PLANT-ATMOSPHERE WATER RELATIONS OF SUGARCANE IN SOUTHERN BRAZIL: A PRELIMINAR ANALISYS

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ABSTRACT: This research evaluated the water relations of a drip-irrigated 2nd ratoon sugarcane crop based on three different spatial scales: field, plant and leaf. The Bowen ratio method was used to evaluate the mass and energy exchanges over the field, further computing the field evapotranspiration (ETc). Sap flow by heat balance methods installed in four representative stalks was used to evaluate the water use at the plant scale, and an infrared gas analyser (IRGA) was used to evaluate leaf transpiration and stomatal conductance at the leaf scale. Evapotranspiration peaks of 7 mm/day were observed under conditions of strong crop-atmosphere coupling and high net radiation values. The mean stomatal conductance ranged from 0.07 and 0.27 mmol/m^{2}s in dry and wet seasons respectively, showing sensitivity to the atmospheric conditions, notably the vapour deficit pressure and wind speed. Canopy water consumption was similar among three used methodologies.

KEYWORDS: sap flow, stomatal conductance, energy balance

RESUMO: O presente trabalho buscou avaliar as relações hídricas da cultura da cana-de-açúcar de segunda soca irrigada por gotejamento subsuperficial baseado em três escalas espaciais: campo, planta e folha. O método da Razão de Bowen foi utilizado para avaliar a troca de massa e energia no talhão, e a evapotranspiração da cultura (ETc). O fluxo de seiva pelo método do balanço de calor foi instalado em quatro colmos representativos, e utilizado para avaliar o uso de água na escala da planta e, um analisador de gás com infravermelho (sigla em inglês IRGA) foi utilizado para avaliar a transpiração e a condutância estomática na escala da folha. Picos de evapotranspiração em torno de 7 mm/dia foram observados quando ocorrem condições de intenso acoplamento planta-atmosfera e alta disponibilidade de radiação. A condutância estomática média variou entre 0,07 e 0,27 mmol/m^{2}s, demonstrando sensibilidade às condições atmosféricas, principalmente ao déficit de pressão de vapor e à velocidade do vento. O consumo de água do canavial foi similar entre as três metodologias utilizadas.

PALAVRAS-CHAVE: fluxo de seiva, condutância estomática, balanço de energia

INTRODUCTION

The sugarcane crop has gained importance in the current decade, mainly because of increasing ethanol and sugar demands. Water deficit stress is a limiting factor in most of the sugarcane regions in Brazil and irrigation is commonly needed to assure minimum levels of yield losses from the stress. In Brazil, there are few studies regarding sugarcane water requirements and the factors affecting water consumption in sugarcane. The Bowen Ratio method (BRM) has been used by many authors to estimate field evapotranspiration. By comparing BRM against water loss at plant and leaf scales, it would be possible to better understand the factors controlling crop water consumption. Plant transpiration may be measured through sap flow using the heat balance (SF) method (Sakuratani, 1981). Leaf transpiration may be computed by an infrared gas analyzer (IRGA) which also provides information on the leaf conductance to water vapour (g_s). Based on g_s and the atmospheric conditions, it is possible to understand the interaction between sugarcane crop canopy and atmosphere through the plant-atmosphere decoupling factor (Ω) (Jarvis and McNaughton, 1986), including the photosynthesis rate and water use efficiency responses to different atmosphere conditions. The objective of this paper was to estimate sugarcane crop water use combining three different methods of *BRM*, *SF* and *IRGA*, to analyze the plant-atmosphere interactions, and to provide new insights for improving sugarcane irrigation management in Brazil.

