Vol. 19(10), pp. 994-1005, October, 2023
DOI: 10.5897/AJAR2023.16449
Article Number: 9EAEE6B71391
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

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African Journal of Agricultural Research

Full Length Research Paper

Irrigation management of sugarcane in the Brazilian Cerrado

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Received 13 July, 2023; Accepted 29 September, 2023

The State of Goiás is the second-largest producer of sugarcane in Brazil. However, it still faces low productivity, primarily due to the lack of sugarcane varieties adapted to this region and its typical water deficit. Therefore, the objective of this work is to evaluate the performance of two sugarcane varieties subjected to different irrigation management practices in the Cerrado of Goiás. The study was conducted at the Federal University of Goiás (UFG) in the experimental area of the School of Agronomy. The experimental design utilized a completely randomized block arrangement in a split-plot design with four replications. The treatments consisted of two sugarcane varieties (RB 92579 and RB 855156) and three irrigation management methods: Rainfed, optimal water range-based and conventional (based on available soil water). These treatments had significant effects on the technological attributes of sugarcane in the Cerrado region of Goiás. Notably, sugarcane plants of the RB 92579 variety exhibited the best results when subjected to irrigation management based on the optimal water range.

Key words: *Saccharum spp*., water deficit, available water.

INTRODUCTION

Brazil is the world's largest producer of sugarcane, followed by India and Australia. In Cerrado Biome, particularly in the States of Goiás and Mato Grosso do Sul in Brazil, there has been an expansion of areas for the cultivation of sugarcane since the end of the last century, and this expansion has intensified more since 2007 (Castro et al., 2010). The State of Goiás is the second largest producer of sugarcane in Brazil. However, in the Cerrado, sugarcane productivity is relatively low, being on average 10% lower than other regions of Brazil, mainly due to a water deficit typical to the region. The effects of water stress on the different stages of development of sugarcane are still not well explained in the scientific literature (Wiedenfeld, 2000). However, it is known that the degree of injury caused by stress depends considerably on the variety, the phenological stage of the plant, and on the duration of stress (Farias et al., 2008). The greater susceptibility of sugarcane to water stress at the higher growth phases causes more severe consequential effects of reducing stem growth rates, phytomass production, and sucrose yield (Simões et al., 2010). In Brazilian cerrado the climate is characterized by a long period of drought and occurrence of summers during the rainy season, thus, in the Cerrado,

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the use of irrigation is an important practice for solving this problem. However, there are few studies on this technique in the production of sugarcane in this region (Simões et al., 2010). It has been observed that conventional sprinkler irrigation techniques bring a satisfactory return when compared to areas conducted without irrigation (Steele et al., 1997). Each irrigation system has specific characteristics with regard to the maintenance of water availability for the crop, which will also depend on the edaphoclimatic characteristics of each region. For sugarcane, drip irrigation has been pointed out as the most advantageous, due to the better use of water and nutrients and the reduction of the weed population, and its less interference in cultural treatments (Steele et al., 1997). The irrigation management of a crop should be based on criteria that allow the application of water to the soil aiming to promote optimal production from an economic point of view (Steele et al., 1997).

Irrigation should be supplied to the soil based on the amount of water taken up by plants, and the timing of irrigation should coincide with the moment when the available soil water reaches a minimum value below which plants begin to show the effects of water deficit, potentially impacting yield. Determining when to irrigate can be achieved through methods that establish threshold values for soil or plant variables (Steele et al., 1997).

In a quantitative approach, efforts are made to define, for irrigation design and management purposes, a percentage of the total soil water availability that can be utilized by the crop (Doorenbos and Pruitt, 1977). The practice of agricultural irrigation has been valued among producers because this technique provides the water demand of crops in periods of drought, bringing productivity to agricultural crops. Irrigation management can be performed by monitoring the climate, crop or available water content in the soil (Bernardo, 1995). Irrigation criteria have been established considering the response of crops to the water factor. However, with no thermal limitations and considering the soil water potential, the resistance to root penetration and the diffusion of oxygen in the soil may also affect plant growth (Letey, 1985).

Thus, depending on the texture and structure of the soil, limitations to plant growth due to reduced aeration or high resistance to penetration may occur within the range of available water (Lapen et al., 2004).

In a soil with a degraded structure, the rate of oxygen diffusion may limit root growth to potentials corresponding to soil moisture at or above field capacity, while excessive resistance to penetration may limit root growth under conditions wetter than the wilting point (Lapen et al., 2004).

The “least limiting water range” (LLWR) is a concept with a single parameter that incorporates, within a water content range, the limitations to plant growth by aeration, available water, and soil resistance to root penetration (Silva et al., 1994).

Water potential is more related to plant growth than available water content (Jensen et al., 1998). Thus, it becomes convenient to express the concept of optimal water range in terms of matrix potential (Boone and Veen, 1994).

Thus, the objective of this work is to evaluate different ways of managing irrigation based on soil water content monitoring in two varieties of drip-irrigated sugarcane in the Cerrado of Goiás.

MATERIALS AND METHODS

Description of the study area

The experiment was carried out at the experimental area of the School of Agronomy at the Federal University of Goiás (UFG), in a sugarcane field, during two harvests (plant cane and first ratoon). The city of Goiânia is at 16º35' S and 49º16' W, at 722 m of altitude.

Weather condition during the study period

The climate of the region, according to the Köppen classification, is Aw (tropical and rainy), characterized by two well-defined periods: a rainy season between October and April, where about 90% of the total annual precipitation occurs, and a dry season from May to September, with low levels of precipitation. The average annual temperature is 22.3ºC, and the minimum and maximum annual temperature averages are 17.1 and 29.2ºC, respectively. The coldest months are June and July, when the average temperature is around 19ºC, with a minimum of 12ºC and a total average annual rainfall of 1,488.5 mm, an average total for the wettest month of 299 .3 mm and 0.0 mm for the driest month, while the average annual total insolation is 2,318.9 h (Alvares et al., 2013). The relative air humidity is low from July to September, causing evaporation levels above 250 mm per month. During the experiment, on average, the meteorological elements remained close to the values recorded in the climatological normals.

