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Cientific Paper

How the components of bioenergy and technological traits are affected by water deficit in sugarcane?

Tadeu Alcides Marques[1]
Jane Rodrigues de Vasconcelos[1]
Alexandrius de Moraes Barbosa[1]
Gustavo Maia Souza[1]
Patrícia Angélica Alves Marques[2]

Abstract

To study the effect of water stress on the production of bioenergy and on the biometric and technological parameters that comprise bioenergy in sugarcane, two treatments were tested: 100% replacement of evapotranspiration and 20% of evapotranspiration, with 10 replicates, using a total of 20 plots, and in a completely randomized design. Biometric, technological and calorimetric analyses were done. Under water stress there was a reduction of biomass and for all the analyzed components (TRS, Pol, Brix and Fiber). The total bioenergy of the system was reduced in the same proportion as the biomass, presenting changes in its composition. The simple sugars (glucose and fructose) showed minor reduction than other components of bionergy.

Keywords: *Saccharum spp.*; Water, Energy; Biomass and Carbohydrate partitioning

Como componentes de la bioenergía y tecnología de la caña de azúcar se ven afectados por el déficit hídrico?

Resumen

Para estudiar los efectos del déficit de agua en la producción de bioenergía y biométrica y parámetros tecnológicos de la caña de azúcar se ha estudiado dos tratamientos: 100% de reemplazo de la evapotranspiración (control) y 20% de sustitución de la evapotranspiración (déficit hídrico) con 10 repeticiones para cada tratamiento. Se realizaron y evaluaron análisis biométricos, tecnológicos y calorimétricos. Bajo déficit hídrico las plantas de caña de azúcar redujeran la biomasa y los componentes (ATR, Pol, Brix y fibra). El bioenergía total del sistema se redujo en proporción a la biomasa, con cambios en su composición. Ya los azúcares simples (glucosa y fructosa) tuvieron reducción menor que los componentes bioenergéticos.

Palabras clave: *Saccharum spp*; agua; energía; biomasa y partición de los hidratos de carbono

Como os componentes bioenergéticos e tecnológicos da cana-de-açúcar são afetados pelo deficit hídrico?

Resumo

Para estudar os efeitos do deficit hídrico na produção de bioenergia e nos parâmetros biométricos e tecnológicos da cana-de-açúcar, foi estudado dois tratamentos: 100% da reposição da evapotranspiração (controle) e 20% de reposição da evapotranspiraçao (deficit hídrico), com 10 repetições para cada tratamento. Foram realizadas e avaliadas análises biométricas, tecnológicas e calorimétrica. Sob deficit hídrico as plantas de cana-de-açúcar tiveram redução na biomassa e nos components avaliados (ATR, Pol, Brix e Fibra). A bioenergia total do sistema foi reduzida na mesma proporção da biomassa, apresentando mudanças em sua composição. Já os açúcares simples (glucose e fructose) tiveram menor redução do que os componentes bioenergéticos.

Palavras chave: *Saccharum spp.*; Água, Energia; Biomassa e partição de carboidratos

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1 Universidade do Oeste Paulista (UNOESTE), CEP 19067-175, Presidente Prudente, São Paulo, Brazil. tmarques@unoeste.br. Author for correspondence.
2 Escola Superior de Agricultura Luiz de Queiroz (ESALQ), CEP 13418-900, Piracicaba, São Paulo, Brazil.

Introduction

In 2013, Brazil was the highest producer of sugarcane in the world, showing an increase of 4.3% compared to the previous years, with 8.5 million hectares distributed in all producing states. The State of São Paulo is the main sugarcane producer, with 4.4 million hectares with an estimated 596.63 million tons pressed, exceeding the 2011/12 season by 6.5% (CONAB, 2012).

Sugarcane is a C4 crop with high photosynthetic rate and efficiency in the use and recovery of CO_2 from the atmosphere. It is adapted to conditions of high light intensity, high temperatures and relative scarcity of water. However, with respect to water demand, this crop requires large amounts of water since 70% of the biomass produced is composed of water (SEGATO et al., 2006). Overall, sugarcane plants require a total rainfall in the range from 1,000 to 2,500 mm annually. During its rapid growth phase, daily peaks of evapotranspired water can reach 5 – 6 mm , depending on the variety, stage of crop development, plant height, leaf area, soil and local climatic conditions. The water requirement is relatively low in the early phase of the plant growth and in the maturation of the stalk. Thus, the developmental stage most susceptible to the occurrence of water deficiency is the period of rapid vegetative growth for the cane-plant and the early growth stage (tiller growth) for the ratoon cane. The occurrence of water stress in these periods causes irreversible negative impacts on the productivity and quality of the raw material (MAULE et al., 2001; INMAN-BAMBER and SMITH, 2005; DANTAS NETO et al., 2006; BRUNINI, 2008; INMAN-BAMBER et al., 2008).

