Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)
http://dx.doi.org/10.1590/1983-21252018v31n419rc

SUGARCANE CROPS WITH CONTROLLED WATER DEFICIT IN THE SUB-MIDDLE SÃO FRANCISCO VALLEY, BRAZIL[1]

WELSON LIMA SIMÕES[2]*, MARCELO CALGARO[2], MIGUEL JULIO MACHADO GUIMARÃES[3], ANDERSON RAMOS DE OLIVEIRA[2], MÍRIAN PAULA MEDEIROS ANDRÉ PINHEIRO[4]

ABSTRACT - Sugarcane is one of the most affected crops by water scarcity. The efficient use of the irrigation water is an alternative to minimize this problem. The objective of this work was to evaluate biometric parameters, yield, and technological quality of sugarcane plants subjected to different controlled water deficit regimes in the sub-middle São Francisco Valley, Brazil. The experiment was conducted in a randomized block design, in two crop cycles, with three replications, with ten treatments consisted of three controlled water deficits (15%, 30%, and 45% of the crop evapotranspiration - ETc), applied at three development stages of the plant—sprouting and tillering (Stage I), grand growth (Stage II), and maturation (Stage III)—and a control with 100% of the ETc throughout the entire crop cycle. The controlled water deficit did not affect the technological quality of the sugarcane in any development stage. The sugarcane yield was higher when using a controlled water deficit of 30% of ETc in the sprouting and tillering stages of the plants. The water deficit of 15% of ETc is recommended for the grand growth, or maturation stages of the sugarcane plants for a greater water use efficiency of the production system.

Keywords: *Saccharum officinarum* L.. Irrigation management. Technological quality. Water use efficiency.

CULTIVO DA CANA-DE-AÇÚCAR COM DEFICIT HÍDRICO CONTROLADO NO SUBMÉDIO DO VALE SÃO FRANCISCO

RESUMO - A cana-de-açúcar é uma das culturas que mais sofrem com a escassez hídrica e, para minimizar esse problema, uma das alternativas é o uso eficiente da água de irrigação. Objetivou-se com este trabalho avaliar os parâmetros biométricos, produtividade e qualidade tecnológica da cana-de-açúcar submetida a diferentes regimes de deficit hídrico controlado, na região do Submédio do Vale do São Francisco. O delineamento experimental utilizado foi em blocos casualizados, com 10 tratamentos e três repetições, sendo três deficits hídricos controlados (15; 30; e 45% da evapotranspiração da cultura - ETc), aplicados nas três fases de desenvolvimento da planta (Fase I - brotação e perfilhamento, Fase II - desenvolvimento e Fase III - maturação) e tratamento controle com 100% da ETc, realizados em dois ciclos de cultivo. A qualidade tecnológica da cana-de-açúcar não foi alterada em função do deficit hídrico controlado nas diferentes fases de desenvolvimento. A produtividade da cana-de-açúcar foi maior utilizando-se deficit hídrico controlado de 30% da ETc na fase de brotação e perfilhamento de desenvolvimento da cultura da cana-de-açúcar. A fim de se garantir maior eficiência do uso da água pelo sistema produtivo, recomenda-se a aplicação de uma lâmina com deficit hídrico de 15% da ETc, nas fases de maior desenvolvimento ou maturação do ciclo da cultura.

Palavras-chave: *Saccharum officinarum* L.. Manejo de irrigação. Qualidade tecnológica. Eficiência no uso da água.

*Corresponding author
[1]Received for publication in 02/20/2017; accepted in 03/12/2018.
Paper extracted from research project.
[2]Embrapa Semiárido, Petrolina, PE, Brazil; welson.simoes@embrapa.br – ORCID: 0000-0003-1474-9410, marcelo.calgaro@embrapa.br – ORCID: 0000-0002-4995-5946, anderson.oliveira@embrapa.br – ORCID: 0000-0003-4089-0995.
[3]Department of Agricultural Engineering, Universidade Federal Rural de Pernambuco, Recife, PE, Brazil; mjmguimaraes@hotmail.com – ORCID: 0000-0002-5497-6442.
[4]Department of Rural Engineering, Universidade Estadual Paulista, Botucatu, SP, Brazil; medeirosmirian@yahoo.com.br – ORCID: 0000-0002-5317-6160.

INTRODUCTION

The semiarid region of the Northeast of Brazil has peculiar soil-climatic characteristics, with low fertility soils, and irregular distribution of rainfall, limiting agricultural production. However, it has a high incidence of solar radiation, showing high yield potential for sugarcane crops when using a correct irrigation management (OLIVEIRA; BRAGA, 2011).

