ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.21, n.9, p.618-622, 2017
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v21n9p618-622

Water productivity for sugar and biomass of sugarcane varieties

Daniel P. V. Leal[1], Rubens D. Coelho[2], Fernando da S. Barbosa[3], Eusimio F. Fraga Júnior[4], Robson Mauri[2] & Lucas da C. Santos[5]

[1] Faculdades Associadas de Uberaba. Uberaba, MG. E-mail: daniel.pvelosoleal@yahoo.com.br (Corresponding author)
[2] Universidade de São Paulo/Departamento de Engenharia de Biossistemas. Piracicaba, SP. E-mail: rdcoelho@usp.br; rmauri.agro@gmail.com
[3] Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas/Campus Inconfidentes. Inconfidentes, MG. E-mail: fernando.barbosa@ifsuldeminas.edu.br
[4] Universidade Federal de Uberlândia/Instituto de Ciências Agrárias. Monte Carmelo, MG. E-mail: eusimiofraga@ufu.br
[5] Universidade Estadual de Goiás/Centro de Ciências Exatas e Tecnológicas. Anápolis, Go. E-mail: lucas.cs21@gmail.com

Key words:
deficit irrigation
second ratoon
evapotranspiration

A B S T R A C T

The aim of this study was to evaluate the water productivity into biomass and into sugar for 23 sugarcane varieties (second ratoon crop) under two levels of drip irrigation. Two experiments were conducted in a greenhouse. Experiment 1 comprised nine sugarcane varieties grown in a clay soil and Experiment 2 was composed of 14 varieties in a sandy-loam soil. Moreover, two irrigation treatments were adopted: T100 - full irrigation with 100% crop evapotranspiration replacement, maintaining soil moisture near field capacity for each variety; and T70 - irrigation with 70% T100 water depth. Water productivity was evaluated in terms of stem fresh biomass (WP_{FB}) and sugar (WP_{GSY}). The results showed that WP_{FB} ranged from 11.45 to 18.45 kg m^{-3}. The highest values were observed for varieties CTC14, CTC6, RB867515, and SP81-3250 (in T100) and for the varieties CTC6 and CTC14 (in T70). The WPGSY values ranged from 1.68 to 2.22 kg m^{-3}, with emphasis placed on CTC6, RB9675-15, SP81-3250, and RB925211 (in T100) and on CTC6, CTC14, and SP81-3250 (in T70).

Palavras-chave:
irrigação com déficit
segunda soqueira
evapotranspiração

Produtividade da água em açúcar e biomassa de variedades de cana-de-açúcar

R E S U M O

Objetivou-se, neste estudo, avaliar a produtividade da água em biomassa e açúcar de 23 variedades de cana-de-açúcar (segunda soqueira) irrigada por gotejamento sob dois níveis de irrigação. Dois experimentos foram instalados e conduzidos em casa de vegetação. Experimento 1: nove variedades em um solo argiloso e Experimento 2: 14 variedades em um solo franco-arenoso. Dois tratamentos de irrigação foram adotados: T100 - plenamente irrigado com reposição de 100% da evapotranspiração de cada variedade, mantendo a umidade do solo próximo à capacidade de campo; e T70 - irrigação com 70% da lâmina aplicada no tratamento T100. Avaliaram-se a produtividade da água em biomassa fresca de colmo (PA_{BFC}) e a produtividade da água em açúcar (PA_{RBA}). Houve variação na PA_{BFC} de 11,45 a 18,45 kg m^{-3}. Observaram-se os maiores valores nas variedades CTC14, CTC6, RB867515 e SP81-3250 (T100) e nas variedades CTC6 e CTC14 (T70). A PARBA variou de 1,68 a 2,22 kg m^{-3}, destaque para as variedades CTC6, RB967515, SP81-3250 e RB925211 em T100 e CTC6, CTC14 e SP81-3250 em T70.

