SHORT NON-REFEREED PAPER

WATER USE AND YIELD OF TWO CONTRASTING SUGARCANE GENOTYPES IN RESPONSE TO DROUGHT STRESS

EKSTEEN AB AND SINGELS A

South African Sugarcane Research Institute, P/Bag X02, Mount Edgecombe, 4300, South Africa
alana.eksteen@sugar.org.za, abraham.singels@sugar.org.za

Abstract

High biomass sugarcane (energy-cane) cultivars may be good candidates for bio-energy production in marginal areas. However, a better understanding is required of how much water would be used during cultivation and of their tolerance to drought. The aim of this study was to compare the drought response in terms of water use and yield of an energy-cane genotype (*Saccharum* species hybrid, genotype 04G0073) to that of a commercially grown sugarcane cultivar (*Saccharum* species hybrid, cultivar N19). Crop transpiration rate for well-watered treatments related well to grass reference evapotranspiration. Under well-watered and mild stress conditions, 04G0073 transpired at a higher rate than N19, due to a higher LAI and g_s. As drought stress intensified, N19 reduced transpiration rates sooner through early stomatal closure and at higher soil water contents than 04G0073. Instantaneous WUE was not different between control treatments, however 04G0073 showed a 21% increase in WUE under drought stress conditions. At final harvest, the well-watered 04G0073 produced 17% more biomass and used 4% more water than N19. However, drought stress caused a yield reduction of 46% in 04G0073 compared with 14% in N19.

Keywords: energy cane, drought stress, biomass, water use efficiency, transpiration

Introduction

Resource capture and use efficiency are important crop physiology parameters. Biomass water productivity (WP_b, also known as water use efficiency, WUE) is determined as the ratio between biomass produced and water used by a crop (Subbarao *et al.*, 1994). WUE is routinely used in the water-based (Raes *et al.*, 2009; Steduto *et al.*, 2009) crop growth models and the average WUE of sucrose-type sugarcane is *ca*. 3.93 kg/m^3 (Thompson, 1976; recalculated for dry matter). Sugarcane is acknowledged as an important crop for electricity generation and as a feedstock for fibrous biomass technologies (Tew and Cobill, 2008; Olivério and Ferreira, 2010). Some sugarcane hybrids and its wild relatives can achieve very high dry biomass yields, up to 90-127 Mg/ha/an (Prasertsak, 2005; Tew and Cobill, 2008). The crop is also shown to stand among most sustainable crops in terms of efficient use of land, water, nitrogen and energy resources (Gerbens-Leenes *et al.*, 2009; De Vries *et al.*, 2010). It was suggested that high biomass sugarcane genotypes use resources (especially water) substantially more efficiently than existing sucrose cultivars. It is not clear from a physiological point of view how such higher WUE could be achieved.

The aim of this study was to investigate the drought response in terms of water use and biomass yield of an energy-cane genotype to that of a commercially grown sugarcane cultivar in a controlled experiment, in order to gain a better understanding of the physiology of sugarcane biomass production in marginal environments.

Methods and Materials

Experiment detail

The study was conducted in a rainshelter facility at Mount Edgecombe (29°42'40"S; 31°02'35"E). Sugarcane cultivar N19, a high sucrose genotype, and a sugarcane/Kans Type I-II genotype (04G0073) were planted in October 2011 and harvested in May 2012. The trial was divided into four plots, with one plot per genotype used as the control (well irrigated) and the other plot used for water-deficit treatment. Field capacity (FC) was 0.18 m^3/m^3 and was determined *in situ* after wetting and draining the soil profile. Permanent wilting point (PWP) was 0.131 m^3/m^3, and was taken to be the last measured soil water content in the stressed plots after all soil water was extracted. Therefore the available soil water content (ASWC) in the soil profile was 49 mm, and the stress point (SP) was assumed to be 50% of ASWC, 0.155 m^3/m^3. All four plots were well-watered and soil water content was maintained above 0.155 m^3/m^3 from October 2011 until 10 February 2012. Water was withheld thereafter on the water-deficit plots. Water treatments are referred to as the 'stressed' (no irrigation after 10 February 2012) and 'control' (well-irrigated) treatments. Two unintended wetting events occurred on 4 March 2012 and on 13 March 2012 due to heavy storms that caused water to intrude into the subsoil through the drainage system.

Experiment measurements

A neutron water meter was used to measure soil water content twice per week from planting until harvest. The top visible dewlap (TVD) leaf width and length were measured for each of the 20 tagged tillers per plot. Green leaf area per tiller (GLA) and per unit ground area (GLAI) was derived from TVD leaf length and width.

A LiCor 6400 was used to measure instantaneous stomatal conductance (g_s), assimilation rate (A_n), and transpiration rate (E_n) at a light intensity of 2000 µmol PAR m^2/s and CO_2 concentration of 400 µmol CO_2 m^2/s. Measurements of g_s were performed on a total of eight TVD leaves per treatment between 08h00 and 11h00 every week during the period when water was withheld. Instantaneous water use efficiency (WUE) was calculated as A_n/E_n (mol m^2/s).

