Acta Agronómica (2020) 69 (2) p 136-144 ISSN 0120-2812 | e-ISSN 2323-0118 doi: https://doi.org/10.15446/acag.v69n2.60246

Water requirements and restrictions to sugarcane in cane plants and ratoon cane cycles in Southern Brazil

Requerimientos y restricciones de agua en caña de azúcar plantilla y soca en el sur de Brasil

Bruno César Gurski [1], *Jorge Luiz Moretti de Souza* [2], *Emerson Gerstemberger* [3], *Ricardo Augusto de Oliveira* [4]

[1]Federal University of Paraná. Department of Soil and Agronomic Engineering. Curitiba, Paraná, Brazil. brunocep@gmail.com
[2]Federal University of Paraná. Department of Soil and Agronomic Engineering. Curitiba, Paraná, Brazil. jmoretti@ufpr.br
[3]Federal University of Paraná. Department of Soil and Agronomic Engineering. Curitiba, Paraná, Brazil. egerstemberger@gmail.com
[4]Federal University of Paraná. Department of Phytotechnics and Plant Health. Curitiba, Paraná, Brazil. rico@ufpr.br

Rec.: 22-09-2016 Acep.: 22-05-2020

Abstract

In a site with a Cfa-type climate in southern Brazil, the water requirements and restrictions for the cultivation of sugar cane (*Saccharum* spp.), in plant and soca (second cut) were characterized. Water availability was calculated based on the daily water balance and evapotranspiration was estimated using the Penman-Monteith method. The thermal and water requirements of sugarcane were calculated taking as reference the agroecological zoning in the state of Paraná, Brazil. Water requirement index did not show limiting factors for the development of the crop both in plant and soca. Water deficit was the most important agroclimatic risk factor. In Paranavaí-PR, Brazil, sugarcane is a safe crop, with possibilities of saving water in the development stage (phase II), with frequent additional irrigation needs of 508.8 mm/crop cycle for plant and 486.5 mm/sugarcane cycle for soca.

Keywords: Climate; *Sacharum* spp.; Southern Brazil; Water balance, Water deficit, WRSI.

Resumen

En un sitio con clima tipo Cfa del sur de Brasil, se caracterizaron los requerimientos y restricciones de agua para el cultivo de caña de azúcar (*Saccharum* spp.) en plantilla y soca (segundo corte). La disponibilidad de agua fue calculada con base en el balance hídrico diario y la evapotranspiración se estimó mediante el método de Penman-Monteith. Los requerimientos térmicos e hídricos de la caña fueron calculados tomando como referencia la zonificación agroecológica en el estado de Paraná, Brasil. El índice de requerimiento de agua no mostró factores restrictivos para el desarrollo del cultivo tanto en plantilla como en soca. El déficit de agua fue el factor de riesgo agroclimático más importante. En Paranavaí-PR, Brasil, la caña de azúcar es un cultivo seguro, con posibilidades de ahorro de agua en la etapa de desarrollo (fase II), con necesidades de riego adicional frecuente de 508.8 mm por ciclo de cultivo en plantilla y 486.5 mm por ciclo de caña soca.

Palabras clave: Balance hídrico; Déficit de agua; Requerimiento hídricos; *Saccharum* sp., Sur de Brasil.

Introduction

Sugarcane (*Saccharum* spp.) is one of the main products of Brazilian agribusiness and the area planted in Paranavaí is booming. In the Paraná State, Brazil, sugarcane occupies an area of 607 thousand hectares, with an annual production of 50 million t and Paranavaí region accounts for 20% of this production (SEAB 2015).

Sugarcane is a semi-perennial crop widely cultivated, subjected to different environmental and management conditions, causing differences over the cycle (Silva et al., 2008); growth and yield are influenced by many environmental factors, but temperature and precipitation are known to be the most influential factors on crop development (Vianna and Sentelhas, 2014).

Water is considered a limiting factor for sugarcane since the potential production is possible with adequate water availability (Inman-Bamber and Smith, 2005). Water stress affects the rate of water absorption, biomass accumulation, structural plant growth and changes the assimilation and sucrose accumulation (Singels et al., 2010). Damage produced by water stress depends on the stress duration, the crop and its development stage. The longer the low water availability period, greater the damage on productivity of stalks and sucrose (Inman-Bamber, 2004).

Systematization of climate data, considering the development stages of crops, contributes to improve resource planning, productivity and environmental sustainability. However, the effect of water stress on sugarcane at different stages of its development is not well defined in literature, affecting estimates of crop behaviour when soil moisture is above or below optimum values (Silva et al., 2013).

The behaviour of production facing climate change in sugarcane management must promote and impellent efficient use of rainwater and minimize restrictive periods for crop development. Detailed knowledge of water dynamics in soil during crop development provides essential elements to establish or improve agricultural management practices aimed to optimize productivity. Water balance enables to assess with detail, water conditions for crop development, allowing the verification of all incomes and outcomes of soil water, according to the peculiarities of the specie, resulting in soil water balance in the period (Brito et al., 2009).

