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Full Length Research Paper

Productivity of fertirrigated sugarcane in subsurface drip irrigation system

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The productivity and fresh phytomass index of sugarcane cultivated at different water replacement levels using a subsurface drip system, with or without N, were analyzed. Sugarcane plants underwent five water replacement levels (100, 75, 50, 25 and 0%), with or without N application (100 kg ha^{-1}) in urea. At harvest-time, stalk productivity, water-use efficiency, gross sugar yield, gross alcohol yield, fresh phytomass of tip, dry leaf phytomass, total fresh phytomass and the ratio between the fresh phytomass of tip and stalk productivity were evaluated. A 100% water replacement increased stalk productivity by 40% compared with drought-stricken area management (water replacement 0%) and high efficiency in the exploitation of photoassimilated in stalk production. N-urea application increased by 14% the gross sugar and alcohol yield. Water deficit (water replacement 0%) caused severe decrease (26%) in total phytomass of the sugarcane plant´s aerial section.

Key words: *Saccharum officinalis*, water replacement, irrigation, nitrogen, water deficit.

INTRODUCTION

With its positive potential energetic balance, it has been brought to the attention of producers that sugarcane culture is a source of energy production (Renouf et al., 2008; Smeets et al., 2009). Sugarcane has traditionally been employed as forage for animal feed or as raw matter for the manufacture of candy, syrup, brandy, sugar and alcohol fuel. However, sugarcane productivity is limited by edaphoclimatic factors such as water and nitrogen deficiency (Gava et al., 2010, 2011).

Water deficit is a main factor in production decrease in most cultures worldwide (Bray et al., 2000), even though its effects must be minimized by irrigation systems.

Irrigation of sugarcane plantations has triggered improvements in the number of harvests and the culture cycle with a productivity increase of over 100% (Dalri et al., 2008). The rational management of water in sugarcane culture by irrigation technology is basic for the maximization of production.

Drip irrigation systems have proved to be highly efficient in water-saving in agriculture. The formation of a wetted bulb in the cultivated soil, especially in areas of intense microorganism activity and high concentration of the culture´s root system is reported (Thorburn et al., 2003). Since nutrient balance is associated with the correct management of irrigation water, nitrogenated fertilizers in the soil undergo chemical and microbial transformations

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Table 1. Chemical characterization of soil in the experimental area.

Layer	pH	OM	P	K	Ca	Mg	Al	H+Al	S	CTC	V
(m)	-	(*g dm*$^{-3}$)	(*mg dm*$^{-3}$)	(mmol dm^{-3})							(%)
0.00 - 0.20	6.2	63.42	7.06	2.04	20.40	16.80	0.0	57.75	41.80	99.55	41.99
0.20 - 0.40	6.6	44.47	2.65	4.09	14.40	13.20	0.0	44.55	31.69	76.24	41.57

pH in distilled water. P and K – extractor Mehlich^{-1}. O.M – Organic matter. V – Saturation by bases.

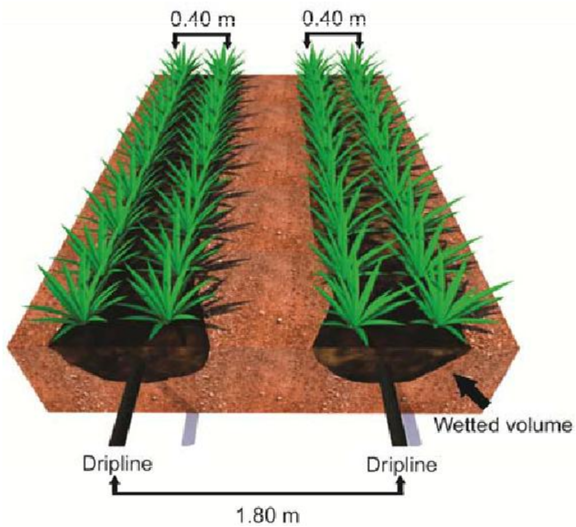

Figure 1. Outline of W-shaped planting and the laying of driplines in treatments with water replacement. Prepared by Eugênio Ângelo Ribeiro Batista and Marconi Batista Teixeira (2013).

which may cause losses to vegetation. For reasons of cost, the development of adequate management of nitrogenated manure is underscored, so that N in sugarcane cultures may be better exploited (Franco et al., 2008). In fact, N deficiency in plants triggers a decrease in chlorophyll and synthesis of essential aminoacids, with a subsequent reduction of photosynthetic rates and less energy for the production of carbohydrates (Epstein and Bloom, 2006).

