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Edaphoclimatic and genetic influence on soil water availability factor for different sugarcane varieties

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Abstract

Sugarcane is grown in all Brazilian states; however, water stress is the main limiting factor of crop productivity in most farming environments (FEN). Thus, the objective was to verify the water availability factor in the soil (factor f) between FEN and sugarcane varieties. The assay was conducted in the Central and Southern Regions of Goiano, in Red Latosol with distinct physical-water attributes among the FEN. Three varieties of sugarcane - Vs (CTC4, RB966928 and RB867515), five factor f (0.41; 0.46; 0.66; 0.72; and 0.84), and two cultivation environments (Goianésia and Quirinópolis), in a sugarcane plant cycle (2019/2020) were evaluated. The randomized block design was used in a factorial scheme (3x5x2), with four replications. The physiological variables (liquid photosynthesis - Lp, stomatic conductance - Sc, leaf transpiration - Lt and temperature gradient leaf atmosphere - TGLA), ton of stalk per hectare - TSH, total recoverable sugars - TRS, ton of POL per hectare - TPH, sugar and alcohol. They were submitted to the F test, mean comparison and quadratic regression. The Sc, Lt and Lp differed statistically between themselves and between FEN, when submitted to the same factor f and Vs, reflecting in penalty in TSH and POL, TRS , sugar and alcohol. Indicating that factor f varies, both between FEN and between Vs. CTC4 has higher productive potential than other Vs; however, more sensitive to soil water depletion (lower factor f), reflecting lower Lp and TSH in both FEN. The factors of soil water availability to avoid water stress were 0.5, 0.49 and 0.47 for RB867515, RB966928 and CTC4, respectively, in Quirinópolis; and 0.47, 0.47 and 0.44 for RB867515, RB966928 and CTC4, respectively, in Goianésia.

Keywords*: Saccharum officinarum*; water depletion in the soil; water stress index; evapotranspiration.
Abbrevaitions: FEN_farming environments; factor f_water availability factor in the soil; Vs_varieties of sugarcane; Lp_liquid photosynthesis; Sc_stomatic conductance; Lt_leaf transpiration; TGLA_temperature gradient leaf atmosphere; TSH_ ton of stalk per hectare; TRS_total recoverable sugars; TPH_ton of POL per hectare.

Introduction

Brazil is the world's largest producer of sugarcane, with 10.04 million hectares (ha), productivity of 76.13 Mg ha^{-1} of stem, 39.35 million tons of sugar and 2.70 billion liters of alcohol. In which the state of Goiás is the second largest national producer with an area of 11.33% and 79.80 Mg ha^{-1}, losing, in an area to São Paulo (50.64% of the area and 79.63 Mg ha^{-1}), and in productivity for Minas Gerais (9.80% of the area and 83.72 Mg ha^{-1}), in the 2019/2020 crop (Conab 2020).
However, in the main sugarcane producing regions, sugarcane plantations suffer a severe penalty for water deficit, which is affected by prolonged periods of drought and droughtaround six months - autumn and winter (Marin and Nassif, 2013; Angels et al., 2020b). However, water stress can be avoided or mitigated by the adoption of soil and water conservation practices, with emphasis on variety selection and management practices, which minimize the effects of water stress on culture.
Faced with water restriction in the dry season and poor distribution in the rainy season in Goiás (Marin and Nassif 2013; Anjos et al., 2020a) there is a need for supply and rational management of water for perennial and semi-perennial cycle crops. In this scenario, the soil water availability factor can be used, either in soil water balance, irrigation management or accelerate sucrose production or deepening of root system as a function of controlled water stress (Doorenbos and Kassam 1994; Bernardo et al., 2009; Trentin et al., 2011; Vieira et al., 2015; Anjos et al., 2017).
In the edaphoclimatic conditions of the Cerrado of Goiano, it is common for sugarcane producers to use the factor f equal to 0.70, that is, soil moisture is replaced when 70% of the available water capacity in the soil is exhausted, without

distinction of variety and environment of cultivation of guacane sugarcane. Others use factor f based on the recommendations of Doorenbos and Kassam (1979), which determined factor f as a function of groups of crop species according to sensitivity to water deficit and maximum evapotranspiration that occurred in the cultivation cycle, without distinction between varieties and phenological phases of the crop. Currently, Vieira et al. (2015) recommends factor f between 0.5 and 0.70 for RB867515 cultivated under edaphoclimatic conditions of Jaíba - MG. It is verified, therefore, that due to these contrasts of factor f values for sugarcane, there is a need to investigate the factor f for each variety under different edaphoclimatic conditions of cultivation. Physiological changes in response to water stress are the most sensitive variables of plants, reflected in their growth and productivity. Machado et al. (2009) observed significant differences in stomatic conductance, leaf transpiration and liquid photosynthesis between and within the same sugarcane varieties when cultivated under different soil moisture conditions, with reflection on biometrics and dry mass of stem. Anjos et al. (2020b) observed that sugarcane varieties vary in their efficiency in water use in biomass production and industrial yield. Therefore, identifying the extent to which soil water depletion can be achieved without impairing crop growth and development at the variety level enables predicting, simulating and handling the water balance in sugarcane trees and its reflection on their productivity. Thus, the present study aimed to verify the water availability factor in the soil (factor f), between FEN and sugarcane varieties.