From information obtained in water balance, the agroclimatic characterization provides a concise inventory of agroclimatic potential and restrictions for plant development, assisting in the formulation of policies and adequacy of crop to circumvent existing limitations and establish short and term development strategies (Silva et al. 2013).

The present study aimed to characterize sugarcane water relations (requirements and restrictions) for climate type Cfa, in Southern Brazil, and identify periods in which water restriction does not produce significant effects on crop yield.

Material and methods

The experiment was conducted in Paranavaí, State of Paraná, Brazil, coordinates 22°58′44″S, 52°27′51″W, and altitude of 480 m. The region has Cfa climate type, subtropical, with average annual rainfall of 1350 mm. The soil was classified as Oxisol, medium texture, with soil bulk density ranging from 1.5 to 1.7 Mg m^{-3} (Alvares et al., 2014).

Agrometeorological data sets available in Paranavaí region (12 years from 1997 to 2009), collected in automatic weather station were analysed. The daily *ETo* was estimated by Penman-Monteith method (Allen et al., 1998). The study includes both cane-plant and ratoon cane, between 1997 and 2009: crop coefficients (*Kc*) were recommended by Allen et al. (1998), whose periods were fitted to the developmental stages proposed by Machado et al. (2009), and the rooting system effective depth (*z*) was recommended by Buso et al. (2009) (Table 1).

The agroclimatic and suitability characterization was based on the methodology proposed by EMBRAPA (2009), which indicates levels of climate risk classification (Table 2). Using sugarcane phenology data, soil profile water retention and climatological elements that were inserted into a local daily water balance, enabling to monitor restriction factors for the crop in all growing seasons. The frost risk in place was based on the data and considerations made by Wrege et al. (2005), considered not restrictive to sugarcane development (Risk = 0.26%).

Water Requirements Satisfaction Index (WRSI) corresponds to a dimensionless value ranging from zero (0) to one (1), with values close to one indicate ideal water supply. Their definition is originated by the ratio between actual evapotranspiration (*ETa*) and crop evapotranspiration (*ETc*) (Vianna and Sentelhas, 2014).

The estimated water components, for both cane-plant and ratoon, were obtained in a climatological water balance (CWB) based on an adaptation of the methodology proposed by Thornthwaite and Mather (1955), because there is no calibration for sugarcane to the climate type in order to use more modern models as

Table 1. Sugarcane rooting system effective depth (*z*), development phases duration and their crop coefficient (*Kc*).

Development phases*	Stage start	Stage end	Duration (days)	*Kc* (dimensionless)	*z* (m)
	---------- Sugarcane plant ----------				
I	April	November	231	0.40	0.60
II	November	April	145	1.25	0.60
III	April	July	108	0.75	0.80
	---------- Ratoon sugarcane ----------				
I	July	October	93	0.40	0.60
II	October	March	160	1.25	0.80
III	March	July	112	0.75	0.80

* I – sprouting to intense tillering; II – growth in stature; III – reduction, growth and sucrose accumulation.

Table 2. Risk classification parameters for sugarcane in Brazil.

Classification	Risk	Consideration	Average Temp.	*WRSI**	Frost risk	Water deficit
A – Indicated	Low	There is no one.	> 19 °C	> 0.6	< 20%	< 200 mm
B – Indicated	Low	Saving irrigation	> 19 °C	> 0.6	< 20%	200 - 400 mm
C – Not indicated	High	Frost risk / thermal shortage	< 19 °C	> 0.6	> 20%	200 - 400 mm
D - Not indicated	High	Intensive irrigation	> 19 °C	< 0.6	< 20%	> 400 mm
E - Not indicated	High	Excess water	—	—	—	—

Source: adapted from EMBRAPA (2009). * WRSI – Water Requirements Satisfaction Index.

Aquacrop. The analysis consisted of a daily sequential CWB, based on daily precipitation (*P*); daily reference evapotranspiration (*ETo*); sugarcane crop coefficient (*Kc*) in development stages; total water capacity (*TAW*); and soil water depletion fraction (*p*) for sugarcane. The output components are daily values of soil water storage (*S*), actual evapotranspiration (*ETa*), water deficit (*Def*) and surplus (*Sur*).

The soil physical parameters were derived from preliminary experiment carried out in the same area and period, being the determinations held with EMBRAPA (1997) methods, and soil water retention parameters obtained from Van Genuchten (1980) equation.

The total water capacity (*TAW*) and readily available water (*RAW*) were determined in a previous study based on soil water depletion fraction (P = 0.65) for sugarcane (Allen et al., 1998). The *TAW* values found were 65.3 and 93.9 mm for the depths of 0.60 and 0.80 m, respectively. To monitor of soil water storage was used the equation proposed by Rijtema and Aboukhaled (1975). The *ETc* values were calculated using the equation $ETc=ETo*Kc$ where *ETc* is the maximum crop evapotranspiration (mm/day), *ETo* is the reference evapotranspiration (mm/day), and *Kc* represents crop coefficient (dimensionless).