The productivity response of irrigated sugarcane depends on a series of factors such as the quantity of water and fertilizers (Dantas Neto et al., 2006), irrigation management, cultivar type, cutting age, and type of soil and climate (Smit and Singels, 2006). Current research characterizes the productivity index and fresh phytomass of sugarcane cultivated at different levels of water replacement using a subsurface drip system, with and without N, allotted throughout the culture cycle.

MATERIALS AND METHODS

The experiment was performed in the experimental area of the Federal Institute of Goiás, campus Rio Verde GO Brazil, 17°48'28"S and 50°53'57"W, mean altitude 720 m, slightly rolling ground relief (slope 6%), red dystrophic latissoil, (LVdf) with mean texture 458, 150 and 391 g kg^{-1} sand, silt and clay, respectively, and chemical characteristics as shown in Table 1.

The experimental design comprised randomized blocks in a 5x2 factorial scheme, with four replications. Treatments consisted of five levels of water replacement (100, 75, 50, 25 and 0%) and two nitrogen (urea) doses (0 and 100 kg N ha^{-1}).

The planting of sugarcane, cultivar RB855453, was performed in a double row (W-shaped), 8 m long, with 1.80 m spacing between the double rows. The distance between the crops in the double row was 0.40 m, with a total area of 35.2 m^2 in each paddock. For treatments with water replacement (WR) a drip tube was placed in the ground at a depth of 0.20 m among the furrows of the double row (Figure 1). The drip tube (DRIPNET PC 16150) comprised a thin wall, 1.0 bar pressure, nominal discharge 1.0 L h^{-1}, and 0.50 m spacing between drippers.

On planting, all furrows of the plots were fertilized with30 kg N ha^{-1} (urea), 120 kg P_2O_5 ha^{-1} (single superphosphate) and 80 kg K_2O ha^{-1} (potassium chloride). Nitrogen was applied by fertirrigation at a dose of 100 Kg ha^{-1}, at 30-day intervals, with 10 applications throughout the development of the sugarcane culture. Potassium fertilization was done partially, in 30% of the furrows, and the remaining part was treated with the irrigation water. Nitrogen and potassium were spread only in the treatment with 0% water replacement.

Table 2. Water volume received at each water replacement level.

WR (%)	WA (mm)	R (mm)	TVW (mm)
RH 0	0	1618	1618
RH 25	126	1618	1744
RH 50	252	1618	1870
RH 75	378	1618	1996
RH 100	504	1618	2122

WR – water replacement; WA – water applied during the experiment; R – rainfall; TVW – Total volume of water received.