Results and Discussion

Climatic conditions of study sites

Fig 1 shows the meteorological elements of the two study environments during the evaluation and conduction period of the experiment at the field level, in addition to the water balance (excess and deficit).

It was found that, relatively, the high wind speed and solar radiation incident on the earth's surface, associated with low relative humidity and the average monthly air temperature (Figs 1a, 1c), made the FEN of Quirinópolis with higher evapotranspirative demand (ETo) than of Goianésia (Fig 1d). However, it was in Goianésia that there was precipitation of 81 mm in June, with this, storage of water in the soil at higher levels during the dry period of the year (Figs 1b and 1d).

It was observed that although in Goianésia there was precipitation (1686 mm) higher than ETo (1630 mm), its irregular distribution provided soil water deficit throughout the dry season (May to September), totaling 408 mm (Fig 1b). Similar results occurred in Quirinópolis, however, with greater intensity, 532 mm, due to the greater irregularity of rainfall and atmospheric demand, during the dry season that coincided with the phase of full and final growth of sugarcane skinberry (90 to 239 days after planting), moments of higher water demand and sensitivity to water deficit by culture (Cardozo and Sentelhas 2013; Angels et al., 2017; Caetano and Casaroli 2017; Casaroli et al., 2019).

In general, Fig 1 verifies that the oscillation of soil moisture and weather conditions during the crop cycle makes it possible to identify the moment that the crop enters water stress as a function of factor f, even if the crop is dry.

With the information of soil conditions and the meteorology of the cultivation sites of sugarcane varieties, and the monitoring of the indicators physiology of water stress associated with the variation of soil water depletion, concomitantly, one can define the exact moment that the plant enters into water stress. Thus, quantify the reflection in its productivity and industrial yield, even if the crop is in a condition of landand.

Effect of the cultivation environment on factor f and its reflection on the physiology of varieties

It was observed that the temperature gradient leaf atmosphere (TGLA), the RB867515, RB966928 and the CTC4, despite presenting similar behaviors, a significant difference ($p \leq 0.05$) was observed between the FEN in at least two of the f-factors evaluated (Figs 2a, 2b and 2c). The similarity of the TGLA of sugarcane varieties in response to the factor f within each FEN is due to the function of temperature in enzymatic performances and they are common for all varieties of sugarcane under study, such as Rubisco and PEPcase (Taiz and Zeiger 2013), and thus the differences in temperature and evapotranspiration between the environments are the main precursor factors of this result, in view, that the dissipation of thermal energy by the plant is through transpiration (Machado et al., 2009; Zarco-Tejada et al., 2012; Taiz and Zeiger 2013).

As for stomatic conductance (Sc) it was observed that the different environments affected the varieties in different ways (Figs 2f, 2e and 2f). Ctc4 and RB966928 were the most sensitive to the variation of the cultivation environment within the same factor f, when compared to RB867515. This fact was verified by the greater number of significant differences between the environments within the same factor f for the varieties CTC4 and RB966928.

Leaf transpiration (Lt) showed interference of FEN within the same factor f in a similar way in all varieties of sugarcane (Figs 2g, 2h and 2i). However, there was a tendency for the environment to interfere significantly only in the smallest factors f (0.41 to 0.66). This indicates that extreme conditions of water restrictions ($f \leq 0.66$), the varieties suffer the same penalties in Lt, regardless of FEN.

As for liquid photosynthesis (Lp) it was observed that the different environments affected the varieties in different ways. CTC4 and RB966928 were the most sensitive to the variation of the environment within the same factor f, when contrasted with RB867515 (Figs 2j, 2l and 2m). This fact was observed by the greater number of significant differences between the environments within the same factor f having been observed in the varieties CTC4 and RB966928.

Fig 2 showed that physiological variables differed statistically between cultivation environments within the same factor f and sugarcane variety. Thus, it is necessary to define a factor f for each FEN of sugarcane variety cultivation, and not a single one for all, as shown in Fig 2 and as reported by Doorenbos and Kassan (1979).

Table 1 shows that the coefficients of equations describing physiological changes as a function of factor f are higher in CTC4, followed by RB966928, independently, of the variable evaluated or FEN. These results classify RB867515 as the most tolerant to water stress, and CTC4 as the most sensitive. Still evaluating the coefficients of the Sc, Lt and Lp models of the two crop environments, it was evident that although Goianésia has higher productive potential of photoassimilates, observed by higher Rs and higher soil moisture during the dry season, it suffers greater penalty in its production, when compared, on the same factor f, with

Table 1. Mathematical-physiological model for prediction of penalty in the physiological variables promoted by the water availability factor in the soil, an indicator factor of the moment when the losses by water deficit (factor f) of three varieties of sugarcane cultivated in two mesoregions began: Centro Goiano and Sul Goiano. Goiás, Brazil, 2019/2020 crop.

