Environmental and genetic manipulation of carbon partitioning between growth and storage in sugarcane

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CRC Sugar Industry Innovation through Biotechnology

SIIB

BSES

Sugarcane for the future

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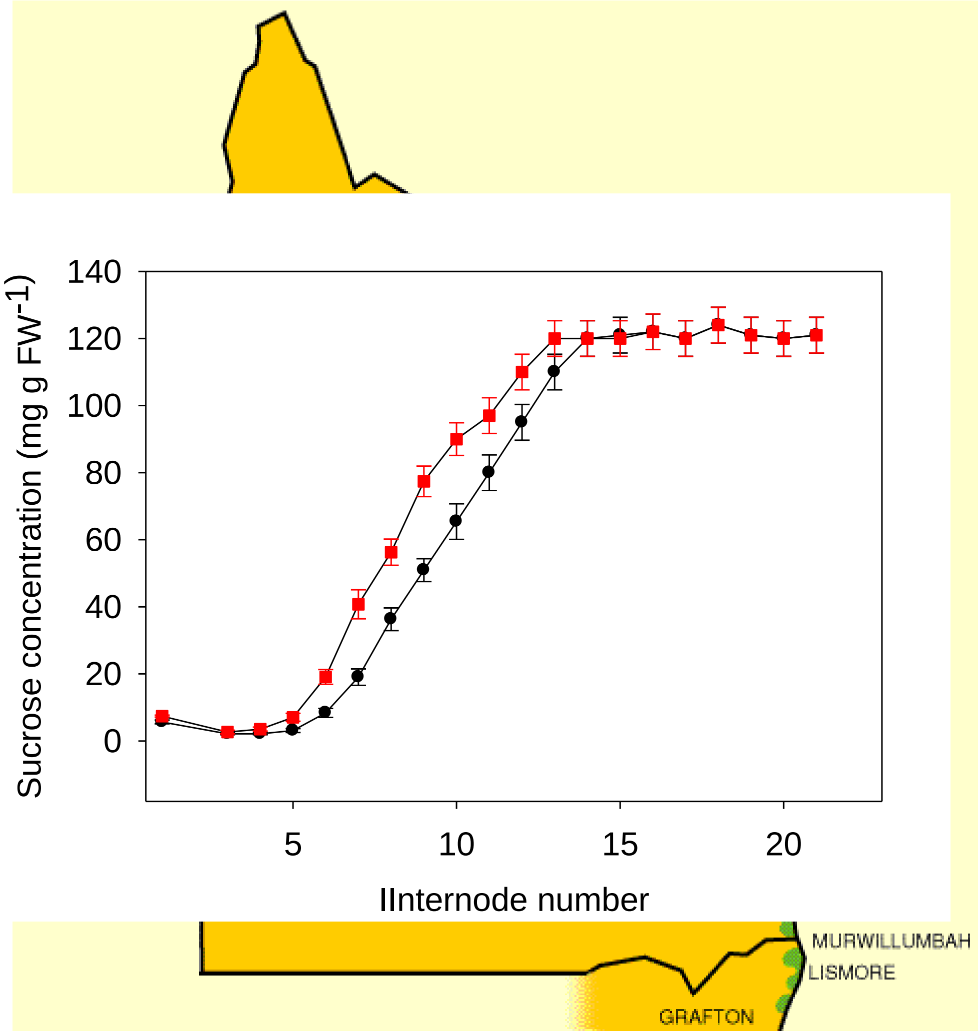
Outline

- Environmental responses of sugarcane
  - Water
  - Temperature
- Genetic variation
- How can we translate this knowledge
  - Agronomy
  - Conventional breeding
  - Transgenic approaches

Why is the response to environment important?

- Sugarcane is harvested over a many months
- Large latitude range of production of commercial sugarcane
- Altered climate
  - Temp
  - CO_2
  - H_20
- Understanding ? of carbon partitioning
  - Difference between high and lo sucrose content genotypes
  - Applicable to soluble sugar and fibre utilization production systems



Experimental system

•Leaf photosynthesis measurement

•Whole photosynthesis canopy measurement

Partitioning control through manipulation of water

- Can we influence partitioning through control of water?
  - Fill as you grow hypothesis
  - Manage water to reduce growth but not photosynthesis

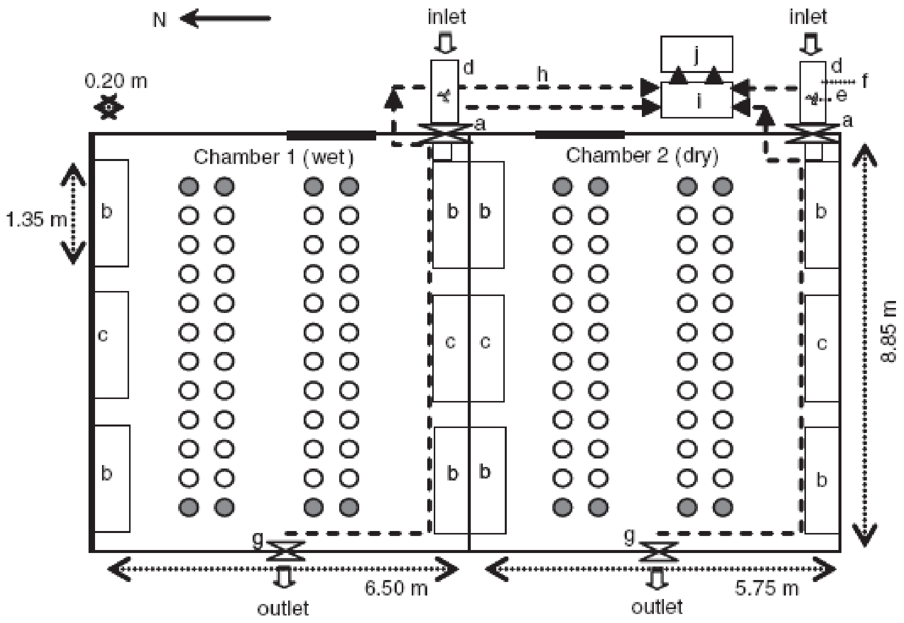


Fig. 1. Plan of the two Tall Plant Facility (TPF) chambers and position of 40 experimental (○) and 16 guard plants (●): (a) Inlet fan (WCE414S, Fantech Pty Ltd, Mulgrave, Vic., Australia), (b) 4.5 m high, and (c) 5.5 m high plenums, (d) inlet tubes 800 mm long and 302 mm ID fitted centrally with (e) small three-cup anemometers (RM Young Co., Traverse City, MI, USA), and (f) a hot-wire anemometer (model 8340, TSI, Carlton, Vic., Australia), (g) 165 mm ID outlet hole, (h) 6 mm ID tubing (- - -), (i) pump (model TD-3LSC, Brailsford & Co. Inc., Antrim, NH, USA) and solenoids (j) infrared gas analyser (IRGA, Li 6262, Li-Cor Inc., Lincoln, NE, USA).

Inman-Bamber, 2008 Australian Journal of Agricultural Science

Plant extension rate reduced

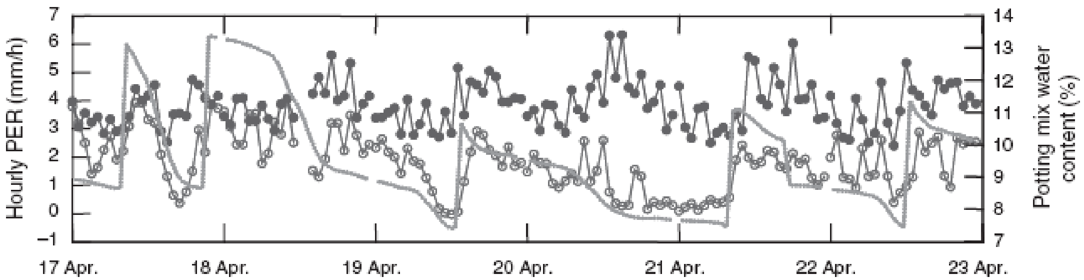


Fig. 4. Hourly plant extension rate of 'wet' (●) and 'dry' (○) sugarcane plants, and water content of the potting mix in the 'dry' watering regime. Water content for the 'wet' treatment is not shown and always exceeded 34%.

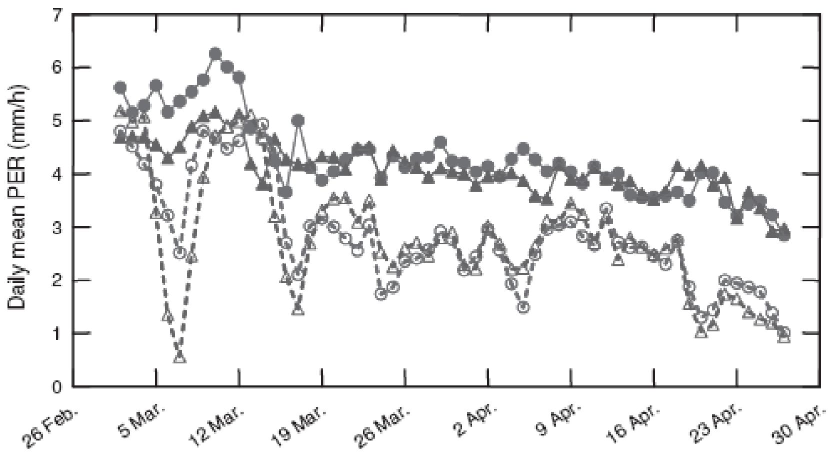


Fig. 3. Daily mean plant extension rate (PER) for well-watered ('wet'; ●, ▲) and stressed ('dry'; ○, △) plants of sugarcane for cultivars Q138 (●, ○) and Q183 (▲, △).