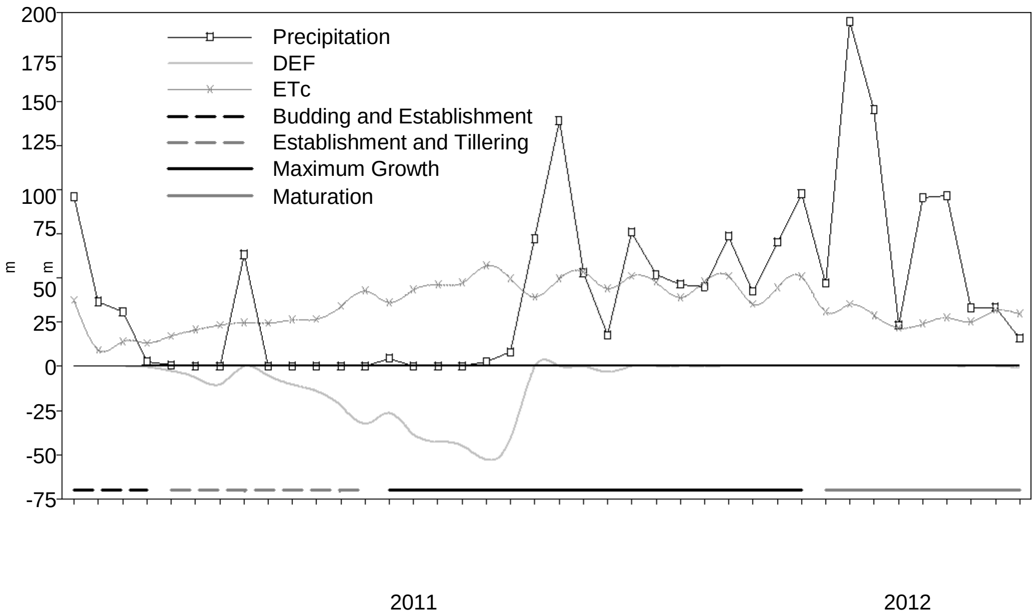

Figure 2. Water balance of sugarcane (0% water replacement) during the experiment. DEF – water deficit; ETc – Evaporation-transpiration of the culture; culture phases (adapted from Doorenbos and Kassam, 1994): Budding and Establishment (Kc = 0.6); Establishment and Tillering (Kc = from 0.9 to 1.1); Maximum growth (Kc = 1.3); Maturation (Kc = from 0.7 a 0.9). Source: INMET – Rio Verde GO Brazil.

Water demand was calculated by a 0.1 kPa puncture digital tensiometer. Tensiometric sensors were placed at a depth of 0.20, 0.40, 0.60 and 0.80 m, at a distance of 0.15, 0.30, 0.45 and 0.60 m from the drip tube, with daily readings of water tension in the soil. The soil's physical and water characteristics were determined by the water retention curve in the soil, with an available water capacity (AWC) of 100 mm. Soil was kept at field capacity in treatments with 100% WR. By the end of the experiment, the water supplemented to the soil was calculated to determine the volume of water provided (Table 2).

A water balance was estimated every ten days and water deficiency (WD) was calculated for the culture period (March 2011 to April 2012) from rainfall data, according to the method by Thornthwaite and Mather (1955), adapted by Camargo (1962). Reference evapotranspiration (Et_0) was calculated according to the equation by Penman-Monteith (Monteith, 1973), with results shown in Figure 2. Total evaporation-transpiration and precipitation reached 1549 and 1618 mm, respectively in the treatment without water replacement.

The useful area in each plot was harvested (central linear meter of the main row) after 395 days of planting. Stalk, tip and dry leaves mass were calculated. These values were used to determine the fresh phytomass of the tip (PT, Mg ha^{-1}), phytomass of the dry leaf (DP, Mg ha^{-1}), total fresh phytomass of the aerial part (TP, Mg ha^{-1}) and the ratio between tip and stalk phytomass (TP:SP, %). The TP:SP ratio was calculated by the division of TP by stalk productivity (SP) and multiplied by 100 for the percentage. The stalks of ten plants per treatment were collected and analyzed in a laboratory to determine gross sugar (GSY) and alcohol (GAY) yield. Stalk productivity (SP, Mg ha^{-1}) was calculated by the proportional ratio of the stalk weight of the sampled area per hectare. The efficiency of water usage (WUE, mm Mg^{-1} ha^{-1}) was determined by the total volume of received water (mm) divided by stalk productivity. Gross sugar (GSY, Mg ha^{-1}) and alcohol (GAY, m^3 ha^{-1}) yield were calculated following the method by Caldas(1998). Results were analyzed by ANOVA. In significant cases, regressions

Table 3. Summary of the analysis of variance for stalk productivity (SP), efficiency in water usage (EWU), gross sugar yield (GSY) and gross alcohol yield (GAY) of sugarcane at different levels of water replacement, with and without N application.

Source	GL	Mean square			
		SP	EWU	GSY	GAY
Water replacement (WR)	4	8424.45**	5.98^{ns}	245.03**	122.70**
Nitrogen (N)	1	6038.38^{ns}	9.43^{ns}	222.45*	110.50*
Interaction WR x N	4	441.10^{ns}	1.06^{ns}	12.61^{ns}	6.31^{ns}
Blocks	3	1712.05^{ns}	4.19^{ns}	36.54^{ns}	18.53^{ns}
Waste	27	1866.16	3.80	40.73	20.63
CV (%)		20.23	21.31	20.58	20.57
Nitrogen (N)		**Means**			
with N		225.82^{a}	8.67^{a}	33.36^{a}	23.74^{a}
without N		201.25^{a}	9.64^{a}	28.64^{b}	20.42^{b}
DMS		28.03	1.27	4.14	2.95

* Significant at 0.01 probability by test F; ** Significant at 0.05 probability by test F; ^{ns} Not significant at 0.05 probability by test F; Means followed by the same letter in the columns do not differ statistically at 0.05 probability by Tukey´s test.

of linear and quadratic were performed for water replacement levels. Nitrogen application means were compared using Tukey test at significance degree α = 0.05.