The obtaining statistical parameters of Probability Density Function (PDF) of best fit and consequently the probability of the CWB components (*ETo, P, S, ETa, Def* and *Sur*) were determined with the following steps: grouping the daily values of CWB components in ten-day periods; setting the frequency distribution with the observed data series; calculating statistical parameters based on five PDF's (range, normal, exponential, triangular and uniform) with the series of ten-day periods values; adherence verification of the ten-day periods values at five PDF's with Kolmogorov-Smirnov test at 5% probability; PDF choice that which best fit to the observed in ten-day periods values; probable values determination (Souza et al., 2013).

Results and discussion

The region presented in the study period (1997-2009) air annual average temperature of 22.9 °C, ranging from 19.0 °C in the coldest month (July) and 25.5 °C in the hottest month (February). The lowest daily value of temperature checked on site, for the analysed period, was 0.2 °C (07/13/2000) and the highest was 38.8 °C (10/29/2007). Annual average precipitation (*P*) was 1422.1 mm/year, with monthly precipitation ranging from zero (August/99, August/07 and September/07) and 469.8 mm/month (October/09) (Figure 1).

In the studied period (1997-2009) mean *P* of 1657.5 mm per cycle and 1333.1 mm/cycle to sugarcane plant and ratoon sugarcane, respectively. Based on considerations of Dantas Neto et al. (2006), it was found that the occurrence of rainfall throughout the years studied was close to the values indicated to the

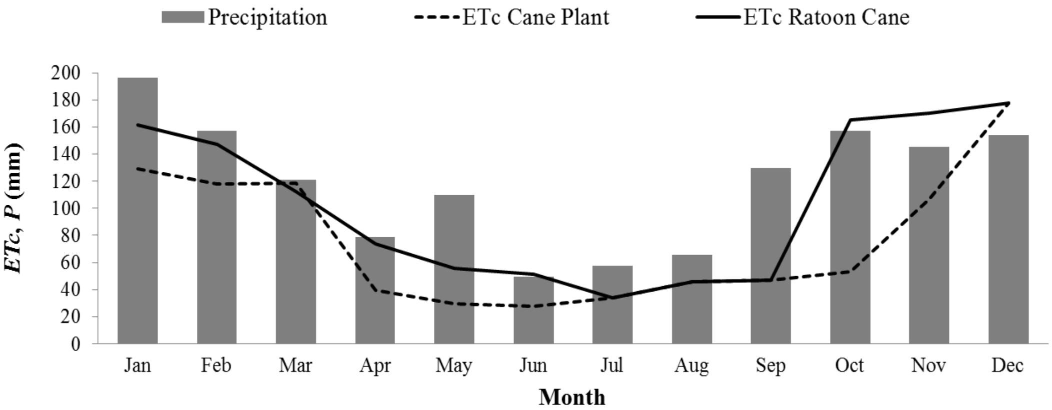

Figure 1. Monthly average values of sugarcane evapotranspiration (*ETc*) and precipitation (*P*), for Paranavaí, in the period 1997-2009.

cultivation of sugarcane, with good distribution of rainfall volumes during vegetative growth. It was found that periods with water demand (*ETc*) were greater than *P*, but in general, trending variables over the studied years were monitored (Figure 1).

Knowledge of total values of the components of CWB, mostly from water stress (*Def*) occurred in the whole cycle of the crop, is essential to understand the constraint parameters for the sugarcane development. The sugarcane with planting in April suffered water stress in the development phase, in partly of the maturation phase, comprising a period from December to May (six months). The ratoon cane, whose regrowth occurred in July, suffered water stress in development phase and part of maturation phase from October to April (six months) (Table 3).

For cane plant, only 33.3% of the seasons analysed had cumulative *Def* along the seasons, below 200 mm/season (Table 3). Values obtained are considered limiting for the cultivation of sugarcane, which, according to EMBRAPA (2009), get climate risk rating of “A-Indicated”. For climate risk rating “B-Indicated”, which covers *Def* range between 200 and 400 mm per season, 41.7% of analysed seasons fit this range, with the caveat to rescue irrigation. For ratoon cane (Table 3) the cumulative *Def* along the seasons presented the same percentage within the climate risk classes recommended by EMBRAPA (2009) for sugarcane, getting between 112.7 and 595.4 mm/season. Vianna and Sentelhas (2014) identified climate risk moderate to very low, for the same type of soil in Maringá, Brazil, corroborating information obtained for Paranavaí, with high or very high risk for every month of the year.

The lowest yields (2004/05, 2007/08 and 2008/09) were 15.4% lower than the average yield in this region (80 t/ha) for ratoon cane. It was possible to verify that not necessarily a higher value of water surplus will reflect in a greater yield, but the results demonstrate a direct relationship between yield and water components (Silva et al., 2013). In this sense, the lowest yields occurred in the seasons with the lowest precipitation, *ETa* and, consequently, the highest water deficits (Table 3). In these seasons, the precipitation was always lower than the crop evapotranspiration (*ETc*).

