REVIEW OF KNOWLEDGE OF SUGARCANE PHYSIOLOGY AND CLIMATE-CROP-SOIL INTERACTIONS

FINAL REPORT
May 2004

Project reference no: CSE006

Organisation: CSIRO Sustainable Ecosystems

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No part of this report is considered confidential

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SUGAR RESEARCH AND DEVELOPMENT CORPORATION

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Commencement Date: 1 July, 2003 **Completion Date:** 30 June, 2004

1. EXECUTIVE SUMMARY

Introduction

Compared to other crops, knowledge of growth mechanisms in sugarcane is inadequate. The question arises as to how much longer can we continue to prosper from sugarcane if knowledge of the growth processes on which our industry depends, remains outdated? Sucrose accumulation and efficient use of resources are primary concerns for this industry. To date we have only limited understanding of climate and management links to sucrose content or CCS and this undermines our ability to manage water, nutrients, varieties and the harvest schedule for maximum CCS and optimum cane yield. Cane and sucrose yields are often below potential for reasons about which we can only speculate (Leslie and Byth, 2000).

In the past, research funds have been directed at opportunities for raising limitations to yield and efficiency of resource use at the gene and enzyme level as well as at the crop and paddock level. There has been no attempt to integrate research or information across these disciplines or to assess where progress toward sustainable production is most likely to be achieved. SRDC recognized that it was now time for each discipline interested in the same processes to get together to find out how their different approaches could be complementary. SRDC also recognised the need to review past data relating to crop growth in the later stages of crop development to see if something could be done about under performing crops during this stage.

Workshop

A three-day workshop was arranged to bring together the world's most significant sugarcane physiologists to Australia to update our knowledge at several levels of plant organization, and to investigate ways of integrating this knowledge.

The workshop was planned over a period of two years with the help of a committee drawn from scientists in CSIRO Plant Industry and Sustainable Ecosystems. Three top international scientists were identified to provide leading papers and to help direct discussion at the workshop. A total of 23 papers were presented and most were of a very high standard. After negotiations with a reputable international journal (Field Crops Research, FCR) the workshop committee was invited to form an editorial panel to review all papers in preparation for a special issue of FCR dealing with the workshop proceedings. The committee has undertaken to deliver reviewed and revised papers ready for publication to FCR by October 2004.

Daily attendance at the workshop (by invitation) varied between 33 and 39 including three delegates from South Africa and one each from USA, Colombia and Mauritius. Australian organizations represented included, CSIRO CSE and PI, BSES, DPI, SRDC, CSR and University of Queensland.

The enthusiasm for establishing links across levels of organization in the production system from molecules to mills was obvious. There was also will expressed to work across organisations in Australia and across the nations represented.

After each session of papers, important points in the session were discussed in a breakout session where critical gaps in our knowledge could be identified. These points were captured in notes taken during the workshop.

At the conclusion of the workshop, delegates were asked to discuss and then present the key issues for future research. Delegates then were asked to prioritize these issues by voting. The most important issues for collaborative research were considered to be 1) sucrose and CCS accumulation pathways, plant physiology and crop/environmental controls, 2) improved water use and nitrogen use efficiency and 3) comparative physiology of germplasm, tracing historical improvement for designing future genotypes.

Finally, the workshop was wrapped up by Dr Richard Richards (wheat physiology and breeding) and Dr Paul Moore (sugarcane physiology, USA). Dr Richards' perspective from a different crop species was indeed inspiring. He felt that with the skill and common purpose expressed during the workshop, the sugar industry stood to benefit a great deal from current and future knowledge of sugarcane physiology. Dr Richards was able to speak from his experience in contributing greatly to the wheat industry through physiology research across many levels of organization.

Research plan

After the workshop key delegates worked on a research plan to increase sugar yield through increased CCS and cane yield and through improved water management, capitalising on better understanding of the interactions between genetics and management. This plan forms the basis of a proposal which was submitted to SRDC for funding in 2003/04, without success. A revised plan will be resubmitted in 2004/05. The research project will also provide an opportunity for scientists at various levels in the 'supply' chain (molecules to mill) to interact and to think about future prospects for the use of the sugarcane plant.