The production of second-generation bioethanol, by the hydrolysis of lignocelluloses, has been the focus of extensive research, mainly seeking alternative crops that reach high bioenergy production. In order to achieve high production of bioenergy, the crop must have rapid growth with high efficiency of energy conversion and, from planting to harvest, the "input" of energy must be lesser than the "output". If these requirements are met, sugarcane is one of the most promising crops (WACLAWOVSKY et al., 2010).

The economic yield of sugarcane results from the production of sucrose, its most valuable component, in addition to reducing sugars, which, in the industrial processing of sugar, generates the molasses. Additionally, cane fiber (bagasse) can be used as an energy source for the power plant itself or for cogeneration of energy for commercialization, improving the efficiency of the utilization of the bioenergy accumulated in the whole plant (REIN, 2007; ROSSETTO, 2012).

The use of bagasse for the cogeneration of renewable electricity, coming from the sun and converted into biomass by plants, can become an important component in the energy grid of many countries. In Brazil the potential production reaches 4GW, equivalent to 25% of the total generated by the Bi-national Itaipu hydroelectric, the largest hydro power plant in South America (GOLDEMBERG, 2010).

The hypothesis of this study was that, under different water conditions, the bioenergy produced by sugarcane, crossing different metabolic pathways, could be portioned differently among the carbohydrate components (simple sugars and fiber). Thus, depending on the climatic conditions, the commercial utilization of the sugarcane bioenergy (first or second ethanol generation, plus co-generation of electricity) could change in annual basis, demanding a flexible matrix energy planning. The aim of this study was to evaluate the effects of water stress on biometric, technological and energetic characteristics of sugarcane, in order to test the above hypothesis.

Materials and Methods

Single-node stalk segments (0.07 m) of sugarcane (*Saccharum* spp.) cv. RB86-7515 were planted in plastic pots (20 L) filled with 12 kg of soil (red-yellow ultisoil). The RB86-7515 cultivar, one of the main varieties in Brazil, displays high productivity, good tillering, low nutritional requirements, high sucrose yield, disease resistance, and drought tolerance (RIDESA, 2008). Fertilization was performed according to the soil chemical analysis (VITTI, 2008), and plants were irrigated daily until the beginning of the drought treatment.

This study was carried out in a growth chamber (Phytotron Eletrolab, modelo El 011, Brazil), where plants were grown for five months at the relative air humidity of 60%, a photoperiod of 14 h with a photosynthetic photon flux density (Q) of 800 $\mu mol\ m^{-2}\ s^{-1}$, and an air temperature of 29/23 °C (day/night). The water deficit treatments were initiated when plants were 30 days old. The water deficit was induced by maintaining the soil moisture in pots at 20% of the soil water retention capacity (SWRC).

As a control, one group of plants was maintained at 100% of SWRC. The soil moisture was monitored through daily pot weighing and watering, following a previously described procedure (CATUCHI et al., 2012). Soil moisture was maintained at approximately 20% of SWRC, where it has a negative effect on sugarcane growth and physiology but does not cause plant death. Considering the morphological factors of the plant and its interference on the water dynamics in the production system, the amount of water to be replaced was multiplied beforehand by the crop coefficient (kc) of sugar cane. The values of kc in phase 01 were considered: 0.50, ranging up to 60 days from planting in the chamber, equivalent to 25% ground cover; and in phase 02: 0.88, characterized by the equivalence of 25 to 50% coverage, considered after 60 days of the plants in the chamber, in keeping with DOORENBOS and KASSAM (1994).

During a period of four months of growth, new tillers were cut off, with the aim of growing only the primary stalk in the pot. After this period the plants were collected for analysis. During the growth of the sugarcane seedlings in the phytotron chamber, biometric measurements of the height of stalks, stalk diameter, number of positive, negative and dry leaves, were scored weekly, according to CASAGRANDE (1991). The technological analyses were performed according to the methodology of FERNANDES (2003), for CP (cane pol), CB (cane brix), CPu (cane purity), RSC (reducing sugars in the cane), CF (cane fiber) and TRS (total recoverable sugars). With (stalk) samples resulting from the technological analyses at the end of the experiment, superior calorific power (ΔHc) analyzes were carried out using a pump calorimeter (model Calc2K brand DDS), according to Marques and Pinto (2013). The samples were dried in a SPENCER oven to constant weight (10 min.), using the methodology of FERNANDES (2003).

All data were subjected to variance analysis ($p < 0.05$) and to the Scott-Knott's means comparison test ($p < 0.05$), according to BANZATTO and KRONKA (2006). The Microcal Origin 6.0 Program was used for the graphical statistical study of variables analyzed in time.