It is also important to note that to obtain a ratoon cane yield higher than the average for the region, the minimum *ETa* must be higher than 913.7 mm/season, as occurred in 1999/00 (Table 3).

Def values (Table 3) cannot represent the effect of water stress at different development phases, because the degree of injury promoted by stress depends considerably on the plant development phase (Silva et al., 2013). For instance, Inman-Bamber and Smith (2005) say that sugarcane has resilience to moderate water stress during phase I. Values of the sequential CWB components for sugarcane and ratoon cycles, in development phases I, II and III, are presented in Table 4.

All development phases presented deficiency, according to Machado et al. (2009) and Silva et al. (2013), the water deficit causes a significant reduction in production in the three development phases of sugarcane, but the development phase II had higher *Def* values compared to others, greater than 13.1 mm/ten-days, for both the sugarcane and ratoon. The identification of this water stress is essential for the management and the consequent crop yield, because this phase is the period of greatest development and increased water demand of the plant.

Greater frequency distribution details of the ten-days CWB components to sugarcane plant and ratoon, at 1997/98 to 2008/09 seasons, in Paranavaí can be checked in Table 5.

Table 3. Yield and components of the water balance performed for the 1997/1998 to 2008/2009 seasons of sugarcane and ratoon cane in Paranavaí, Southern Brazil.

Season	*ETo*	*ETc*	*ETa*	*P*	*Def*	*Sur*	*ETa/ETc*	Yield**
	------------------------------ (mm/season) ----------------------------							(t/ha)
	------------------------------ Sugarcane ------------------------------							
1997/98	1593.5	1218.3	1074.6	1829.6	143.7	805.9	0.88	***
1998/99	1529.7	1214.3	1049.1	1879.6	165.2	862.4	0.86	***
1999/00	1752.6	1341.7	1003.5	1626.2	338.2	592.4	0.75	***
2000/01	1618.0	1234.5	1160.3	1875.6	74.3	708.1	0.94	***
2001/02	1685.3	1306.0	1042.2	1819.4	263.8	792.8	0.80	***
2002/03	1700.3	1279.5	1127.2	1948.4	152.4	811.8	0.88	***
2003/04	1642.9	1269.6	1024.6	1805.4	245.1	743.0	0.81	***
2004/05	1631.6	1293.5	854.8	1907.6	438.7	1045.1	0.66	***
2005/06	1660.6	1283.7	940.9	1636.8	342.8	702.9	0.73	***
2006/07	1714.1	1304.2	1093.2	1589.0	211.0	474.6	0.84	***
2007/08	1728.1	1312.6	875.6	1127.8	437.0	269.9	0.67	***
2008/09	1654.4	1292.7	596.7	1016.0	696.1	451.7	0.46	***
Mean	1659.3	1279.2	986.9	1671.8	292.3	688.4	0.77	***
*s**	62.3	39.0	154.2	304.1	171.9	210.5	0.13	***
CV*	3.8	3.1	15.6	18.2	58.8	30.6	16.93	***
	------------------------------ Ratoon cane ------------------------------							
1997/98	1279.5	1180.0	1067.3	1625.0	112.7	551.6	0.90	130.60
1998/99	1235.3	1174.0	1020.6	1492.6	153.5	443.0	0.87	130.16
1999/00	1442.5	1320.0	913.7	1251.6	406.3	341.1	0.69	98.99
2000/01	1268.0	1198.6	1068.3	1659.0	130.4	586.9	0.89	140.83
2001/02	1387.6	1270.6	1043.2	1439.0	227.5	464.2	0.82	127.94
2002/03	1330.9	1233.7	1056.5	1479.2	177.2	408.6	0.86	115.79
2003/04	1327.8	1250.5	962.0	1508.8	288.4	500.3	0.77	141.60
2004/05	1359.4	1249.0	879.8	1284.6	369.3	426.1	0.70	66.00
2005/06	1294.6	1203.9	951.0	1373.8	252.9	433.1	0.79	154.19
2006/07	1382.0	1263.9	1026.6	1359.8	237.3	369.3	0.81	***
2007/08	1363.4	1252.6	791.9	1003.6	460.7	147.6	0.63	67.92
2008/09	1367.4	1256.9	661.5	812.6	595.4	221.9	0.53	69.12
Mean	1336.5	1237.8	953.5	1357.5	284.3	407.8	0.77	113.01
SD	58.9	42.1	125.5	245.7	147.2	126.1	0.11	32.38
CV	4.4	3.4	13.2	18.1	51.8	30.9	14.74	28.65

* *SD* – standard deviation; CV – coefficient of variation. ** The harvest of the ratoon cane (second cut) occurred in two-year-old plants.
*** There was no harvest in the season.