Ref. 207-2016 – Received 20 Dec, 2016 • Accepted 10 Mar, 2017 • Published 25 Jul, 2017

Introduction

Sugarcane is one of the main crops in Brazil, and it has been increasingly grown because of its great potential for biofuels. Since the energy crisis caused by the oil price rises, there has been a worldwide increase in the search for alternative fossil fuels, boosting the demand for sugar and ethanol from sugarcane crops (Nassif et al., 2014). In order to meet this demand, sugarcane cultivation, which had been previously concentrated in areas with high water availability, expanded to areas with limited conditions, especially to the states of Goiás and Mato Grosso do Sul (Brazil). Besides such limitations, these areas have been often exploited with no proper planning, making use of unsuitable plant varieties. As a result, yields are lower than the expected values.

Irrigation is necessary to minimize the vulnerability of crops in these lands of expanding agricultural frontiers; however, in many areas, water is a limiting factor for household use and animal consumption, as well as for food production (Brito et al., 2012). For this reason, it is essential to produce sugarcane under irrigation, so that a full water supply could be provided in these locations. Conversely, a certain degree of irrigation deficit may be interesting; therefore, information regarding water-use efficiency becomes essential.

Among several indicators of water-use efficiency (Pereira et al., 2012), Silva et al. (2014) highlighted crop water productivity (CWP), economic water productivity (EWP), and nutrient use efficiency (NUE). The term water productivity (WP) should be used to express the quantity of a product or service produced by a certain amount of water. Regarding crops, this factor can be estimated by dividing the content of yielded biomass by the amount of water spent during the crop cycle, which includes rainfall, irrigation water, and evapotranspiration (Di Paolo & Rinaldi, 2008; Pereira et al., 2002). For Inman-Bamber & Smith (2005), an adequate and strategic water management along sugarcane cycle is fundamental, and WP can be used for irrigation setting and decision making, thus increasing this farming system production and profitability.

Due to an increased demand for sugar and ethanol, besides the little data on water productivity for Brazilian sugarcane varieties and its given importance for farming in water-limited areas, this study aimed to evaluate the water productivity for fresh stem biomass and sugar yields, testing 23 sugarcane varieties (second ratoon crop) under three levels of drip irrigation.

Material and Methods

The experiment was conducted in a greenhouse at the Department of Biosystems Engineering, "Luiz de Queiroz" College of Agriculture (ESALQ/USP), in Piracicaba (SP), Brazil. The local geographical coordinates are 22° 42' 32" S and 47° 37' 45" W, at a 548-m average altitude. The experiment was carried out from February 2011 to February 2012, which corresponded to the second ratoon crop. The varieties were planted in 2009, in the same year as the setting of both experiments, named as Experiment 1 and Experiment 2. Concrete pots were spread out in the greenhouse along four rows. The pots were 1.08-m long, 0.93-m width (~ 1.0 m^2), and 0.65-m deep (0.5-m^3 volume). These recipients were filled out with one layer of gravel (0.05 m) covered with a geotextile (Bidim™), followed by one layer of soil (0.60 m), which was properly homogenized.

Two of the four rows were assigned as Experiment 1 and filled with clay soil, classified as Eutrophic Red Nitosol (Alfisol); the other two rows were Experiment 2, being filled with sandy loam soil texture, classified as Red-yellow Latosol (Oxisol). Tables 1 and 2 show the hydro-physical and chemical soil characteristics, respectively. Undisturbed soil samples were used for hydro-physical analysis; sampling was performed with metal volumetric rings at depths of 0-20, 20-40, and 40-60

Table 1. Water content at field capacity (θ_{fc}), soil moisture at permanent wilting point (θ_{pwp}), total available water capacity (Wa), soil bulk density (DB), density of soil particles (DP), and total porosity (Pt)