Sugarcane (*Saccharum officinarum* L.) is a C4 plant, consequently, it has a competitive and efficient photosynthetic apparatus, even in conditions of high temperatures and limited water (LOPES et al., 2011). Its crop water requirements are different depending on the development stage. The development stages of sugarcane are sprouting and tillering, characterized by slow growth (Stage I); grand growth, when the plant height increases rapidly, and accumulated dry matter reaches 75% (Stage II); and maturation, characterized by slow growth and accumulation of 11% of the total dry matter (Stage III) (INMAN-BAMBER; SMITH, 2005). Irrigation technologies are used to meet the sugarcane water requirements and ensure its good sprouting and development in semiarid regions. Silva et al. (2012) evaluated an irrigated sugarcane crop in the São Francisco Valley, Brazil, and found satisfactory tillering. Moreover, sugarcane crops in semiarid regions of Brazil have high biomass accumulation when grown under irrigated conditions (SILVA et al., 2014a).

Irrigation management strategies with controlled water deficit, without compromising the crop yield, can save water, energy, and labor, avoiding wasting water, which is a highly limiting and costly factor in the semiarid region (OLIVEIRA et al., 2016a). Thus, information on the effects of water deficit on the physiology of this crop is essential for an irrigation management capable of increasing water use efficiency (AZEVEDO et al., 2011).

Water deficits during the sugarcane crop cycle were studied by several authors using different irrigation depths, showing positive trends for the plant morphophysiological and productive parameters with increasing water availability (MAURI, 2012; PEDROZO et al., 2015). However, some cultivars respond differently, with greater development and productivity when subjected to irrigation depths lower than 100% of evapotranspiration (RODOLFO JÚNIOR et al., 2016; OLIVEIRA et al., 2016a). Controlled water deficit is one of the strategies used in irrigated crops to improve and synchronize some physiological stages and, consequently, to achieve greater yields. Irrigation management strategies such as controlled water deficit can be an alternative of great success potential in sugarcane crops, since these plants have well-defined development stages that can be used to define the water deficits. However, analyzing the water use efficiency is important, since defining a low water depth at a certain stage that does not alter the sugarcane yield may not result in the best water use efficiency.

Thus, the objective of this work was to evaluate biometric parameters, yield, and technological quality of sugarcane plants subjected to controlled water deficit regimes in the Sub-Middle São Francisco Valley, Brazil.

MATERIAL AND METHODS

The experiment was conducted in the municipality of Juazeiro BA, Brazil, in an experimental sugarcane field at the São Jorge Farm (9°27'13.90"S, 40°26'27.04" W, and altitude of 395), which belongs to the Agroindústrias do Vale do São Francisco (Agrovale). The soil of the experimental area is a Cambissolo Vértico (Inceptsol), according to the classification of the Jacomine et al. (2013); its characteristics were analyzed at the Embrapa Semi-Arid Soil Laboratory (Table 1).

Table 1. Soil physical and chemical characteristics of the experimental area.

OM	pH	EC	K	Ca	Mg	Na	Al	H+Al	SB	CEC	V	Cu	Fe	Mn	Zn	P
g kg^{-1}	-	dS m^{-1}	cmolc dm^{-3}								%	mg dm^{-3}				
7.86	6.4	0.32	0.24	4.4	1.9	0.04	0.05	2.47	6.58	9.05	73	2.2	28.6	56.5	2.2	5.34

OM = organic matter; EC = electrical conductivity of the soil saturation extract; SB = sum of exchangeable bases; CEC = effective cation exchange capacity; V = base saturation index.

The climate of the region was classified as BSwh, according to the Köppen classification, which is characterized by a negative water balance, resulting from an average annual rainfall of less than 550 mm, average insolation of 2,800 h year^{-1}, average annual temperatures of 21ºC to 32ºC, average evaporation of 2,900 mm year^{-1}, and average relative humidity of 63% (EMBRAPA, 2014).

The experiment was conducted in a randomized block design with ten treatments and three replications. The treatments consisted of three controlled water deficits (15%, 30%, and 45% of the crop evapotranspiration - ETc) applied at three development stages of the plant sprouting and tillering (Stage I) (107 days), grand growth (Stage II) (182 days), and maturation (Stage III) (76 days) and a control with 100% of the ETc throughout the entire crop cycle. The experiment was carried out in two crop cycles, totaling 30 experimental plots, composed of five 12 m long double rows of sugarcane plants.

The sugarcane (variety VAT 90212) bud chips was planted in the rows at density of 12 buds per meter, in double rows spaced 0.70 m x 1.30 m apart. Plants from the three central double rows were used for evaluations, disregarding one meter at the extremities of the rows, consisting in an evaluation area of 60 m^2.

