Field Crops Research 168 (2014) 86–100

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Water relations of two contrasting sugarcane genotypes

Alana Eksteen*, Abraham Singels, Sivuyile Ngxaliwe

South African Sugarcane Research Institute, 170 Flanders Drive, Private Bag X02, Mount Edgecombe, Durban, South Africa

ARTICLE INFO

Article history:
Received 10 April 2014
Received in revised form 19 July 2014
Accepted 15 August 2014
Available online 16 September 2014

Keywords:
Water stress
Leaf water potential
Sap flow
Stomatal conductance
Transpiration

ABSTRACT

High-fibre sugarcane (energy-cane) cultivars have generated a lot of interest as candidates for bio-fuel production in marginal areas, especially when cellulosic ethanol is also considered. However, a better understanding is required of how much water would be used during cultivation and of their response to drought in terms of water relations. The aim of the study was to investigate the water relations of a high-fibre sugarcane hybrid (Saccharum spp F1 hybrid, 04G0073, referred to as G73) under well watered and drought stress conditions, and compare it with that of a traditional sugarcane cultivar (Saccharum spp, cultivar N19). This would help with a better understanding of the underlying physiology of differences in water use and drought response between high-fibre and traditional sugarcane. The trial consisted of four plots which were planted in a rainshelter facility at Mount Edgecombe, South Africa in October 2011. Two plots received adequate water for the duration of the trial (well-watered treatments), while the other two received no water after 10 February 2012 (water stress treatments), except for the unintended intrusion of water into the root zone on 3 March 2012. The experiment ended on 7 May 2012. Volumetric soil water content was measured with a neutron water meter and daily sap flow was recorded using the non-intrusive heat-balance method. Leaf water potential (ψ_L) was measured periodically with a pressure chamber, while stomatal conductance was measured periodically with a LiCor 6400. The study has shown that the heat balance method (constant heat source) of measuring sap flow velocity is a suitable technique for estimating transpiration rate in sugarcane. Transpiration rates of well-watered G73 were higher (11%) than that of well-watered N19, presumably due to a higher green leaf area index (GLAI) (6%). There was no evidence to suggest that parameters for calculating maximum evapotranspiration using the Penman-Monteith or FAO method need to be adjusted for high-fibre varieties. Transpiration rates of N19 were reduced sooner and at higher levels of soil water status, than that of G73, as water stress levels increased. G73 had the ability to maintain higher stomatal conductance (g_s) than N19 at the same soil water status level, even though leaf water potential was similar between the genotypes. Higher transpiration rates of stressed G73 plants facilitated extended extraction of water from a drying soil profile, which could be a detrimental trait in marginal areas where long dry spells are common. Reduced rates of transpiration and water extraction from the soil profile through stomatal control could be a desirable trait for survival and optimal biomass production in marginal areas. G73 had higher biomass yield (12%) and WUE (10%) under well-watered conditions compared with N19 but water stress reduced both yield and WUE of G73 by 44% and 24%, respectively. The data obtained from the current study will be used for deriving crop parameters for sugarcane crop models with regards to energy-cane genotypes and may be useful in identifying marginal areas suitable for energy-cane cultivation.

1. Introduction

Sugarcane is acknowledged as an important bio-energy crop (Tew and Cobill, 2008; Olivério and Ferreira, 2010) that could contribute to the growing need for renewable energy. Sugarcane is high yielding (Waclawovsky et al., 2010) and has been shown to use resources (land, water, nitrogen and energy) efficiently (Gerbens-Leenes et al., 2009; De Vries et al., 2010). Bio-ethanol can be produced from the fermentation of soluble sugars in stems, while 2nd generation technology enables the production of ethanol from cell wall sugars derived from cellulose and hemicellulose in stem and leaf fibre (de Souza et al., 2013; Diasa et al., 2009; Ragauskas et al., 2006; Waclawovsky et al., 2010). This will greatly enhance the potential ethanol output from sugarcane and at the same time address concerns regarding ethanol production from

---

* Corresponding author. Tel.: +27 31 508 7447; fax: +27 31 508 7579.
E-mail addresses: alana.eksteen@sugar.org.za, alana.eksteen@gmail.com (A. Eksteen).

http://dx.doi.org/10.1016/j.fcr.2014.08.008

food crops in high potential production areas (de Souza et al., 2013; Waclawovsky et al., 2010). Cellulosic ethanol technology also opens up the possibility to produce ethanol from high-fibre, low-sucrose energy cane (Alexander, 1985).

There are indications that high-fibre energy cane (F1 hybrid crosses of *Saccharum* spp. with its wild relatives (*S. spontaneum, Erianthus* spp. and *Miscanthus* spp.) or crosses between F1 hybrids and *Saccharum* spp. (BC1 generation hybrids)) produces higher biomass yields than traditional cultivars (Alexander, 1985; Silva et al., 2007; Kim and Day, 2011) and better tolerates harsh environmental conditions (Tew and Cobill, 2008). This makes them an ideal feedstock for bio-ethanol production (Canilha et al., 2012). High-fibre energy cane could therefore be used for biomass production in marginal production areas where resource levels are low, such as low rainfall areas or areas with poor soils. Higher biomass yields can only be achieved by increased capture of resources (mainly radiation and water) and/or by increased conversion efficiency of captured resources to biomass. It is therefore important to better understand water relations of high fibre sugarcane, and particularly how they use water and cope with dry conditions in comparison with conventional sugarcane. This information is needed for reliable determination of the feasibility of growing high-fibre sugarcane for biomass production in marginal areas. Water relations of traditional sugarcane has been researched extensively (Hsiao, 1973; Inman-Bamber and de Jager, 1986a,b; Abayomi and Lawal, 1998; Ali et al., 1999; Singels et al., 2000; Singels and Inman-Bamber, 2002; Inman-Bamber and Smith, 2005; Smit and Singels, 2006; Koonjah et al., 2006; Silva et al., 2007). In contrast, very little is known about the physiology of high-fibre sugarcane, especially with respect to water relations. In an excellent review of sugarcane water relations, Inman-Bamber and Smith (2005) reported on water use determination, and the role of leaf area, leaf water potential, and stomatal conductance on water use and drought tolerance. Transpiration rate is determined by energy exchanges at the cropped surface (atmospheric and crop factors) and internal energy gradients in the soil-plant-atmosphere system (Inman-Bamber and Smith, 2005). Stomata on the leaves respond to these factors in order to regulate transpiration through the stomatal aperture. This control is represented in the Penman-Monteith equation (Monteith, 1981) as bulk surface resistance (Allen et al., 1998), or alternatively, canopy conductance (g_c). The relationship between g_c and stomatal conductance (g_s) is given by (McGlinchey and Inman-Bamber, 1996):