Depth layer (m)	θ_{fc}	θ_{pwp}	Wa (mm)	DB	DP	Pt (%)	Particle fraction		
							Sand	Silt	Clay
	cm^3 cm^{-3}			kg dm^{-3}			g kg^{-1}		
Eutrophic Red Nitosol (Alfisol)									
0-0.20	0.41	0.26	29.85	1.30	2.70	52.60	313.0	148.0	539.0
0.20-0.40	0.42	0.26	31.54	1.30	2.70	53.00	310.0	161.0	529.0
0.40-0.60	0.45	0.28	32.27	1.30	2.70	51.70	301.0	173.0	526.0
Red-yellow Latosol (Oxisol)									
0-0.20	0.23	0.11	24.22	1.50	2.70	42.30	75.10	7.80	17.10
0.20-0.40	0.23	0.10	25.62	1.50	2.70	43.40	74.50	8.00	17.50
0.40-0.60	0.24	0.13	21.76	1.70	2.60	36.00	74.40	8.60	17.00

θ_{cc} - Moisture level corresponding to -4.85 kPa matric potential; θ_{pmp} - Moisture level corresponding to matric potential -1500 kPa

Table 2. Chemical properties of the soils in Experiment 1 and 2

Depth layer (m)	pH $CaCl_2$	O.M. (g dm^{-3})	P	S	K	Ca	Mg	H+Al	SB	T	V %
			(mg dm^{-3})		(mmol$_c$ dm^{-3})						
Eutrophic Red Nitosol (Alfisol)											
0-0.20	5.20 c	15.00	24.00 c	220.00 d	1.40 b	51.00 d	14.00 d	28.00	66.40	94.70	70.00 c
0.20-0.40	5.20 c	16.00	28.00 c	87.00 d	1.00 b	44.00 d	10.00 d	31.00	55.00	86.10	64.00 c
Red-yellow Latosol (Oxisol)											
0-0.20	5.10 c	12.00	123.00 d	33.00 d	0.50 a	28.00 d	4.00 b	24.00	32.50	56.60	57.00 c
0.20-0.40	4.80 d	14.00	63.00 d	22.00 d	0.50 a	20.00 d	3.00 b	26.00	23.50	49.20	48.00 b

Lowercase letters stand for nutrient-content classes; a - Very low level; b - Low level; c - Average level; d - High level; e - Very high level cm. Core samples were saturated and subjected to tensions of -1, -2, -4 and -6 kPa (tension table), and to tensions of 10, 30, 50, 100, 500, 1000, and 1500 kPa (Richards' extractor device), to obtain the water retention curve in the soil (EMBRAPA, 1997). For chemical analysis, 14 simple samples were collected, one from each pot, resulting in a composite sample for each soil type at the depths of 0-20 and 20-40 cm. Based on the interpretation of data the fertilizer recommendations were formulated, as proposed by Raij et al. (1997), for an expected minimum productivity of 150 t ha^{-1}.

Fertilization was performed through fertigation, being the recommended doses of N and K_2O split into monthly applications, based on crop mineral absorption. As for P_2O_5, the dose was applied in a single fertigation. The doses of N, P_2O_5, and K_2O were 140, 80, and 180 kg ha^{-1}, respectively, for both soil types. Fertilizers were dissolved directly in fertigation tank solution, being distributed to the pots simultaneously.

The variation sources were sugarcane varieties - VAR (23) with six replications a vase, in addition to irrigation depths - T (2), which were full irrigation (T100) and deficit irrigation (T70).

The soil for planting each variety was chosen according to recommendations of Brazilian research centers. For instance, in Experiment 1, a clay soil (higher fertility) was used for RB855536, RB855453, RB925211, RB867515, SP89-1115, SP81-3250, CTC14, CTC8, and CTC6; yet in Experiment 2, a sand soil (lower fertility) was taken for RB925345, RB855156, RB966928, RB72454, RB92579, IACSP95-5000, SP83-2847, SP90-3414, SP79-1011, CTC17, CTC15, CTC9, CTC2, and Caiana (Brazilian original material).