Extension rate reduced by 41%

Inman-Bamber, 2008 Australian Journal of Agricultural Science

Photosynthesis reduced less

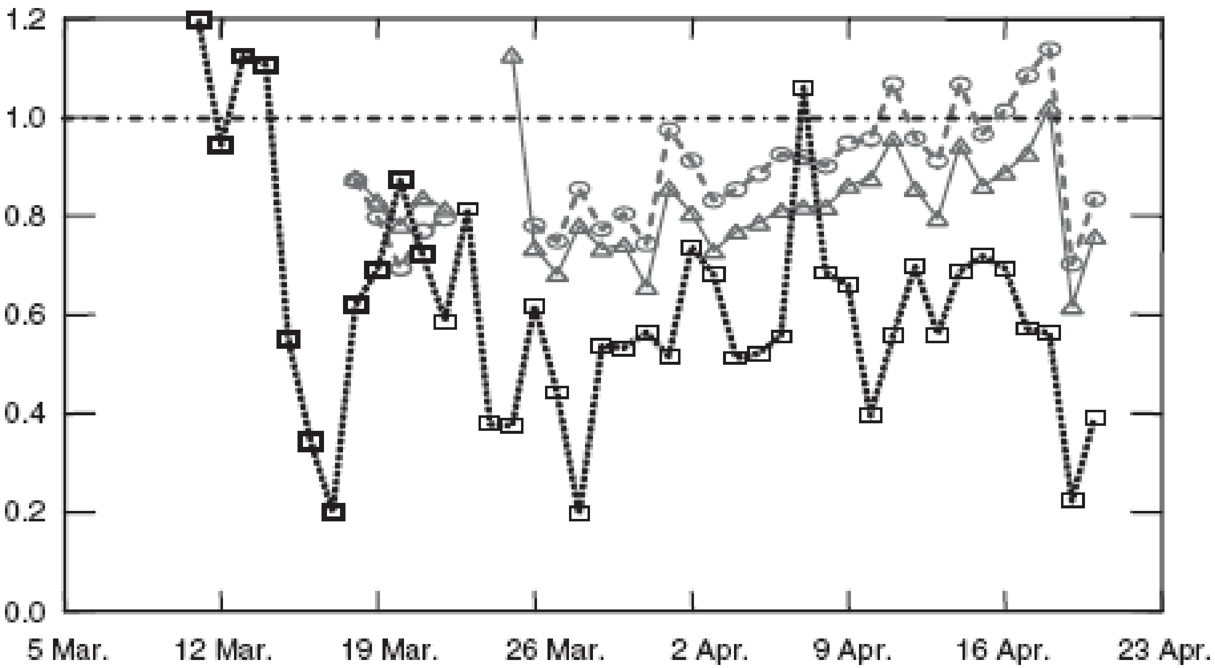


Fig. 8. Photosynthesis per pot (P_P, solid line, Δ) and per m^2 leaf area (P_A, broken line, ○) and plant extension rate (PER, dotted line, □) of 'dry' plants, all relative to photosynthesis and PER of 'wet' plants of sugarcane. Data were excluded when solar radiation <10 W/m^2.

Photosynthesis reduced by 18%

Inman-Bamber, 2008 Australian Journal of Agricultural Science

Partitioning changes

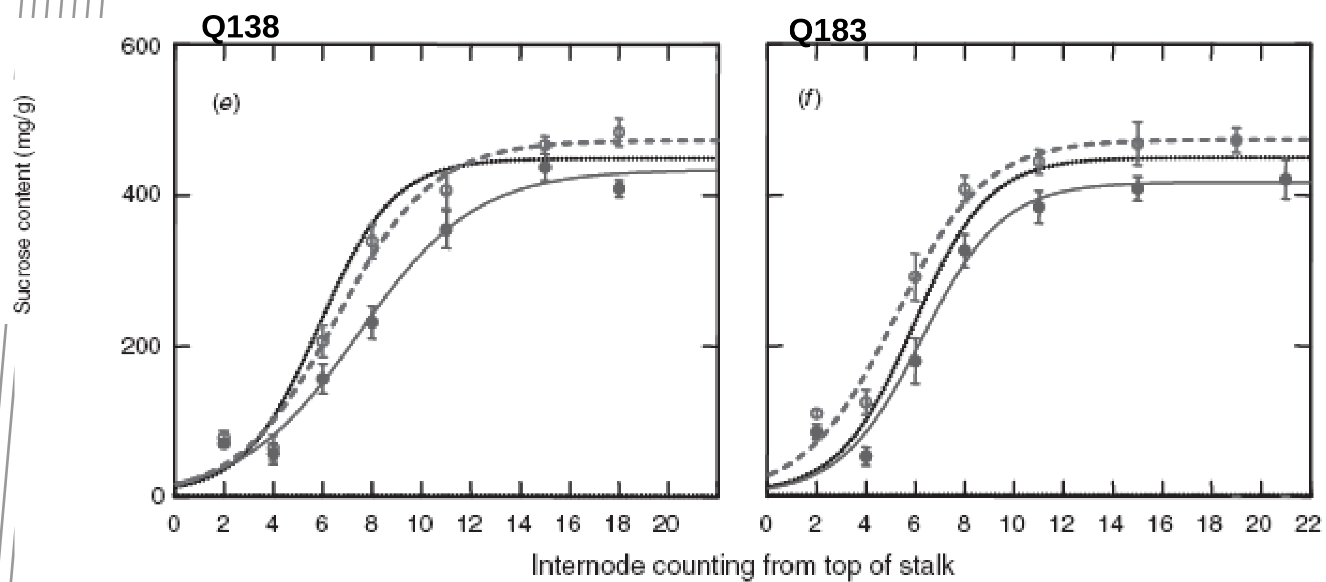


Fig. 10. Mean sucrose content (SCd) of dry matter of sugarcane internodes determined on (*a*, *b*) 2 March (*c*, *d*), 30 March and (*e*, *f*) 20 April for 'wet' (●) and 'dry' plants (○) of cultivars (*a*, *c*, *e*) Q138 and (*b*, *d*, *f*) Q183. Lines produced by a Gompertz function $[a/(1 + \exp(b - c \times N))]$ where $N =$ internode number and *a*, *b* and *c* coefficients, fitted by least-squares. Gompertz function for (*a*) is repeated as a dotted line in other graphs as a reference.

- Biomass down 19%
- Mass of tops (leaves) down 37%
- Sucrose increase 27%

- Biomass can be re-directed if plant elongation is reduced

Inman-Bamber, 2008 Australian Journal of Agricultural Science

Experimental system used to understand genetic variation

- Experiment with 4 clones
  - Two high sucrose
  - Two low sucrose

Clone	Phot. per pot ($mL\ CO_2/s$) Exp1	Phot. per pot ($mL\ CO_2/s$) Exp2	Phot. per m^2 ($mL\ CO_2/s.m$) Exp1	Phot. per m^2 ($mL\ CO_2/s.m$) Exp2
KQ97-2599	0.148	-	0.275	-
KQ97-2835	0.199	0.468	0.240	0.161
Q117	0.161	-	0.220	-
KQ97-5080	0.146	0.462	0.284	0.153
P	<0.001	0.64	<0.001	0.142
SEM	0.011		0.011	