MATERIAL AND METHODS:

The study was carried out in a 2nd ratoon crop with a cultivar CTC 12. Sugarcane was planted in double line spacing (0.50 x 1.50 m) and harvested after 365 days, in March 2012, in Piracicaba, State of São Paulo, Brazil (22º41’55”S, 47º38’40”W, 540 m). The 0.3 hectares field received full subsurface drip irrigation without water deficit. A Bowen ratio method was used to evaluate the mass and energy exchanges over the field with two forced ventilation psychrometers (Marin et al., 2001). Measurements of dry and wet temperatures (ºC) were performed, with a height difference of 1.0 m between them, with the lower measurement maintained at 0.5 m above canopy level, following sugarcane plant growth. A net radiometer and two soil heat flux instruments were also installed. The crop evapotranspiration was determined according to equation 1.

$$LE = \frac{Rn - G}{1+\beta} \rightarrow ETc = \frac{Rn - G}{\lambda(1+\beta)} \quad (1)$$

were *Rn* is the net radiation (MJ/m^{2}d), *G* is the soil heat flux (MJ/m^{2}d), β is the Bowen ratio, *LE* is the latent heat flux (MJ/m^{2}d), and λ is the latent heat of evaporation.

The Bowen ratio values (β) were calculated for each 15 minutes interval based on the temperature gradient values (ΔT), the vapour pressure gradient values (Δe) and psychometric constant (γ). BRM can show some variability in values, which were checked according to Perez et al. (1999). In periods when the results presented such variability, interpolations were done. For periods exceeding 2 hours of variable data, that data was discarded. Only daytime values are calculated using the BRM method.
Sap flow measurements by the heat balance method (Sakuratani, 1981) were performed in four representative stalks, which were used to evaluate the water use at the plant scale. Four sap flow sensors were installed on representative stalks at an internode. An infrared gas analyzer (IRGA) was used to evaluate leaf transpiration and stomatal conductance (gs). The measurements were done between 8 am to 4 pm. The values of *gs* were transformed to leaf diffusive resistance (rs) and the decoupling factor (Ω) was computed by equation 2:

$$\Omega = \frac{ra}{1+\left[\left(\frac{\gamma}{s+\gamma}\right)*rs\right]} \quad (2)$$

where *ra* is the canopy aerodynamic resistance, *rs* is the stomatal resistance to vapour diffusion (which is the inverse of *gs*) and γ is the psychrometric constant.
Conceptually, the extreme values for the decoupling factor are as follows: $\Omega \rightarrow 1$ as $rs/ra \rightarrow 0$, implying that the net radiation is the only contributor to the evapotranspiration process and that vegetation is completely decoupled from atmospheric conditions, and $\Omega \rightarrow 0$ as $rs/ra \rightarrow \infty$ indicating complete coupling of vegetation with atmospheric vapour pressure deficit and wind speed (Marin and Angelocci, 2011).

RESULTS AND DISCUSSION

The BRM measurements recorded evapotranspiration differences during the crop growth cycle. The mean value of ETc was 87% of ETo, resulting in an average crop coefficient of 0.9 which ranged from 0.9 to 1.1 during dry and wet seasons, respectively. A maximum ETc of 7 mm/day was observed under favourable environmental conditions (Figure 1-A). When mean leaf area index was 2.7 during early season growth (Figure 1-B), ETc and ETo maximum was 4.5 mm/day. These values represent the transition between wet and dry periods in the period of initial crop growth. An increase in evapotranspiration was observed starting in July (Figure 1-C), due to dry air masses in the region and maximum temperatures of over 30ºC resulting in high atmospheric demand and water availability. At the end of the year (Figure 1-D), ETc and ETo were higher due to the high temperature and solar radiation. Under these conditions, the sugarcane crop reached peak evapotranspiration >7 mm/day. The ETc values in the present study corresponded with data reported by Inman-Bamber and McGlinchey (2003) who evaluated sugarcane evapotranspiration in Australia and Swaziland using BRM, resulting in a crop coefficient varying between 0.9 and 1.5, and mean ETc of 5.2 mm/day and the ETo of about 4 mm/day.