RESULTS

There was no significant interaction between water replacement and nitrogen doses for any of the characteristics evaluated in the sugarcane plants (Table 3). The water replacement (WR) factor caused a significant effect at 1% probability for the following variables: stalk productivity (SP), gross sugar yield (GSY) and gross alcohol yield (GAY). On the other hand, application of nitrogen (N) significantly affected the GSY and GAY results (Table 3), although the water-use efficiency (WUE) was not influenced by any factor evaluated (Table 3).

Stalk productivity (SP) responded to water replacement with a linear increase, following regression analysis (R^2 = 0.75) (Figure 3A). Consequently, a 0.4% increase in stalk productivity was obtained for each 1% water replacement provided, equivalent to 0.7 Mg ha^{-1} yield. Maximum stalk productivity was obtained in the 100% WR management with an estimated mean of 40% higher than that of drought management (WR 0%) at 178 Mg ha^{-1} (Figure 3A).

The estimated maximum gross sugar yield (GSY) amounted to 35 Mg ha^{-1} obtained by 80.2% water replacement, and therefore a 61% increase compared with treatment without any water replacement (Figure 3B). The maximum curve peak showed gross alcohol yield (GAY) of 25.34 m^3 ha^{-1} obtained by 79.7% water replacement. Mean GAY reached 22.15 m^3 ha^{-1}, whereas the lowest rate was 15.82 m^3 ha^{-1}, in the drought treatment (WR 0%), or rather, 56.25% decrease when compared with the highest yield (Figure 3C).

Mean GSY and GAY rates in sugarcane fertilized with 100 kg N ha^{-1} were respectively 33.36 Mg ha^{-1} and 23.74 m^3 ha^{-1} (Table 3). Nitrogenated manure had an increase of approximately 16% for these variables compared with plants which did not receive any nitrogen (Table 3).

Total phytomass (TF) and tip and stalk phytomass ratios (PT:SP) were significantly affected by water replacement treatments. Nitrogen affected PT significantly (Table 4) but the interaction between water replacement and nitrogen application (WR x N) did not significantly influence any of the variables analyzed (Table 4). Total phytomass in drought reached 249.5 Mg ha^{-1}, with a 35.3% decrease in yield obtained with 100% water replacement and a response of 337.7 Mg ha^{-1} (Figure 4A). The effects of nitrogenated fertilization only occurred for tip phytomass (PT), with a 14.7% increase (Table 4).

The relationship between tip and stalk phytomass (PT:SP) underscored the response of the development of the tip compared with the sugarcane stalk yield. The variable provided a quadratic response due to water replacement (R^2 = 0.74), where the highest PT:SP was reported in drought management (WR 0%), with mean PT:SP at 37% (Figure 4B). The above result revealed a tip development of 0.37 Mg ha^{-1} for each megagram of stalk produced. However, when the stalk´s low productivity with this treatment was compared with the others, the significant PT:SP response became a limiting factor attributed to the low exploitation of photosynthetic products in the production of stalks.

Further, treatment with 100% WR also had a high PT:SP ratio with a mean rate of 33.3%. Since the SP yield was high, the ratio became a positive factor. A high PT:SP ratio is very important for culture yields when one