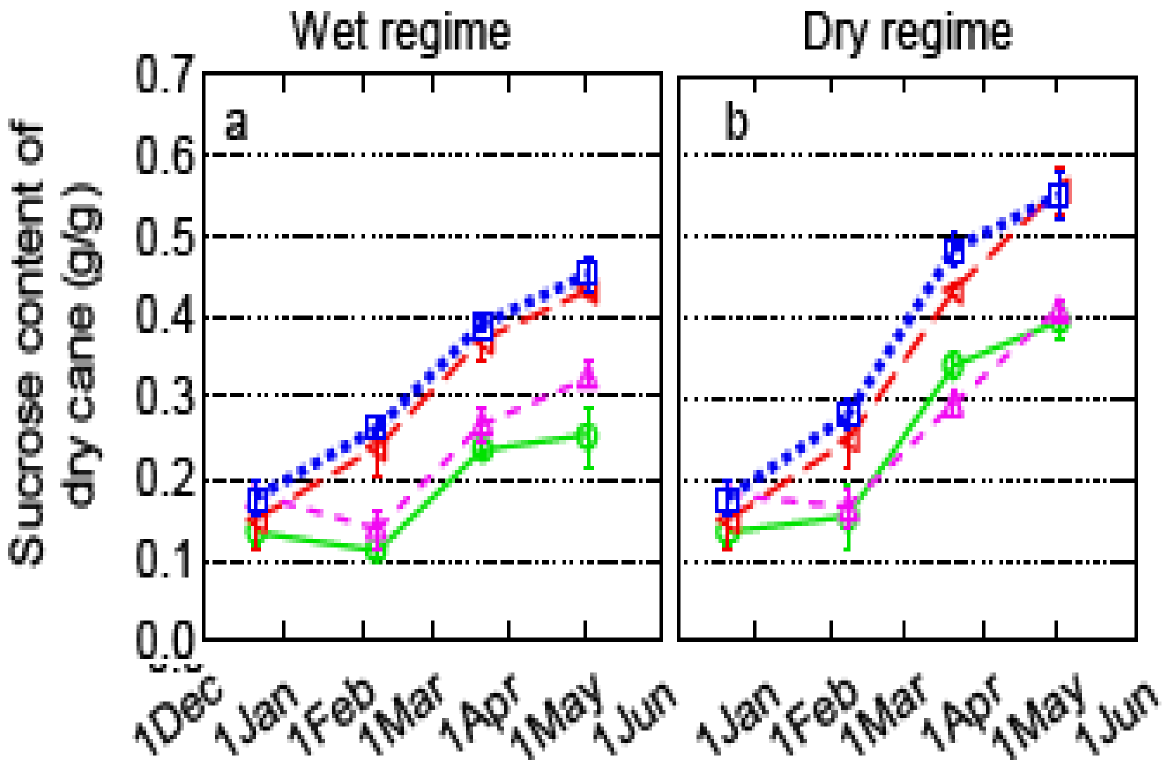
Low sucrose

High sucrose

Photosynthesis was not different between high and low sucrose clones

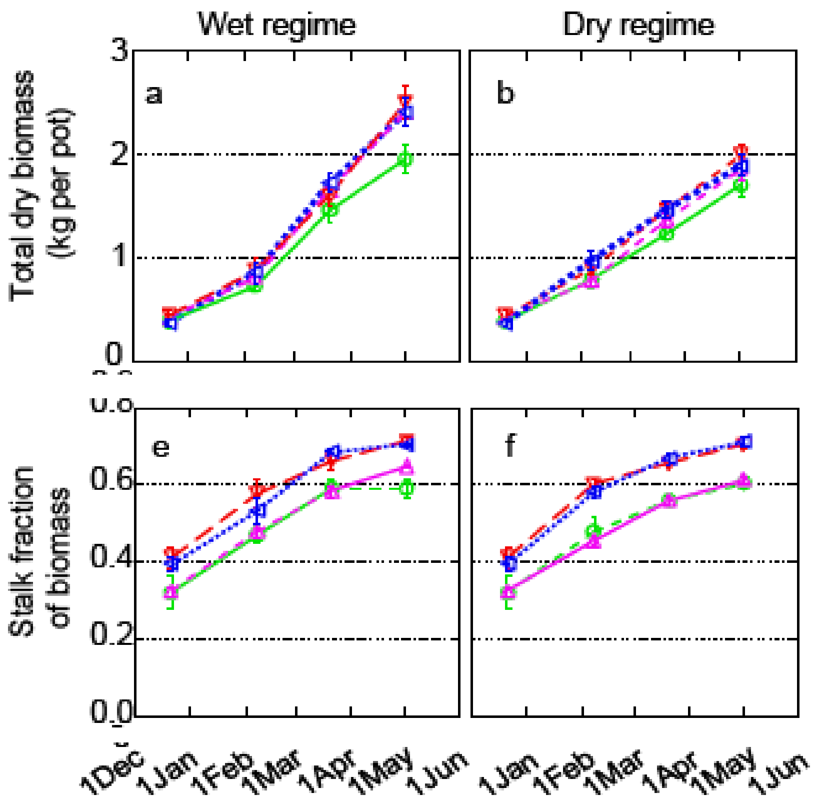
Inman Bamber et al, 2009 Crop and Pasture Science

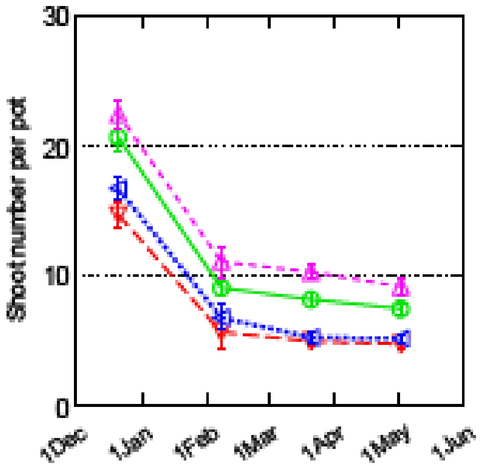
Sucrose content through time



Inman Bamber et al, 2009 Crop and Pasture Science

Partitioning of biomass

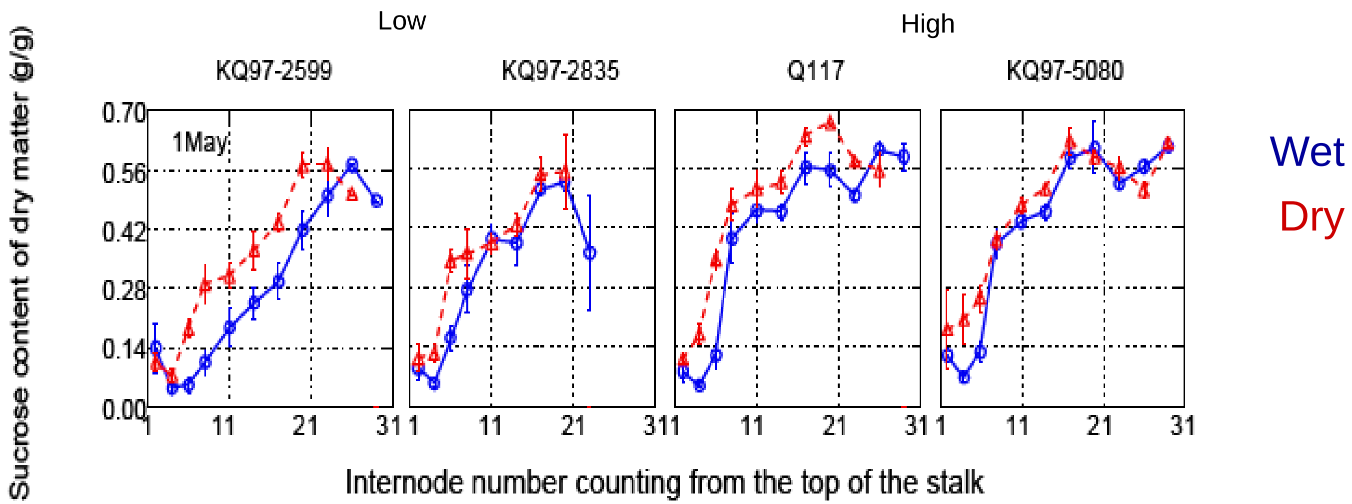




Partitioning to stalk biomass – driven by fewer stalks was the distinguishing feature