Soil

The soil where the experiment was installed was classified as Dystrophic Red Latosol, with clayey texture (Embrapa, 2009), and particle size composition of 614.4 g of clay, 77.8 g of silt, and 307.8 g of sand kg^{-1} soil.

For soil chemical characterization in the experimental area, samples were collected from the layers 0 to 20 cm and 20 to 40 cm. The analyses were carried out at the UFG soil analysis laboratory (Table 1). Among the various types of soils found in state of Goiás, the latosol is the most frequent, occupying more than 50% of the entire extension of Goiás (Barbalho et al., 2013), with characteristics similar to the soil used in this experiment.

Treatments and experimental design

The experiment was conducted using a completely randomized blocks in a split-plot design with four replications. The treatments consisted of two varieties of sugarcane (RB 855156 and RB 92579) and three ways of carrying out irrigation management viz., (a) rainfed, b) based on the optimum water range, and c) conventional based on the water available in the soil. The sugarcane varieties

Table 1. Soil chemical characteristics in the experimental area of the layer from 0 to 0.20 m.

OM	pH (H_2O)	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	CEC
g dcm^{-3}		mg dm^{-3}			cmolc dm^{-3}		
7.0	5.2	9.6	99	2.0	0.9	0.0	6.4
V	**S**	**$P_{Reman.}$**	**Zn**	**Fe**	**mn**	**Cu**	**B**
%	mg dm^{-3}	MG L^{-1}			mg dm^{-3}		
51.7	22.7	13.6	4.4	18.2	20.3	24.6	0.4

pH in H_2O: ratio 1:2.5. CEC: cation exchange capacity. P, K, Fe, Zn, Mn, Cu: Mehlich extractor^{-1}. Ca^{2+}, Mg^{2+}, Al^{3+}: KCl 1 mol L^{-1}. H + AL: method $Ca(OAc)_2$ 0.5 mol L^{-1}, pH 7. Organic matter: Organic C x 1.724 – Walkley Black.

were assigned to the main plot while the irrigation management treatments were assigned to the sub-plots.

The experimental plots were consisted of twelve rows of sugarcane spaced 1.5 m apart, with a length of 15 m. The net area of the plot was 270 m^2, and each block consisted of two plots occupying an area of 540 m^2. The experiment total area was 2,160 m^2.

Irrigation system

In state of Goiás, sugarcane has been irrigated using sprinkler irrigation systems; center pivot and microsprinkler (drip) (Barbosa et al., 2012). The application of water was done using a drip irrigation system that supplied water in a continuous strip of soil. The system consisted of a motor-pump set, a disc filter, a fertilizer injector, an irrigation controller, pressure gauges, and connections. It included a main line of 32-mm polyethylene hoses and lateral lines of drip tubes with a 16 mm external diameter. The self-compensating emitters used were of the 'in-line' type, with a flow rate of 1.6 L h^{-1}. The piping of lateral lines was made of low-density polyethylene, with an external diameter of 16 mm and an internal diameter of 13 mm. At the entrance of each sub-plots, a control head was installed which was equipped with suction and anti-vacuum valves and a solenoid valve. This setup helps the isolation between treatments in order to allow water and fertilizers to enter only the desired lateral lines. The fertilization of the plants was performed using a fertilizer injector that is part of the drip irrigation system.

Irrigation management

Irrigation management was carried out by monitoring the water content in the soil with the aid of gas-permeated moisture sensors coupled to a Hidrosense MRI irrigation controller. Irrigations were carried out daily, and the applied water depths were calculated to raise the soil moisture to the corresponding field capacity in the case of conventional management and to raise the humidity corresponding to the upper limit of the optimum water range (LLWR) in the case of the LLWR-based management. Irrigations were carried out in full, with interruption of water application at the end of the cycle for the crop to accumulate sugar (Vieira et al., 2013).

To ensure uniformity in the supply of water to treatment plots, periodic tests were carried out to verify the uniformity of water distribution in the system using the methodology of Merrian and Keller (1978), thus estimating the Christensen uniformity coefficient.

Procedure for determining the optimum water range

Before planting sugarcane, soil samples were taken at three points along a diagonal line within each plot, 6.6 m apart from each other and at the extremes 2 m from the edge of the plot. Six undisturbed soil samples were collected per plot at a depth of 0 to 0.3 m with cylinders measuring 6.40 cm in diameter and 2.50 cm in height.

To determine the LLWR, curves of water retention and resistance to soil penetration were plotted. To obtain the curves, the undisturbed samples were initially saturated and then subjected to the following voltages: 0 hPa (saturated), 60 and 80 hPa in a tension table, and 100, 330, 600, 1,000 and 15,000 hPa obtained in a Richards chamber (Embrapa, 2009). The retention curve was fitted by non-linear regression using the mathematical model as described by Genuchten (1980). After reaching equilibrium in each of the specified stresses, the masses of samples were obtained. They were later used to carry out soil penetration resistance (PR) measurements using an electronic bench penetrometer. The soil penetration resistance curve was fitted using the function proposed by Busscher (1990).

The LLWR was determined using the procedures described by Silva et al. (1994) considering critical moisture values associated with matric potential, soil resistance to penetration, aeration porosity, and permanent wilting point.

Evaluation of the experiment and statistical analysis

At harvest, stalk population weight was determined manually form each experimental net plot area and then converted to hectare basis. Soon after taking the weight, ten stalk samples were taken to laboratory and the following quality parameters were determined: i) soluble solids content of the juice (BRIX, %), ii) sucrose content (POL, %), iii) juice purity (quantification), iv) fiber (quantification), vi) total recoverable sugars (TRS), and vi) ton of POL per hectare – TPH (obtained by multiplying the POL value by the actual productivity).