Hourly stem sap flow was measured from February 2012 until harvest by the stem heat balance method (Dynagage Flow 32-1K system, Dynamax Inc.). Sap flow gauges were attached to the stems of four N19 plants per treatment, and on three 04G0073 plants per treatment (one stem on each plant). The gauges were changed three times during the 77 day experiment, and at each gauge fitment, stem diameter and LAI were measured. Stem diameter and LAI were used to determine parameter values in the calculation of sap flow rate.

Daily stem sap flow was calculated from hourly values and converted to estimated crop transpiration (T_{SAP}) by multiplying stem sap flow with stem population density. Dry above-ground biomass yield was determined destructively by sampling 2 m of cane rows and determining dry matter content.

Results and Discussion

T_{SAP} of the 04G0073 control treatment was higher than the N19 control treatment for most of the measurement period (77 days) (Figure 1). Drought stress reduced T_{SAP} of both N19 and 04G0073 in the first eight days of the experiment, and N19 had a severe reduction in T_{SAP} to approximately 0mm/day after 14 days of drought stress. During the brief drought stress release period, 04G0073 seems to have recovered quickly and fully and T_{SAP} values of the stressed treatment were comparable or slightly higher than that of the 04G0073 control treatment. T_{SAP} of the N19 stressed treatment, however, never reached that of the control treatment during this period. During the second drought stress period, T_{SAP} of N19 and 04G0073 were similarly reduced in response to drought stress. T_{SAP} of N19 was significantly reduced below well-watered values at a much higher soil water content, and g_s was reduced by much more (55-97% lower than the control treatment) compared to that of 04G0073 (15-67% lower than the control treatment).

T_{SAP} of both control treatments showed a close relationship with grass reference evapotranspiration (ET_0 as defined by Allen and Pruitt, 1991) The average ratio between T_{SAP} and ET_0 was 0.71 ($R^2 = 0.36$) and 0.81 ($R^2 = 0.47$) for N19 and 04G0073, respectively. The higher values of 04G0073 (on average 14% higher than those of N19) could not be explained fully by higher LAI values, as T_{SAP} of 04G0073 was significantly higher than that of N19 at similar LAI values, suggesting that g_s is a key driver.

Instantaneous A_n was 17% higher in 04G0073 control treatments compared with N19, confirming results from sap flow measurements, whereas E_n was 20% higher. A_n and E_n were reduced by drought stress in 04G0073 (25% and 29%, respectively) whereas drought stress reduced A_n and E_n in N19 by 41% and 31%, respectively. Instantaneous WUE was similar between control treatments, however, WUE of the stressed 04G0073 treatment was 21% than the control treatment.

In the control treatments, 04G0073 had a 17% higher dry biomass yield compared with N19 (28.9 t/ha and 34.1 t/ha in N19 and G73, respectively). Biomass yields of N19 and 04G0073 was reduced by 14% and 46%, respectively, due to drought stress (24.1 t/ha and 18.7 t/ha in N19 and G73 stressed treatments). Biomass yield of stressed 04G0073 was 25% lower than stressed N19.

In summary, the high fibre sugarcane genotype 04G0073 produced more biomass than the high sucrose sugarcane cultivar N19 under well-watered conditions only. This genotype also transpired at a higher rate than N19 under well-watered and mild stress conditions by having a higher LAI as well as higher g_s. This resulted in the continued rapid extraction of water out of the soil profile by 04G0073, to a point where severe stress limited growth more severely compared with the N19 stressed treatment. This information can be used for deriving crop parameters for models to determine the feasibility of growing different sugarcane genotypes for bio-energy production in marginal areas with intermittent drought stress.

Acknowledgements

The authors would like to acknowledge Yuriy Tsupko for trial design, Sivuyile Ngxaliwe and the South African Sugarcane Research Institute (SASRI) technical team for trial measurement assistance.