Inman Bamber et al, 2009 Crop and Pasture Science

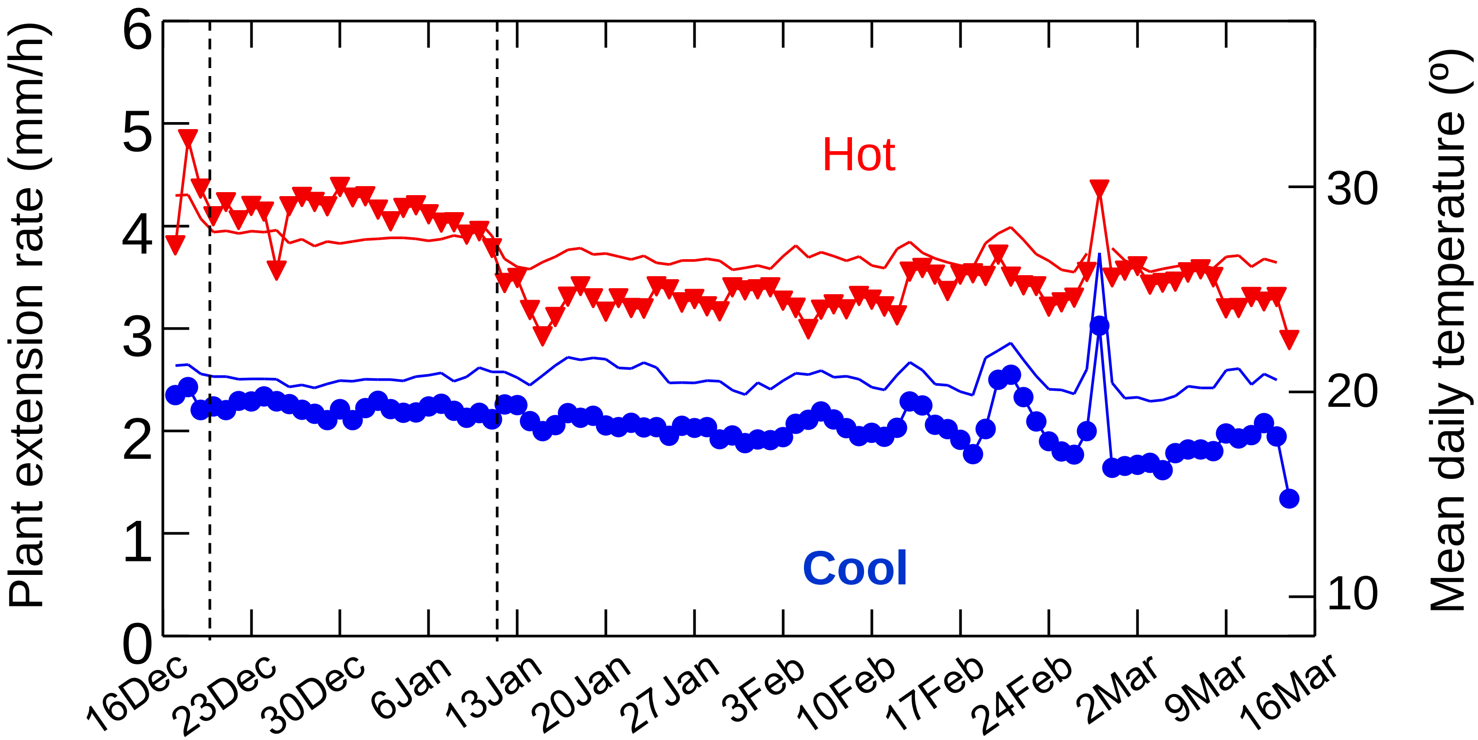
Sucrose content by internode



- Internodes of low sucrose clones can accumulate as much as high sucrose clones
- Variation in the response to reduced soil water
- Genetic differences in sucrose content seems to be in partitioning to stalks, leaves and stems.
- Is this the general case?

Inman Bamber et al, 2009 Crop and Pasture Science

Daily mean plant extension rate controlled by temperature rather than water deficit