Goianésia					Quirinópolis			
Variety	Equation	R^2	Factor f	CV %	Equation	R^2	Factor f	CV %
RB 867515	$TGLA = 36.212f^2 - 36.02f + 10.209$	0.87	0.50	33.65	$TGLA = 46.847f^2 - 49.091f + 14.212$	0.79	0.52	21.33
	$Sc = -1.2992f^2 + 1.1292f$	0.83	0.43	4.03	$Sc= -1.1624f^2 + 1.0707f$	0.76	0.46	3.20
	$Lt = -19.261f^2 + 20.328f$	0.48	0.53	11.23	$Lt = -10.975f^2 + 11.835f$	0.80	0.54	6.95
	$Lp = -145.24f^2 + 135.52f$	0.79	0.47	3.98	$Lp = -116.03f^2 + 115.99f$	0.77	0.49	5.18
CTC 4	$TGLA = 39.201f^2 - 39.063f + 10.72$	0.84	0.50	34.32	$TGLA = 48.315f^2 - 49.697f + 14.257$	0.91	0.51	22.11
	$Sc = -1.4465f^2 + 1.2213f$	0.85	0.42	5.63	$Sc = -1.4715f^2 + 1.3208f$	0.75	0.45	4.22
	$Lt = -24.555f^2 + 23.182f$	0.59	0.47	11.57	$Lt = -14.112f^2 + 14.199f$	0.72	0.50	9.23
	$Lp = -167.96f^2 + 148.56f$	0.80	0.44	5.59	$Lp = -155.67f^2 + 147.7f$	0.85	0.47	7.12
RB 966928	$TGLA = 56.537f^2 - 56.658f + 15.081$	0.97	0.50	36.29	$TGLA = 50.829f^2 - 53.248f + 14.869$	0.85	0.52	22.51
	$Sc = -1.4242f^2 + 1.2457f$	0.96	0.44	4.34	$Sc = -1.137f^2 + 1.0526f$	0.68	0.46	4.93
	$Lt = -22.653f^2 + 22.935f$	0.69	0.51	11.80	$Lt = -10.196f^2 + 11.151f$	0.85	0.55	8.78
	$Lp = -159.16f^2 + 148.58f$	0.89	0.47	3.84	$Lp = -123.86f^2 + 122.04f$	0.89	0.50	3.48

R^2_Coefficient of determination; f_water availability factor in the soil; a and b are the coefficients of the equations; TGLA_temperature gradient leaf atmosphere (°C); Lt_leaf transpiration (mmol H_2O m^{-2} s^{-1}); Sc_stomatic conductance (mol H_2O m^{-2} s^{-1}); Lp_liquid photosynthesis (µmol CO_2 m^{-2} s^{-1}); and CV_coefficient of variation.

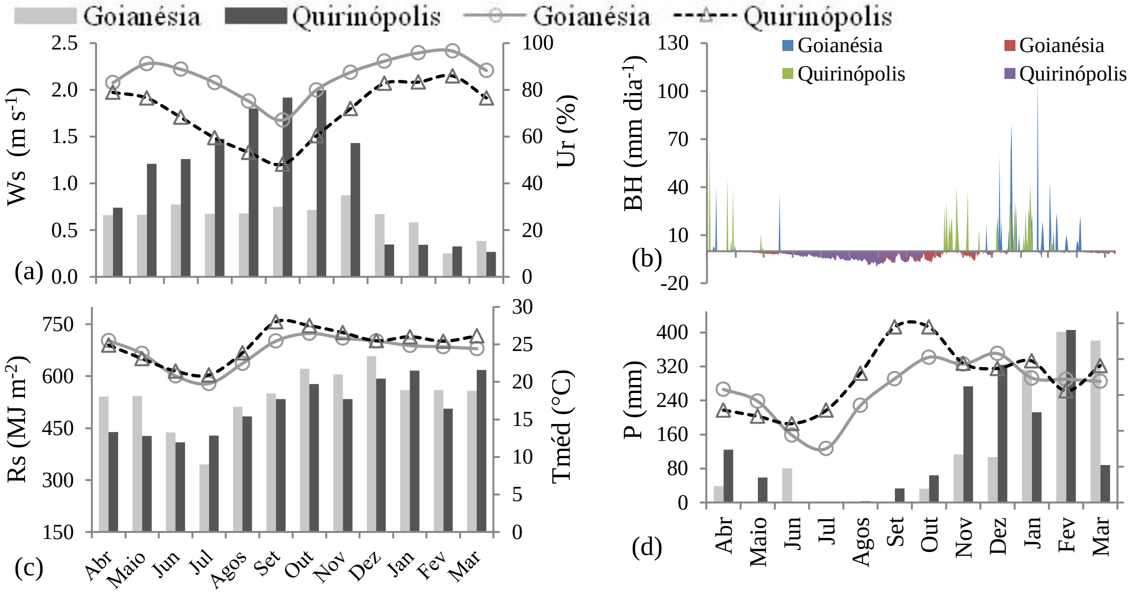

Fig 1. Wind speed - Ws (bars), average relative humidity - your (lines) (Fig a), excess and deficit - BH (Fig b), global radiation - Rs (bars), average air temperature -Tmed (lines) (Fig c), precipitation - P (bars), reference evapotranspiration - ETo (lines) (Fig d), of two mesoregions: Centro Goiano (Goianésia) and Sul Goiano (Quirinópolis), during the sugarcane cultivation cycle. Goiás, Brazil, 2019/2020 crop.