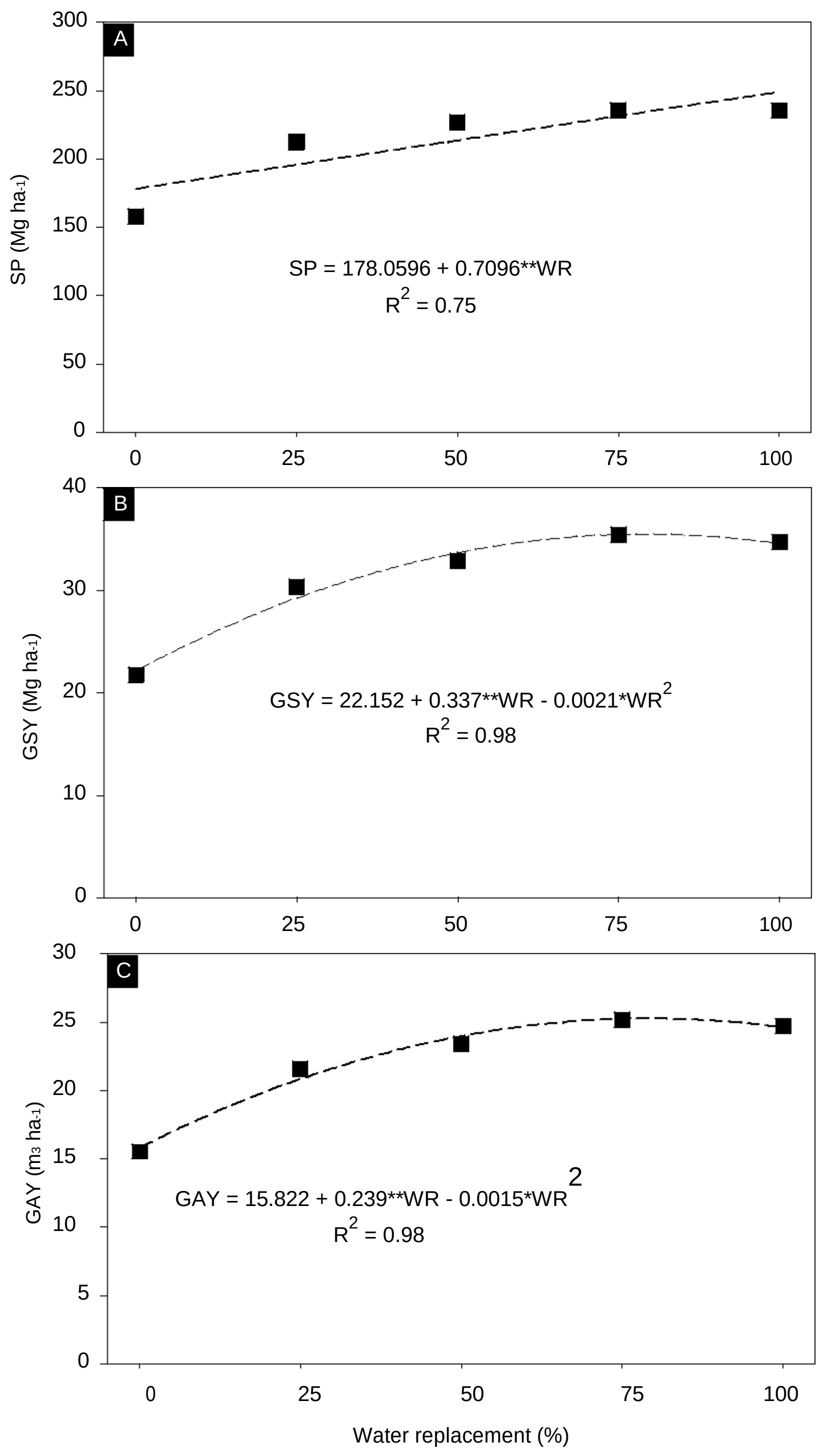

Figure 3. Effects of water replacement (WR) on the productivity of stalks (SP) (A), o gross sugarcane yield (GSY); (B) gross alcohol yield (GAY); (C) in sugarcane.

considers that the higher the production of carbohydrates by photosynthesis the higher the architecture of the leaf area. However, the assimilation of carbohydrates should be taken into account so that they can be exploited in stalk production.

High production of sugarcane tips should also be considered with regard to the hay wastes on the ground during harvest. The lowest PT:SP ratio was reported in

Table 4. Summary of analysis of variance for stalk phytomass (SP), phytomass tip (PT), dry leaf phytomass (DP), total phytomass (TF) and ratio between phytomass tip and stalk phytomass (PT:SP) of sugarcane at different levels of water replacement, with and without nitrogen.