Analysing the statistical parameters of ten-days components for CWB, considering the development phases of sugarcane and ratoon (seasons 1997/98 to 2008/09), it was verified for cycles cane plant and ratoon that *ETo*, *P*, *Def* and *Sur* components set up the Gamma distribution, being 75% the probability to occur *Def* ≤ mm/ten-days. The *ETc*, *S* and *ETa* components showed no adjustment to any of tested distributions. The highest *ETa* decennial values occurred during the development phase II, differing in only 7.7% between cane plant and ratoon. The mean values found for this phase were 35.9 mm/ten-days and 38.9 mm/ten-days, respectively.

Simple registry of potential water deficit does not necessarily imply penalizing productivity, being convenient to analyze the Water Requirements Satisfaction Index (WRSI) that seeks to divide in classes the water risk levels. According to EMBRAPA (2009), values above 0.6 indicate that the plant is supplied with water, having no effects on production. It was verified that the culture systems (plant and ratoon), behaved in a similar way as to supply the water needs of sugarcane in Paranavaí (Figure 2).

For cane plant (Figure 2a) every period corresponding to the development phase I (budding to heavy tillering) had WRSI values above 0.6, indicating adequate water supply. For the development phase II (growth in stature) 25% of the analysed periods (2004/05, 2007/08 and 2008/09) had values below the recommended range, indicating possible reduction of plant growth due to water deficit. In development phase III (reduced growth and sucrose accumulation) 25% of the analysed periods also had lower values than recommended. However, Inman-Bamber and Smith (2005) consider that a desirable restriction at phase III forces the physiological rest and sucrose enrichment.

Table 4. Average water balance components, in various development phases of sugarcane and ratoon, held for the 1997/1998 to 2008/2009 seasons in Paranavaí, Southern Brazil.

Development phases	*ETo*	*ETc*	*P*	*"P – ETc"*	*ETa*	*Def*	*Sur*
	---------------------------------- (mm/phase) ----------------------------------						
Sugarcane							
I	771.5	308.6	735.4	426.7	292.0	16.6	428.0
II	611.7	764.7	643.8	−120.9	528.1	236.5	158.0
III	282.0	211.5	278.3	66.8	158.8	52.7	91.7
Ratoon sugarcane							
I	318.7	127.5	270.6	143.1	112.3	15.2	146.7
II	697.2	871.2	753.7	−117.5	627.9	243.3	144.4
III	325.8	244.4	308.8	64.4	203.0	41.4	103.7

Table 5 - Frequency distribution of decennials Water Requirements Satisfaction Index (WRSI) to sugarcane and ratoon cane in seasons 1997/98 to 2008/09, in Paranavaí, Brasil.

Sugarcane plant			Ratoon cane		
Classes	Frequency	Probability (%)	Classes	Frequency	Probability (%)
0.0 -| 0.1	24	4.08	0.01 -| 0.11	21	4.73
0.1 -| 0.2	13	2.21	0.11 -| 0.21	11	2.48
0.2 -| 0.3	10	1.70	0.21 -| 0.31	11	2.48
0.3 -| 0.4	17	2.89	0.31 -| 0.41	18	4.05
0.4 -| 0.5	17	2.89	0.41 -| 0.51	11	2.48
0.5 -| 0.6	14	2.38	0.51 -| 0.60	11	2.48
0.6 -| 0.7	23	3.91	0.60 -| 0.70	20	4.50
0.7 -| 0.8	21	3.57	0.70 -| 0.80	24	5.41
0.8 -| 0.9	27	4.59	0.80 -| 0.90	28	6.31
0.9 -| 1.0	422	71.77	0.90 -| 1.00	289	65.09

For ratoon cane (Figure 2b) 91.7% of the corresponding periods to the development phase I (budding to intense tillering) had WRSI values greater than 0.6, indicating adequate water supply. For the development phase II (growth in stature) 16.7% of the analysed periods (seasons 2007/08 and 2008/09) had lower values than recommended. According to Dantas Neto et al. (2006) and Oliveira et al. (2011), bad distribution and reduction of rainfall during the growth of sugarcane cause production drop and shortens the useful crop life, forcing the early renewal of sugarcane. In development phase III (reduced growth and sucrose accumulation) only 8.3 % of the analysed periods (2008/09) had lower values than recommended.

Interestingly, shorter intervals (ten-days) may have WRSI values well restrictive to crop development. Therefore, the need for ten-days WRSI frequency distribution analysis (Table 5).

Ratoon cane cycle, in development phase I, presented 89.2% higher WRSIs to 0.62, lower value than the submitted by sugarcane plant (≈ 96% WRSIs> 0.62). Probably, the result is due to the planting period and duration of the development phase (Table 2), which is distinct for the cane plant cycles (duration 231 days, from April to November) and ratoon cane (duration 93 days, June-October). The ratoon cane has limited its initial development to the winter season and early spring.

For development phase II, it was found that the cane plant cycle (≈ 66.7% WRSIs > 0.62) had increased restrictions to development that ratoon cane (≈ 72.4% WRSIs > 0.62), indicating that the occurrence period of the development phase II (145 days, from November to April) of cane plant provided less water supply that recorded for ratoon cane (160 days from October to March) (Table 1).