Table 2. Ton of stalk per hectare (TSH), ton of POL hectare (TPH), total recoverable sugar (TRS), sugar and alcohol of three varieties of sugarcane cultivated under the edaphoclimatic conditions of Goianésia (Amb-G) and Quirinópolis. Goiás, Brazil, 2019/2020 crop.

Variety	TSH (Mg ha^{-1})		TPH (Mg ha^{-1})		TRS (kg Mg^{-1})		Sugar (kg Mg^{-1})		Alcohol (L Mg^{-1})	
	Amb-G	Amb-Q	Amb-G	Amb-Q	Amb-G	Amb-Q	Amb-G	Amb-Q	Amb-G	Amb-Q
RB867515	156.5aA	153.7aB	19.3aB	24.8aA	125.3aA	136.6aB	119.8aB	130.7aA	74.1aB	80.8aA
RB966928	141.5abB	142.7abA	17.5aA	21.5abB	126.0abA	130.4aA	120.5aB	124.8bA	74.5aA	77.1aB
CTC 4	127.5bA	116.2bB	16.6aA	16.1bA	131.5bA	118.2bB	125.8bA	113.0bB	77.8bB	69.9bA
Average	141.8	137.5	17.8	20.8	127.6	128.4	122.1	122.8	75.4	75.9
DMS-V	28.9	27.3	4.6	5.1	6.0	8.4	6.5	8.0	4.0	5.6
CV-V (%)	13.7	9.2	14.7	3.4	3.6	3.4	3.6	3.4	3.6	3.4

Columns with the same lowercase letter and rows with the same uppercase letter do not differ statistically (p ≥ 0.05), according to the Tukey. DMS-V test_significant minimum difference for average differences between significant varieties; CV_coefficient of variation for varieties.

