

# THE RESPONSE OF SUGARCANE TO WATER STRESS: PRELIMINARY RESULTS FROM A COLLABORATIVE PROJECT

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## Introduction

Sucrose accumulation is the end result of many interrelated physical and biological processes, which are affected by water stress. Quantitative knowledge of the effect of water stress on these processes could lead to more accurate predictions of sucrose content and sucrose yield. This in turn could lead to higher sucrose content and yields by better use of limited irrigation and better drying off management. The aim of this communication is to report the preliminary results of a collaborative investigation into the effects of water stress on biomass accumulation, biomass partitioning and plant extension. The communication focuses on (1) the sensitivity of the different processes to water stress (2) the change in biomass components due to water stress, and (3) the implications of the findings for irrigation management.

*Keywords:* water stress, sucrose, partitioning, irrigation, plant extension

## Methods

Two water stress experiments were conducted during 1999 and two during 2000. Two trials (M99 and M00) were conducted in the rainshelter facility at Mount Edgecombe, South Africa. M99 is fully described by Singels *et.al.* (2000). The other two trials (B99 and B00) were conducted under normal field conditions in the Burdekin, Ayr, Australia (Table 1).

In each experiment, irrigation was applied regularly to avoid stress until the crop reached a predetermined stage. Irrigation to half the plots was then suspended. M00, B99 and B00 did receive some rain or irrigation during the drying off period (Table 1).

Leaf (LE) and stalk (SE) extension were recorded continuously during the dry off period as described by Inman-Bamber (1995). Aerial dry mass (ADM), stalk dry mass (SDM), stalk sucrose content on a dry mass basis (SC) and soil water content were also measured periodically during this period.

The average fraction of daily ADM increments partitioned to stalk was derived from the slope of an adjusted linear relationship between SDM and ADM. Firstly, SDM and ADM for each treatment in each trial were subjected to linear regression analysis. Then the Ward 95% confidence interval test (SYSTAT, SPSS Inc, Chicago, IL) was invoked to prove that the x- intercept for stressed and well watered cane did not differ significantly for any of the experiments. The mean x-intercept was then included ('forced') in the regression model for each data set. Finally the Ward test of significance was applied to the slopes of the adjusted regression model.

**Table 1. Experimental details of four water stress experiments.**

Experiment:	B99	B00	M99	M00
Location	18°4'S 146°0'E, elev.10m		29°4'S 31°2'E, elev. 96m	
Total available moisture (mm)	205		126	
Variety	Q96	Q96	NCo376	NCo376
Row spacing (m)	1.5	1.5	1.2	1.2
Irrigation system	Furrow	Furrow	Surface drip	Sub-surface drip
Crop age at start of dry off period (days after planting)	151	195	101	155
Dry off period	21Sep-10Nov	28Apr-15Oct	15Feb-28Apr	14Mar-10May
Rainfall and irrigation during drying off period (mm)	63	52	0	30
Mean temperature (°C)	24.8	20.1	24.64	22.06
Mean radiation (MJ/m <sup>2</sup> /d)	22.3	16.9	18.04	14.69
Mean evaporation (mm/d)	4.8	3.4	4.00	2.83

The fraction of daily SDM increments partitioned to sucrose was derived from fitting (by eye) a curvilinear relationship between sucrose mass (SM) and SDM. Eq. 1 and 2 describes the relationship for low and high values of SDM respectively.

$$SM = \frac{1}{2} b \cdot SDM^2 \text{ when } SDM < a/b \quad (1)$$

$$SM = a (SDM - \frac{1}{2} \cdot a/b) \text{ when } SDM > a/b \quad (2)$$

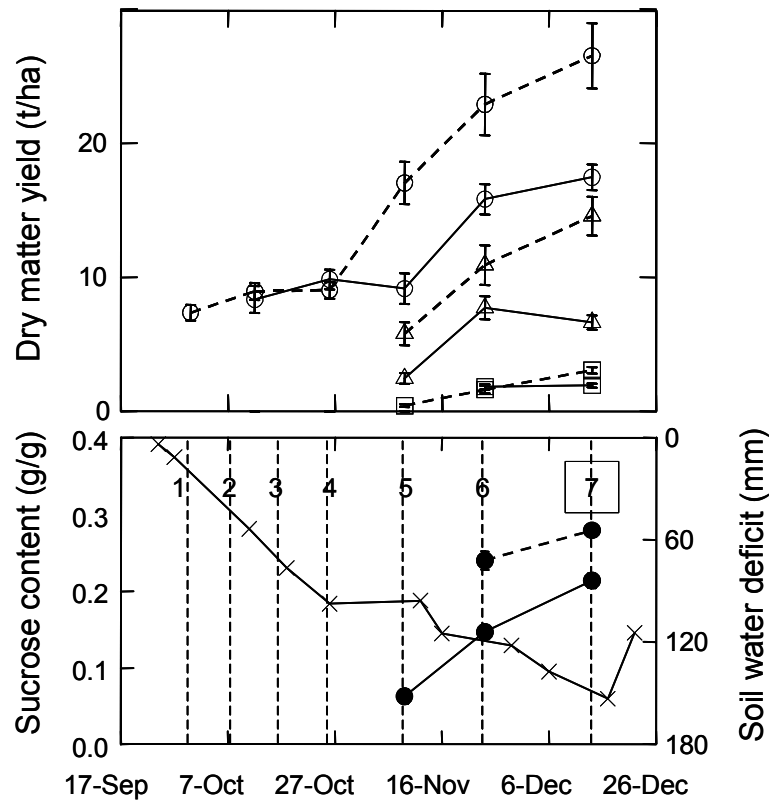
where  $a$  is the maximum partitioning rate of stalk mass increments to sucrose (taken as 0.58 t/t) and  $b$  is a temperature and water stress dependent parameter. The slope of relationship described by eq. 1 and 2 ( $dSM/dSDM = b \cdot SDM$  and  $dSM/dSDM = a$ ) equals the daily partitioning fraction for any given SDM.