The irrigation depths applied to each treatment were: a) T100 or full irrigation: 100% potential evapotranspiration replacement, for each variety, and keeping soil moisture close to the field capacity; and b) T70 or deficit irrigation: 70% of the T100. These treatments started at 105 days after previous crop harvesting, which corresponds to the end of tillering and beginning of stem elongation.

Irrigation was made by a dripping system, individually controlled by solenoid valves. It comprised two drip lines per vase (in-line emitters) with compensating emitters kept at a nominal flow rate of 2 L h^{-1}. These drip lines were placed on the soil surface; each line contained five emitters spaced 0.2 m apart, totalizing ten emitters per vase at a total nominal flow rate of 20 L h^{-1}.

For irrigation management, three tensiometers were installed at three soil depths representing each assessed layer: 0.1 m (0-0.2 m), 0.3 m (0.2-0.4 m), and 0.5 m (0.4-0.6 m) in T100 treatments for each variety. Readings were carried out through the digital puncture.

The analysis of water productivity, i.e. water-use efficiency, was based on weighing fresh sugarcane stems and measuring sugar yield. Water productivity was estimated as fresh stem and sugar yields per hectare divided by the volume of water applied. After estimation, the data were filtered by eliminating two outliers, resulting four replications per analysis.

Stem yield per hectare - SYH (t ha^{-1}) was estimated considering the area occupied by crop canopy (~ 1.8 m^2). This method was used to extrapolate the results to a field condition, which is more close to reality.

Gross sugar yield - GSY (t ha^{-1}) stands for sugar production per unit area, taking into account the SYH and TRS (Eq. 1).

$$GSY = \frac{SYH \cdot TRS}{1000} \quad (1)$$

where:

GSY - gross sugar yield, t ha^{-1};

SYH - sugarcane stem yield per hectare, t ha^{-1}; and,

TRS - total recoverable sugar per hectare, kg t^{-1}.

The TRS of sugarcane varieties is estimated by technological parameters, being determined after harvesting, as the method described by CONSECANA (2006).

The specific water consumption of each replication was calculated based on the total volume applied to each vase and dry matter weight of leaves.

The means of water productivity (WP) were compared by Tukey's test at 5% probability to identify statistical differences among varieties and between irrigation depths. The analyses were carried out using SISVAR software (System Analysis of Variance for Balanced Data) (Ferreira, 1999).

Results and Discussion

Water productivity for sugarcane fresh biomass (WP_{FB})

Table 3 displays the results of water productivity for fresh biomass (WP_{FB}) for different sugarcane varieties and according to two irrigation levels (T100 and T70).

The results of Experiment 1 ranged from 11.73 to 16.89 kg m^{-3} in T100 and from 11.46 to 18.45 kg m^{-3} in T70. Overall, there was an increase of 0.45 kg m^{-3} when comparing T70 with T100. As can be seen in Table 3, there were no significant differences among the varieties regarding WP_{FB} in both irrigation treatments (T100 and T70). The outstanding variety for both T100 and T70 was CTC 14, yielding 16.89 and 18.45 kg m^{-3} WP_{FB}, respectively. These outcomes highlight the ability of this variety in converting water into the fresh stem biomass even if under water deficit. On the other hand, RB855536 and RB855453 varieties showed the lowest WP values in both treatments (T100 and T70).

Table 3 illustrates that, in Experiment 2, there was no significant difference among the varieties for T100. However, for T70, only Caiana had significantly lower results if compared to the others. In T100, WP_{FB} ranged from 11.97 to 15.78 kg m^{-3}. While in T70, this value increased in 0.39 kg m^{-3} if compared to T100, ranging from 8.13 to 16.53 kg m^{-3}.

Among all treatments, two of the sugarcane varieties stood out for the best results, for instance, Caiana in T100 and RB72454 in T70.

