Sugarcane for water-limited environments: 3.Transpiration efficiency of commercial and wild relatives of sugarcane

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Abstract

Two different replicated pot experiments were conducted under glasshouse conditions in 2 years to determine the variation in transpiration efficiency (TE) in a set of genetically diverse sugarcane clones. In both experiments, thirteen test clones (six commercial varieties and seven introgression clones selected based on their field performance) were grown in pots containing 25 kg soil in a glasshouse under 1500 photosynthetically active radiation (PAR) and 28 - 38^{0}C temperature. During the entire duration of the two experiments (Experiment 1 and Experiment 2), fully irrigated (100% field capacity, FC) and half-irrigated (50% FC) treatments received 51, 24 and 58, 37 kg of water, respectively. Biomass accumulations in 50% FC treatment in Experiment 1 and Experiment 2 were 39% and 13% lower than the fully irrigated treatment. The corresponding TE (gDM/kg water) was 3.5 and 3.8 higher in 50% FC treatment. Under low vapour pressure deficit (VPD) in Experiment 1 with the reduction in water supply, TE increased steadily in the introgression clones than commercials. However, this trend has changed substantially when the VPD was high as in Experiment 2, suggesting the large impact in VPD on TE in sugarcane under varying water regimes. Further investigations are necessary to understand the contrasting patterns of stomatal responses to water-limited conditions under different VPD.

Key Words
Sugarcane, introgression clones, transpiration efficiency, biomass accumulation

Introduction

Water limitation is a major determinant of sugarcane crop productivity worldwide (Carr and Knox, 2011). In Australia, based on the sugar industry data, water stress has been estimated to cost the industry an average $260 million per annum (Inman-Bamber, 2007). We are currently conducting a multi-disciplinary research, including trait modelling and field assessments, to understand the key biological factors limiting sugarcane crop performance in water stressed conditions. The field experiments conducted so far indicate wide variation for total biomass (dry matter) production (TDM), cane yield (TCH) and commercial cane sugar (CCS) among the 131 genetically diverse clones tested under water-limited conditions. In these experiments commercial clones out-performed the introgression clones under mild and moderate stress conditions while all of them grew poorly when stress was severe. It is hypothesised that the intrinsic growth potential (yield under well irrigated conditions) of some selected and unselected clones help them maintain relatively high productivity in a range of moderate stress conditions. While the physiological basis of this growth potential is unclear, trait simulation experiments indicate a significant yield advantage by improving transpiration efficiency (TE) under mild and moderate stress conditions. Quantifying the genetic variation of TE for a number of sugarcane clones under field conditions is very challenging; hence, a glasshouse pot experiment protocol for TE measurement was established. This study reports the experiments investigating the genetic variation in water use and TE among a set of sugarcane clones (covering both low and high yield reduction clones in stress treatments in the field) under glasshouse conditions.

Methods

Glasshouse conditions

The experiments were conducted in a glasshouse with no control on temperature (28 - 38^{0}C and 1500 PAR) and humidity, but protected from rain. A weather station installed inside the glasshouse monitored the temperature and humidity during the experimentation (Experiment 1: 16 January - 20 May 2010; Experiment 2: 5 March - 20 May 2011

Test clones
Ten clones were selected for the Experiment 1 based on their performances under irrigated and water stress conditions in a field trial at Dalbeg. They were Q183^{A}, QC91-580, Q190^{A}, KQ228^{A}, Q208^{A}, CT04-69, QB01-5, CT04-951, CT05-830 and CT05-645. The patterns of moisture extraction of these clones under water limited conditions were investigated in the Dalbeg field trial. Seven clones, Q183^{A}, KQ228^{A}, Q208^{A}, CT05-594, CT04-450, CT05-583 and BUSTER (sorghum) were tested in the Experiment 2.

Planting and pot preparation
A ratio of 1:1 peat moss and sand was used as the potting medium. The initial gravimetric moisture content of the potting medium was determined from measurements on 5 randomly selected samples. The moisture content at the field capacity (FC) was determined (36% gravimetric moisture content) saturation and drain technique used by Ivandic *et al.*, 2000. To ensure uniform moisture content in respective water treatments, the moisture content of all pots was measured with the Minitraser (Time Domain Reflectometry, TDR Soil Moisture Instruments). Also, to apply the same bulk density in each pot, soil (25 kg) was evenly packed by applying uniform pressure. Two plants were grown in each pot and two water treatments (approximately 50 and 100% FC) with three replications were applied in both experiments. The treatments were applied when plants were at 7-8 leaf stage. The soil moisture content was maintained approximately at 50% FC in the water stress treatment while the full amount of water required for 100% FC was added to the well-watered treatment. However, during the day, the moisture content in the water stress treatment and well-watered treatment fluctuated from 40-50% FC (14-18% gravimetric moisture content) and 85-100% FC (30-36% gravimetric moisture content), respectively. To adjust the moisture content of each pot in two water treatments, moisture measurements were taken at 8 am every morning. At each irrigation, the amount of water applied to each pot was recorded and at the end of the experiment, the total water supplied was calculated. An impermeable 3-cm Styrofoam layer over soil was used to prevent evaporation during the experiments.