The water depths applied in the experiment were calculated based on the ETc. The reference evapotranspiration (ET_0) was obtained using data (Table 2) from a meteorological station installed near the study site, and the Penman-Monteith method modified by Allen et al. (1998). The crop coefficient (Kc) used for the irrigation management was the conventionally used by the São Jorge Farm, which were obtained in previous studies (Table 3).

Table 2. Average annual temperature (T) and evapotranspiration (ET_0), and monthly precipitation (P) during the experiment.

	2012			2013			2014		
	T	ET_0	P	T	ET_0	P	T	ET_0	P
January	-	-	-	34.6	8.4	76.9	33.5	9.3	34.9
February	-	-	-	35.6	10.1	0.0	33.7	8.7	35.6
March	-	-	-	35.6	9.3	44.8	33.7	8.4	41.0
April	-	-	-	33.7	8.0	0.0	32.3	6.6	180.4
May	-	-	-	32.5	6.7	0.0	30.9	5.7	0.0
June	-	-	-	31.6	6.8	0.0	30.9	6.0	0.0
July	30.5	6.8	0.0	31.1	7.2	10.3	-	-	-
August	30.7	7.8	0.0	31.3	7.9	0.0	-	-	-
September	33.1	9.4	0.0	33.5	9.5	0.0	-	-	-
October	34.3	10.4	0.0	34.5	10.1	0.0	-	-	-
November	34.6	8.8	24.9	33.8	8.6	18.3	-	-	-
December	35.3	10.1	0.0	33.2	7.0	118.4	-	-	-

Table 3. Crop coefficients (Kc) used in the São Jorge Farm, Juazeiro, BA, Brazil.

Plant age (months)										
00 to 01	01 to 02	02 to 03	03 to 04	04 to 05	05 to 06	06 to 09	09 to 10	10 to 11	11 to 12	12 to 13
Crop coefficients (Kc)										
0.45	0.65	0.8	1	1.1	1.15	1.15	1.1	1	0.9	0.9

A subsurface drip irrigation system was used; it was installed at a depth of 0.20 m, between the sugarcane double rows, spaced 0.70 m apart, with self-compensating emitters spaced 0.5 m apart with flow of 1.6 L h^{-1}. Trifluralin (1 L ha^{-1} per cycle) was applied at the beginning of the water stress for harvesting, to avoid interference of roots in the drippers. The irrigation depths were automatically controlled by a valve control panel, coupled to hydraulic valves with solenoids; this enabled the release of the exact amount of water defined for each treatment.

Cultural practices and agrochemical applications followed the crop requirements, using the integrated pest and disease management. Fertilization at planting consisted of 550 kg of N-P-K (25-05-15) per hectare, using urea, MAP, and potassium chloride, based on the soil chemical analyzes (Table 1). Topdressing fertilization was carried out via fertigation, using venture injectors, three times a week, following the farm's schedule.

Two sugarcane crop cycles were evaluated first and second cycles of the same plants from July 2012 to June 2014. All plots were subjected to the water depth of 100% of ETc in both cycles until the plants reached a mean height of 0.20 m, then, the treatments with controlled water deficit were applied. The crops were harvested at 12 months after emergence of the plants; thus, plants of first cycle were harvested in June 2013, and plants of second cycle was harvested in June 2014.

At each harvest, ten plants per plot were selected and their number of live leaves, internodes, and tillers, and stem diameter, height, and yield were evaluated. The stem diameter was measured with a digital caliper, considering the average of the diameters measured between the fifth and sixth internodes of three selected plants (three replications). The stem height was measured with a tape ruler, considering the distance from the soil to the ligule of the first open leaf.

Regarding the analyses of the technological quality, 10 stems per plot were randomly collected and sent to the Agrovale's laboratory to determine their soluble solids contents (°Brix), industrial fiber percentage, juice purity, crude sugar percentage, sucrose content, and moisture, according to the methodology proposed by Farias et al. (2009).

At the end of the two crop cycles, the water use efficiency of the water regimes was determined; it consisted of the ratio between the crop yield (kg ha^{-1}) and the applied water depths plus precipitation (mm).

The data were processed and subjected to analysis of variance to find significant difference between the treatments (water depths) and crop cycles. Significant means of the crop cycles were compared by the Tukey's test, and significant means of the treatments were compared by the Scott-Knott's test (p<0.05), using the statistical program SISVAR (FERREIRA, 2014).