$$g_c = g_s\,(0.5\,\mathrm{GLAI}) \tag{1}$$

where GLAI is green leaf area index.

Meinzer and Grantz (1989) demonstrated that g_c only regulates transpiration when crops are water-stressed using the decoupling coefficient (Ω) which describes the relationship between g_c and aerodynamic conductance for water vapour transfer (g_a). Inman-Bamber and Smith (2005) maintained that, because of this, full canopy transpiration rate of well-watered crops will differ little between cultivars.

Grantz and Meizner (1991) suggested that stomata responded to vapour pressure gradients and photon flux density. Smith et al. (1999) and Grantz and Meizner (1990) suggested that stomata also responded to hormonal root signals under drought stress. Saliendra et al. (1991) and Inman-Bamber and de Jager (1986b) found that some cultivars closed stomata at much higher leaf water potentials (ψ_L) than others, suggesting that this relationship is cultivar-specific. Smit and Singels (2006) found that cultivar NCo376 maintained higher g_s for longer and at lower soil water contents than drought susceptible cultivar N22, as an imposed water stress event unfolded. However, the g_s vs ψ_L relationship was similar for these two cultivars. Olivier and Singels (2003) found that N22 was more sensitive to water stress than N25 and N14, showing a much larger cane yield reduction when irrigation was reduced by 50%.

Inman-Bamber and Smith (2005) identified early stomatal closure, osmoregulation and reducing effective leaf area through leaf rolling and accelerated leaf and stalk senescence as drought adaptation traits in sugarcane. Blum (1996) and Chaves et al. (2003) found that drought tolerant genotypes reduce transpiration under dry conditions through early stomatal closure thereby conserving soil moisture and allowing plants to maintain an adequate water status to sustain critical physiological and biochemical processes. However, stomatal closure often leads to a decline in biomass accumulation because carbon assimilation (photosynthesis) is also reduced (Sinclair et al., 1994).

Crop water relations studies rely heavily on the determination of crop water use. Water use from an unstressed, fully canopied sugarcane crop can be estimated from weather data using the FAO56 approach which relates crop evapotranspiration (ET_c) to grass reference evapotranspiration (ET_o) using a crop coefficient (K_c) (Allen et al., 1998). Values of K_c for fully canopied sugarcane range from 1.1 to 1.5, depending on climatic conditions, with a typical value of 1.25 (Allen et al., 1998, Inman-Bamber and McGlinchey, 2003). Actual ETc can also be estimated using the energy balance (e.g. Inman-Bamber and McGlinchey, 2003; Olivier et al., 2010), lysimetry (e.g. Thompson and Boyce, 1967; Olivier and Singels, 2012) or soil water balance (e.g. Singels et al., 2000; Rossler et al., 2013; Olivier et al., 2013) approach. A drawback of these methods is that the two components of ET_c, namely evaporation from the soil (E), and transpiration (T) from the crop canopy, cannot be separated.

Crop transpiration can be estimated by monitoring the flow rate of stem sap through heat balance techniques. This method has not been used as widely in sugarcane as in other crops. Chabot et al. (2002) used steady state heat balance sap flow measurements to estimate the contribution of a water table to sugarcane water use. They found that transpiration from sap flow measurements exceeded transpiration measured with a lysimeter by 13.5%. Chabot et al. (2005) found that sugarcane transpiration determined from sap flow exceeded reference evapotranspiration by 35% and ascribed this to errors associated with sap flow sensors as well as to the process of scaling up from stem level to canopy level. In this study stem sap flow per unit leaf area was scaled up to canopy level using leaf area index estimated from stem diameter. The sap flow technique was also used by Nassif and Marin (2013).

The aim of the study was to investigate the water relations of a high-fibre sugarcane hybrid under well watered and drought stress conditions, and compare it with that of a traditional sugarcane cultivar. This would help with gaining a better understanding of the underlying physiology of differences in water use and drought response between high-fibre and traditional sugarcane. It is hoped that this would help in deciding the feasibility of growing high-fibre sugarcane in marginal areas for bio-energy production.

The specific objectives were to estimate crop evaporation (referred to as transpiration) from sap flow measurements using the steady state heat balance method, and relate this to plant canopy characteristics (green leaf area, stomatal conductance and leaf water potential), atmospheric conditions (reference evapotranspiration and vapour pressure deficit) and soil water status. A secondary objective of the study was to quantify the potential productivity of the two genotypes under water stressed and well-watered conditions by recording biomass yield and water use efficiency over the growing period.

2. Materials and methods

2.1. Experimental details

The study was conducted at the South African Sugarcane Research Institute (SASRI) rainshelter (29°42′40″S, 31°02′35″E). Two contrasting sugarcane genotypes (N19 a high sucrose cultivar,