Overall, the findings of this study are quite similar or slightly higher than are those of other papers. For instance, Robertson & Muchow (1994), who performed studies in South Africa, Hawaii, and Australia, reported values between 4.8 and 12.1 kg m^{-3}. Additionally, there was a study by Rabnawaz

Table 3. Water productivity for fresh biomass (WP_{FB}), for different sugarcane varieties and irrigation depths (T100 and T70)

WP_{FB} (kg m^{-3} or kg x 10 mm^{-1} ha^{-1} or t ML^{-1})		
Varieties	T100	T70
Eutrophic Red Nitosol (Alfisol)		
CTC14	16.89 aA	18.45 aA
CTC6	15.79 abA	16.44 abA
RB867515	15.53 abA	14.10 bcA
SP81-3250	14.42 abA	14.63 abcA
SP89-1115	13.36 abA	14.25 bcA
CTC8	12.84 abA	13.78 bcA
RB925211	12.76 abA	13.78 bcA
RB855536	12.57 bA	11.46 cA
RB855453	11.73 bA	13.07 bcA
Average	13.99	14.44
CV (%)	12.52	13.83
Red-yellow Latosol (Oxisol)		
SP90-3414	15.78 aA	15.54 aA
SP83-2847	15.48 aA	14.71 aA
CTC15	14.78 aA	15.63 aA
CTC9	14.66 aA	13.99 aA
RB966928	14.66 aA	16.53 aA
Caiana	14.12 aA	8.13 bB
SP79-1011	14.12 aA	16.00 aA
RB92579	13.92 aA	14.78 aA
RB855156	13.90 aA	14.36 aA
CTC2	13.81 aA	13.66 aA
CTC17	13.74 aA	14.04 aA
RB925345	13.71 aA	16.02 aA
RB72454	12.06 aB	15.07 aA
IACSP95-5000	11.97 aA	13.73 aA
Average	14.05	14.44
CV (%)	7.63	14.08

*Values followed by the same uppercase letter in the lines and lowercase letter in the columns do not differ from each other at 0.05 probability by Tukey's test

Table 4. Water productivity for gross sugar yield (WP_{GSY}), for different sugarcane varieties and irrigation depths (T100 and T70)

WP_{GSY} (kg m^{-3} or kg x 10 mm^{-1} ha^{-1} or t ML^{-1})		
Varieties	T100	T70
Eutrophic Red Nitosol (Alfisol)		
CTC6	2.22 aA	2.25 abA
RB867515	2.20 aA	1.96 bcA
SP81-3250	2.15 abA	2.22 abcA
RB925211	2.00 abA	2.20 abcA
SP89-1115	1.96 abA	1.97 bcA
CTC14	1.96 abB	2.60 aA
RB855453	1.94 abA	2.18 abcA
CTC8	1.82 abA	1.82 bcA
RB855536	1.68 bA	1.71 cA
Average	1.99	2.10
CV (%)	8.97	12.68
Red-yellow Latosol (Oxisol)		
RB966928	2.47 aA	2.77 aA
SP90-3414	2.32 abA	2.12 bA
RB855156	2.32 abA	2.19 abA
CTC9	2.26 abA	2.22 abA
SP83-2847	2.26 abA	2.07 bA
SP79-1011	2.16 abcA	2.48 abA
CTC15	2.13 abcA	2.27 abA
RB92579	2.12 abcA	2.18 abA
CTC17	2.10 abcA	2.17 abA
CTC2	2.07 abcA	2.04 bA
RB72454	1.93 abcA	2.16 abA
RB925345	1.87 abcB	2.24 abA
IACSP95-5000	1.79 bcA	1.95 bA
Caiana	1.58 cA	0.99 cB
Average	2.10	2.13
CV (%)	11.37	18.07

*Values followed by the same uppercase letter in the lines and lowercase letter in the columns do not differ from each other at 0.05 probability by Tukey's test

et al. (2015) describing WP values for sugarcane from 2.22 to 3.50 kg m^{-3}.

When studying water-use efficiency indicators in sugarcane industry, Silva et al. (2011) recorded a WP of 9.49 kg m^{-3} for stems of the variety RB 92579.