Results and Discussion

The technological components analyzed showed a reduction in mass when the plants were subjected to water stress, but the decrease did not occur proportionally for the different components. The TRS and CP decreased in the same proportion as the sugarcane mass, since the concentration values remained the same. On the other hand, CB and ARC decreased in a lesser proportion than the reduction in sugarcane mass, because their percentage values increased. Additionally, CF decreased in a higher proportion than the mass, since its percentage values were significantly reduced (Tables 1 and 2). The plant swerved part of the energy that should have been used for the production of fiber to the synthesis of sugars, mainly glucose and fructose.

This indicates that, under water deficit conditions, the sugarcane improves its metabolism to ATP synthesis (glycolysis + Tricarboxylic acid cycle + cellular respiration) (KUBIEN and SAGE, 2007). This behavior is due to the plant's need for increased ATP production to maintain homeostasis. The bioenergy values (Table 3) showed no differences between the treatment (15.95 MJ kg^{-1} in the stalk). These results are close to those presented by AMTHOR (2010) for others crops such as soybeans (19.1 MJ kg^{-1}), sorghum (17.2 MJ kg^{-1}), corn (17.5 MJ kg^{-1}) and sunflower (16.7 MJ kg^{-1}). AMTHOR (2010) also found small differences in relation to the amount of energy present in different parts of the plant; for example, the following values were found in soybean crops: root 18.3 MJ kg^{-1}; shoot 17.2 MJ kg^{-1}; leaf 19.0 MJ kg^{-1} and seeds 22.8 MJ kg^{-1}.

Although, the stress situation did not cause differences regarding the concentration of bioenergy (MJ kg^{-1}), total bioenergy (MJ) showed a huge reduction for treatment with water deficit, proportional to the decrease in biomass (Table 1). There was no specific metabolic pathway diversion of bioenergy allocation, only a reduction of the system's total energy due to water stress. Overall, the plant converted the carbohydrates that it would use for fiber production into metabolites for easy conversion into ATP (glucose + fructose), in order to increase the energy availability to power the homeostasis processes under water deficit conditions. According to INMAN-BAMBER et al. (2005), the reduction in growth, as a first response to water stress, restricts cell growth and elongation, decreases or completely stops leaf growth and alters the soluble solids in the sap.

Regarding bioenergy values in the roots, we observed the same behavior such as in the shoot. Total bioenergy presented strong reduction in the water deficit treatment, but there were no differences in the concentration of bioenergy per mass unit,. The root system presented reduced growth in length and mass when the plant was subjected to water stress (Table 3).

The biometric parameters evaluated

Table 1. F Test for the variables studied

Technological Variables		
Variation Factor	**F**	**CV%**
Total mass	125.17**	21.32
Cane pol	N/A	18.41
Cane brix	23.05**	11.62
Cane purity	17.64**	15.97
Cane reducing sugars	21.83**	24.42
Total recoverable sugars	N/A	14.36
Cane fiber	24.70**	21.18
Sucrose mass	51.37**	34.77
Solids mass	74.87**	23.81
Glucose + Fructose mass	18.30**	37.91
TRS mass	60.21**	31.05
Fiber mass	123.46**	25.79
Bioenergy of the Stalk (TJ ha^{-1})		
Variation Factor	**F**	**CV%**
Total mass	273.85**	18.44
MJ kg^{-1}	N/A	8.33
Bioenergy	220.04**	20.51
Bioenergy of the Root (TJ ha^{-1})		
Variation Factor	**F**	**CV%**
MJ kg^{-1}	N/A	10.83
Bioenergy	23.35**	67.03
Root Length		
Variation Factor	**F**	**CV%**
Mass	12.21**	65.17
Length	22.81**	16.53

Table 2. Technological variables in relation to treatments, T1 (100%) and T2 (20%) of H_2O replacement.

Trat	Cane Pol	Cane Brix	Cane Purity	Cane RSC	Cane Fiber	TRS	Sucrose	Solids	G+F	TRS	Fiber	Total Mass
			(%)			(g kg^{-1})				(g)		
T1	14.57^a	20.74^b	69.57^a	1.44^b	16.58^a	147.64^a	36.76^a	51.91^a	3.57^a	37.20^a	41.30^a	250.03^a
T2	13.23^a	27.66^a	48.90^b	2.62^a	9.32^b	145.60^a	7.16^b	14.97^b	1.41^b	7.88^b	5.11^b	54.21^b

Lower case letters differ in the column ($p<0.05$) for Scott-Knott.

Table 3. Calorimetrical variables in relation to the treatments, T1 (100%) and T2 (20%) of H_2O replacement.