Source	**GL**	**Mean square**			
		PT	**DP**	**TF**	**PT:SP**
Water replacement (WR)	4	466.81^{ns}	29.38^{ns}	12479.74*	68.70*
Nitrogen (N)	1	1060.28*	4.85^{ns}	11678.62^{ns}	16.11^{ns}
Interaction WR x N	4	394.20^{ns}	18.90^{ns}	1766.33^{ns}	43.97^{ns}
Blocks	3	39.48^{ns}	26.77^{ns}	1281.65^{ns}	56.80
Waste	27	213.36	33.69	3281.06	23.32
CV (%)		22.51	38.27	19.51	15.70
Nitrogen (N)					
with N		70.03^{a}	14.81^{a}	310.67^{a}	31.39^{a}
without N		59.73^{b}	15.51^{a}	276.50^{a}	30.12^{a}
DMS		9.47	3.76	37.16	3.13

* Significant at 0.01 probability by test F; ** Significant at 0.05 probability by test F; ^{ns} Not significant at 0.05 probability by test F; Means followed by the same letter in the columns do not differ statistically at 0.05 probability by Tukey´s test.

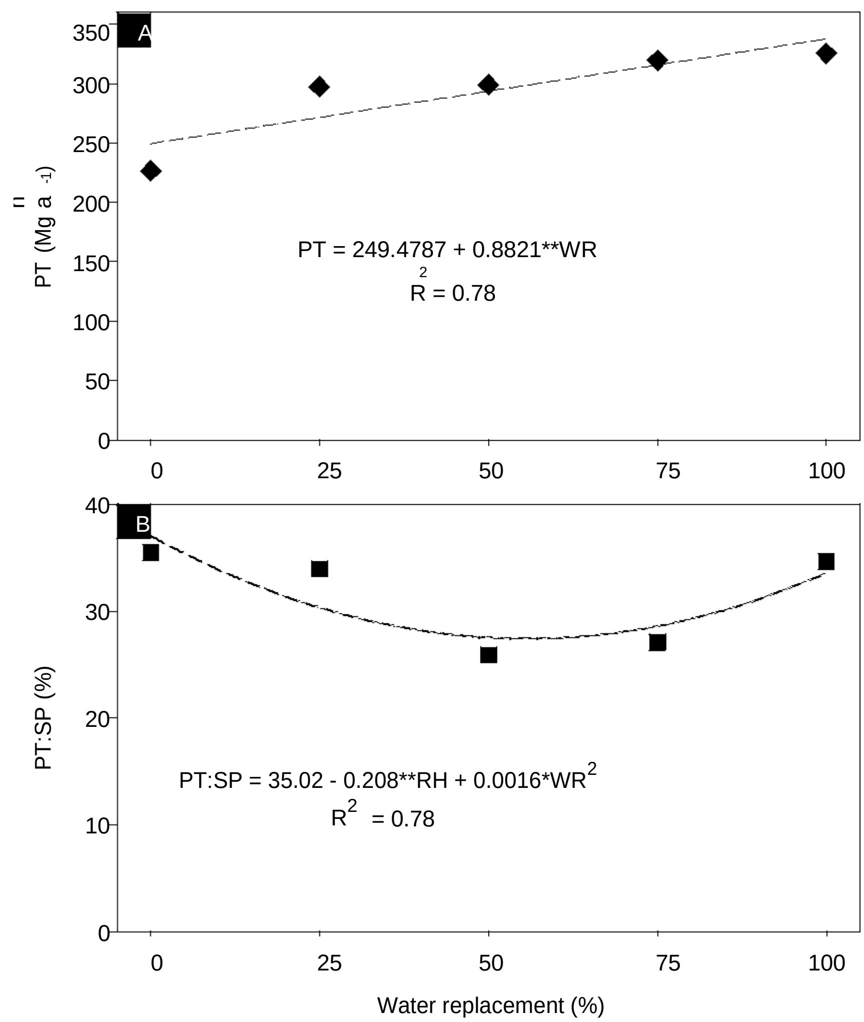

Figure 4. Effects water replacement (WR) on total phytomass (TF) (A), and ratio of phytomass tip and stalk (PT:SP) (B) in sugarcane.

water replacement at 56%, with an estimated mean of 27.4%.