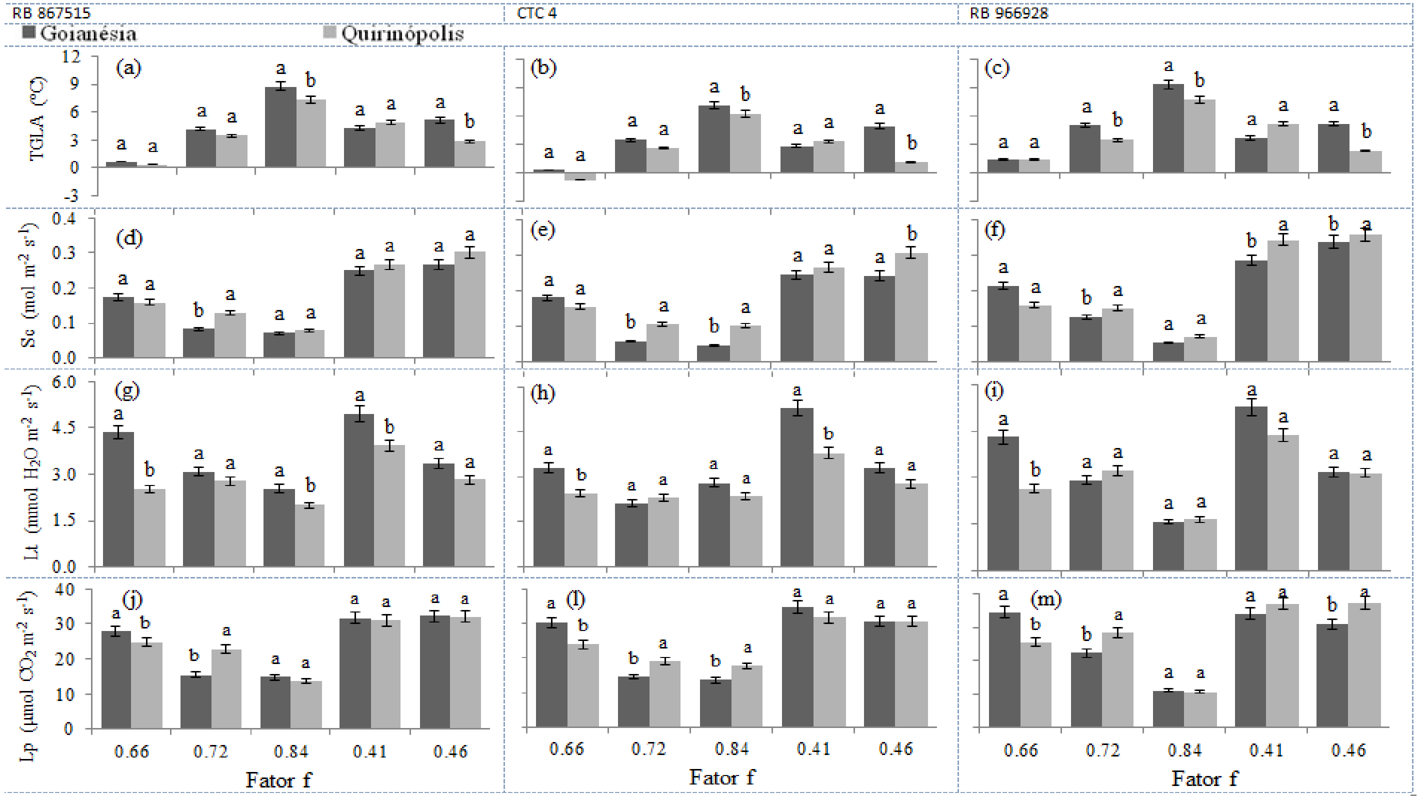

Fig 2. Indicadores fisiologicos de estresse hídrico of three varieties of sugarcane grown in different environments and water availability factor in the soil (Factor f). Goiás, Brazil, 2019/2020 crop. Bars, with their respective standard errors, in the same factor f and variety and with the same letters do not differ statistically (p≥0.05), among themselves by the Tukey test between cultivation environment. TGLA_temperature gradient leaf atmosphere; Lt_leaf transpiration; Sc_stomatic conductance; Lp_liquid photosynthesis.

Table 3. Soil particle size, particle density (Pd), and soil (Sd), total porosity (Tp), humidity in the field capacity (θfc), and permanent wiltpoint (θpwp), and S index (S), along the soil profile of two municipalities in Guadel.

Layer	Clay	Silt	Sand			Tp	θfc		
m	---------- g kg^{-1}-------------			----- g cm^{-3}------		%	-------		
Quirinópolis									
0.00 - 0.20	707	175	118	2.42	1.08	54.25	0.43	0.28	9.98
0.20 - 0.40	747	133	120	2.91	1.10	52.09	0.41	0.25	6.61
0.40 - 0.60	757	132	111	2.83	1.18	55.11	0.42	0.25	7.13
0.60 - 0.80	737	189	74	2.79	1.09	---	---	---	---
Goianésia									
0.00 - 0.20	515	112	373	2.61	1.34	41.34	0.33	0.20	6.12
0.20 - 0.40	515	128	361	2.51	1.37	42.57	0.33	0.19	7.15
0.40 - 0.60	533	104	362	2.48	1.16	43.56	0.33	0.18	7.21
0.60 - 0.80	523	121	156	2.50	1.17	---	---	---	---

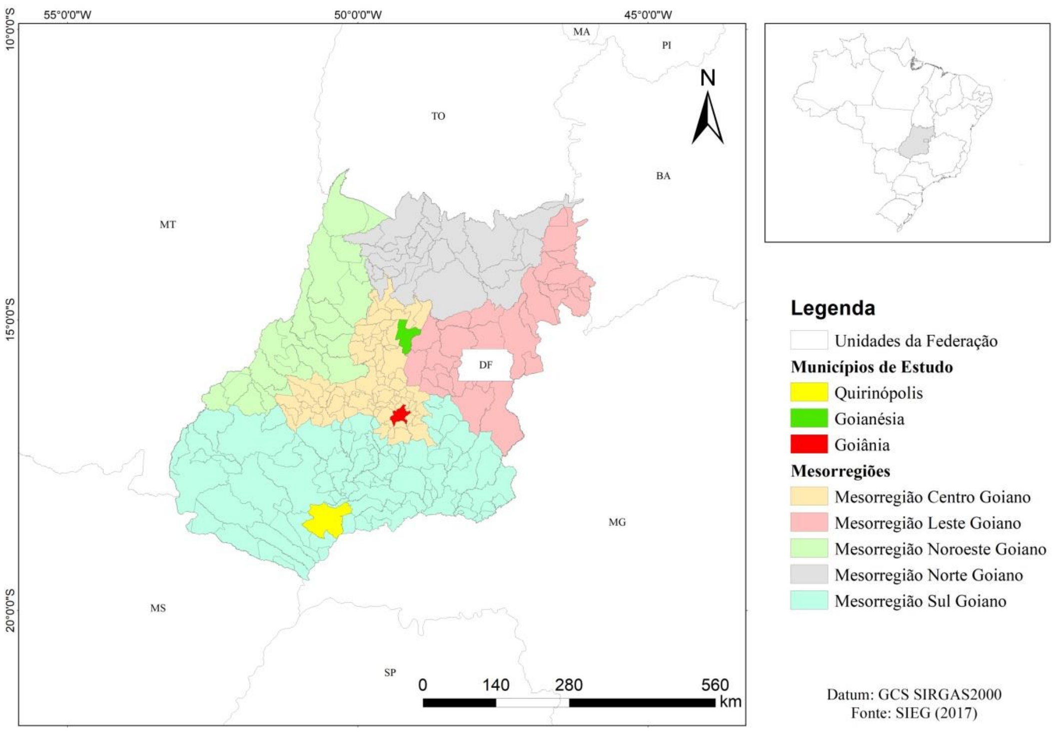

Fig 3. Location map of the areas under study (Quirinópolis and Goianésia). Goiás, Brazil, 2019/2020 crop.