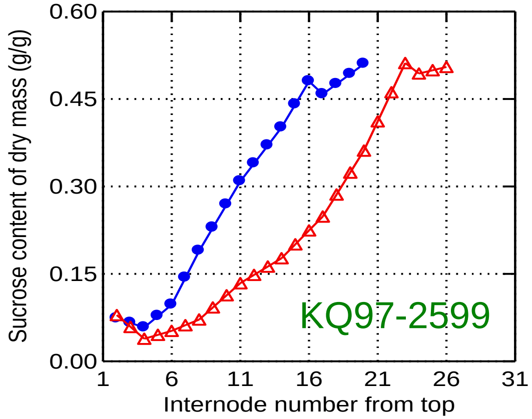
42% reduction in PER

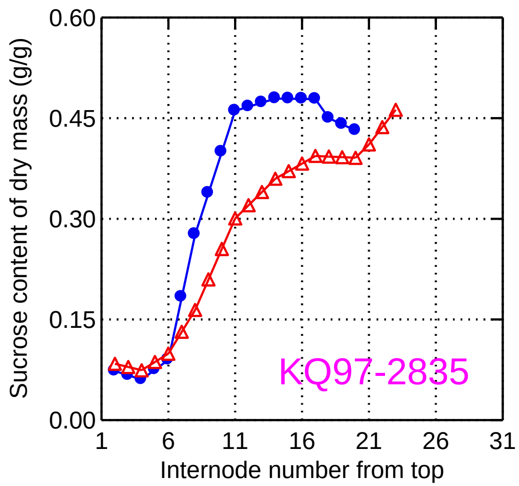
14% reduction in photosynthesis

Same cultivars tested

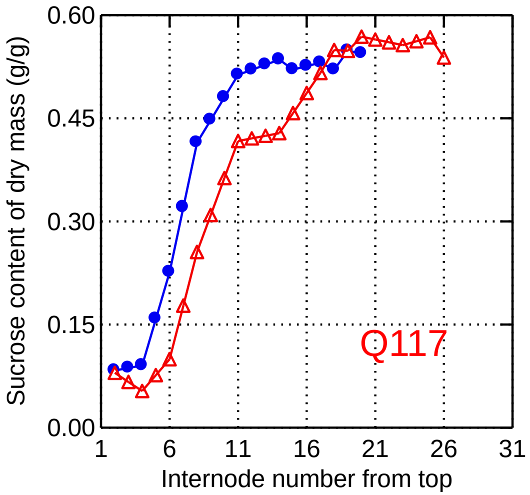
Similar sucrose outcome

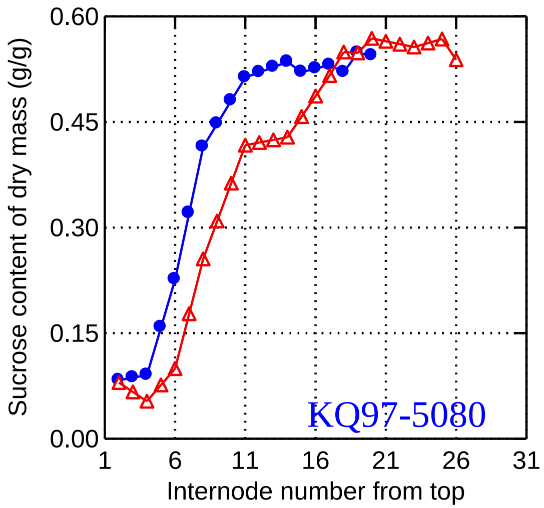
Low sucrose



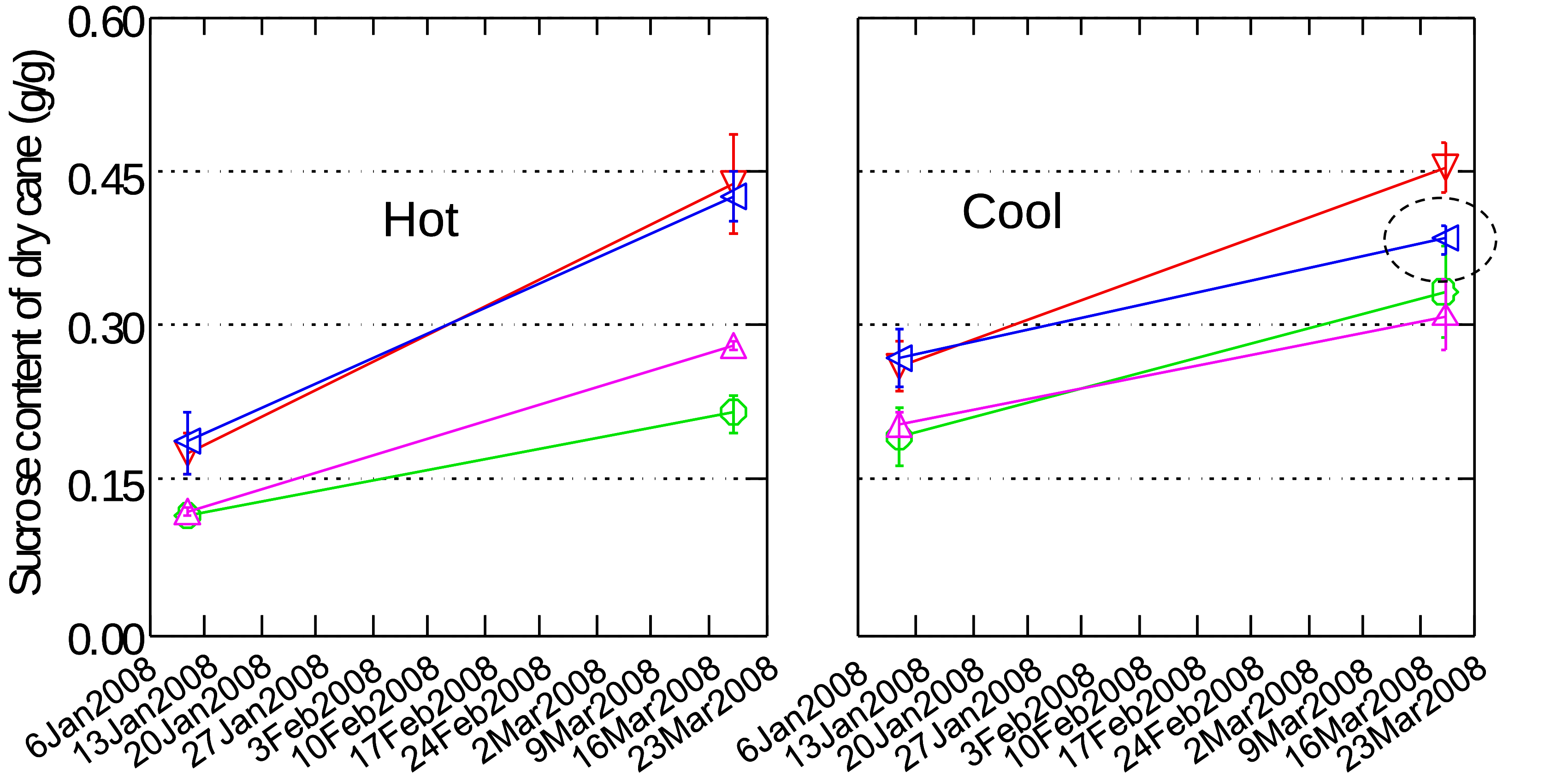


High sucrose





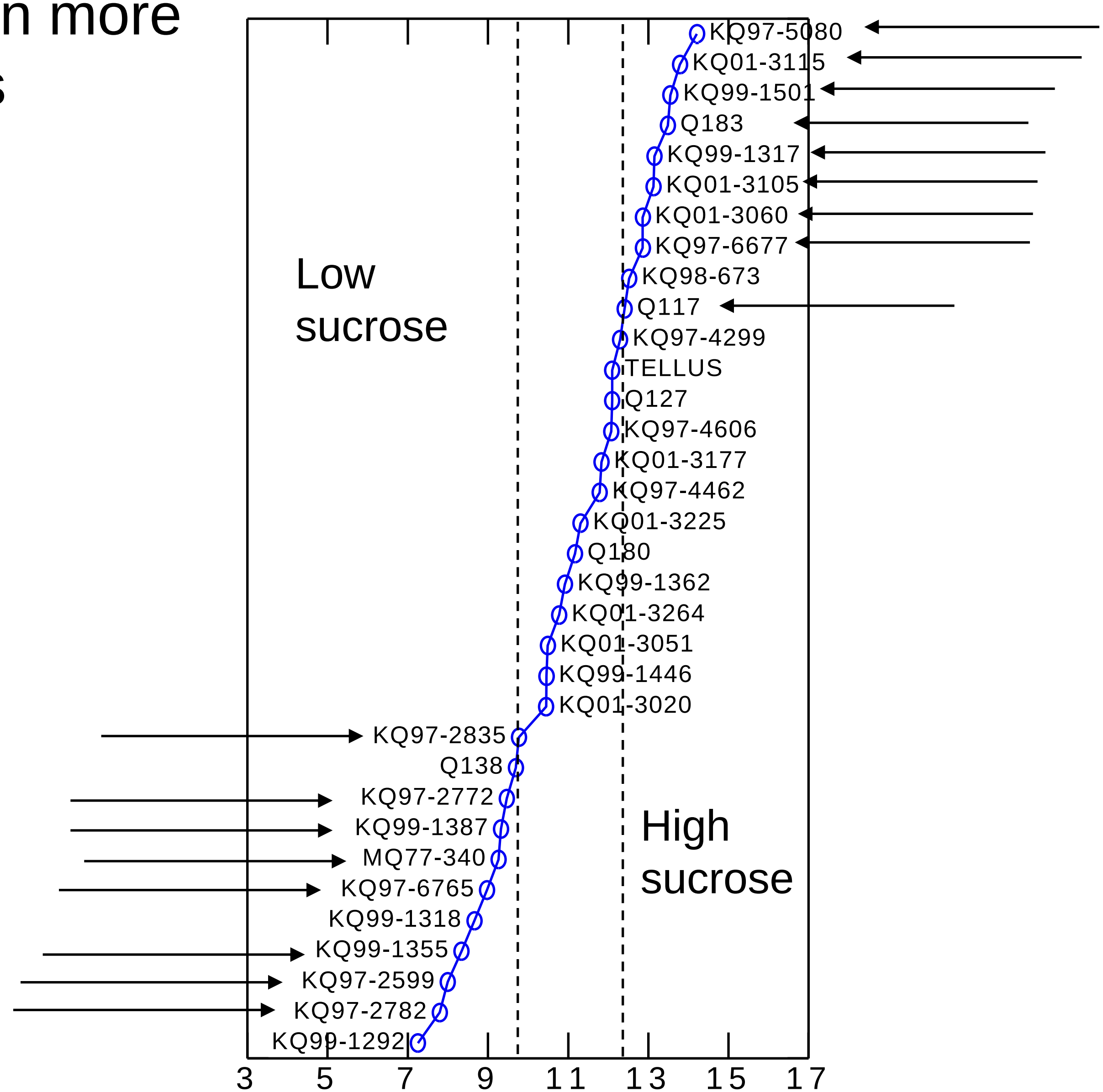
Differences due to genotype



Low sucrose High sucrose

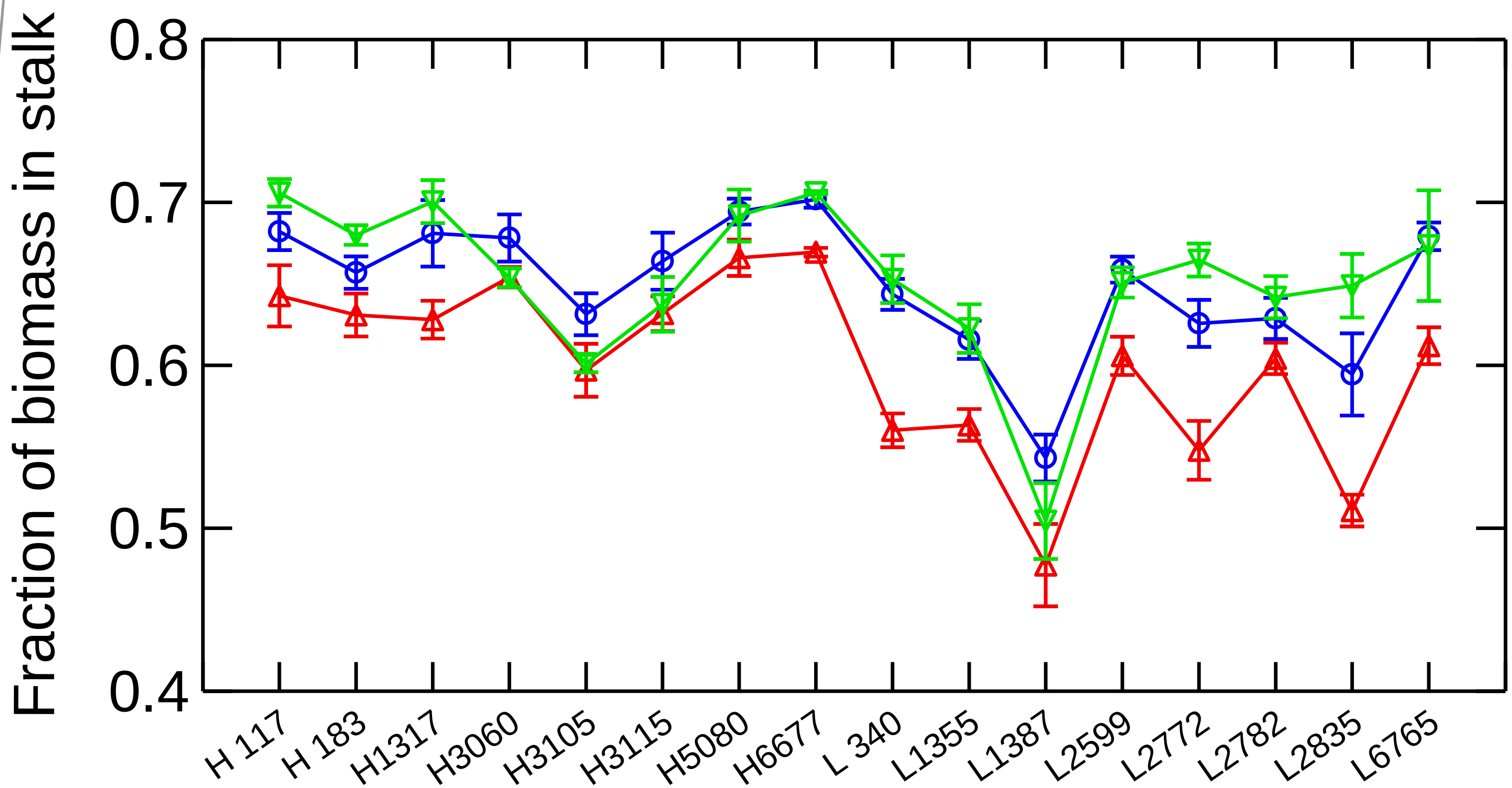
KQ97-2599 (—○—), KQ97-2835 (--△--), Q117 (▪–▽▪–), KQ97-5080 (▪▪▪◁▪▪▪)

Tested in more cultivars



Sucrose content in propagation plots June 07 (%)

Fraction of biomass in the stalk



- 10% higher in high than in low sucrose types
- 8 % higher in low than in high temperature
- temperature x clone types interaction was significant (p=0.037)
- response to temperature greater
    - for low sucrose clones (11%) than
    - for high sucrose clones (5%).