This means that 0.274 Mg ha^{-1} of sugarcane tips was actually required for each megagram of stalks per hectare (Figure 4B). Given that a 218 Mg ha^{-1} stalk yield is attained with 56% water replacement, according to the trend for SP (Figure 2), the plants' high efficiency in the assimilation of carbohydrates produced in photosynthesis must be recognised.

DISCUSSION

The reported water balance showed that during phases with high water demand by the sugarcane, namely, during tillering and initial growth, a water deficit occurred. The intensity and duration of this period, especially at the start of the growth phase, decreased the productivity through a reduction in growth rates. Within the context of drought, water failed to put a turgescence pressure on the cell wall and, therefore, growth increase failed to occur (Taiz and Zeiger, 2013).

Similar to most poaceae, sugarcane requires great quantities of water for development since it has a high efficiency in using and recovering CO_2 from the air under conditions of high irradiancy and temperatures (Segato et al., 2006).

The highest rates in the productivity of stalks and the accumulation of total phytomass were reached when 100% water replacement took place, with a respective increase of 40 and 35% in productivity compared with plants during drought (WR 0%). This showed that the long dry winter caused yield decrease in spite of the occurrence of adequate rainfall during the summer. In some periods, irregular rainfall may also limit the growth of sugarcane plants (Ometto, 1980).

Mean stalk production, estimated at 213.5 Mg ha^{-1} was higher than that reported by Carvalho et al. (2009) and Oliveira et al. (2009). These results were due to the high rainfall rate during the experimental period (1618 mm) and to water availability coupled with the application frequency of the irrigation treatments. The data corroborated the importance of irrigation technology for the maximization of the culture´s genetic potential and for obtaining high productivity rates.

Water replacement and nitrogenated fertilization by fertirrigation affected the productivity and quality of the sugar. Sugarcane cultivar RB 855536 had a 57% increase, or rather, a 24.7 Mg ha^{-1} yield of sugar when it received a total water volume of 1714 mm during the cycle (Gava et al., 2011), whereas sugarcane cultivar RB 72454 had a loss of technological quality when irrigation was 130 mm higher than control treatment (Dalri et al., 2008).

Doses of 157 kg ha^{-1} of N and 148 kg ha^{-1} of K_2O for cover fertilization provided a significant increase in sugarcane technological quality, with a respective increase of 39.8 and 42.2% for GSY and GAY, featuring a yield of 12.58 Mg ha^{-1} sugar and 8.91 m^3 ha^{-1} alcohol (Dantas Neto et al., 2006).

The relevant effect of nitrogen on PT may be assigned to small doses of fertilizers throughout the culture cycle, with an absorption increase and a beneficial usage of nitrogen (Singh and Mohan, 1994; Ng Kee Kwong et al., 1999) due to a higher synchronization of availability and nutrient absorption by the plants (Gava et al., 2010). The treatment mean PT was 70 and 59.7 Mg ha^{-1}, respectively, with and without nitrogen.

Consequently, water replacement triggered an increase in stalk productivity compared with drought management. Nitrogen-urea applications in small doses throughout the culture cycle improved the sugarcane's technological indexes. Lack of water caused a heavy decrease in the total phytomass of the sugarcane's aerial parts. High stalk yield was recorded compared with tip phytomass with 100% water replacement and demonstrated the plants' high efficiency in the assimilation of carbohydrates produced by photosynthesis. When the plant phytomass was taken into account, nitrogen only increased the production of the tip phytomass.

Conflict of Interest

The author(s) have not declared any conflict of interests.

Abbreviations: AWC, Available water capacity; **DP,** Dry leaf phytomass (Mg ha-1); **ET0,** Reference evaporation-transpiration; **GAY,** Gross alcohol yield (m3 ha-1); **GSY,** Gross sugarcane yield (Mg ha-1); **Mg,** Megagram; **PT:SP,** Fresh phytomass of tip and stalk productivity ratio (Mg ha-1); **PT,** Fresh phytomass of tip (Mg ha-1); **R,** Rainfall (mm); **SP,** Stalk productivity (Mg ha-1), **TP,** Total fresh phytomass (Mg ha^{-1}); **WD,** Water deficit; **WUE,** Water-use efficiency.

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REFERENCES

Bray EA, Bailey-Serres J, Weretilnyk E (2000). Response to abiotic stress. In: Buchanan BB, Gruissem W, Jones RL. (eds). Biochemistry and molecular biology of plants. Rockville: Am.erican Soc.iety of Plant Physiologists. pp. 1158-1203.