Quirinópolis. This may be related to the lower AWC observed in Goianésia (Table 3).

Table 1 shows that the lowest factors f (obtained by the inversion point of the curve, calculated by the relationship between the coefficients b and a of the equations – fator f = (-b)/-(2*a)) were observed in Goianésia, CTC4 and in the stomatic conductance of all varieties, indicating that they are the most sensitive to soil water deficit. On the other hand, it was verified by the higher factors f that RB867515 and leaf transpiration, regardless of variety, as less sensitive to water depletion in the soil.

Another important point is that even Sc initiating its limitation in factor f lower than all other physiological variables, it only begins to limit liquid photosynthesis after factor f increases, so the factor f indicated for the crop can be based on photosynthesis and not on factor f for Sc. For example, the CTC4 variety cultivated in Goianésia showed a limitation in Sc only when factor f was equal to 0.42, however, it only started to affect net photosynthesis when factor f reached 0.44, so the factor f indicated for CTC4 is 0.44 and not 0.42. This behavior was also observed in RB867515 and RB966928, both in Quirinópolis and Goianésia. These results corroborate those found by Gonçalves et al. (2010), who evaluated, in a greenhouse, the responses of four varieties of sugarcane (SP79-1011, RB72454, RB98710 and RB92579) submitted to water stress during the initial phase of vegetative growth, and observed that water stress reduced stomatic conductance in some varieties without altering the rate of liquid photosynthesis.

When evaluating the sequence of factor f that initiated the limitations in the physiological variables of sugarcane varieties cultivated in the two cultivation environments (Table 1), it is possible to organize them in order of the beginning of interference in the Lp. For example, the RB857515 cultivated in Goianésia can be organized as follows: Sc+TGLA+Lt.

Note that as the depletion of water in the soil increases each response variable reaches its factor f and adding in this example we can reorganize the production of Lp. In this example we can reorganize as follows: Sc (f=0.47)+TGLA(f=0.50)+Lt(f=0.53). Thus, one can use only the Lp equation to simulate the penalties suffered by water depletion in the soil, considering that it is already included the effects of the other variables.

Effect of the growing environment on productivity and industrial yield

It was verified that the Ton of stalk per hectare (TSH), average among the varieties of sugarcane under the edaphoclimatic conditions of Goianésia (Amb-G) was 141.8 Mg ha^{-1}, since in Quirinópolis (Amb-Q) it was 3% lower (4.3 Mg ha^{-1}) (Table 2). These differences were significant ($p \leq 0.05$) between the cultivation environments in all varieties. In addition, RB867515 and BR966929 showed the highest yields, however, they did not differ statistically from each other within the same FEN. These results corroborate the physiological behaviors observed, both among sugarcane varieties and between environments as a function of factors f (Fig 2 and Table 1).

It was observed that the average ton of POL hectare (TPH) among sugarcane varieties in Quirinópolis was 20.8 Mg ha^{-1}, where as in Goianésia it was 14.4% lower (3.0 Mg ha^{-1}), and these significant differences ($p \leq 0.05$) between the cultivation environments only for varieties RB867515 and BR966929 (Table 2). In addition, RB867515 and BR966929 showed the highest yields, however, they did not differ statistically from each other within the Amb-G of CTC4. These results show that although Goianésia obtained higher TSH lost in the apparent sucrose content of sugarcane (THP) than for the sugar-energy industry, the higher the POL contents, the better (Galo 2013).

It was found that FEN significantly influenced the TRS yield of RB867515, and Goianésia (125.3 kg Mg^{-1}) obtained lower yield than in Quirinópolis (136.6 kg Mg^{-1}) (Table 2). Similar results were observed with RB966928, even with lower intensity (difference of only 4.4 kg Mg^{-1}). On the other hand, the Amb-G favored CTC4 in the total amount of sugars (sucrose, glucose and fructose) - TRS, with 10.22% more than in Quirinópolis, differing statistically ($p \leq 0.05$), between environments and the other two varieties of sugarcane. These results are related to the intensity and duration of water deficit being higher in Amb-Q than in Amb-G (Figs 1b and 1e), during the maturation phase of the crop - may to june (360 to 455 days after planting).

It is interesting to portray that in the edaphoclimatic conditions of Goianésia, CTC4 presented TRS up to 5.5 kg Mg^{-1} higher than RB867515 and BR966929 (Table 2). Based on the variable, CTC4 for Amb-G can be recommended, however, the TSH of the other varieties reached up to 29.0 Mg ha^{-1} more than CTC4, in the same FEN that CTC4 obtained better TRS, therefore, an accurate cost-benefit evaluation is required to opt for one variety in favor of the other.

As for sugar and alcohol production, it was observed that FEN significantly influenced ($p \leq 0.05$) in the three varieties of sugarcane, however, differently. Rb867515 and BR966929 being favored by Amb-Q and CTC4 by Amb-G (Table 2). It was also found that even if there were no significant differences between RB867515 and BR966929 in Amb-G, as for sugar and alcohol production, in the environment with higher water deficit and soil dryness (Amb-Q), RB867515 showed to be more tolerant to water stress than BR966929, producing 4.5% (5.9 kg Mg^{-1}) of sugar and 4.6% (3.7 L Mg^{-1}) of alcohol higher than BR966929.