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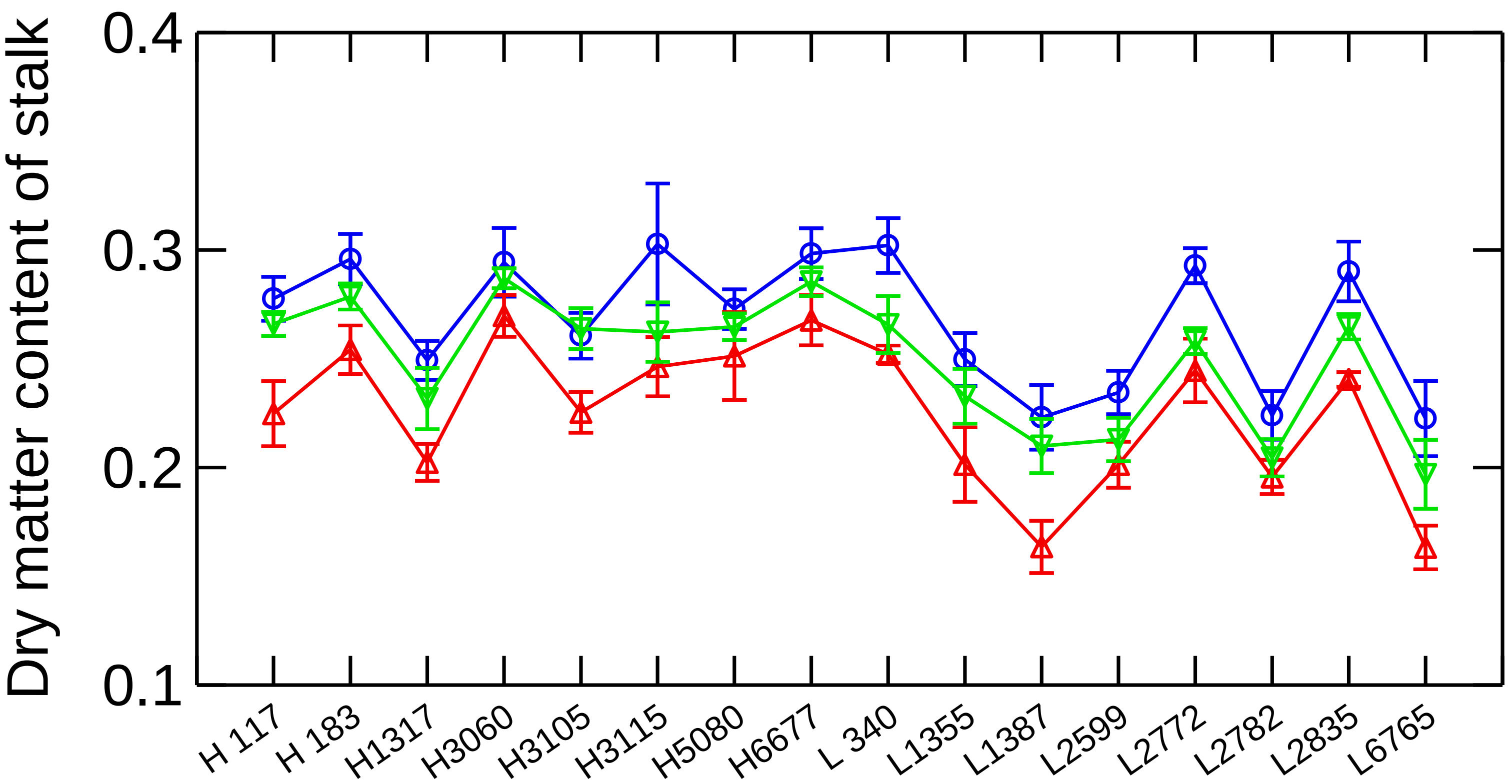
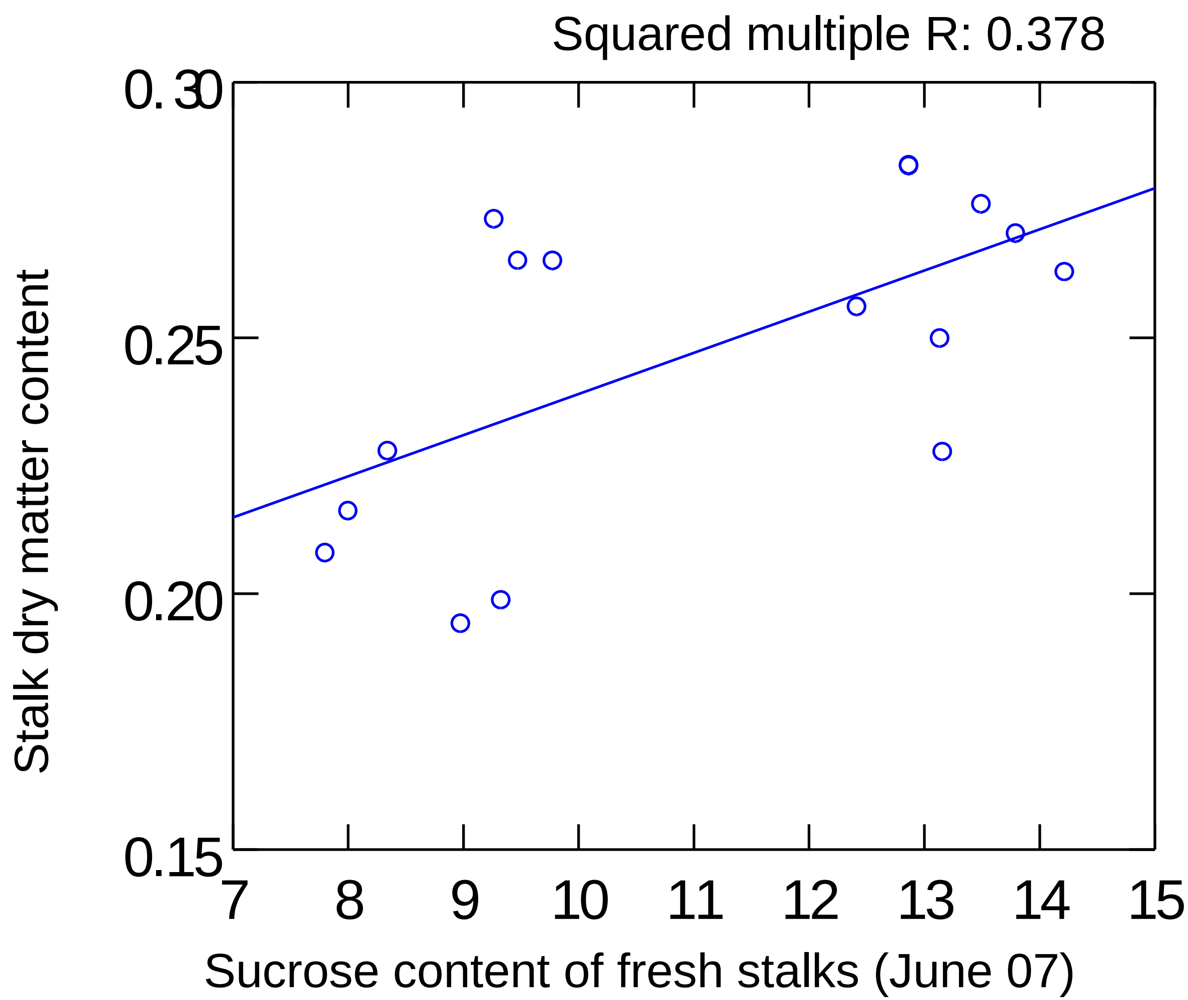
Dry matter content of stalks



- increased with time
- 19% higher in the cool
- 13% higher in high than in low sucrose types

No sucrose data yet but…

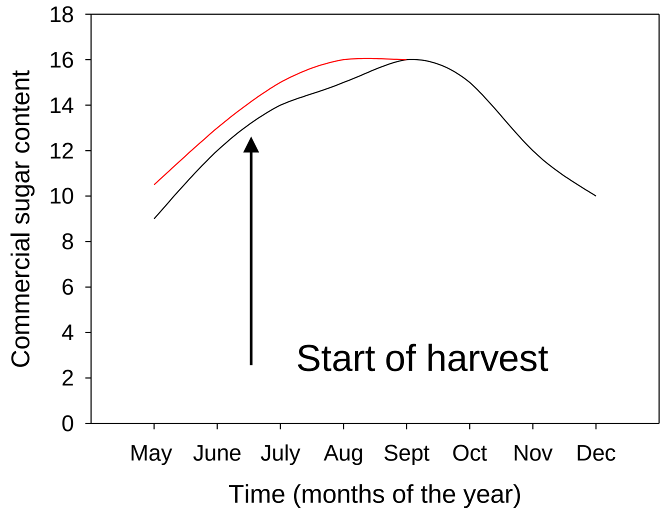
Glasshouse data



Field data

High early varieties

- Commercial levels of sucrose before and at the start of the harvest season
- High value
  - Increased harvest season, capital utilisation etc
- Response to environment or inbuilt genetics?
  - Shown genotypic differences in response to environmental variables
  - Shown genotypic differences in partitioning