Singh et al. (2007) obtained values for sugarcane plant and ratoon crops of 7.1 and 6.3 kg m^{-3}, respectively. However, these results were lower than those reported by Inman-Bamber & Smith (2005), who cited an upper limit of 27.0 kg m^{-3} as potential WP when the crop is irrigated.

Unlike this experiment, Oliveira et al. (2011) observed increasing WP values when the crop was fully irrigated. These authors investigated eleven different sugarcane varieties and observed a water-use efficiency of 7.01 kg m^{-3} in rainfed and of 14.03 kg m^{-3} irrigated plants. In short, these results show that water deficit may increase or even decrease WP of sugarcane plants.

Conversely, while assessing three sugarcane varieties under rainfed and irrigated conditions, Gava et al. (2011) noticed that the variety SP80-3280 under irrigation showed the highest WP; however, the opposing view was expressed in RB867515 and RB855536 during plant-crop cycle. Nevertheless, during the ratoon-crop cycle, Gava et al. (2011) pointed out higher WP values in all varieties under irrigated conditions.

Water productivity for gross sugar yield (WP_{GSY})

Table 4 demonstrates the results of water productivity gross sugarcane yield (WP_{GSY}) for different sugarcane varieties and according to two irrigation levels (T100 and T70).

In experiment 1, as shown in Table 4, there were differences among varieties in both irrigation depths (T100 and T70). WP_{GSY} in T100 ranged from 1.68 to 2.22 kg m^{-3}, while in T70, WP_{GSY} had an increase of 0.11 kg m^{-3} increased compared to T100, ranging from 1.71 to 2.60 kg m^{-3}. For both of the irrigation depths, CTC14 stood out, showing improved results for the T70.

Significant differences were found for WP_{GSY} with respect to Experiment 2 (Table 4) when comparing the varieties, under both irrigation conditions. The WP_{GSY} variations were from 1.58 to 2.47 kg m^{-3} in T100, and from 0.99 to 2.77 kg m^{-3} in T70.

It is a noteworthy highlight that the variety RB966928 showed a great potential in terms of GSY when subjected to water deficit. According to Gava et al. (2011), water-use efficiency differences are derived from the capacity of each genotype to develop water deficit tolerance.

Both irrigation depths showed significant differences between each other for the sugarcane varieties RB925345 and Caiana, while the former had better conditions under deficit (T70) the other did under full irrigation (T100).

The results obtained in this study were higher than those found by Silva et al (2011), who estimated WP as a function of sugarcane ETc and obtained a value of 1.22 kg m^{-3} for the variety RB92579. Gava et al. (2011) observed WP for sugarcane of 0.83 to 1.44 kg m^{-3}, when studying the varieties RB867515, RB855536, and SP80-3280.

Conclusions

1. The Brazilian sugarcane varieties show a great variation in water productivity for fresh biomass of sugarcane (WP_{FB}), with an emphasis being placed on CTC14 under both irrigation treatments.

2. The main highlight was the RB966928 variety, which showed the best performance under both irrigation treatments.

Literature Cited

Brito, L. T. de L.; Cavalcanti, N. de B.; Silva, A. de S.; Pereira, L. A. Produtividade da água de chuva em culturas de subsistência no semiárido pernambucano. Engenharia Agrícola, v.32, p.102-109, 2012. http://dx.doi.org/10.1590/S0100-69162012000100011

CONSECANA - Conselho dos Produtores de Cana-de-Açúcar, Açúcar e Álcool do Estado de São Paulo. Manual de instruções. 5.ed. Piracicaba: CONSECANA, 2006. 112p.

Di Paolo, E.; Rinaldi, M. Yield response of corn to irrigation and nitrogen fertilization in a Mediterranean environment. Field Crops Research, v.105, p.202-210, 2008. https://doi.org/10.1016/j.fcr.2007.10.004

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária - Centro Nacional de Pesquisas de Solos. Manual de métodos de análises de solo. 2.ed. Rio de Janeiro: EMBRAPA, 1997. 212p.