RESULTS AND DISCUSSION

The controlled water deficits used did not affect the stem diameter, plant height, and number of tillers of the sugarcane plants; they had means of 25.75 mm; 3.11 m; and 15 tillers per linear meter, respectively. Although sugarcane plants of first crop cycle presented, on average, more live leaves than those of the second cycle (Table 4), no significant effects on the leaf area were found; it had mean of 3,813.54 cm².

Table 4. Number of live leaves (NLL), number of internodes (NI) and yield of sugarcane plants (cultivar VAT 90212) in two crop cycles.

Cycle	NLL	NI	Yield (Mg ha^{-1})
First	6.5 b	20.53 b	122.03 b
Second	8.0 a	25.85 a	142.15 a
CV (%)	13.32	8.06	8.16

Means followed by the same letter in the columns are similar by the Tukey's test at 5% probability.

The numbers of live leaves and internodes, and yield of the sugarcane plants were higher in the second cycle (Table 4). Yield differences between crop cycles are reported by several authors (SILVA et al., 2014a; SILVA et al., 2014b; HANAUER et al., 2014), with plants presenting different results as a function of the management and genetic material evaluated. The highest yield of plants of second cycle may be connected to the adequate post-harvesting management of the first cycle. According to Vasconcelos (2011), the death or renewal of the sugarcane root system is not dependent on the sugarcane cutting, but on the hydrological condition to which the crop is subjected in a given development stage. Thus, part of the root system may eventually be lost after harvesting when the water availability is inadequate. However, the root remnant facilitates and increases the plant's growth capacity during the reestablishment process for the new cycle, which results in higher yields.

These results confirm those found by Hanauer et al. (2014), who evaluated three sugarcane clones in Santa Maria RS, Brazil, and found increased yield for the SP 711406 clone from the first to the second cycle, and no significant differences between cycles of the IAC 822045 and CB 4176 clones. Silva et al. (2014b) evaluated the productive potential of 11 sugarcane varieties subjected to drip irrigation as a function of the crop cycle and found higher stem yield for the first cycle; and the variety IAC SP933046 presenting higher yield in second cycle. Therefore, the plant growth reduces under water deficit conditions, especially the shoot, due to an adaptive response that results in a lower water consumption by the plant; the main effect of water stress is the significant loss of plant weight, decreasing the crop yield (FREIRE; LEÃO; MIRANDA, 2012).

The analysis of the ten water regimes showed significant yield differences (p<0.05) (Figure 1). The treatment that received water depth of 100% of ETc throughout the entire crop cycle had average yield of 135.13 Mg ha^{-1}. However, the highest yield (154.25 Mg ha^{-1}) was achieved with a water depth of 70% of ETc in the sprouting and tillering stages (Stage I). This occurred probably because of the root system of the plant is forming (first cycle), or reestablishing (second cycle) at this stage.

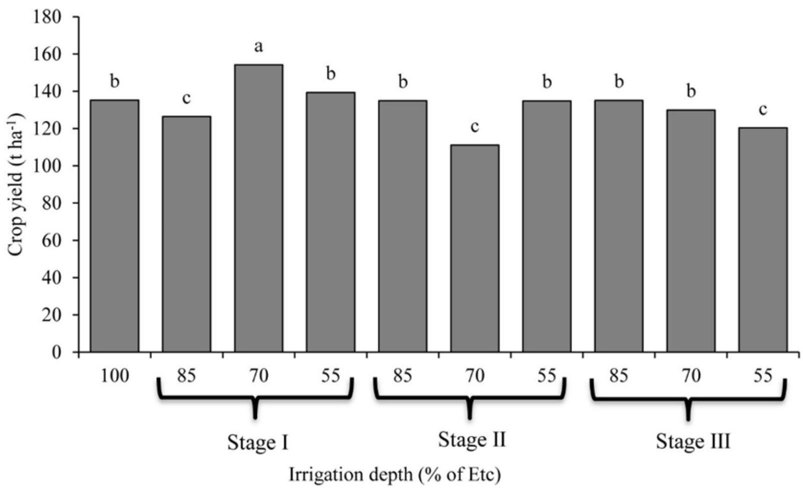

Figure 1. Average yield of sugarcane crops subjected to different water depths in two crop cycles. Means followed by the same letter are similar by the Scott-Knott's test at 5% probability.

Roots of sugarcane plants in formation explore reduced volume of soil at this stage. However, the lower water depth applied (55% of the ETc) may have been insufficient to meet the water requirements of the plants; similarly, the excess soil moisture (85% and 100% ETc) probably hindered the soil aeration and the full root development.