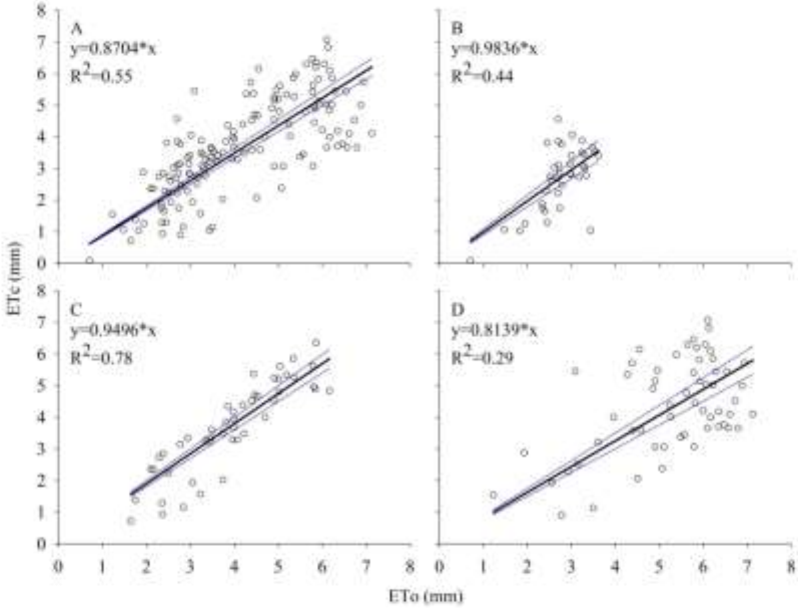

Figure. 1. Crop evapotranspiration (ETc – mm/day) vs. reference evapotranspiration (ETo – mm/day) in 2011 for the whole year (A), a wet period with early growth from April to June (B), a dry period from July to September (C), and a period from October to December (D).

The *SF* measurement period was performed at the end of the crop cycle as described in Figure 1-D, which in Southern Brazil in the summer is a period of high solar radiation and temperatures. The 10 days sensors recorded similar rates with *SF* method (Table 1). Daily stalk transpiration measured by *SF* ranged from 3.15 to 5.98 mm, totalizing 43 mm on 10 days period of measurements. Chabot et al. (2005) found in Morocco that sugarcane grown in a lysimeter with SF method consumed 8 mm per day on average, but explaining that *SF* may overestimate transpiration up to 35%.

Table 1. Daily sap flow (L/day and L/m^2leaf) and estimated transpiration (T – mm) at 2012 for ten different days.

	Day of Year									
	41	42	43	44	45	46	47	48	49	50
SF (L/stalk)	0.64	0.43	0.41	0.34	0.35	0.39	0.44	0.63	0.60	0.38
SF (L/m^2leaf)	1.87	1.25	1.19	0.99	1.03	1.14	1.28	1.84	1.75	1.11
T (mm)	5.98	4.01	3.82	3.15	3.30	3.66	4.10	5.90	5.61	3.56

During a dry period in September (Figure 2), there was lower radiation and consequently lower transpiration rates and stomatal conductance than during the wet season in February (Figure 2-B). During the same time period, the decoupling factor (Ω) had little variability during the dry period, however, variability was greater with a peak around 13:30 h during the wet period, result of the increase of wind speed. Mean values of Ω were similar over both wet and dry periods (dry period, 0.28; wet period, 0.31), indicating that the sugarcane crop was strongly coupled to the atmosphere even in periods of water deficit. These results are different from those observed by Silva et al. (2012) for a furrow-irrigated sugarcane crop in Northern Brazil, where decoupling factors ranged from 0.74 under irrigation to 0.6 when irrigation was stopped. These data suggest net radiation was the main driver in the warm and dry regions in controlling evapotranspiration, while, in colder and wetter seasons, the vapour pressure deficit and wind speed were the main drivers controlling evapotranspiration of the sugarcane crop.