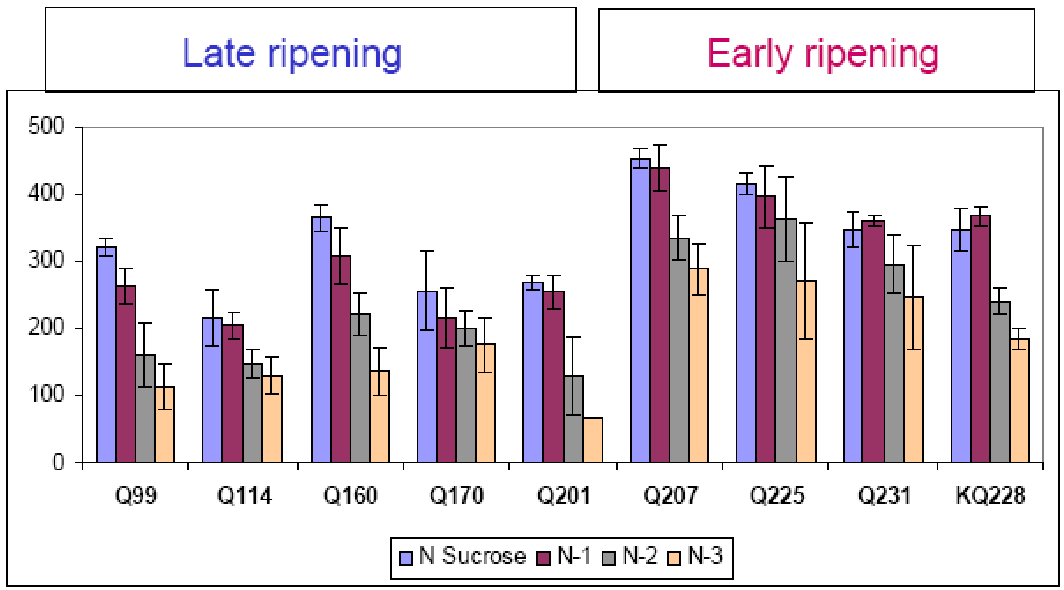


High early sucrose – genetic component

Key findings - Highlights

HES varieties accumulate more sucrose in older internodes as early as 3 months

Internode Sucrose (mg/g DW) - 3 months



Varieties

Fong Chong et al., in preparation

Physiological findings

- Partitioning can be manipulated in a controlled way experimentally
  - Differences between genotypes in response to water deficit and temperature
  - Higher temperatures whilst good for yield will reduce sucrose content
  - In a warmer environment selection of less responsive genotypes may help
  - High sucrose content is associated with greater partitioning to stalk material – harvest index!
- The early sugar phenotype is operating throughout development
- Experimental system is soon to be used for CO_2 experiments
  - Important to understand these responses for investment decisions

Challenges

- Identification of a trait explaining sucrose accumulation in most high sucrose clones is difficult
  - Screening enough clones for a pattern to emerge
  - Not all traits can be screened at a young stage of growth
- How can we translate this knowledge
  - Agronomy
  - Conventional breeding
  - Transgenic approaches

Agronomy

- **POINTERS FOR BETTER FARMING AND RESEARCH FROM SUGARCANE PHYSIOLOGY**
- INMAN-BAMBER N G, et al.,
- Sugar Cane International 2008.

- **POINTERS FOR BETTER FARMING AND FISHING FROM SUGARCANE PHYSIOLOGY**
- INMAN-BAMBER N G, et al.,
- As quoted in Web of Science

Irrigation strategy – an example

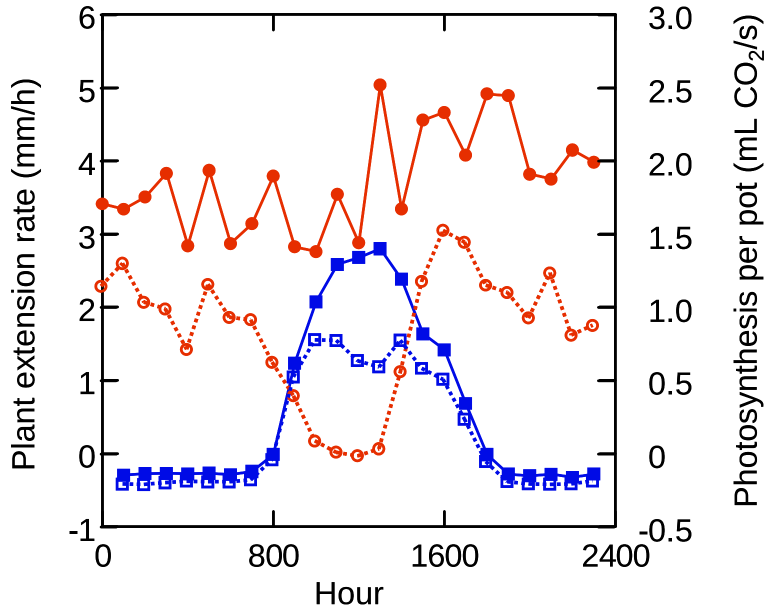


Figure 2. Plant extension rate (●,○) and photosynthesis (■,□) during 18 April 2006 in potted plants in a glasshouse with abundant (●■) and limited irrigation (○,□).

- •Practice was to irrigate when 50% elongation rate reached
- •Combination of field and glasshouse experiments has demonstrated this to be conservative
- •30% of elongation rate before biomass penalty

If we were dealing with wheat

- Line with trait x Elite

50	F1 X Elite
75	BC1 X Elite
88	BC2 X Elite
94	BC3 X Elite
97	BC4 X Elite
98	BC5 X Elite

Introgression of a physiological trait

- Keys to success
  - Genetic region to account for a large proportion of the variation
  - Homozygous backcross parents
    - Easily recovered phenotype in an elite background
  - Rapid generation time

Small size of effects

- Polyploid genome
- Complex traits
- Small QTL or association effects (2-10%)

Trait	No. of markers	% variation explained
Fiji	5	32
Pachymetra	6	26
Smut	11	60

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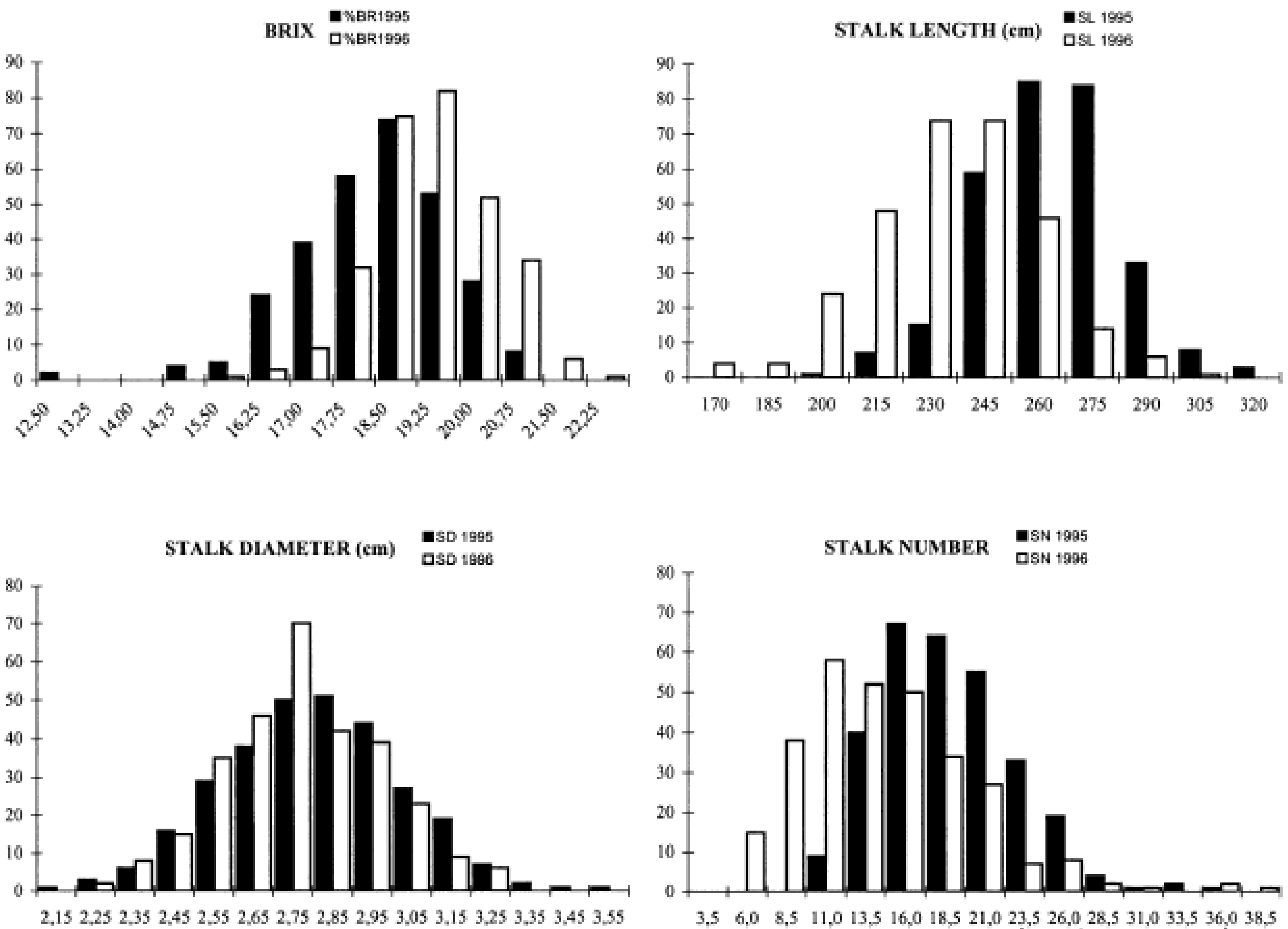
Elite sugarcane parents are highly heterozygous



Hoaru et al., Theor Appl Genet (2002)

Heterogyzosity rather than polyploidy the problem

Can we decrease the generation time of sugarcane?