The highest yield found was higher than that found by Silva et al. (2014b) (127.86 Mg ha^{-1}) for the variety RB867515 when evaluating the productive potential of sugarcane crops subjected to drip irrigation as a function of varieties and cycles. However, Machado et al. (2009) found no effect of the controlled water deficit applied in the initial stage on plant height, stem dry weight, and soluble solid contents in the juice of plants of the genotype IACSP 94-2094 when evaluating growth and yield of two sugarcane genotypes in Campinas SP, Brazil, under the same conditions of the present study.

The crops under controlling water deficits in Stage I had higher yield than those under controlling water deficits in other development stages, presenting approximately 140 Mg ha^{-1}, not differing from the treatment without deficit (135.1 Mg ha^{-1}). This denotes that the controlled water deficit in the Stage I of the sugarcane cycle is advantageous, with water savings and, consequently, energy savings, and similar yield to those reached with 100% of the ETc (Figure 2). The water stress applied in Stage I represents a period of acclimatization of the plants that make them to equal or surpass the yield of plants with no water stress.

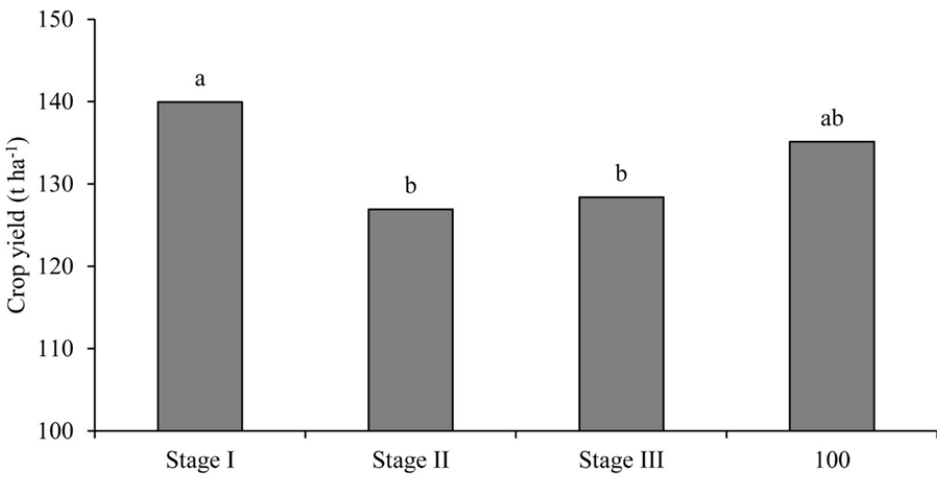

Figure 2. Average yield of sugarcane crops subjected to different water depths in three development stages (Stage I, Stage II, and Stage III), and no water stress (100% of ETc), in two crop cycles. Means followed by the same letter are similar by the Tukey's test at 5% probability.

Plants subjected to controlled water deficits in Stage II presented lower yields, with lower number of stems per hectare, but with similar results to those with water stress in Stage III, and the control (100% of ETc). Lower yields with water deficits in Stage II is normal, since the longest development period occurs in this stage, which comprises a period of approximately 150 days (MARAFON, 2012), about 60% of the total crop cycle. Therefore, the plants were subjected to a longer time of stress due to water deficit. According to Willadino and Camara (2010), the longer the water deficit time, the greater the damages on the plants due to water stress.

The applied water regimes had no significant effect on the parameters of technological quality, with average sucrose content (SC) of 16.72%, juice purity (JP) of 85.29%, total recoverable sugars (TRS) of 13.17%. Similar results were found by Carvalho et al. (2008) who found no effects of irrigation depths in technological quality of sugar cane. Oliveira et al. (2016b) evaluate the technological quality of seven sugarcane cultivars subjected to four water depths (based on ETc) and found preserved technological quality, even in the plants subjected to the lowest water depths.

The SC and JP found in both crop cycles are within the values recommended by Ripoli and Ripoli (2004) above 14% for SC, and above 85% for JP. The TRS was below the recommended level above 15%. This may be related to inherent characteristics of the cultivar. The plants of first cycle presented higher °Brix (19.45) and moisture (68.98%) than those of second cycle. The plants of second cycle had higher percentages (15.8%) of industrial fiber than those of first cycle (Table 5).

Table 5. Technological quality of sugarcane juice soluble solids contents (°Brix), moisture, and percentage of industrial fiber—of plants of two crop cycles.

Cycle	°Brix	Moisture	Fiber%
First	19.45 a	68.98 a	14.63 b
Second	15.62 b	67.78 b	15.80 a
CV (%)	8.44	1.38	6.04

Means followed by the same letter in the columns were similar by the Tukey's test at 5% probability.