Caldas C (1998). Manual de análises selecionadas para indústrias sucroalcooleiras. Maceió: Sindicato da Indústria e do Álcool do

Estado de Alagoas., P. 424.
Camargo AP (1962). Contribuição para a determinação da evapotranspiração potencial no Estado de São Paulo. Bragantia, Campinas., 21:163-203.http://dx.doi.org/10.1590/S0006-87051962000100012
Dalri AB, Duenhas LH, Garcia CJB, Cruz RL. (2008). Subsurface drip irrigation on sugarcane yield and quality. Irriga. 13(1):1-11. .
Epstein E, Bloom A (2006). Nutrição mineral de plantas; princípios e perspectivas. Londrina: [s.n.]., P. 402.
Franco HCJ, Trivelin PCO, Faroni CE, Vitti AC, Otto R (2008). Aproveitamento pela cana-de-açúcar da adubação nitrogenada de plantio. Revista Brasileira de Ciência do Solo. 32(spe):2763-2770.
Gava GJC, Kölln OT, Uribe RAM, Trivelin PCO, Cantarella H (2010). Interação entre água e nitrogênio na produtividade de cana-de-açúcar (Saccharum sp.). In: Crusciol CA. (Org.). Tópicos em ecofisiolgia da cana-de-açúcar. 1. ed. Botucatu: FEPAF. 1:49-66.
Gava GJC, Silva MA, Silva RC, Jeronimo EM, Cruz JCS, Kölln OT (2011). Produtividade de três cultivares de cana-de-açúcar sob manejos de sequeiro e irrigado por gotejamento. Revista Brasileira de Engenharia Agrícola e Ambiental, 15(3):250-255.http://dx.doi.org/10.1590/S1415-43662011000300005
Monteith JL (1973). Principles of environmental physics. Edward Arnold, London. P. 241.
Ng Kee Kwong KF, Paul JP, Deville J (1999). Drip-fertigation - a means for reducing fertilizer nitrogen to sugarcane. Exp. Agric. 35(1):31-37.http://dx.doi.org/10.1017/S0014479799001040
Ometto JC (1980). Parâmetros meteorológicos e a cultura da cana-de-açúcar. Piracicaba: ESALQ, P.17.
Renouf MA, Wegener MK, Nielsen LK (2008). An environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugars for fermentation. Biomass Bioenergy. 32(12):1144-1155.http://dx.doi.org/10.1016/j.biombioe.2008.02.012
Segato SV, Mattiuz CFM, Mozambani AE (2006). Aspectos fenológicos da cana-de-açúcar. In: Segato SV, Pinto AS, Jendiroba E, Nóbrega JCM. Atualização em produção de cana-de-açúcar. Piracicaba, pp.19-36.
Singh PN, Mohan SC. (1994). Water use and yield response of sugarcane under different irrigation schedules and nitrogen levels in a subtropical region. Agric. Water Manage. 26(4):253-264.http://dx.doi.org/10.1016/0378-3774(94)90012-4
Smeets EMW, Bouwman LF, Stehfest E, Van Vuuren DP, Posthuma A (2009). Contribution of N2O to the greenhouse gas balance of first generation biofuels. Global Change Biol. 15(1):1-23.http://dx.doi.org/10.1111/j.1365-2486.2008.01704.x
Smit MA, Singels A. (2006). The response of sugarcane canopy development to water stress. Field Crops Res.earch, 98(2-3): 91-97.http://dx.doi.org/10.1016/j.fcr.2005.12.009
Taiz L, Zeiger E (2013). Plant Physiology, 5th edition. Ed. Sinauer Associates. P. 690.
Thorburn PJ, Dart IK, Biggs IM, Baillie CP, Smith MA, Keating BA (2003). The fate of nitrogen applied to sugarcane by trickle irrigation. Irrigation Sci. 22(3-4):201-209.http://dx.doi.org/10.1007/s00271-003-0086-2
Thornthwaite CW, Mather JR (1955). The water balance. Centerton, N.J.: Drexel Institute of Technology -– Lab. Climatol. P. 104. (Publications in Climatology, v.8, n.1).