Review of growth in ageing crops

In Australian sugarcane crops, growth in terms of radiation use efficiency (RUE) can slow down well before final crop harvest, despite conditions that are considered favourable for growth. In order to assess the extent and cause of this reduced growth phenomenon (RGP), results from 14 experiments previously conducted under high input conditions were examined. From these experiments, 34 treatments were selected with the knowledge that nutrients and water were non-limiting and that the yields obtained were limited only by temperature and radiation. In 50% of treatments, RUE declined significantly at some stage after seven months of growth, evidence of the RGP. In most of these cases lodging occurred before the onset of the RGP but there were cases where lodging occurred without the RGP and where RGP occurred without lodging. Another possible factor responsible for RGP is low nitrogen (N) content of leaves in ageing crops despite liberal amounts of N fertiliser having been applied to the experiments. After accumulation of 40 t/ha biomass (about 100 t/ha cane), specific leaf N content of almost half of the treatments fell below a concentration that is known to be critical for photosynthesis in maize. The characteristic of low specific leaf N in ageing cane has been noted before but attempts to boost the leaf N level in ageing crops have not been successful. After the onset of reduced growth, RUE was correlated with the rate of stalk death which indicates that stalk death could also be responsible for the RGP. Factors such as lodging, reduced leaf N content and stalk death may be difficult to control through management but they could be avoided to some extent by harvesting crops soon after growth slows down. Breeding and selection for more erect crops, with higher leaf N content and better tiller survival could help to overcome this problem.

2. BACKGROUND

While wheat overshadows sugar as a foreign exchange earner for Australia (about 3:1) it overwhelms sugar as a subject of physiology research. As a measure of world wide physiological knowledge available for these crops, one database (CAB Abstracts) contained more than 4500 abstracts on wheat physiology compared to less than 500 on sugarcane physiology for the same period. Poor knowledge of sugarcane physiology was noted in the list of recommendations from the interim review of the CP2002 project:

> ‘The most significant remaining gaps in sugar industry R&D knowledge infrastructure are (1) insufficient basic and strategic knowledge and (2) insufficient use of systems approach to conduct and integrate R&D. With regard to the former, knowledge of sugarcane genetics, physiology and nutrition is low when compared with crops such as wheat, rice and soybeans’.

Workshop

A workshop was proposed to call on physiologists from different backgrounds and countries to consider all known limitations to sucrose yield accumulation and resource use efficiency, in order to collate current knowledge of, and to set priorities for future research on cane physiology. There are no recent reviews on sugarcane crop physiology. The last was by Alexander (1973). The scope of a workshop and subsequent proceedings would need to be limited to issues relevant to production in Australia. Nevertheless this would be attractive to scientists in a large number of production areas. Workshops on sucrose accumulation have been held at various times in the past decade and no doubt good research has been reported and later inspired by these events. It is important that current knowledge is not only collated and recorded in a systematic way but that this knowledge leads to tangible outputs such as improved modelling capability of the production system or improved direction for cane breeding and selection.

Review of factors responsible for reduced growth in large crops

Early stages of crop development can usually be explained by current knowledge of tillering, leaf area expansion, photosynthesis and stress physiology. However growth often slows down in later stages of development for reasons that are not at all clear. This slowing of growth is at least partly responsible for industry yields being well below yields that should be attainable based on current knowledge of crop physiology. In addition to the workshop this project aimed at reviewing past work on radiation use efficiency to learn as much as possible about the physiology of the reduce growth phenomenon. This knowledge will help to bridge the gap between actual and attainable yields.

3. OBJECTIVES

Knowledge of physiological processes important for profitability and sustainability in sugarcane production is poor compared to other crops. This project will identify knowledge gaps in sugarcane crop and plant physiology, and will develop a strategy for research that will benefit sugarcane production systems in order to make them more profitable, environmentally sustainable and socially responsible.