The sugarcane soluble solid contents decreased from the first to the second cycle. Contrastingly, Simões et al. (2015) found an increase in soluble solid contents in sugarcane plants from the first to the third crop cycle. The soluble solid contents found were also lower than those found by Carvalho et al. (2008) (20.56°Brix), who evaluated 11 sugarcane crops (1986 to 1997) subjected to irrigation depths in the state of Paraíba, Brazil.

According to Oliveira et al. (2016b), high irrigation depths generates greater dilutions of soluble solids and, therefore, this variable tends to decrease with water replenishments.

The percentage of industrial fiber increased from the first to the second cycle, as also found by Simões et al. (2015). The percentage of industrial fiber were higher than those recommended by Ripoli and Ripoli (2004) who defined as ideal values between 11% to 13%. According to Castro and Kluge (2001), the fiber content in the stem is a disadvantageous factor in the industrial process since sugarcane milling is usually regulated for canes with approximately 12.5% fiber. Each addition of 0.5% in fiber content reduces 10% to 20% the milling yield, reducing approximately 1 kg of sugar per Mg.

Fiber content is directly related to the genetic characteristics of each cultivar. Thus, cultivars that meet the recommendations (11% to 13%) must be selected for ethanol or sugar production. However, this can be considered a favorable factor for energy cogeneration from bagasse burning, which requires higher percentage of fiber than those recommended to produce ethanol and sugar. Although according to Matsuoka et al. (2012), the genetic improvement of sugarcane is prioritizing the production of fiber for energy purposes.

A deeper analysis for the selection of irrigation depth based on controlled water deficit must consider the biometric developmental characteristics of the sugarcane cultivars, and their yield, and technological quality. However, a more pressing need is the development of more accurate techniques that can be the base for more sustainable systems. Thus, analyzing the water use efficiency (WUE) is essential, because the higher yield that can be achieved may not coincide with the better WUE.

Considering both crop cycles, the plants of first cycle presented higher WUE index, i.e., they had a stronger response to irrigation and produced more biomass per mm of water applied (Table 6).

Table 6. Water use efficiency (WUE) of sugarcane crops in two crop cycles.

Cycle	WUE (kg ha^{-1} mm^{-1})
First	95.84 a
Second	88.72 b
CV (%)	7.98

Means followed by the same letter in the columns are similar by the Tukey's test at 5% probability.

The WUE found in the two cycles were higher than those reported by Souza et al. (2012), who analyzed WUE of sugarcane crops based on several studies and concluded that it is possible to produce 50 to 80 kg ha^{-1} of sugarcane stems per millimeter of water. However, the experiment in the present study was conducted under irrigated conditions, using a subsurface drip irrigation system, which increases the WUE. The reduced water losses by evaporation due to the subsurface drip irrigation may explain the increased WUE found. According to Levidow et al. (2014), such practices enhance the viability of the activity, and promote environmental sustainability.

Higher WUEs were found when the crops were subjected to water deficits of 15% in Stages II or III (Figure 3). Contrasting these results with those in Figure 2, the water deficit that resulted in the highest yield is not the one with higher WUE; the water deficit of 30% was among the treatments that presented the lowest WUE.

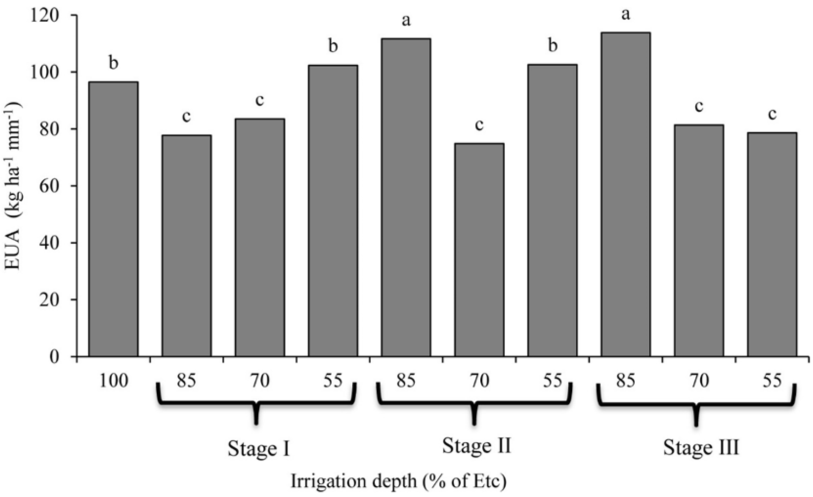

Figure 3. Water use efficiency of sugarcane plants subjected to different water depths in three development stages (Stage I, Stage II, and Stage III), and no water stress (100% of ETc), in two crop cycles. Means followed by the same letter are similar by the Scott-Knott's test at 5% probability.