The occurrence period of the development phase III is similar to the cane plant and ratoon cane cycles (Table 1). As a result of the similarity of duration and time of occurrence of periods, satisfactory WRSIs (WRSI > 0.62) differed by 5.2% (cane plant ≈ 79.6% and ratoon cane ≈ 84.8%).

Agroclimatic characterization in Paranavaí, for the analysed period (1997-2009), concluded that the cumulative *Def* throughout the seasons of cane plant ranged from 74.3 to 696.1 (mm/season), in seasons 2000/01 and 2008/09, respectively, with an average of 305.9 mm/season. For ratoon cane, *Def* ranged between 112.7 and 595.4 mm/season (season 1997/98 and 2008/2009), with an average of 299.9 mm/season, with a risk of frost lower than 20% and annual average temperature of 22.9°C. The average WRSI was 0.80 to cane plant and 0.76 for ratoon cane. Based on this information, and the methodology proposed by EMBRAPA (2009) it was found that Paranavaí has a low agroclimatic risk for sugarcane cultivation, with classification of

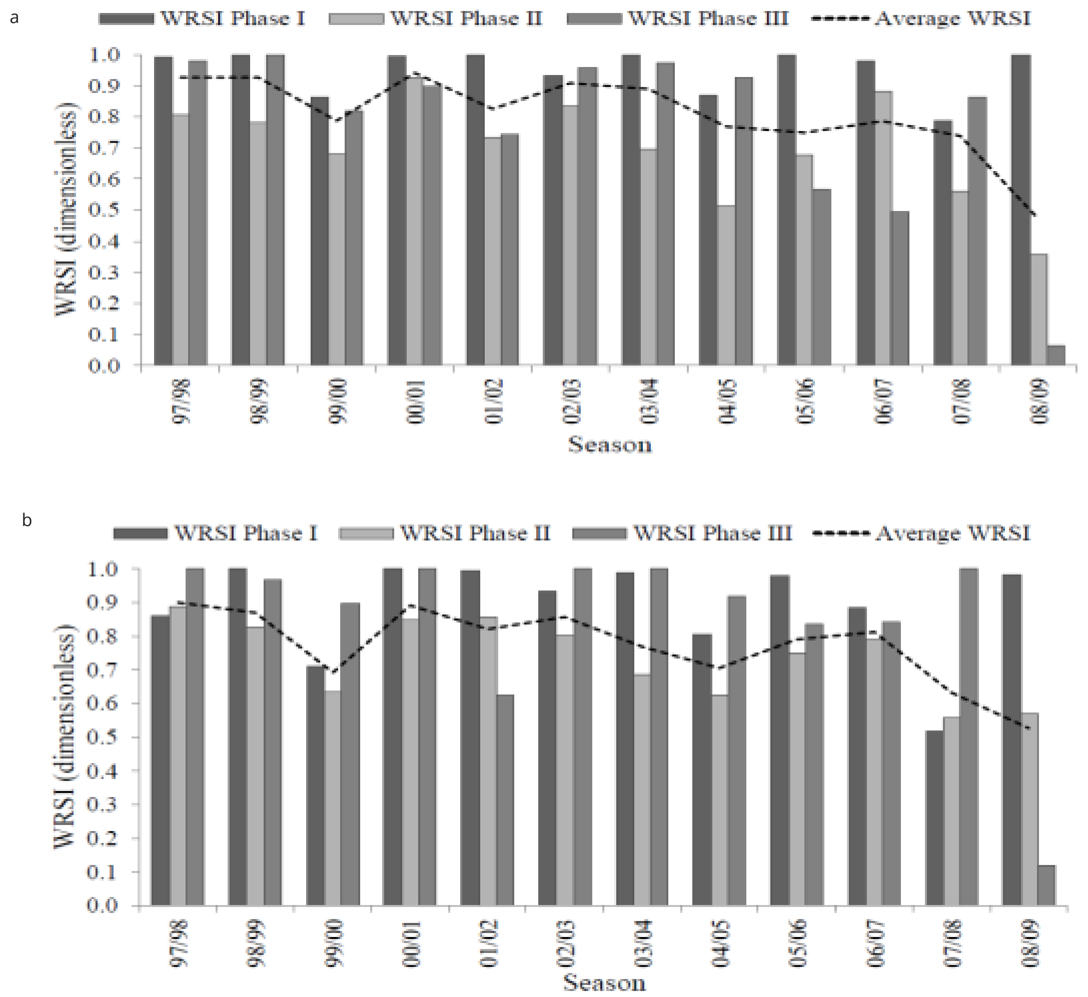

Figure 2. Water Requirements Satisfaction Index (WRSI), considering the development phases of sugarcane plant (**a**) and ratoon cane (**b**), seasons 97/98 to 2008/09, in Paranavaí, Southern Brazil.

Indicated (B), with the caveat to saving irrigation in the development phase II (growth in stature), to cane plant and ratoon cane.