Objectives of the project are to:

- Review current knowledge of sugarcane physiology and climate-crop-soil interactions in order to establish a foundation on which to build future research and to cite and summarize current knowledge in a single publication.
- Explore links between biochemistry, plant physiology and crop physiology in order to establish a framework for transferring technology across these levels and to the commercial production level.

- Identify physiological processes that are most suitable for manipulation in order to improve sucrose production and efficiency of resource use.
- Improve knowledge of factors responsible for reduced growth in large crops by reworking existing data gathered for other reasons.
- Collaborate worldwide to fill relevant knowledge gaps in sugarcane crop physiology.

4. RESEARCH METHODOLOGY

4.1 Workshop

Planning for the workshop started in 2001. An organising committee was formed from scientists in CSIRO divisions of Plant Industry (Dr Graham Bonnet, Dr Chris Grof) and Sustainable Ecosystems (Dr Geoff Inman-Bamber, Dr Mark Smith, Dr Sarah Park and Dr Peter Thorburn). Mr Bill Andrew (*AECgroup*) was asked to facilitate the meeting and Bill joined the committee in the early stages of planning. The committee decided to invite delegates to the workshop rather than offer an open call. The number was to be limited to 40 delegates to help achieve the workshop aims both to gather world knowledge on sugarcane physiology and to achieve consensus on future research priorities. The committee members were in touch with the most significant physiologists but to make sure we did not miss any reputable physiologists a literature search was conducted. This did not pickup anyone who was not already known. We also asked one of the worlds most respected cane physiologists, Dr Paul Moore, if we had missed anyone. He suggested that we ask Dr Fred Meinzer who no longer worked in cane. Dr Meinzer was asked but declined the invitation to attend. The best international physiologists were offered assistance with airfare and accommodation out of project funds. The cost of the workshop held at Clear Mountain near Brisbane on 1 to 4 September 2003, was covered by project funds.

Meeting of minds of a diverse group of scientists is an excellent way to develop strategies for future research aimed at improving knowledge of the basic chemical, physical and biological processes which underpin profitability and sustainability of sugar production. The intention was to gain consensus amongst such a diverse group firstly about the physiological processes which are most important for profitability and sustainability and then to gain consensus about what research is needed most for each of the selected processes. A framework (Fig 1) for the workshop was built gradually by the organising committee. This was circulated to all participants who were encouraged to prepare papers and presentations with the integration of all levels of plant organisation in mind. The framework was used to derive a program for the workshop based on four themes; integration, growth and development, assimilation and partitioning. The framework represented sugarcane physiology mainly at the cell to whole crop levels. It captured most of the components of these levels that were discussed at the workshop but did not include the molecular level or the crop to mill level which were also discussed in some detail at the workshop.