Data analysis

Data of the evaluated characteristics were submitted to analysis of variance by F test at 1 and 5% probability. When there was a significant effect in the analysis of variance, the data obtained were submitted to Tukey test at 5% probability.

RESULTS AND DISCUSSION

Soil physical attributes and optimal water range

As for the soil physical attributes, the particle density was 2.60 Kg m^{-3} and the soil density was 1.45 Kg m^{-3}. The

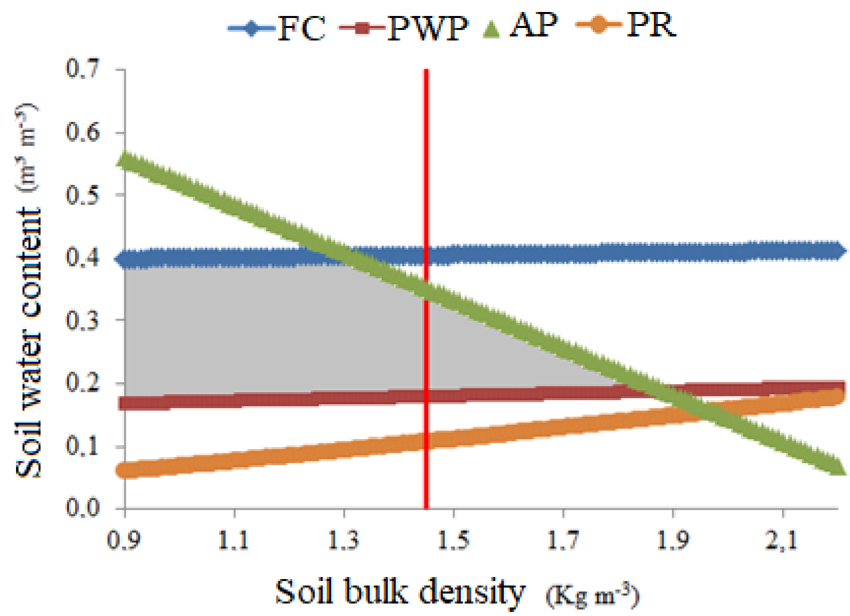

Figure 1. Variation of volumetric moisture according to soil bulk density for critical levels of field capacity (FC), aeration porosity (AP), permanent wilting point (PWP), and soil mechanical resistance to penetration (PR). The shaded area represents the optimum soil water interval and the red line represents the variation of moisture at the density of 1.45 kg m^{-3}.

value of soil density in the experimental area shows that the surface layer of the soil might have been compacted. According to Klein (2006), the average density of clayey soils predominant in the Brazilian Cerrado should range in between 0.9 and 1.3 Kg m^{-3}. In sugarcane cultivation, compaction is commonly caused by machine traffic during planting, cultural practices, harvesting and transport, with a consequent reduction in macroporosity, which ultimately leads to increase in soil density resulting in a decreases in water infiltration and penetration, and growth of the plant root system (Soane and Ouwerkerk, 1994). The ability of roots to penetrate the soil profile decreases as soil density and strength increase. In soils with low moisture, soil cohesion and resistance to penetration increase and the hydrostatic pressure of root cells decreases, with consequent reduction of force in the root cap and in the meristematic region, to overcome soil resistance (Hamza and Anderson, 2005). In general, 2.0 to 2.5 MPa is considered a critical soil resistance range, with a significant reduction in root growth (Taylor, 1971).

Sugarcane is the most affected crop by changes in soil physical conditions as a result of mechanized harvesting, and compaction may promote reductions of more than 50% in the volume of soil macropores. In turn, this structural change may affect the sustainability of this agricultural activity, as this class of pores determines the rate of water movement in the soil (Severiano et al., 2010).

Moisture values related to field capacity, resistance to penetration, and permanent wilting point increased with increasing soil bulk density, while soil moisture relative to aeration porosity decreased with increasing soil bulk density (Figure 1). The upper limit of the OWR, up to the density of 1.27 kg m^{-3}, was the relative moisture at field capacity. After this density value, the upper limit was aeration porosity. The critical density at which the LLWR equals to zero was 1.80 kg m^{-3}. The average stresses in equilibrium with the moisture corresponding to field and aeration capacity were -5.6 and -7.4 kPa, respectively.

The aeration porosity being the limiting factor in the concept of the optimum water range (LLWR) shows that aeration in the region of the root system of irrigated plants, based on the LLWR concept, was satisfactory, while in irrigated plants, based on the conventional management, it may have led to a deficiency in soil aeration. It is noteworthy that in inadequate conditions of soil aeration, it may compromise the normal growth of roots, which tend to concentrate in the superficial layer of the soil, affecting the development of plants (Weaich et al., 1992). In the case of sugarcane, when the root system is concentrated in the surface layer of the soil, plants may fall over and lose mass in stems, with a consequent reduction in stem productivity. This may also make mechanical harvesting difficult (Carlin et al., 2008).

Satisfactory soil aeration ensures an ideal environment for the development of roots since the plant requires energy in both the respiration of maintenance of the biomass and the growth. Enabling gas exchanges between soil and atmosphere, the soil oxygen, through root respiration, may intensify the processes involved in