Ferreira, D. F. Sistema para análise de variância para dados balanceados (Sisvar). Lavras: UFLA, 1999. 92p.

Gava, G. J. de C.; Silva, M. de A.; Silva, R. C. da; Jeronimo, E. M.; Cruz, J. C. S.; Kölln, O. T. Produtividade de três cultivares de cana-de-açúcar sob manejos de sequeiro e irrigado por gotejamento. Revista Brasileira de Engenharia Agrícola e Ambiental, v.15, p.250-255, 2011. https://doi.org/10.1590/S1415-43662011000300005

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

Nassif, D. S. P.; Marin, F. R.; Costa, L. G. Evapotranspiration and transpiration coupling to the atmosphere of sugarcane in southern Brazil: Scaling up from leaf to field. Sugar Tech, v.16, p.250-254, 2014. https://doi.org/10.1007/s12355-013-0267-0

Oliveira, E. C. A. de; Freire, F. J.; Oliveira, A. C. de; Simões Neto, D. E.; Rocha, A. T. da; Carvalho, L. A. de. Produtividade, eficiência de uso da água e qualidade tecnológica de cana-de-açúcar submetida a diferentes regimes hídricos. Pesquisa Agropecuária Brasileira, v.46, p.617-625, 2011. https://doi.org/10.1590/S0100-204X2011000600007

Pereira, L. S.; Cordery, I.; Iacovos, I. Improved indicators of water use performance and productivity for sustainable water conservation and saving. Agricultural Water Management, v.108, p.39-51, 2012. https://doi.org/10.1016/j.agwat.2011.08.022

Pereira, L. S.; Oewis, T.; Zairi, A. Irrigation management under water scarcity. Agricultural Water Management, v.57, p.175-206, 2002. https://doi.org/10.1016/S0378-3774(02)00075-6

Rabnawaz; Khan, M. J.; Sarwar, T.; Khan, M. J. Comparative study of crop water productivity at farm level under public and civil canal irrigation systems in Peshawar, Pakistan. Sarhad Journal of Agriculture, v.31, p.175-182, 2015. https://doi.org/10.17582/journal.sja/2015/31.3.175.182

Raij, B. van; Cantarella, H.; Quaggio, J. A.; Furlani, A. M. C. Recomendações de adubação e calagem para o estado de São Paulo. 2.ed. Campinas: Instituto Agronômico, 1997. 285p. Boletim Técnico, 100

Robertson, M. J.; Muchow, R. C. Future research challenges for efficient crop water use in sugarcane production. Proceedings of Australian Society of Sugar Cane Technologists, v.16, p.193-200, 1994.

Silva, T. G. F. da; Araújo Primo, J. T.; Silva, S. M. S. e; Moura, M. S. B. de; Santos, D. C. dos; Silva, M. da C.; Araújo, J. E. M. Indicadores de eficiência do uso da água e de nutrientes de clones de palma forrageira em condições de sequeiro no semiárido brasileiro. Bragantia, v.73, p.184-191, 2014. https://doi.org/10.1590/brag.2014.017

Silva, T. G. F. da; Moura, M. S. B. de; Zolnier, S.; Soares, J. M.; Vieira, V. J. de S.; Gomes Júnior, W. F. Demanda hídrica e eficiência do uso de água da cana-de-açúcar irrigada no semiárido brasileiro. Revista Brasileira de Engenharia Agrícola e Ambiental, v.15, p.1257-1265, 2011. https://doi.org/10.1590/S1415-43662011001200007

Singh, P. N.; Shukla, S. K.; Bhatnagar, V. K. Optimizing soil moisture regime to increase water use efficiency of sugarcane (*Saccharum* spp. hybrid complex) in subtropical India. Agricultural Water Management, v.90, p.95-100, 2007. https://doi.org/10.1016/j.agwat.2007.02.008