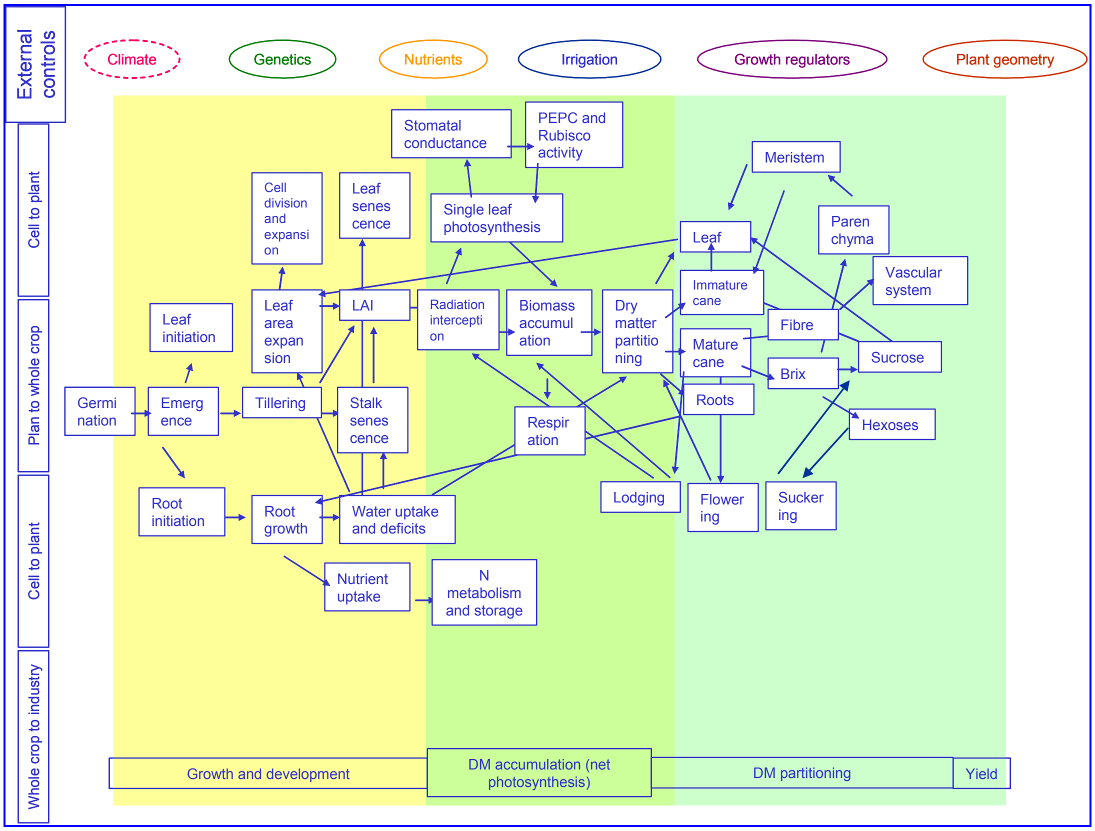

Fig 1 Physiological framework for the workshop

4.2 Review of factors responsible for reduced growth in large crops

Methods for the review of factors responsible for reduced growth in large crops are described fully in the paper by Park et al. which was presented at the workshop (Appendix 1). Fourteen experiments were included in the analyses of factors responsible for reduced growth in large crops. The experiment sites extended from Ingham in the Far North of Queensland (18.6^{o} S) to Grafton in northern New South Wales (29.4^{o} S), and the Ord region of Western Australia (15.7^{o} S). Mean daily temperatures ranged from 27.1 ^{o}C in Kununurra in Western Australia, to 18.6 ^{o}C in Harwood, New South Wales. Annual rainfall (or for the duration of the experiments) ranged from 377 mm in Ayr, Queensland, to 1857 mm in Harwood, New South Wales, although irrigation was used to supplement rainfall where soil moisture was likely to be limiting. Crop duration ranged from 8 to 24 months and included both plant and ratoon crops grown between April 1991 and September 2000. Cultivars Q96, Q99, Q117, Q138 and TS65-28 were included in the analyses, and row spacing was between 1.44 and 1.5 m. In order to control soil borne diseases, many of the soils in the experiments received a fumigation treatment.

Thirty-four treatments were selected from the experiments with the assumption that resources were non-limiting (i.e. crops were receiving full irrigation and grown with a minimum N fertiliser application of 200 kg/ha per cropping season). Crops that were subject to a drying-off treatment were excluded from the analyses.

In many experiments the fraction of radiation intercepted (*Li*) was measured using tube solarimeters. In experiments where *Li* was not measured, it was estimated using leaf area index (*LAI*) an extinction coefficient, ($k = 0.4$) in Beer's law ($Li = 1 - e^{-kLAI}$).

Daily radiation intercepted was calculated as *Li* multiplied by daily incident solar radiation. This was then summed over the duration of the crop to produce cumulative radiation intercepted (MJ/m^2). Net above-ground biomass was determined from 15m^2 quadrats as the sum of trash (defined as dead leaves and sheaths still attached to the cane stalks), millable stalks, cabbage (defined as the immature top of the stalk plus green leaf sheaths), and green leaf blades. The relationship between net above-ground biomass (g/m^2) and cumulative radiation intercepted was plotted for all treatments and the maximum radiation-use efficiency (RUE) was calculated by firstly fitting a linear regression to all the data points. The last data point (*i.e.* the latest date) was then removed from the data set and a linear regression was again fitted to the dataset. This procedure continued until no further improvement could be gained in the proportion of variance accounted for by the model (Robertson et al., 1996). The onset of the reduced growth phenomenon (RGP) was determined as the sample date at which no further improvement in the proportion of variance accounted for could be gained.