For the studied seasons (1997/98 to 2008/09) it was observed that all seasons in period demanded supplemental irrigation, in at least one development phase (Table 6). The cane plant demanded higher values of supplemental irrigation in relation to ratoon cane, which can be explained by the architecture of the root system, in cane plant its mainly explores the topsoil compared to ratoon cane, which presents an

Table 6. Estimated irrigation sheet on water balance, considering the development phases of cane plant and ratoon cane in 1997/98 to 2008/09 seasons, in Paranavaí, Southern Brazil.

Phase	Season											
	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09
Cane plant (mm season^{-1})												
I	43.1	0.0	88.3	0.0	43.7	88.1	0.0	87.6	43.3	85.9	174.4	44.0
II	267.4	313.4	403.8	218.7	409.7	314.9	372.0	462.0	317.5	232.3	498.9	597.4
III	61.2	0.0	62.7	0.0	123.8	0.0	0.0	69.2	184.7	185.5	126.0	185.9
Total	371.6	313.4	554.8	218.7	577.2	403.0	372.0	618.9	545.6	503.8	799.3	827.3
Ratoon cane (mm season^{-1})												
I	42.8	0.0	88.4	0.0	43.6	0.0	0.0	44.3	43.3	42.6	86.2	87.4
II	191.5	316.1	449.4	258.2	320.9	316.9	519.1	445.5	328.0	321.0	445.4	514.3
III	0.0	0.0	124.5	0.0	189.3	0.0	0.0	61.6	187.3	123.8	0.0	247.2
Total	234.2	316.1	662.2	258.2	553.8	316.9	519.1	551.3	558.6	487.3	531.6	848.9

increase in operating deeper layers. The smallest root distribution in depth directly affects the *TAW* values, reducing water range available to the plant and providing greater number of irrigations for maintaining proper water storage to the plant (Silva et al., 2013).

The development phase II, both in cane plant as ratoon cane, were the periods had greater need for supplemental irrigation. At this phase the crop has its largest development, requiring more water to conduct gas exchange with the atmosphere (Inman-Bamber and Smith, 2005). Cane plant and ratoon cane cycles showed similar mean values of supplemental irrigation in the development phase II, with 367.3 and 368.8 mm/phase, respectively. The total water sheet varied between 218.7 and 848.9 mm/season, with an average 508.8 mm/season for cane plant and 486.5 mm/season for ratoon cane.

Conclusions

The average level of Water Requirements Needs Index does not demonstrate restrictive factors to the development of sugarcane in cycles cane plant and ratoon cane. Water deficit is the most important factor in agroclimatic risk classification for the cultivation of sugarcane for cycles cane plant and ratoon cane. Paranavaí is able to sugarcane cultivation, but it is possible to save irrigation water during the crop development stage (phase II). Sugarcane in Paranavaí needs supplemental irrigation of 508.8 mm/season to cane plant and 486.5 mm/season to ratoon cane with higher frequency of irrigation in the development phase II.

References

Allen, R. G.; Pereira, L. S.; Raes, D.; Smith. M. 1998. *Crop evapotranspiration: guidelines for computing crop water requirements*. Rome: FAO. http://www.fao.org/3/x0490e/x0490e00.htm

Alvares, C.A.; Stape, J.L.; Sentelhas, P.J.; Gonçalves, J.L.M.; Sparovek, G. 2014. Koppen's climate classification map for Brazil. *Meteorologische Zeitschrift*. 22 (6), 711-728. https://doi.org/10.1127/0941-2948/2013/0507

Brito, A. D.; Libardi, P. L.; Ghiberto, P. J. 2009. Water balance components in soils cropped to sugarcane, with and without nitrogen fertilization. *Revista Brasileira de Ciência do Solo*. 33(2), 295-303. http://dx.doi.org/10.1590/S0100-06832009000200007

Buso, P. H.; Koehler, H. S.; Zambon, J. L.; Ido, O. T.; Bespalhok-Filho, J. C.; Weber, H.; Oliveira, R. A.; Zeni Neto, H. 2009. Sugarcane root system of RB855536 variety planted in one bud and three buds setts. *Scientia Agraria*. 10(5), 343-349. http://dx.doi.org/10.5380/rsa.v10i5.15185

Dantas Neto, J.; Figueredo, J. L.; Farias, C. H.; Azevedo, H. M.; Azevedo, C. A. 2006. Response of sugarcane, second leaf, to irrigation levels and topdressing manuring. *Revista Brasileira de Engenharia Agrícola e Ambiental* 10(2), 283-288. http://dx.doi.org/10.1590/S1415-43662006000200006

EMBRAPA. Centro Nacional de Pesquisa de Solos. 1997. *Manual de métodos de análise de solo*. 2. ed. Empresa Brasileira de Pesquisa Agropecuária. Rio de Janeiro. Brazil. 212 p. https://www.agencia.cnptia.embrapa.br/Repositorio/Manual+de+Metodos_000fzvhotqk02wx5ok0q43a0ram31wtr.pdf