Biomass harvest
In both experiments, each clone was planted in nine pots. Three pots were harvested at the commencement of the water treatments to determine their initial biomass weight, while the other six pots were used for the two treatments, each replicated three times. All leaf, stem and root biomass were taken into account. At the end of the treatment, the whole plants were partitioned into leaf, stem and root, and fresh and dry weights were recorded. All the samples were oven dried at 80^{0}C for about 5 days to obtain their respective dry weights. Finally, total biomass was used to calculate the TE of each clone. The TE for the experimental period of growth was estimated as total biomass (g dry matter)/total water (kg) used (gDM/kg water).

Results

Weather conditions in glasshouses during experimentation
The weather conditions in two glasshouse experiments were different in terms of humidity and VPD during the experimentation. The average humidity in the Experiment 1 was about 85% and hence the VPD was around 0.5 kPa. The Experiment 2 had relatively low humidity, around 60%, and the VPD was above 2.0 kPa in most of the days during the experiment (Figure 1).

Variation in biomass production
In both experiments, clones demonstrated significant variation in biomass production under well-watered and water-limited conditions. The average biomass reduction under 50% FC in the Experiment 1 was 39.6% whereas in Experiment 2 it was 12.7%. Part of the variation in biomass reduction between two experiments could be accounted for the rate of stress and crop age at harvest (86 days and 75 days, respectively). Among the 3 commercial clones in both experiments, KQ228^{A} and Q183^{A} had more biomass reduction (56 and 57%, $P<0.05$) under 50% FC in Experiment 1 than Q208^{A} ($P<0.05$). In contrast, KQ228^{A} and Q183^{A} had the lowest reduction under 50% FC (3.7 and 7.7%) in Experiment 2, where the VPD was high. The introgression clones followed similar responses to water-limited conditions in Experiment 1 and 2 (Table 1). The Q208^{A} had 38% and 23% biomass reduction in the two experiments.

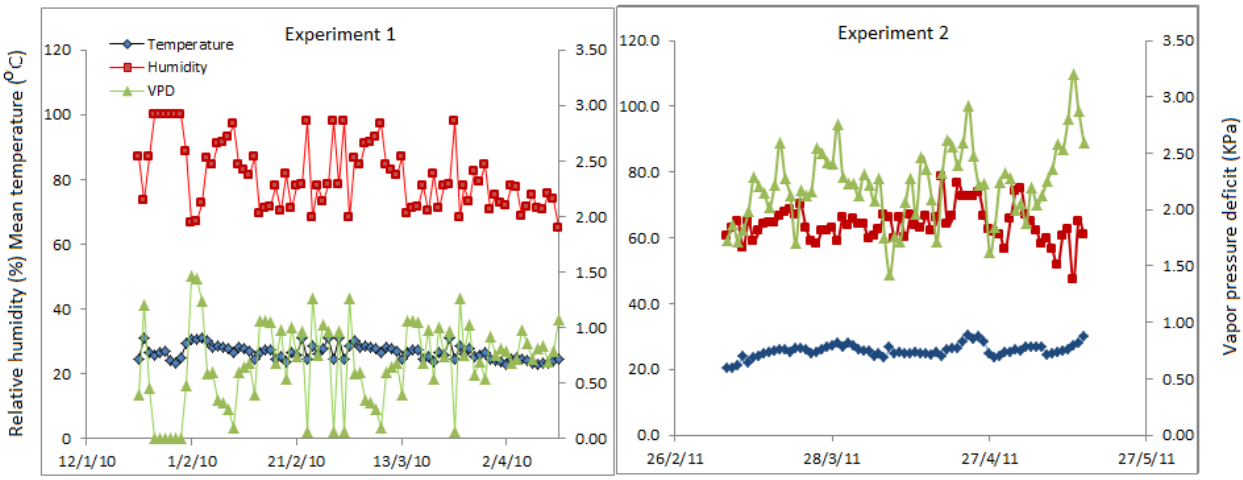

Figure 1. Temperature, humidity and vapour pressure deficit (VPD) in two glasshouse experiments conducted in 2010 and 2011.

Table 1. Variations in clones for total biomass accumulation, total water use and transpiration efficiency (TE) under 50% and 100% FC in Experiment 1 and 2 in the glass houses.