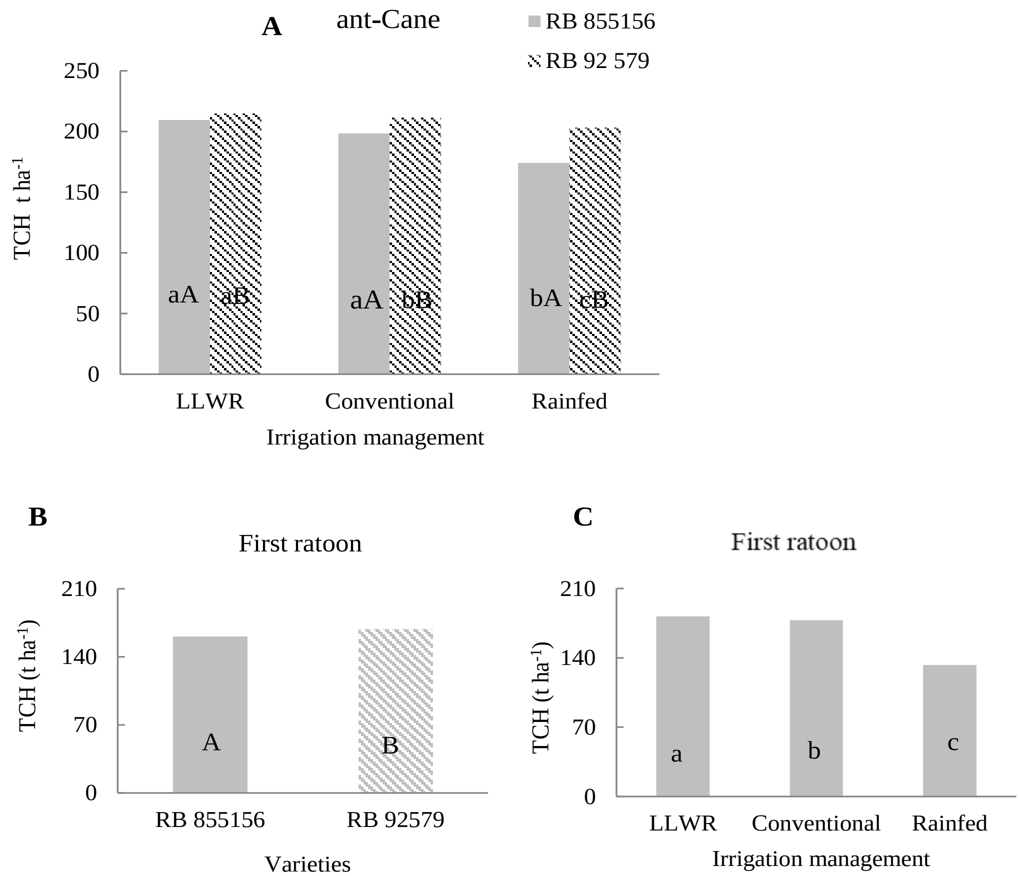

Figure 2. Sum of the mean yield values (TCH) as a function of irrigation management and varieties. Different uppercase letters indicate differences between varieties (P<0.05) and different lowercase letters indicate differences between managements (P<0.05).

meeting the energy demand required to elongate and expand roots in order to absorb and accumulate more nutrients (Ferri, 1985).

Based on these results, average daily irrigation times for the RB 855156 variety were 1:25 in conventional management and 1 h in management based on the LLWR. For the RB 92579 variety, the average daily irrigation times were 1:10 and 50 min in the conventional management and based on the LLWR, respectively. The shorter irrigation time between the two varieties of sugarcane irrigated based on the optimal water range can result in greater savings in water and electricity consumed in pumping water, with a consequent reduction in the cost of production. Marques et al. (2006) studied the economic viability of irrigation in Piracicaba and found for the central pivot type equipment a share of 38.36% of the cost with pumping water in the annual variable cost.

Stem productivity - TCH

For the first cycle, the best result in TCH from the interaction between the irrigation managements and the varieties when the RB 92579 variety was irrigated based on the LLWR management, resulted in a value of 214.81 t ha^{-1}. The lower productivity (174.08 t ha-1) occurred with the cultivation of the RB 855156 variety under rainfed conditions. For the second cycle, the TCH were 182.02, 178.16, and 132.84 t ha^{-1} when plants were irrigated by managements based on LLWR, conventional and rainfed, and 168.06 and 160.06 t ha^{-1} for the RB 92579 and RB 855156 varieties, respectively (Figure 2).

The best performance of the RB 92579 variety, when irrigation management was carried out based on the LLWR, might have been due to the fact that the plant maintained the turgor of its cells, allowing the continuity of the processes of plant growth, expansion, cell division, and photosynthesis and, as a consequence, increased productivity of stems (Inman-Bamber and Smith, 2005).

The higher productivity of stems of the RB 92579 variety, like its growth, when plants received irrigation water managed according to the LLWR, might have been occurred due to the condition of better soil aeration provided by this management. The range of the LLWR also indicates a risk of crop exposure to soil physical stress and the magnitude in which the structural condition

Table 2. Mean squares for ºBrix, fiber (%), juice purity, juice POL (%), TRS and TPH of sugarcane varieties irrigated under different irrigation managements.

VF	DF	ºBrix	Fiber (%)	Juice purity (%)	Juice POL (%)	TPH (t ha^{-1})	TRS (Kg t^{-1})
Plant-cane							
Blocks	3	0.01^{ns}	0.08^{ns}	0.89 ^{ns}	0.03^{ns}	1.56^{ns}	1.96^{ns}
Varieties (V)	1	4.72**	1.90**	165.58**	21.62**	80.77**	954.82**
Error 1	3	0.07	0.03	2.47	0.07	0.36	5.30
Irrigation (I)	2	7.80**	0.97**	3.44^{ns}	12.70**	297.76**	741.80**
VxI	2	1.99**	0.06^{ns}	1.15^{ns}	3.48**	2.42^{ns}	189.82**
Error 2	12	0.03	0.07	6.90	0.03	1.23	2.69
Total	23						
CV1 (%)		1.29	1.56	1.73	1.42	2.19	1.43
CV2 (%)		0.84	2.13	2.89	1.00	4.03	1.02
General Mean		21.19	12.13	90.90	19.34	27.56	161.50
1ª Ratoon							
Blocks	3	0.006^{ns}	0.23^{ns}	0.87^{ns}	0.035^{ns}	0.84^{ns}	2.05^{ns}
Varieties (V)	1	4.95**	1.74**	162.18**	22.17**	44.28**	991.89**
Error 1	3	0.07	0.10	2.43	0.076	0.19	5.51
Irrigation (I)	2	8.16**	1.79**	3.37^{ns}	12.98**	163.35**	770.64**
VxI	2	0.03**	0.12 ^{ns}	1.13^{ns}	3.53**	1.33^{ns}	197.26**
Error 2	12	2.08	0.74	6.75	0.04	0.67	2.79
Total	23						
CV1 (%)		1.29	1.57	1.73	1.42	2.18	1.43
CV2 (%)		0.84	2.14	2.89	0.99	4.03	1.02
General Mean		21.68	11.66	89.97	19.54	20.42	164.60