Trat	Calorimetry of the stalk			Calorimetry of the root		Root production	
	Bioenergy		Total mass	Bioenergy			
	(MJ kg-1)	(MJ)	(g)	(MJ kg-1)	(MJ)	(g)	(m)
T1	15.90^a	4.04^a	250.0^a	15.12^a	2.86^a	186.38^a	0.91^a
T2	16.00^a	0.86^b	50.0^b	15.17^a	0.78^b	51.17^b	0.61^b

Lower case letters differ in the column ($p<0.05$) for Scott-Knott.

throughout the time (diameter, height and leaf total) showed higher values of angular coefficient of the growth curves in well-watered plants, indicating that water stress significantly affected plant growth. By the relationship between the angular coefficient for the treatments (T2/T1), we observed the following reductions: For the diameter, the ratio was 0.75; for the height, the growth rate was 0.51; and for the leaves, the rate was 0.69 (Figure 1). The results are in agreement with the literature stating that the water stress contributes to reduction in phytomass and leaf number, and promotes internode shortening, leading to lower productivity (INMAN-BAMBER et al., 2008; MACHADO et al., 2009; GAVA et al., 2011).

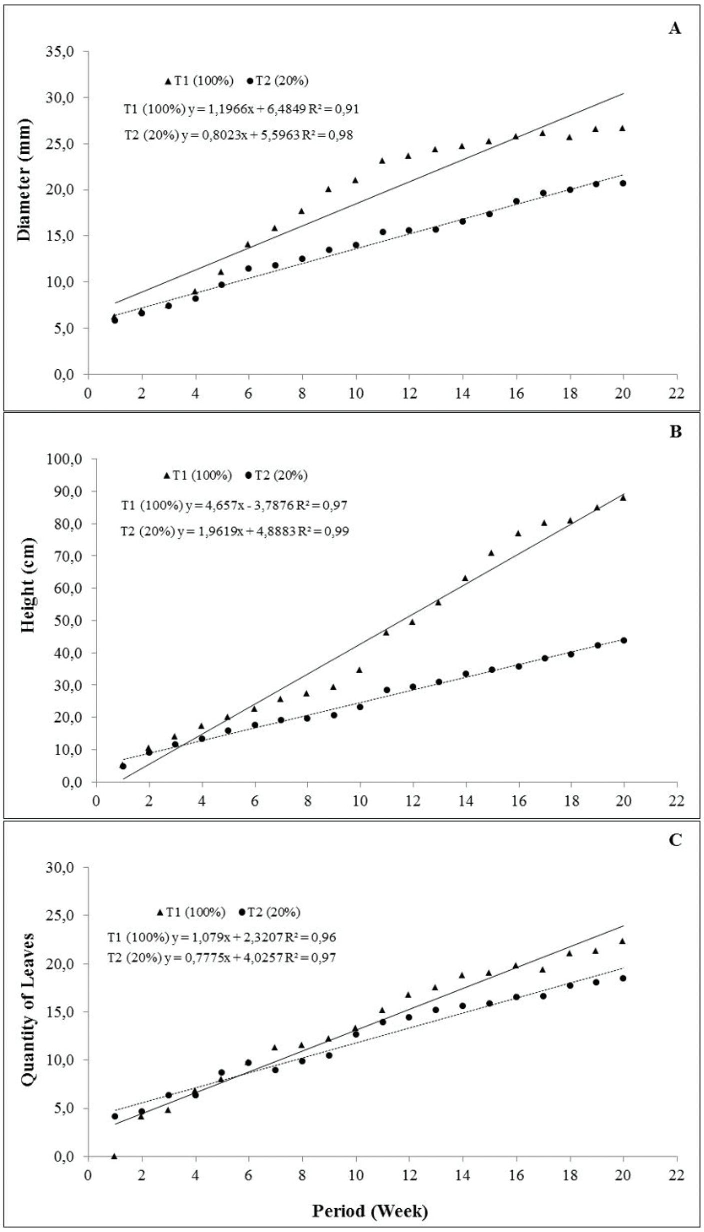

Figure 1. A-Average diameter values of the stalks during the experiment for the Treatments (T1 e T2). B-Height values of the stalks during the experiment for the Treatments (T1 and T2). C-Total leaf values during the experiment for the Treatments (T1 and T2).

Sugarcane in the field undergoes these exacerbated effects, because a smaller leaf area causes a lower transpiratory capacity and a reduction in the conversion of energy into metabolites, thereby generating sequential constraining effects. There is also deviation in what is supposed to become fiber, to simple sugars and ATP. This fact undermines further recovery when there is no longer a shortage of water. As the environmental panel of ONU presents a heating scenario in the time, inevitably stressful situations will be increasingly frequent and information about the behavior of components of bioenergy will be strategic for public policy decisions. The bioenergy production can be derived of fiber or simple sugars, but under water stress was observed a tendency of higher reduction in fiber than in soluble sugars synthesis.

Conclusions

The total bioenergy was reduced in the same proportion as the biomass, and its percentage composition was altered.

Water stress reduced the biomass of sugarcane and all the mass amounts of the analyzed technological components (TRS, Pol, RSC, Brix and fiber);

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