The water depths applied in Stage I reduced the WUE. Similarly, Mauri (2012) evaluated sugarcane crops under water deficit and found significantly reduced WUE when the water deficit was applied at the initial stage of plant growth. However, the highest WUE found in Stage II with controlled deficit of 15% of ETc confirms the results found by Silva et al. (2011), who evaluated the WUE of sugarcane crops in the semiarid region and found higher WUE between the seventh and eighth month of the crop cycle, period of the greatest crop development. The highest WUE of plants subjected to water deficit of 15% of ETc in Stage II or Stage III was a positive result, since it denotes that controlled water deficits can be applied in this crop to save water and energy, without significant losses in yield. The choice for a water depth which provides the highest yield (70% of ETc in Stage I) or the highest WUE (85% of ETc in Stages II or III) will depend on the local financial and environmental return of these irrigation managements.

CONCLUSIONS

The biometric parameters and technological quality of the sugarcane juice were not affected by the controlled water deficits applied in the different development stages of the plants. The sugarcane yield was higher when using a controlled water deficit of 30% of ETc in Stage I sprouting and tillering. The water deficit of 15% of ETc in plants at

Stages II (grand growth) or III (maturation), improved the water use efficiency of the sugarcane crop.

REFERENCES

ALLEN, R. G. et al. **Crop evapotranspiration: guidelines for computing crop water requirements**. Rome: FAO, 1998. 300 p.

AZEVEDO, R. A. et al. Sugarcane under pressure: an overview of biochemical and physiological studies of abiotic stress. **Tropical Plant Biology**, New York, v. 4, n. 1, p. 42–51, 2011.

CARVALHO, C. M. et al. Resposta dos parâmetros tecnológicos da terceira folha de cana-de-açúcar submetida a diferentes níveis de irrigação. **Revista Brasileira de Ciências Agrárias**, Recife, v. 3, n. 4, p. 337-342, 2008.

CASTRO, P. R. C.; KLUGE, R. A. **Ecofisiologia de culturas extrativas**: cana-de-açúcar, seringueira, coqueiro, dendezeiro e oliveira. Cosmópolis, SP: Stoller do Brasil, 2001. 138 p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Centro de Pesquisa Agropecuária do Tropico Semiárido. **Médias anuais da estação agrometeorológica de Mandacaru**. Juazeiro-BA, 2014. Disponível em: <http://www.cpatsa.embrapa.br:8080/servicos/ dadosmet/cem-anual.html>. Acesso em: 23 abr. 2018.

FARIAS, C. H. A. et al. Qualidade industrial de cana -de-açúcar sob irrigação e adubação com zinco, em Tabuleiro Costeiro paraibano. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 13, n. 4, p. 419-428, 2009.

FERREIRA, D. F. Sisvar: a guide for its Bootstrap procedures in multiple comparisons. **Ciência e Agrotecnologia**, Lavras, v. 38, n. 2, p. 109-112, 2014.

FREIRE, A. L. O.; LEÃO, D. A. S.; MIRANDA, J. R. P. Acúmulo de massa seca e de nutrientes em gliricídia em resposta ao estresse hídrico e a doses de fósforo. **Semina. Ciências Agrárias**, Londrina, v. 33, n. 1, p. 19-26, 2012.

HANAUER, J. G. et al. Desenvolvimento e crescimento foliar e produtividade de cana-de-açúcar em cultivo de cana-planta e de cana-soca. **Bioscience Journal**, Uberlândia, v. 30, n. 4, p. 1077-1086, 2014.

INMAN-BAMBER, N. G.; SMITH, D. M. Water relations in sugarcane and response to water deficits. **Field Crops Research**, Amsterdam, v. 92, n. 2/3, p. 185-202, 2005.

JACOMINE, P. K. T. et al. **Sistema brasileiro de classificação de solos**. 3. ed. rev. e ampl. Brasília, DF: Embrapa, 2013. 353 p.

LEVIDOW, L. et al. Improving water-efficiency irrigation: prospects and difficulties of innovative practices. **Agricultural Water Management**, Amsterdam, v. 146, n. 16, p. 84-94, 2014.

LOPES, M. S. et al. Enhancing drought tolerance in C4 crops. **Journal of Experimental Botany**, Oxford, v. 62, n. 9, p. 3135-3153, 2011.

