good water availability slows down the maturation process.

Oliveira et al. (2012) reported that a high humidity in the soil affects the sucrose accumulation of the plant, which is positively correlated with moisture and reducing sugars and negatively associated with sucrose. This situation was observed in the present study, in which the cultivars had high values of moisture and reducing sugars and an unsatisfactory sucrose accumulation, ratified by the low values of the Brix, Pol, ART, and purity parameters.

In an Am climate, Oliveira et al. (2012) obtained an average of 24.31%, 20.98%, 18.34%, and 85.38% for the parameters of Brix, Pol, ART, and purity, respectively. The Brix for the cultivar RB83-5486, grown in an Aw climate, was 24.17% (Capone et al., 2011). On the other hand, Dantas, Figueredo, Farias, Azevedo and Azevedo (2006) reported Brix and Pol values of 19.08% and 17.75%, respectively, for the cultivar SP79-1011 grown in an Aw climate. In the Am and Aw climate conditions there are drought periods, and the reduced rainfall results in a water deficit, which contributes to sugarcane maturation.

The fiber content of the cultivars is above the standard levels of the sugar and ethanol industry. Fiber is important for plant support, to avoid tipping. Under Af climate conditions, the cultivars had a high fiber content, but tipping still occurred, which prevented mechanic harvest. The values for the fiber content were higher than those observed by Oliveira et al. (2012) under Aw climate conditions, which ranged from 11.03% to 12.51%. According to Oliveira et al. (2012), the longer the vegetative period lasts, the higher the fiber content.

Conclusion

The IACSP93-6006, RB83-5486, and SP79-1011 cultivars had high yields per hectare. However, the technological attributes were inadequate for the sugar and ethanol industry. Therefore, sugarcane intended for industrial purposes should not be grown under Af climate conditions.

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