EMBRAPA. Centro Nacional de Pesquisa de Solos. 2009. *Zoneamento agroecológico da cana-de-açúcar*. Rio de Janeiro. Empresa Brasileira de Pesquisa Agropecuária. 55 p. https://www.researchgate.net/publication/301624955_Zoneamento_Agroecologico_da_Cana-de_Acucar_Expandir_a_producao_preservar_a_vida_garantir_o_futuro

Inman-Bamber, N. G. 2004. Sugarcane water stress criteria for irrigation and drying off. *Field Crops Research*. 89(1), 107-122. https://doi-org.ezproxy.unal.edu.co/10.1016/j.fcr.2004.01.018

Inman-Bamber, N. G.; Smith, D. M. 2005. Water relations in sugarcane and response to water deficits. *Field Crops Research*. 92(2-3), 185-202. https://doi.org/10.1016/j.fcr.2005.01.023

Machado, R.S.; Ribeiro, R. V.; Ribeiro-Marchiori, P. E.; São Pedro-Machado, D. F.; Caruso-Machado, E.; de Andrade-Landell, M G. 2009. Biometric and physiological responses to water deficit in sugarcane at different phenological stages. *Pesquisa Agropecuária Brasileira*. 44(12), 1575-1582. http://dx.doi.org/10.1590/S0100-204X2009001200003

Oliveira, E. C.; Freire, F. J.; Oliveira, A. C.; Neto, D. E. S.; Rocha, A. T.; Carvalho, L. A. 2011. Productivity, water use efficiency, and technological quality of sugarcane subjected to different water regimes. *Pesquisa Agropecuária Brasileira*. 46(6), 617-625. http://seer.sct.embrapa.br/index.php/pab/article/view/10222

Rijtema, P.E.; Aboukhaled, A. 1975. *Crop Water Use*. p. 5. In: Aboukhaled, A.; Arar, A.; Balba, A.M.; Bishay, B.G.; Kadry, L.T.; Rijtema, P. E.; Taher, A. *Research on crop water use, salt affected soils and drainage in the Arab Republic of Egypt*. FAO Regional Office for the Near East, 104 p. https://edepot.wur.nl/370376

Silva, M. A.; Jeronimo, E. M.; Lucio, A. D. 2008. Height of cut and harvest period effects on tillering and yield of sugarcane. *Pesquisa Agropecuária Brasileira*. 43(8), 979-986. http://dx.doi.org/10.1590/S0100-204X2008000800005

Silva, V.P.R.; Silva, B.B; Albuquerque, W.G.; Borges, C.J.R.; Sousa, I.F.; Dantas Neto, J. 2013. Crop coefficient, water requirements, yield and water use efficiency of sugarcane growth in Brazil. *Agricultural Water Management*. 128, 102-109. https://doi.org/10.1016/j.agwat.2013.06.007

Singels, A.; Van Den Berg, M.; Smit, M. A.; Jones, M. R.; Van Antwerpen, R. 2010. Modelling water uptake, growth and sucrose accumulation of sugarcane subjected to water stress. *Field Crops Research*.

117(1), 59-69. https://doi-org.ezproxy.unal.edu.co/10.1016/j.fcr.2010.02.003

SEAB. Secretaria da agricultura e do abastecimento. 2015. *Prognosis of sugarcane* 2014/2015. Departamento de Economia Rural. URL: http://www.agricultura.pr.gov.br

Souza, J. L. M.; Jerszurki, D.; Damazio, E. C. 2013. Functional relations between probable and average rainfall in Brazilian regions and climates. *Pesquisa Agropecuária Brasileira*. 48(7), 693-702. http://dx.doi.org/10.1590/S0100-204X2013000700001

Thornthwaite, C. W.; Mather, J. R. 1955. *The Water Balance*. Drexel Institute of Technology, Laboratory of Climatology, Hydrometeorology. 104 p.

Van Genuchten, M. 1980. A closed-form equation for predicting the conductivity of unsaturated soils. *Soil Science Society of American Journal.* 44(5), 892-898. https://doi.org/10.2136/sssaj1980.03615995004400050002x

Vianna, M. S; Sentelhas, P. C. 2014. Simulation of the water deficit risk in sugarcane-crop expansion regions in Brazil. *Pesquisa Agropecuária Brasileira.* 49(4): 237-246. http://dx.doi.org/10.1590/S0100-204X2014000400001

Wrege, M. S.; Caramori, P. H. C.; Gonçalves, A.; Bertonha, A.; Ferreira, R. C.; Caviglione, J. H.; Faria, R. T.; Lourenço, P. S.; Gonçalves, S L. 2005. Potential regions for sugarcane cultivation in the State of Paraná, Brazil, based on frost risk analysis. *Revista Brasileira de Agrometeorologia.* 13(1), 113-122. https://www.esalq.usp.br/departamentos/leb/aulas/lce630_ANTIGA_SENTELHAS/EC_2_2016_2_ZonCana.pdf