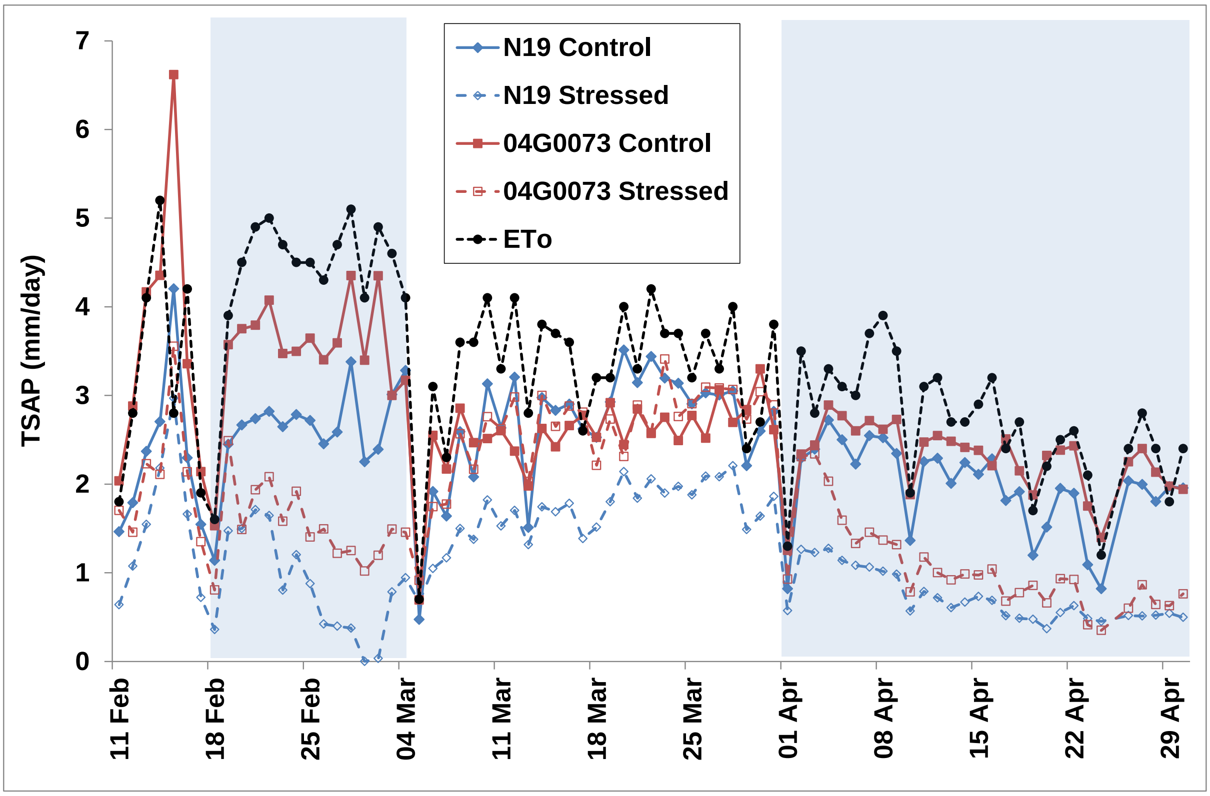

Figure 1. Daily transpiration per unit ground area (T_{SAP}) for the different treatments, compared to grass reference evapotranspiration (ETo) as defined by Allen and Pruitt (1991). The shaded portions indicate drought stress periods.

REFERENCES

Allen, R and Pruitt, W (1991). FAO-24 Reference Evapotranspiration Factors. Journal of Irrigation and Drainage Engineering 117 (5) : 758 – 773.

De Vries SC, Van de Ven G, Van Ittersum MK and Giller KE (2010). Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques. *Biomass and Bioenergy* 34: 588-601.

Gerbens-Leenes W, Hoekstra AY and Van der Meer TH (2009). The water footprint of bioenergy. *PNAS* 106(25): 10219-10223.

Olivério JL and Ferreira FM (2010). Cogeneration – a new source of income for sugar and ethanol mills, or Bioelectricity – a new business. *Proc Int Soc Sug Cane Technol* 27: 1-13.

Raes D, Steduto P, Hsiao TC and Fereres E (2009). AquaCrop – the FAO crop model to simulate yield response to water: II. Main algorithms and software description. *Agronomy Journal* 101(3): 438-447.

Steduto P, Raes D, Hsiao TC, Fereres E, Heng L, Izzi G and Hoogeveen J (2009). AquaCrop: A new model for crop prediction under water deficit conditions. *Options Méditerranéennes, Series A* 80: 285-292.

Subbarao GV, Johansen C, Rao RCN and Wright GC (1994). Transpiration efficiency: Avenues for genetic improvement. pp 785-806 In: M Pessarakli (Ed.) *Handbook of Plant and Crop Physiology*. New York - Basel - Hong Kong: Marcel Dekker, Inc.

Prasertsak P (2005). Sustainable sugarcane biomass production and utilization in Thailand: Potential and possibilities. pp 1-4 In: *First Biomass-Asia Workshop*, January 19-21, 2005. Tokyo-Ibaraki, Japan. Available at: http://www.biomass-asia-workshop.jp/biomassws/01workshop/material/Praphan-Prasertsak.pdf

Tew TL and Cobill RM (2008). Genetic improvement of sugarcane (*Saccharum* spp.) as an energy crop. pp 249-272 In: W Vermerris (Ed.) *Genetic Improvement of Bioenergy Crops*. Springer Science+Business Media, LLC.

Thompson GD (1976). Water use by sugarcane. *S Afr Sug J* 60(11-12): 593-600 and 627-635.