MACHADO, R. S. et al. Respostas biométricas e fisiológicas ao déficit hídrico em cana-de-açúcar em diferentes fases fenológicas. **Pesquisa Agropecuária Brasileira**, Brasília, v. 44, n. 12, p. 1575-1582, 2009.

MARAFON, A. C. **Análise quantitativa de crescimento em cana-de-açúcar**: uma introdução ao procedimento prático. Aracaju: Embrapa Tabuleiros Costeiros, 2012. 29 p. (Documentos, 168).

MATSUOKA, S. et al. Bioenergia da cana. In: SANTOS, F.; BORÉM, A.; CALDAS, C. (Eds.). **Cana-de-açúcar**: bioenergia, açúcar e álcool. 2. ed. Viçosa: UFV, 2012. v. 1, cap. 20, p. 487-517.

MAURI, R. **Relações hídricas na fase inicial de desenvolvimento da cana-de-açúcar submetida a deficit hídrico variável**. 2012. 103 f. Dissertação (Mestrado em Ciências: Área de Concentração em Irrigação e Drenagem) – Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba, 2012.

OLIVEIRA, A. R.; BRAGA, M. B. **Florescimento e acamamento de cultivares de cana-de-açúcar submetidas a diferentes lâminas de irrigação**. Petrolina: Embrapa Semiárido, 2011. 23 p. (Boletim de Pesquisa e Desenvolvimento, 87).

OLIVEIRA, A. R. et al. Análise biométrica de cultivares de cana-de-açúcar cultivadas sob estresse hídrico no Vale do Submédio São Francisco. **Revista Energia na Agricultura**, Botucatu, v. 31, n. 1, p. 48 -58, 2016a.

OLIVEIRA, A. R. et al. **Influência de lâminas de irrigação nas características tecnológicas de cana-de-açúcar**. Petrolina: Embrapa Semiárido, 2016b. 22 p. (Boletim de Pesquisa e Desenvolvimento, 127).

PEDROZO, C. A. et al. Differential morphological, physiological, and molecular responses to water deficit stress in sugarcane. **Journal of Plant**

Breeding and Crop Science, Amsterdam, v. 7, n. 7, p. 226-232, 2015.

RIPOLI, T. C. C.; RIPOLI, M. L. C. **Biomassa de cana-de-açúcar**: colheita, energia e ambiente. 2. ed. Piracicaba, SP: Barros & Marques Ed. Eletrônica, 2004. 302 p.

RODOLFO JÚNIOR, F. et al. Produtividade e qualidade de variedades de cana-de-açúcar de terceira soca sob regime hídrico variável. **Nativa**, Sinop, v. 4, n. 1, p. 36-43, 2016.

SILVA, M. A. et al. Potencial produtivo da cana-de-açúcar sob irrigação por gotejamento em função de variedades e ciclos. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 18, n. 3, p. 241–249, 2014b.

SILVA, T. G. F. et al. Demanda hídrica e eficiência do uso de água da cana-de-açúcar irrigada no semiárido brasileiro. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 15, n .12, p. 1257–1265, 2011.

SILVA, T. G. F. et al. Biometria da parte aérea da cana soca irrigada no Submédio do Vale do São Francisco. **Revista Ciência Agronômica**, Fortaleza, v. 43, n. 3, p. 500-509, 2012.

SILVA, T. G. F. et al. Biomassa seca acumulada, partições e rendimento industrial da cana-de-açúcar irrigada no Semiárido brasileiro. **Revista Ceres**, Viçosa, v. 61, n. 5, p. 686-696, 2014a.

SIMÕES, W. L. et al. Respostas de variáveis fisiológicas e tecnológicas da cana-de-açúcar a diferentes sistemas de irrigação. **Revista Ciência Agronômica**, Fortaleza, v. 46, n. 1, p. 11-20, 2015.

SOUZA, J. K. C. et al. Importância da irrigação para a produção de cana-de-açúcar no Nordeste do Brasil. **Revista Educação Agrícola Superior**, Brasília, v. 27, n. 2, p. 133-140, 2012.

VASCONCELOS, A. C. M. Dinâmica do desenvolvimento radicular da cana-de-açúcar. In: VASCONCELOS, A. C. M.; DINARDO-MIRANDA, L. (Eds.). **Dinâmica do desenvolvimento radicular da cana-de-açúcar e implicações no controle de nematóides**. 2. ed. Americana: Adônis, 2011. cap. 1, p. 11-44 p.

WILLADINO, L. G.; CAMARA, T. R. Tolerância das plantas à salinidade: aspectos fisiológicos e bioquímicos. **Enciclopédia Biosfera: Centro Científico Conhecer**, Goiânia, v. 6, n. 11, p. 1-23, 2010.