5. RESULTS AND DISCUSSION

5.1 Workshop

A full report on the workshop in the form of a draft technical report is attached as Appendix 2.

Three top international scientists were identified to provide leading papers and to help direct discussion at the workshop. A total of 23 papers were presented and most were of a very high standard. After negotiations with a reputable international journal (Field Crops Research = FCR) the workshop committee was invited to form an editorial panel to review all papers in preparation for a special issue dealing with the workshop proceedings. The committee has undertaken to deliver reviewed and revised papers ready for publication to FCR by October 2004.

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After the workshop key delegates worked on a research plan to increase sugar yield per ha through increased CCS and cane yield and through improved water management, capitalising on better understanding of the interactions between genetics and management. Specifically this research plan aims to:

- To better understand the interactions between sugarcane genetics (gene expression) and environment (including management) with respect to sugar accumulation (which is a current gap in knowledge of sugarcane physiology);
- To improve crossing, variety selection and cane management for increased CCS, yield and water use efficiency
- To establish the impact of management of selection trials on type of varieties released
- To establish the physiological basis of variety improvement to guide future crossing and selection
- To develop novel irrigation strategies for correcting traits for low CCS and lodging

To promote better management practice for maximising sugar yield and reducing water use.

This plan forms the basis of a proposal which was submitted to SRDC for funding in 2003/04 without success. A revised plan will be resubmitted in 2004/05. The research project will also provide an opportunity for scientists at various levels in the 'supply' chain (molecules to mill) to interact and to think about future prospects for the use of the sugarcane plant.

5.2 **Review of factors responsible for reduced growth in large crops**

The results of the research on factors responsible for reduced growth in large crops are described fully in the paper by Park et al. (Appendix 1).

In 50% of treatments, radiation use efficiency (RUE), defined as the amount of biomass accumulated per unit radiation intercepted, significantly declined between approximately 223 and 665 days after crop start. The high incidence of RGP observed in the analyses (a) challenges the previously held assumption that a constant value of RUE can be used to adequately describe biomass accumulation in sugarcane as a function of cumulative light interception, and (b) suggests that relatively low growth rates during the later phases of the cropping season are frequently experienced throughout the Australian sugar industry.

Mean maximum RUE in the plant crop (1.70 g/MJ) was greater than in ratoon crops (1.46 g/MJ). The values of 1.70 and 1.46 g/MJ, which include an estimate of unrecoverable senesced material are below the previously used values of 1.8 and 1.65 g/MJ for plant and ratoon crops respectively. As there was no effect of location, cultivar, crop duration, ratoon crop class or fumigation treatment on RUE for the periods either before or after the onset of reduced growth, it would appear that RUE is predominantly influenced by crop class. Despite the differences in RUE between the two crop classes, the difference in the number of RGP incidences was not significant different for plant and ratoon crops.

In order to gain a greater mechanistic understanding of the factors likely to be associated with the onset of the RGP, the relative time of lodging, specific leaf nitrogen (SLN), stalk number and seasonal temperature were all considered individually. Declining SLN and increasing stalk loss were associated with RGP, however other factors such as lodging, mean temperature and an increase in the number of chilling injury events cannot be discounted as contributing causal factors.

6. OUTPUTS

Key outputs from this project were:

1) A well organized and well attended international workshop on sugarcane physiology
2) A technical report on the workshop
3) A special issue containing about 16 papers on sugarcane physiology in a reputable international journal. This special issue will serve as an update on world knowledge of

sugarcane physiology.

4) Priorities for future research and a research plan and proposal to address these issues
5) Better linkages between molecular biologists, plant and crop physiologists and plant breeders in Australia and world wide.
6) A review of radiation use efficiency in sugarcane (Appendix 1)

7. EXPECTED OUTCOMES

The following outcomes are expected after implementation of the workshop's recommendations and research proposal.