Materials and Methods

Location of the study site

The experiment was conducted in the experimental field of the Boa Vista Plant and jalles machado plant located in Quirinópolis (18°34'01" S and 50°26'44" W; and 446 m altitude) and in Goianésia (15º12'03'' S; 48º59'02'' W; and 580 m altitude), respectively (Fig 3), in the crop year 2019/2020, without the use of irrigation. According to the classification of Koppen (Alvares et al., 2013).

Statistical design and treatments

The design was in randomized blocks, with four replications, in a factorial scheme (3x5x2), being three varieties of sugarcane (Saccharum spp): CTC4; RB966928 and RB867515, five factors of soil water availability (factor f): 0.41; 0,46; 0,66; 0,72; and 0.84 and two production environments: Goianésia and Quirinópolis, with distinct edaphoclimatic attributes (Table 3). Each plot was composed of seven lines of seven meters, with 1.5 m from each other, totaling 98 m^2, being the useful area to the three central lines.

Soil identification, corrections, fertilization and physical-hydric analysis

The soil of the production environments was classified according to the Brazilian Soil Classification System (Santos et al., 2018), as typical Dystrophic Red Latosols (LVd), in both cultivation environments, even presenting distinct physico-water attributes (Table 3).

The correction of acidity, toxic elements and soil fertility was performed by the Plants, which consisted of subsoiling up to 0.50m and detorroamento with toothed roller, in both tests. Soon after, 1500 to 2000 kg ha^{-1} of dolomytic limestone was applied on the soil surface, raising the base saturation to 50%, and 800 to 1000 kg ha^{-1} agricultural gypsum, in addition to 100 kg ha^{-1} of P_2O_5 in the form of natural phosphate (aiming at the correction of phosphate, acidity, and toxic elements).

In the planting were applied in the areas of 280 to 315 kg ha^{-1} of phosphate mineral fertilizer (MAP), together with a syrup composed of biozyme (0.250 L), sodium molybrate (0.306 kg) and regent (0.100g). At the bottom of the planting groove, 400 to 500 kg ha^{-1} of formulated 08-25-25 (N-P-K) were added. The results of the soil chemical analyses were interpreted by the concentration ranges according to criteria proposed by Souza & Lobato (2004) and only for the micronutrient Fe were adopted the criteria proposed by the Soil Fertility Commission of Goiás (Cfsg 1988).

For the physical-hydric analyses of the soils, deformed and undisturbed samples were collected, whose determinations of granulometry, particle density and total porosity (Table 3) were performed according to Embrapa's Manual of Soil Analysis (Embrapa 2017).

The undisturbed samples, collected at depths of 0.0 - 0.20 m; 0.20 - 0.40 m; 0.40 - 0.60 m and 0.60 - 0.80 m, with the aid of volumetric rings of 4.8 cm in diameter and 3.0 cm in height, particle density and water retention curve were used to determine the water retention curve at 0 stresses; 6; 10; 30; 100; 300; 500 and 1500 kPa, in the soil physics laboratory of Embrapa Meio-Norte. To do so, used Richards' pressure chambers with porous plate (Richards 1965). The water retention curves were adjusted based on the mathematical model proposed by Van Genuchten (1980) using the Soil Water Retention Curve - SWRC, Beta 3.0 software (Dourado Neto et al., 2000). The humidity in the field capacity corresponds to the inversion point of the curve (S index) and the humidity at the permanent wilting point the voltage of 1500 kPa.

Installation of monitoring and meteorological elements

Planting was carried out on March 11, 2019 (Quirinópolis), and on March 18, 2019 (Goianésia), using three tolets with five vegetative yolks per linear meter, in grooves with 0.30m depth. The lines were spaced in two meters between each other, aiming to facilitate physiological evaluations throughout the crop cycle, which occurred in the central line of each plot. The harvest occurred on May 21, 2020 (cycle of 437 days), in Quirinópolis, and on June 16, 2020 (cycle of 455 days), Goianésia.

As the crops were dry, in the water balance of water in the soil, rainfall was considered as inlet and evapotranspiration of the crop as an outlet. To estimate the reference evapotranspiration (ETo), Penman-Monteith (Allen et al., 1998) was used. The data entering the model were obtained from an automatic meteorological station installed about 30 m from the experimental area in both municipalities, which recorded during the conduct of the tests the average air temperature (Tmed, °C); (Tmax, °C), and minimum (Tmin, °C); relative humidity (RH, %); wind speed (Ws, m s^{-1}); precipitation (P, mm), and global solar radiation (Rs, MJ m^{-2} day^{-1}).

Crop evapotranspiration (ETc) was obtained by the ETo and product the crop coefficient (Kc) (Allen et al., 1998). The Kc in the regrowth and establishment phase (from zero to 40 days after planting), of 0.45; in the edween phase (from 40 to 120 days after planting), ranging from 0.40 to 1.25; in the full growth phase (from 121 to 305 days after planting), from 1.25; and in the maturation phase (from 306 to 381 days after planting), from 0.75, and from the 365 days after planting (DAP) considered, constant and equal to 0.75.