Significant ($P < 0.05$); **significant ($P < 0.01$); ns: not significant.

restricts plant productivity (Silva et al., 1994). Soils with preserved structure present restrictions only in terms of water deficit. However, when compaction reaches excessive levels, aeration becomes deficient under conditions of high water content, and soil resistance to root penetration which can restrict plant productivity by soil drying (Lapen et al., 2004).

The production of stems per hectare expressed in tons (TCH) indicates a longevity potential of the sugarcane field. This is a fundamental characteristic for the crop economy, as it represents a longer interval between planting and renewal of the area. According to Silva et al. (2010), an economically productive sugarcane field must be conducted for at least five to six cuts or until the average productivity reaches around 65 t ha^{-1}. Therefore, the irrigation managements proposed in this work, with emphasis on the LLWR, provided a productivity expectation well above the minimum required for area renewal, indicating that these varieties under this management could be more profitable due to their reduction in operating renovation costs.

As for the lower productivity achieved with the RB 855156 variety when cultivated in rainfed conditions, confirms that this variety does not adapt to the water deficit conditions that may occur in the dry season of the Cerrado. Low water availability negatively affects the growth of agricultural crops and is the main cause of low productivity (Flexas et al., 2006). Plants tend to reduce water loss by partially closing stomata, which prevents the reduction of water potential under conditions of water deficit. With water potential values in the plant leaf around -1.3 MPa, cell elongation is practically zero, and leaf elongation is more affected by lack of water than stem elongation is (Inman-Bamber and Jager., 1986). Water deficiency also causes a marked leaf senescence and restriction to the emergence of new leaves. The degree of these changes is due to the intensity of water stress and depends on the variety (Smit and Singels, 2006).

Technological attributes of sugarcane

In the first and second planting cycles, there was a significant interaction between the treatments as for the soluble solids content (°Brix) found in the sugarcane juice (Table 2). The best result obtained in both years was when plants were irrigated based on LLWR management, while the worst when no water was supplied through irrigation. However, the interaction in both years produced

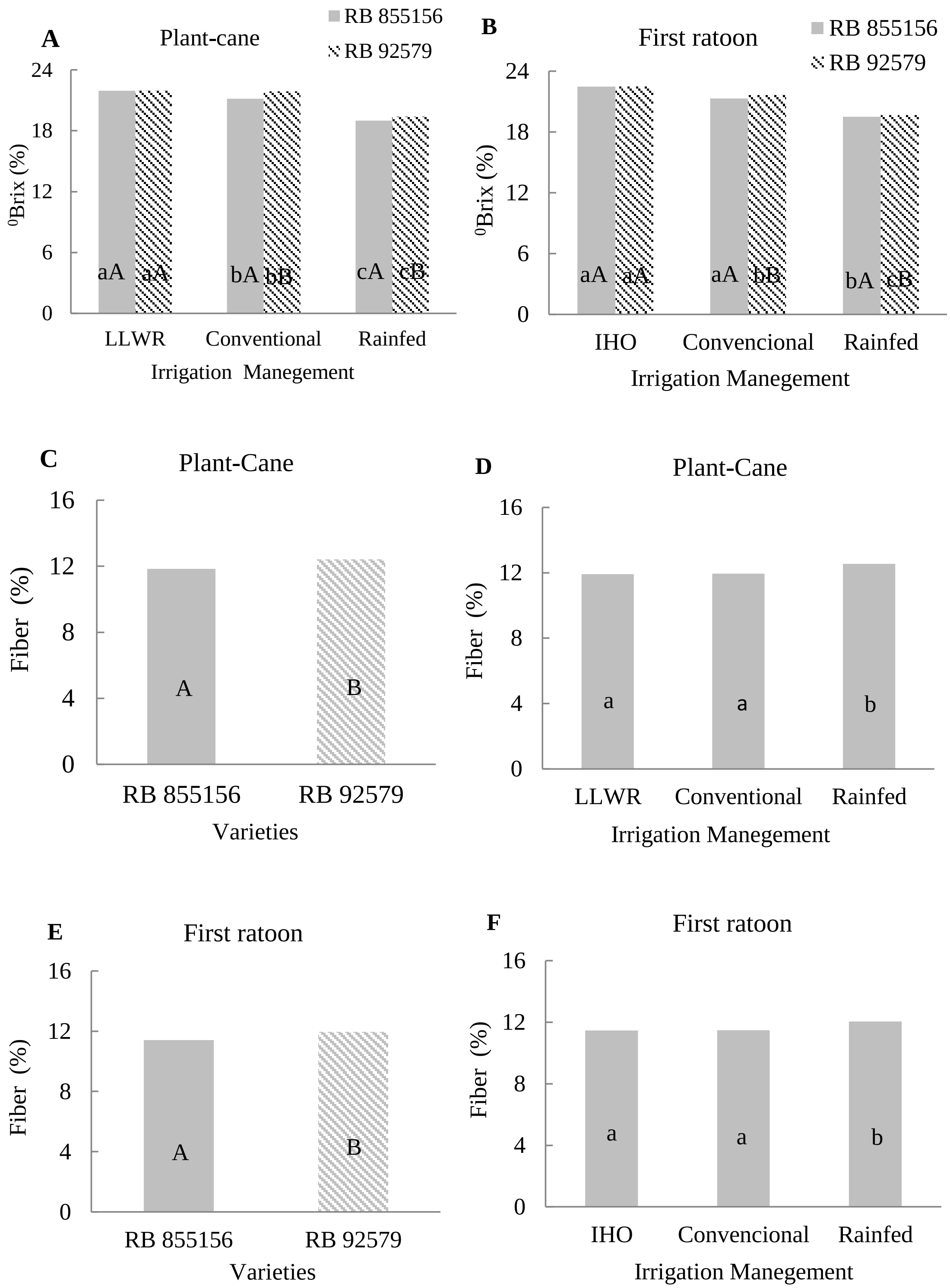

Figure 3. Variation of total soluble solids (°Brix) in sugarcane juice and fibers as a function of varieties and irrigation management. Different uppercase letters indicate differences between varieties (P<0.05) and different lowercase letters indicate differences between managements (P<0.05).