## Results and Discussion

The progression over time of the onset of stress for the different growth processes for the B99 experiment is illustrated in Figure 1.

LE was affected first during the onset of stress, followed by SE, and then ADM and SDM. The sink for growth (LE and SE) was therefore affected earlier during the drying off process than the source (ADM). This resulted in increased partitioning of assimilate to stored sucrose such that sucrose yield was greater in stressed than in well-watered sugarcane in certain conditions. When stress progressed to severe levels the photosynthetic capacity of the plant was affected so that biomass and sucrose accumulation slowed down and eventually ceased. A similar sequence of the onset of water stress was observed in all experiments.

Thresholds of soil water content associated with onset of water stress differed between trials. In M99 for example, biomass accumulation was not affected until available soil water content dropped to 35% of TAM compared with approximately 50 % for M00 and B99. It has been well established that evaporative demand plays an important role in determining stress thresholds (Denmead and Shaw, 1962). Soil water content alone is not necessarily good indicator of plant stress.



**Figure 1a (top) and 1b (bottom). Development of a) dry matter yield components of wet (broken lines) and dry (solid lines) treatments in B99; aerial dry mass (ADM, O), stalk dry mass (SDM, Δ) and sucrose mass (SM, □) and b) sucrose content (SC, ●) and soil water deficit (X). Vertical gridlines in (b) show stress status in the dry treatment; 1) leaf elongation (LE) reduced, 2) stalk elongation (SE) reduced and LE reduced to 50%, 3) SE reduced to 50%, 4) total fresh biomass reduced and SE reduced to 25%, 5) ADM, cane yield and SDM reduced, 6) SC increased, and 7) SM reduced.**

The response of biomass components to water stress is summarized in Table 2. Large reductions in ADM and SDM were only observed after severe water stress was imposed (B99, M99 and to a lesser extent M00). Significant responses in sucrose yield and content were observed in all the experiments. The subsequent interruption of water stress cancelled much of the gain in sucrose mass and content quoted in Table 2 for the B99 and B00 experiments.

**Table 2. Magnitude of peak response (difference between stressed and well watered treatment) of different biomass components and partitioning fractions to water stress. Values in brackets are percentages of well watered control. Non-significance is indicated by NS.**

Variable	M99	M00	B99	B00
ADM (t/ha)	-10.75 (40)	-5.84 (20)	-9.05 (34)	NS
SDM (t/ha)	- 6.7 (47)	-2.93 (16)	-7.91 (54)	NS
SM (t/ha)	+0.93 (86)	+0.96 (15)	+3.7 (32)	+5.4 (42)
SC (%)	+12.76 (60)	+6.94 (19)	+13.6 (99)	+8.0(29)

The average fraction of ADM increments partitioned to stalks did not change significantly in three experiments while it increased significantly in the M00 experiment as a result of water stress (see Table 3). The differences in well watered stalk partitioning between experiments could be explained by the different temperature regimes (Table 1) experienced by the crop. Cooler temperatures caused slower leaf growth rates and therefore less partitioning to leaves and more to stalks.

Highly significant responses in the average partitioning of SDM increments to sucrose were determined for the M99, M00 and B99 experiments (Table 3). It should be noted that these were relatively young crops and a large part of the stalk was immature. This immature stalk was filled rapidly with sucrose as soon as water stress limited the expansion of other sinks (LE and SE). Although the response in the B00 (much older, larger cane than the other three experiments) was not significant, the sustained effect over time led to significant increases in sucrose mass and content (Table 2). The differences in well watered sucrose partitioning between experiments are probably due to temperature differences.

**Table 3. Partitioning fractions for the different experiments. Values in brackets are percentages of well watered control. Non-significance is indicated by NS.**

<b>Variable</b>	<b>M99</b>	<b>M00</b>	<b>B99</b>	<b>B00</b>
<u>Stalk partition fraction</u>				
Well watered	0.66	0.79	.66	.91
Stressed	0.67	0.84	.66	.90
Difference	NS	0.05	NS	NS
<u>Sucrose partition fraction</u>	<u>at SDM=8</u>	<u>at SDM=8</u>	<u>at SDM=8</u>	<u>at SDM=30</u>
Well watered	0.32	.32	.21	.58
Stressed	0.50	.36	.56	.58
Difference	+0.18 (56)	+0.04 (13)	+0.35 (166)	NS

Thresholds of soil water content and plant extension rate are commonly used in South Africa and Australia (Shannon *et.al.*, 1996) irrigation scheduling criteria. The findings from this study confirmed that the onset of water stress is determined by soil water availability as well as evaporative demand. Inefficiencies could arise if soil water content was the sole criterion. Models that integrate, climate, plant and soil processes are likely to provide the best guidance for irrigation scheduling (McGlinchey *et.al.*, 1995).

The study showed that cane yield was not affected by water stress until stalk extension rate dropped to 25% of the well-watered control in the BB99 experiment, compared with the irrigation criterion of 50%. The effect of prolonged scheduling using a stalk extension criterion of 25% will have to be tested before general recommendations can be made.

The information obtained will form the basis for revised guidelines for irrigation management under water restrictions, as well as for increasing sucrose yields through gradual drying off towards the end of the cycle. Results indicate that large responses in sucrose yield and content are possible.

This research has benefited from the collaborative approach in that concepts of sugarcane-water relations were tested across a diverse set of environments using different research facilities. This allowed a broad perspective to be gained on the effect of water stress on plant expansion and sucrose accumulation.

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