Photo Brendan Kidd

Transgenics

- An attractive alternative approach
- Given the plasticity of metabolism – are “non-metabolic” (developmental processes) a better option?
- You have seen yesterday that this has some challenges of its own

Concluding remarks

- We can identify traits influencing sucrose content
- We can identify variation in physiological response to environment
- Can we drive increased production?
  - Sometimes through agronomy
- Different ways of achieving the end result (yield, sucrose etc…)
  - On average a particular mechanism may have a positive impact
  - But interaction with other parts of the genome make a breeding approach difficult
  - Genetic lesions via transgenesis a future option
    - Need to understand key genes behind the traits
- Node by node sucrose data being used to build new sucrose accumulation model
  - South African/Australian collaboration
- Model systems may be useful
  - Need to translate to a more complex genetics
  - Does the model operate in the same way

Acknowledgements

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- Michael Hewitt
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Thank you

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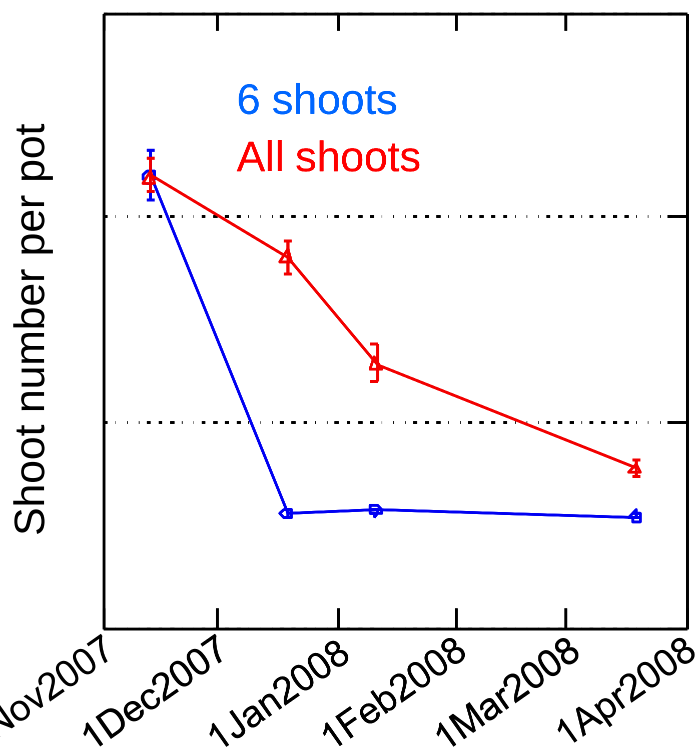
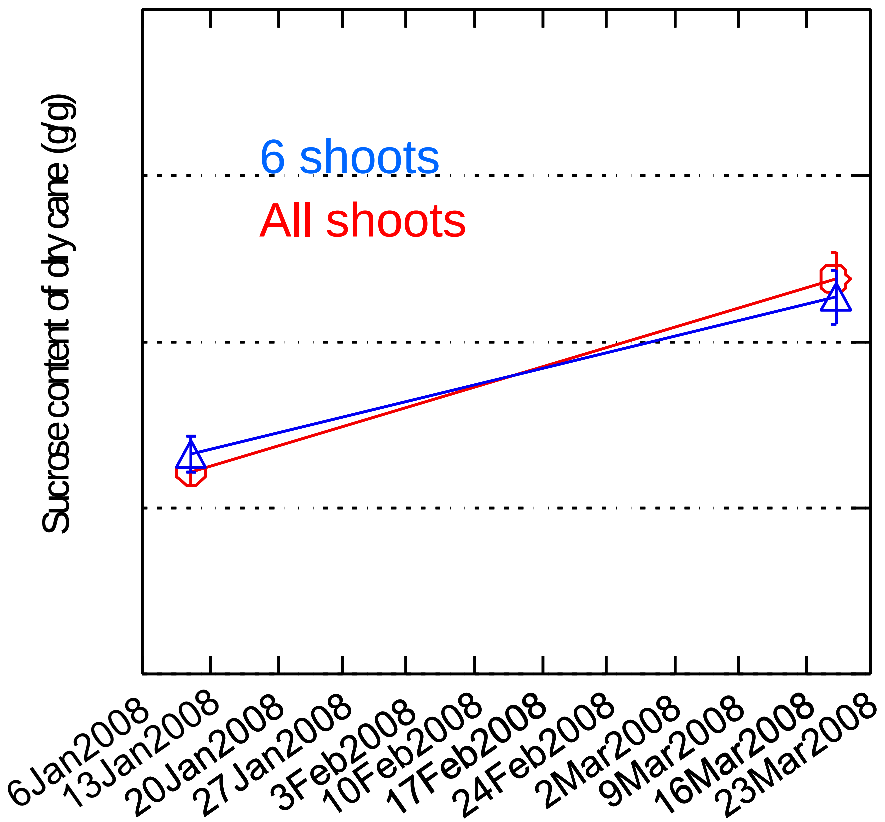
No effect of stalk number





Temperature effects on sucrose accumulation

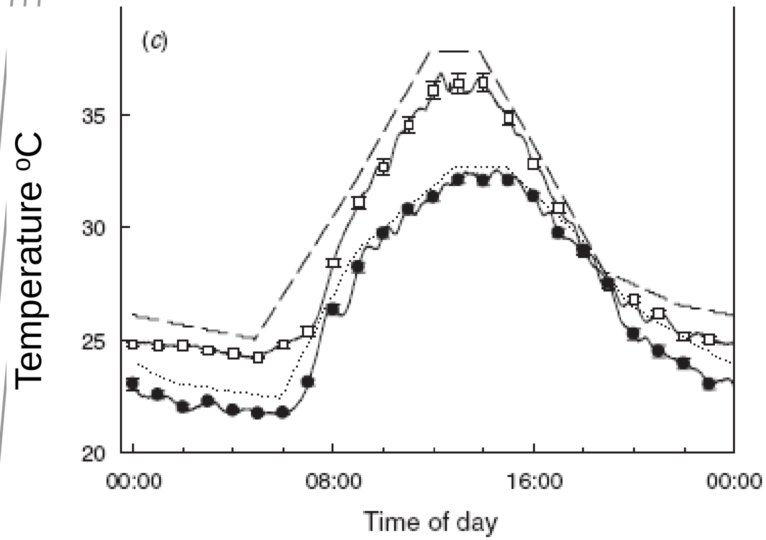


Table 3. Number of nodes and height of plants in Expt 2
The number of nodes and height to the last fully expanded leaf of stalks for 2 cultivars of sugarcane, Q117 and Q158, grown in 2 temperature regimes. Within columns, means followed by different letters are significantly different at $P = 0.05$

Temp.	Number of nodes		Height to last visible dewlap (m)	
	Q117	Q158	Q117	Q158
Low	18.8b	14.3b	2.53	3.00a
High	21.5a	17.0a	2.59	2.80b

More, shorter internodes

Bonnett et al., 2006, AJAR

Temperature effects on sucrose accumulation

Temp. regime	Component	Internode −20	Internode −12	Internode −8	Internode −4
			Q117		
Low	Sucrose	103 (5.5)a	40.2 (6.4)n.s.	20.6 (2.6)n.s.	5.47 (0.85)n.s.
High		73.3 (8.9)b	32.0 (3.4)n.s.	19.0 (3.4)n.s.	5.78 (0.34)n.s.
Low	Glucose	2.55 (0.73)b	10.6 (2.4)n.s.	12.6 (1.6)n.s.	9.61 (0.88)a
High		9.30 (0.96)a	13.3 (1.9)n.s.	15.4 (0.62)n.s.	12.7 (0.56)b
			Q158		
Low	Sucrose		67.8 (6.7)a	40.1 (6.7)a	25.2 (3.8)a
High			20.0 (5.8)b	15.5 (2.4)b	7.97 (1.6)b
Low	Glucose		16.1 (0.76)b	18.8 (1.5)b	17.6 (3.0)n.s.
High			21.3 (1.1)a	23.9 (1.2)a	18.4 (1.6)n.s.

Bonnett et al., 2006, AJAR

Effect of increased temperature > 35^{o}C

- More, shorter internodes
  - Increased fibre (nodes)
  - Rate of development increased at higher temperatures than modelled
    - Indicates we will have more to learn to get ready for increased temperature
- Altered partitioning
- Genetic variation for the response