Experiment 1

Clones	Total biomass (g)			Total water used (kg)			Transpiration efficiency (gDM/kg H_2O)		
	50% FC	100% FC	Reduction %	50% FC	100% FC	Reduction %	50% FC	100% FC	Increase by stress
CT04-69	431.1	537.1	19.7	23.4	47.9	51.1	18.4	11.8	6.6
CT04-951	510.5	679.5	24.9	33	54.9	39.9	15.4	12.4	3.0
CT05-645	330.0	488.0	32.4	20.1	49.6	59.5	16.4	9.8	6.6
CT05-830	293.8	339.5	13.5	19.7	41.6	52.6	14.8	8.2	6.6
KQ228[A]	336.9	765.2	56.0	21.7	53.1	59.1	15.5	14.3	1.2
Q183[A]	360.7	854.7	57.8	22.1	56.3	60.7	16.3	15.2	1.1
Q190[A]	345.9	768.9	55.0	22.2	53.3	58.3	15.6	14.4	1.2
Q208[A]	473.9	767.6	38.3	28.7	53.0	45.8	16.5	14.5	2.0
QB01-5	537.6	687.9	21.8	31.5	51.9	39.3	17.0	13.3	3.7
QC91-580	350.8	689.1	49.1	21.2	52.9	59.9	16.4	13	3.4
Mean	**397.1**	**657.8**	**39.6**	**24.4**	**51.5**	**52.6**	**16.2**	**12.7**	**3.5**
Lsd 5% Treatments		**138.9**			**19.8**			**2.45**	
Clones		**112.2**			**13.2**			**1.67**	

Experiment 2

Clone	Total biomass (g)			Total water use (kg)			Transpiration efficiency (gDM/kg H_2O)		
	50% FC	100% FC	Reduction %	50% FC	100% FC	Reduction %	50% FC	100% FC	Increase by stress
BUSTER	83.6	125.5	33.4	12.9	15.9	18.9	6.5	7.9	-1.4
CT04-450	579.6	918.6	36.9	50.2	96.7	48.1	11.6	9.5	2.1
CT05-583	402.1	458.5	12.3	40.0	50.5	20.8	10.1	9.1	1.0
CT05-594	507.5	559.4	9.3	48.0	78.8	39.1	10.6	7.1	3.5
KQ228[A]	457.8	475.4	3.7	41.0	54.0	24.1	11.2	8.6	2.6
Q183[A]	433.9	470.1	7.7	36.1	57.7	37.4	13.3	8.6	4.7
Q208[A]	394.3	511.6	22.9	34.3	56.4	39.2	12.6	8.9	3.7
Mean	**422.5**	**484.2**	**12.7**	**37.5**	**58.6**	**36.0**	**11.7**	**7.9**	**3.8**
Lsd 5% Treatments		**68.9**			**14.8**			**2.11**	
Clones		**42.2**			**11.2**			**1.37**	

Variation in water use

Experiment 1 which was conducted under low VPD had a low water use in the water-limited (50% FC) treatment and it was on average 53% lower than the fully watered treatment (Table 1). In Experiment 2 clones under 50 and 100% FC had more water use, about 38 and 59 kg respectively, than those in Experiment 1. It is likely that the low VPD in Experiment 1 affected stomatal functions in all clones under water-limited conditions and resulted in low biomass production. However, under non-stress conditions, most of the clones were able to utilise more water even when the VPD was low. Under favourable conditions for stomatal functions (relatively high VPD) in Experiment 2, the clones utilised more water in 50% FC and produced higher biomass than in Experiment 1. This result demonstrates the impact of VPD on stomatal functions and water relations in sugarcane.

Variation in transpiration efficiency

Total biomass accumulation, total water use and transpiration efficiency (TE) in Experiment 1 and 2 are presented in Table 1. There was a significant difference ($P<0.05$) between treatments and clones for TE. However, clone × treatment interactions were not significant in both experiments. The TE was higher in 50% FC (16.2 g/kg water) than in the treatment with 100% FC (12.7 g/kg water) in Experiment 1. A similar trend in TE was observed in Experiment 2, with 11.7 and 7.9 gDM/kg water produced under 50 and 100% FC, respectively. The TE observed in Experiment 1 is relatively higher than the values reported by Robertson *et al*. (1996) for sugarcane (8 g/kg at a VPD of 1 kPa). Nevertheless, the Experiment 2 observations under well irrigated conditions are comparable with the previous observations. Some introgression clones (CT05-830 and CT05-645) in Experiment 1 also showed comparable TE to the values reported earlier by Keating *et al*.(1999). It is worth noting that the commercial varieties generally had much higher TE than most of the other clones under well-watered treatment, but not under stressed conditions at extremely low VPD. Also most of them recorded a higher reduction in biomass than the introgression clones under 50% FC. A contrasting result was obtained in Experiment 2 (higher VPD), where the same set of commercial clones had substantial improvement in TE than the introgression clones under water-limited conditions.

Conclusion

Under low VPD and water-limited (50% FC) conditions, commercial varieties showed smaller changes in TE than the introgression clones. Interestingly, broadly adapted KQ228^{A}, Q183^{A} and Q190^{A} had small increase in TE under high VPD and water-limited conditions. This data, although preliminary, suggests the existence of considerable genetic variability for TE in sugarcane germplasm and the necessity for further understanding of environmental variables on TE in order to exploit this variation for sugarcane improvement.

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