- Higher yielding varieties with more CCS
- Increased efficiency of variety selection
- Increased water use efficiency through better variety/management combinations
- More erect crops and more efficient harvesting
- Higher CCS through better drying off guidelines
- Improved ways of doing research through wide disciplinary interaction

8. FURTHER RESEARCH NEEDS

These are described fully in the research proposal in Appendix 3 and are summarised here.

Sucrose (or CCS) accumulation, water use efficiency and the physiology of variety improvement were identified as the most critical knowledge gaps for improved yield and resource use at the international cane physiology workshop in September 03.

Breeders have increased cane yield of commercial varieties over the past five decades but less so CCS (Jackson, 2004). While pathways of CCS accumulation are being investigated at the molecular and cellular levels, there is no concurrent work at the crop level. To what extent will genetic improvements be modified by management and the environment? Conversely, to what extent does management and environment influence the selection process? How come released varieties lodge so readily when lodging is a severe constraint to yield (Singh et al, 2000)?

It is critical to know which aspects of crop physiology (including CCS and lodging) can be manipulated through a combination of management and genetic changes to increase sugar content and cane yields.

9. RECOMMENDATIONS

It is recommended that the research proposal along the lines of that provided in Appendix 3 be implemented. This proposal is the culmination of extensive reviewing and reporting of current knowledge of sugarcane physiology by the world's best sugarcane physiologists. Critical knowledge gaps have been identified and now need to be filled.

We also recommend revision of radiation use efficiency coefficients in the APSIM model based on the review of Park et al (Appendix 1). This will need to be done carefully using the past validation dataset to verify the revision and new datasets to validate the changes.

10. LIST OF PUBLICATIONS

Papers received to date that are either ready for publication[a], require minor or moderate revision[b] or have been internally reviewed and are now being reviewed externally[c] are:

1) Integration of Sucrose Accumulation Processes across Hierarchical Scales: Towards Developing an Understanding of the Gene to Crop Continuum, Paul H. Moore[a]
2) The historical and future contribution of crop physiology and modelling research to sugarcane production systems, Shaun Lisson, Mike Robertson, Brian Keating and Geoff Inman-Bamber[c]
3) Modelling nitrogen dynamics in sugarcane systems: Recent advances and applications, Peter Thorburn, Elizabeth Meier and Merv Probert[c]
4) Water relations in sugarcane and response to water deficits. Geoff Inman-Bamber and Mark Smith[c]
5) Opportunities for improved radiation interception by sugarcane: theory and practice M.A. Smit, A. Singels, R.A. Donaldson & KA Redshaw[b]
6) Using industry information to identify key agronomic and economic problems in the Sugar Industry, Roger Lawes and Bob Lawn.[a]
7) Progress and prospects in genetic improvement in sucrose accumulation, Phillip Jackson[c]
8) An examination of sucrose metabolism and accumulation from the laboratory to the field. Peter Albertson and Grof[c]
9) Discovery of the important genes responsible for sucrose accumulation in maturing stem, Rosanne Casu, John Manners et al[a]
10) Increasing the utility of genomics in unravelling sucrose accumulation. Derek Watt, Deborah Carson, et al[a]
11) Defining the path of sucrose transport and compartmentation of sucrose accumulation in the stem and its control points, Rae, Bonnett, Casu, Grof[a]
12) Opportunities for improved biomass production and partitioning in sugarcane: theory and practice. A. Singels, R.A. Donaldson & M.A. Smit[a]
13) Shoot and stalk dynamics and the yield of sugarcane crops in tropical and subtropical Queensland, Australia. M.J. Bell and A.L. Garside[b]
14) Flowering and lodging, physiological-based traits affecting cane and sugar yield. What do we know of their control mechanisms and how do we manage them? Nils Berding and Alan P. Hurney[c]
15) Agronomic impact of sucker development in sugarcane under different environmental conditions. N. Berding, A.P. Hurney, B. Salter and G.D. Bonnett.
16) Environmental stimuli promoting sucker initiation in sugarcane, G.D. Bonnett, B. Salter, N. Berding, and A. P. Hurney[c]
17) Decline in radiation use efficiency with age in sugarcane under high input conditions. S. E. Park, G. Inman-Bamber and M. Robertson[c]
18) Growth and Function of the Sugarcane Root System. D.M. Smith, N.G. Inman-Bamber and P.J. Thorburn[c]