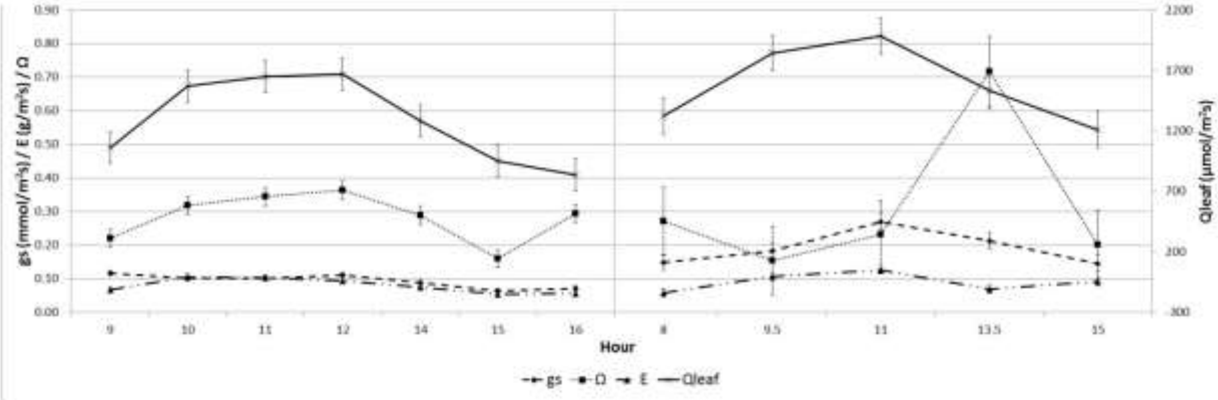

Figure 2. Stomatal conductance (gs), transpiration rate (E), decoupling factor (Ω) and photosynthetically active radiation on leaves (Qleaf) on September 30, 2011 (A) and February 01, 2012 (B). Error bars mean standard deviation.

The different methodologies for assessing water use in a sugarcane crop agreed with each other. *BRM* estimates of water use were slightly higher than leaf transpiration (Tleaf) in the dry season (3.6 and 3.4 mm/day, respectively), and this difference may be due to soil water evaporation. In the wet season, a good correlation between *BRM* (evapotranspiration), *Tleaf* (leaf transpiration) and *SF* (plant transpiration) method water use estimates was maintained (4.4, 4.2 and 4.3 mm/day respectively). Given these results came from independent and different methodologies, they may also be regarded an indicator of the data reliability.

CONCLUSIONS

In an irrigated sugarcane production area in Brazil, water consumption of the sugarcane crop was highly correlated with atmospheric conditions, notably the vapour deficit pressure and wind speed. Sugarcane crop water use through *BRM*, *Tleaf* and *SF* were consistent, showing reliability in of both methodologies. The crop Kc ranged between 0.9 and 1.1 in studied period.

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REFERENCES

CHABOT, R. et al. Evaluation of the sap flow determined with a heat balance method to measure. Agricultural Water Management, v. 75, p. 10-24, 2005.

INMAN-BAMBER, N.G.; MCGLINCHEY, M.G. Crop coefficients and water-use estimates for sugarcane based on long-term Bowen ratio energy balance measurements. Field Crops Research, v. 83, p. 125-138, 2003.

JARVIS, P.G.; MCNAUGHTON, K.G. Stomatal control of transpiration: scaling up from leaf to region, Advances in Ecological Research, v. 15, p. 1-49, 1986.

MARIN, F.R.; ANGELOCCI, L.R. Irrigation requirements and transpiration coupling to the atmosphere of a citrus orchard in Southern Brazil. Agricultural Water Management, v. 98, p. 1091-1096, 2011.

MARIN, F.R. et al. Construction and evaluation of aspired thermocouple psychrometer. [abstract in english] Scientia Agricola, v. 58, p. 839-844, 2001.

PEREZ, P.J. et al. Assessment of reliability of Bowen ratio method for partitioning fluxes. Agricultural and Forest Meteorology, v. 97, p. 141-150, 1999.

SAKURATANI, T. A heat balance method for measuring water sap flow in the stem of intact plant. Journal of Agricultural Meteorology, v. 39, p. 9-17, 1981.

SILVA, T.G.F.S. et al. Decoupling factor in an irrigated sugarcane crop in the lower-middle São Francisco. [abstract in English] Revista Brasileira de Engenharia Agrícola e Ambiental, v. 16, p. 849-858, 2012.