Daily soil moisture recording and determination of factors f

From the 84 DAP, volumetric humidity (θ, m^3 m^{-3}) of the soil profile stratified in layers from 0.20 to 0.20m to 1 (one) m depth was recorded, by EC-5 sensor, every 60 minutes, stored and controlled by a datalogger (Emb50, Decagon), calibrated (Pereira et al., 2018). The daily factors f for sugarcane varieties were estimated according to the drying and moistening cycles of the soil throughout the growth and development of the crop. For this purpose, the Equation (Eq.) was used. [4] which was deducted from the Eqs. [1], [2] and [3]. Water is easily available (WEA) in mm.

$$\mathrm{WEA} = \mathrm{AWC} * \mathrm{f} \quad [1]$$

So:

$$\mathrm{WEA} = (\theta\mathrm{fc} - \theta\mathrm{crit}) * \mathrm{f} \quad [2]$$

Eqs equaling. [1] and [2] one has:

$$\mathrm{AWC} * \mathrm{f} = (\theta\mathrm{fc} - \theta\mathrm{crit}) * \mathrm{Z} \quad [3]$$

So:

$$\mathrm{f} = \frac{[(\theta\mathrm{fc} - \theta\mathrm{crit}) * \mathrm{Z}]}{\mathrm{AWC}} \quad [4]$$

Being, θfc the humidity in the field capacity (m^3 m^{-3}); θcrit critical humidity, or humidity recorded by EC5 during the crop cycle (m^3 m^{-3}); and Z the effective depth of the root system (mm); AWC available water capacity (mm); and f the supposed factor of water availability in the soil being tested for sugarcane, dimensional.

The available water capacity in the soil – (AWC, mm) was defined by Eq. [5] using the data in Table 3, em que θpwp is the water content in the permanent wilting point. With effective depth of the initial root system of 0.30m and final of 0.60m (Sousa et al., 2013; Rossi Neto et al., 2018). It considered daily root growth, up to 305 DAP, of 0.98 mm day^{-1}.

$$\mathrm{AWC} = (\theta\mathrm{fc} - \theta\mathrm{pwp}) * \mathrm{f}$$

Record of sugarcane water stress indicators

The variables analyzed in response to soil water depletion (f tested factors) of each variety of sugarcane plant were: liquid photosynthesis (Lp), in µmol CO_2 m^{-2} s^{-1}; stomatic conductance (Sc), in mol m^{-2} s^{-1}; leaf temperature (Tf), in °C; leaf transpiration (Lt), in mmol H_2O m^{-2} s^{-1}, both in the middle third of leaf limb of leaves 1+ (Kuijper 1915), of 12 ermins and three readings per son, totaling 36 readings in each plot, always between 8 and 12 o'clock in the morning. For this purpose, we used a portable infrared gas analyzer, IRGA (LI-COR), model LI-6400 XT with photosynthetically active radiation (PAR) of 2000 µmol m^{-2} s^{-1}, defined in the field from the light curve.

Physiological readings were made in phenological stages: peredonation at 84 DAP; full growth in 124, 164, 201, 247 and 249 DAP; and maturation in 327 and 375 DAP. The leaf temperature gradient in °C was obtained by the difference between leaf temperature (°C) and air temperature (°C).

In the post-harvest analyses, the plants of the plots were harvested, weighed and determined to mass in kg m^{-2}, from which they obtained the Ton of stalk per hectare (Mg ha^{-1}). From this, 10 stems were randomly chosen per plot, and taken to the laboratory of quality analysis of sugarcane broth from the mills for the following technological evaluations: total recoverable sugar – TRS (Mg ha^{-1}); and ton of POL per hectare - TPH (Mg ha^{-1}): obtained by multiplying the POL value by the current productivity. Based on these data, the productivity of VHP Sugar with 99.3º Z and 0.15% humidity, in kg ha^{-1}, and hydrated alcohol in L ha^{-1}, according to standards N-133 and N-135, respectively (Consecana 2006) were estimated.

Statistical analysis

The data were submitted to variance analysis, by the "F" test, for diagnosis of significant effect and the unfolding of the cultivation environment for each variety of sugarcane were compared to each other by the Tukey test (p ≤ 0.05). Quantitative treatments (levels of factor f within each variety of sugarcane) were submitted to quadratic regression analyses according to ferreira's recommendations (2000). The software used Sisvar 5.7 Build 91 (Ferreira 2011).

Conclusion

CTC4 has higher productive potential than other sugarcane varieties, however, more sensitive to soil water depletion (lower factor f), reflecting lower Lp and TSH in both cultivation environments. In Goianésia, sugarcane enters water stress with a factor f 3% lower than in Quirinópolis. Thus, the factors of soil water availability to avoid water stress were 0.50, 0.49 and 0.47 for RB867515, RB966928 and CTC4, respectively, in Quirinópolis; and 0.47, 0.47 and 0.44 for RB867515, RB966928 and CTC4, respectively, in Goianésia.

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