a non-significant differences between the varieties when plants were irrigated based on the LLWR (Figure 3). It should be noted that °Brix is also a parameter adopted by CONSECANA to assess the ripening and the quality of sugarcane for industrial purposes.

On average, the °Brix value recorded for the juice of the two varieties irrigated based on the LLWR in the two cycles were 21.96%, that is, 8.96% which were higher than the recommended minimum (13%) for sugarcane to present conditions for sample collecting for a detailed technological analysis (Barbosa et al., 2012). The water availability during the phenological cycle of the crop probably favored the progressive accumulation of sucrose in the isodiametric cells of the stem parenchymal tissue, reflecting on the recorded °Brix value (Silva et al., 2004). With irrigation, there is an increase in the solubility and transport of minerals in the soil solution towards the roots of plants. Therefore, this positive effect may also be a consequence of a greater absorption of calcium and magnesium by the plant made available by fertilization. As a result, this allowed the maintenance of the soil pH close to 6.0, favoring and reducing the toxic effects of Al, Mn and Fe, with an increase in the cation exchange capacity (CEC) and soil microbial activity (Souto et al., 2008), which might have contributed to a greater plant nutrition acquisition and increase in juice quality.

The percentage of fiber present in sugarcane stems was influenced by the treatments evaluated in the two evaluation cycles (Figure 3). On average, the percentages of fibers found in stems differed in the two evaluated sugarcane varieties, with RB 92-579 and RB 85-5156 values of 11.62 and 12.17%, respectively. The fiber percentage values found in stems of irrigated plants were the same statistically but differed from those found in rainfed plants. On average, the percentage of fibers in irrigated plants was 11.7% and in non-irrigated plants it was 12.17%.

Technologically, the stem is composed of fiber and juice. Fiber refers to the water-insoluble matter found in sugarcane (Silva et al., 2004). The fundamental tissue within the stem is the parenchyma or supporting tissue, which contains cells primarily responsible for storing sucrose (Oliveira et al., 2012). In addition to storing sucrose, the fibrous component provides support to stems and plays an important role in the industrial process of juice extraction and in the co-generation of energy (Silva et al., 2004). The percentages of fibers achieved with the treatments evaluated in this study were close to the ideal range for sucrose extraction (11 to 13%) (Table 2). This percentage of fiber is also sufficient to produce bagasse with properties that maintain the calorific value of boilers. Fiber content in sugarcane below 10.5% is undesirable, as it leads to a low energy balance in the mills, necessitating the burning of a greater amount of bagasse to maintain the calorific value in boilers (Silva et al., 2004). It should also be noted that when sugarcane has low fiber content, the plant will be exposed to mechanical damage during haulage, which favors contamination and losses cane quality. Low fiber contenting cane can also lead to lodging or breakage of the stem, which ultimately results in losses at the time of mechanized harvesting and loss of sugar in the water during the washing process (Barbosa et al., 2012). Furthermore, a plant with low fiber content may be susceptible to the penetration of microorganisms into the stem through cracks, with a consequent contamination and even stimulating the production of dextrans, which affects the quality of sugar and the industrial efficiency (Oliveira et al., 2012).

The influence of irrigation on fiber percentage may have favored carbon assimilation in the plant as well as the synthesis and translocation of proteins and carbohydrates, which resulted in an increase in the amount of sucrose in plant cells, thereby reducing the total reducing sugars in the juice (Korndörfer, 1990). In addition, the greater hardness of stems induced by the application of irrigation might have contributed to the resistance to the cane during the different phenological stages against the pests and diseases. This becomes an important quality characteristic of sugarcane as it constitutes an obstacle to the attack of pests such as *Diatraea saccharalis* (Campos and Macedo, 2004).

As for juice purity, in the two cycles, there was a significant difference only for the evaluated sugarcane varieties, while the percentage of apparent sucrose in the juice (pol) was influenced by the interaction of treatments (Figure 4).

On average, the juice purity of the RB 92579 and RB 855156 varieties was 93.05% and 87.83%, respectively. These values are considered adequate for the production of sugar and alcohol (Segato et al. 2006). Sugarcane juice purity above 80% indicates a product free of substances that have optical activity, such as reducing sugars, polysaccharides, and some proteins (Segato et al., 2006).

The purity of the sugarcane juice is directly related to the soluble solids content of the juice (Brix). Therefore, the lower purity content in the juice of the RB 85-5156 variety may be the conditioning factor for the low values of this attribute.

In percentage of apparent sucrose, the best result was obtained from the RB 92579 variety irrigated using the LLWR management (mean of 19.1%), while the lowest result was obtained in the variety RB 855156 cultivated in rainfed conditions (average 6.61%).

The superiority of the POL characteristic of the juice of the RB 92579 variety irrigated through LLWR management indicates a behavior in maturity of this variety, which can be harvested early because it presents greater accumulations of sucrose at the same time of the cycle of the RB 855156 variety. On the other hand, the RB 855156 variety, with lower rates of sucrose accumulation in its stem, is suitable for mid-late harvest. The lower percentage of sucrose found in the juice of the RB 855156 variety, when cultivated in the rainfed system, can be attributed to the water deficit that occurred during cultivation. In line with this, Guimaraes et al. (2008) reported that the sucrose content (POL) of this variety is negatively influenced by water deficit conditions.

For sugar productivity (TPH), in both cycles there was

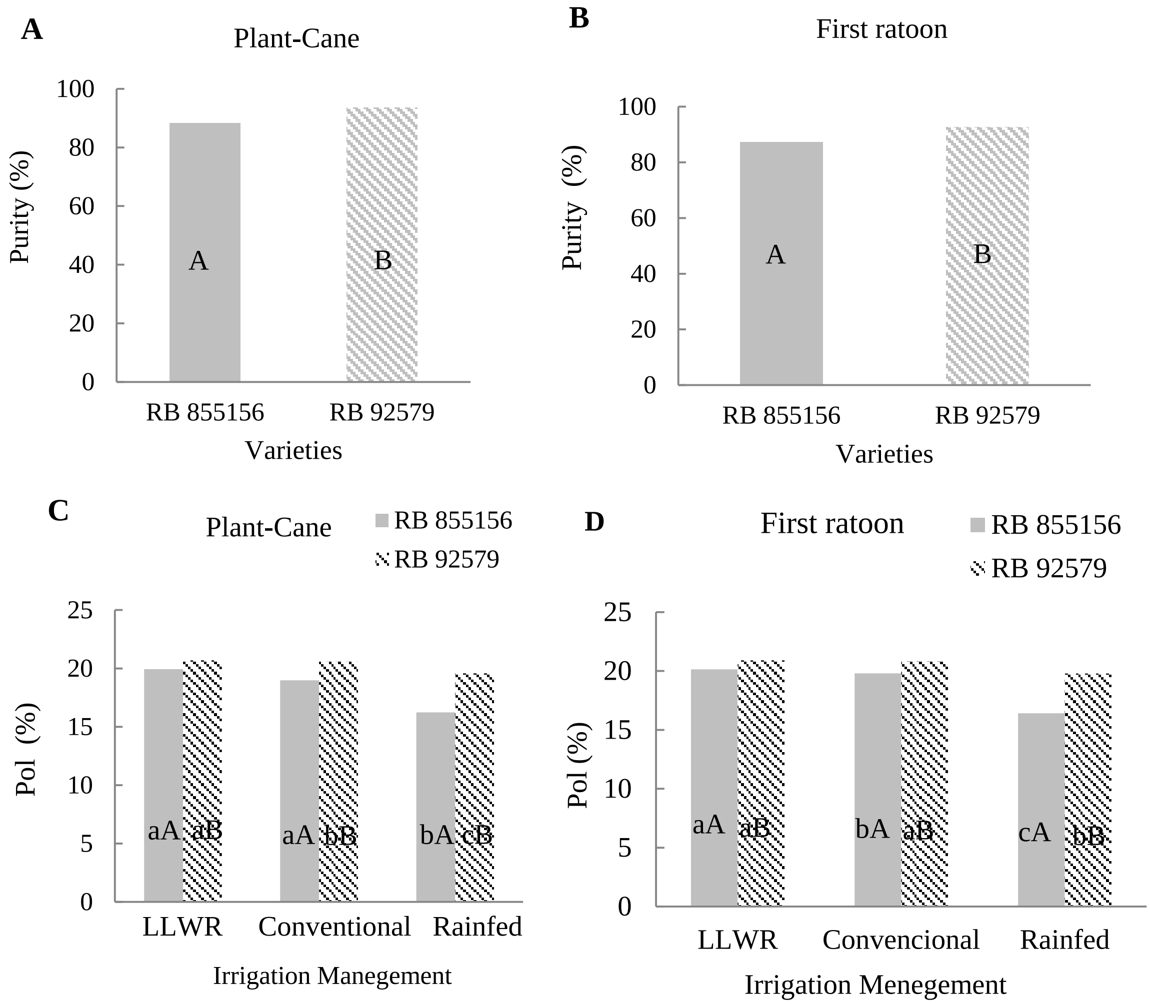

Figure 4. Purity and percentage of apparent sucrose in the juice (POL) of sugarcane as a function of irrigation management and varieties. Different uppercase letters indicate differences between varieties (P<0.05) and different lowercase letters indicate differences between managements (P<0.05).

an independent effect of irrigation management and varieties. The cultivation of the RB 92579 variety and the use of LLWR irrigation management are the factors that provided the best results (Figure 5). The sugar yield of the RB 92579 variety was 23.76 kg ha^{-1}; when the plants were irrigated based on LLWR management, it was 27.81 kg ha^{-1}. It is noteworthy that high TPH values (greater than 20 kg ha^{-1}) show a great economic viability in industrial processing (Landell and Bressiani, 2008).

As for the TRS, there was a significant difference among treatments (Figure 5). The RB 92579 variety irrigated using LLWR management showed the highest amounts of TRS in both cycles (average of 173.4 kg of sugar t^{-1} of cane), while the RB 855156 variety showed the lowest result when cultivated in rainfed conditions (average of 140.62 kg of sugar t^{-1} of cane).

The reduction in TRS production when plants were irrigated based on conventional management, as already reported, can be attributed to the lack of adequate aeration of the root system, with a consequent reduction in the respiration capacity of roots. This can occur both in tolerant and non-tolerant plants, which inhibit the formation of leaf primordia and lead to a decrease in leaf expansion (Lizaso et al., 2001). It should be noted that, in sugarcane, sucrose synthesis is carried out first in the leaves and subsequently translocated to stems (Oliveira et al., 2012). Therefore, the reduction in the leaf area of plants cultivated under these conditions might have been resulted from the reduction in the production of TRS in rainfed and irrigated areas based on conventional management.

It is also noteworthy that the plants cultivated in rainfed conditions, during the summer periods, may have been subjected to water deficit conditions, with a consequent reduction in TRS production (Figure 5). If water deficit occurs in a period of rapid crop development, as

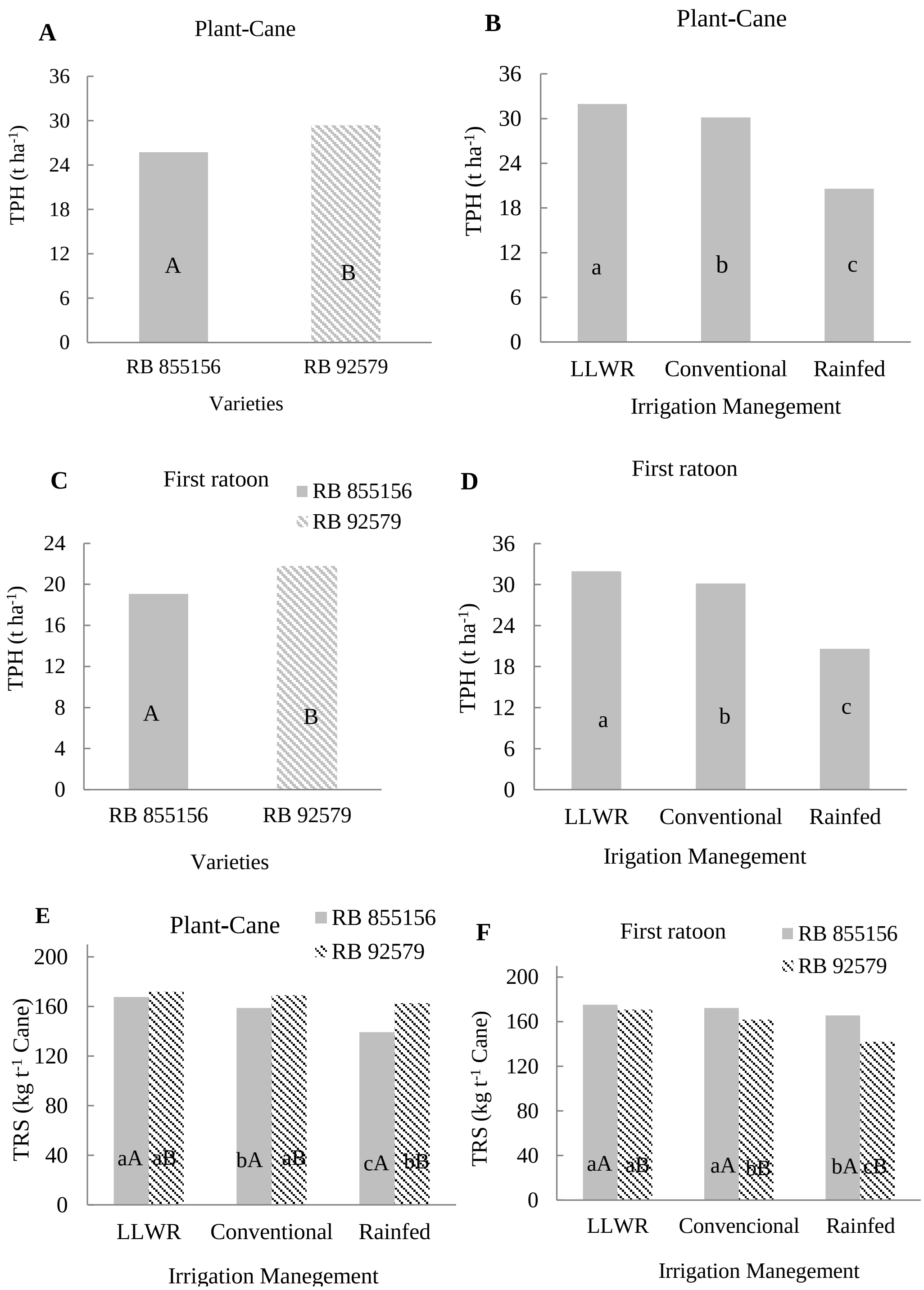

Figure 5. Mean values of TPH and TRS in the deployment of irrigation management and varieties. Different uppercase letters indicate differences between varieties (P<0.05) and different lowercase letters indicate differences between managements (P<0.05).

observed in this work, the increase in the leaf area increases the plants' need for a greater amount of water in order to exchange gases with the atmosphere (Pires et al., 2008). Inman-Bamber and Smith (2005) report that the susceptibility of sugarcane to water deficit is greater when plants are in the stem elongation phase, which causes serious damage to phytomass production and sucrose yield (Silva et al., 2004).

Therefore, the higher production of TRS recorded in irrigated plants based on OWR management, compared to plants cultivated in a rainfed regime, may be associated with the maintenance of soil aeration and full irrigation management, which intensifies tillering and elongation of stems and, consequently, anticipates the physiological maturation of sugarcane and promotes the increase of sucrose levels in the cells of the stem (Tognetti et al., 2003). It should be noted that in Brazil, sugarcane has been marketed based on its qualitative indices.

The better the quality of the raw material, the higher the price paid per ton of stems. All indexes discussed in this work are used as a calculation source to determine the amount of total recoverable sugars, expressed in kg of TRS t^{-1} of sugarcane. The results of this research show that the quality of the raw material can be improved with the use of an irrigation management and a variety more adapted to the environment.

Conclusion

The treatments caused significant effects on the technological attributes of sugarcane in the Cerrado region of Goiás. Plants of the sugarcane variety RB 92579, when irrigated based on the optimal water range management, present the best results.

For soil density value of 1.45 Kg m^{-3} the upper limit of the LLWR was the aeration porosity and the lower limit was the permanent wilt point.

The sugarcane variety RB 92579 was more adapted to the soil and climate conditions of the Brazilian cerrado, when compared to the RB 855156 variety. Due to the variability of soil structure, water management in irrigated agriculture, for the purpose of optimal production of sugarcane, must take into account not only the conventional limits of the water availability range but also the other factors incorporated into the LLWR.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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