11. REFERENCES

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Leslie, J.K and Byth, D.E. (2000). An analysis of sugar production issues in the Ord River Irrigation Area. SRDC Technical Report No 01/2000, Robertson, M.J., Wood, A.W., Muchow, R.C., 1996. Growth of sugarcane under high input tropical conditions. I radiation use, biomass accumulation and partitioning. Field Crops Research, 48, 11-25.

Singh G, Chapman SC, Jackson PA and Lawn RA (2000). Lodging a major constraint to high yield and ccs in the wet and dry tropics. *Proceedings of the Australian Society of Sugar Cane Technologists*. **22,** 315-321

Appendix 1

Decline in radiation use efficiency with age in sugarcane under high input conditions

S. E. Park[1], G. Inman-Bamber[2] and M. Robertson[3]

[1]Tropical Landscapes - Production Systems, CSIRO Sustainable Ecosystems, Level 3, Queensland Bioscience Precinct, 306 Carmody Road, St Lucia, QLD 4067;
[2]Tropical Landscapes - Production Systems, CSIRO Sustainable Ecosystems, Davies Laboratory, University Road, Townsville, QLD 4814,
[3]Agricultural Landscapes, CSIRO Sustainable Ecosystems, Level 3, Queensland Bioscience Precinct, 306 Carmody Road, St Lucia, QLD 4067

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Appendix 2

Sugarcane Physiology 2003

Integrating from Cell to Crop to Advance Sugarcane Production
2 to 4 September, Brisbane

SRDC Technical Report – DRAFT MAY 2004

Executive summary

Compared to other crops, knowledge of growth mechanisms in sugarcane is inadequate. The question arises as to how much longer can we continue to prosper if knowledge of the growth processes on which our industry depends, remains outdated? Sucrose accumulation and efficient use of resources are primary concerns for this industry. To date we have only limited understanding of climate and management links to sucrose content or CCS and this undermines our ability to manage water, nutrients, varieties and the harvest schedule for maximum CCS and optimum cane yield. Cane and sucrose yields are often below potential for reasons about which we can only speculate (Leslie and Byth, 2000).

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Compared to other crops, knowledge of growth mechanisms in sugarcane is inadequate. One literature database displayed more than 4500 abstracts on wheat physiology compared to less than 500 on sugarcane physiology for the same period. The question arises as to how much longer can we continue to prosper if knowledge of the growth processes on which our industry depends remains outdated? Sucrose accumulation and efficient use of resources are primary concerns for this industry. To date we have only limited understanding of climate and management links to sucrose content or CCS and this undermines our ability to manage water, nutrients, varieties and the harvest schedule for maximum CCS and optimum cane yield. Cane and sucrose yields are often below potential for reasons about which we can only speculate (Leslie and Byth, 2000).

In the past, research funds have been directed at opportunities for raising limitations to yield and efficiency of resource use at the gene and enzyme level as well as at the crop and paddock level. There has been no attempt to integrate research or information across these disciplines or to assess where progress toward sustainable production is most likely to be achieved. For example biochemists are interested in genetic and physiological limits of sucrose storage in the cane stalk whereas crop physiologist are interested in the climate/plant interactions responsible for sucrose accumulation. SRDC recognized that it was now time for each discipline interested in the same processes to get together to find out how their different approaches could be complementary. Sucrose accumulation in nature depends on processes at a molecular scale as well at the paddock scale. Research funding in recent years has required integration across the value chain of the sugar industry. The same argument applies to integration across disciplines concerned with sucrose metabolism and sucrose yield.

A three-day workshop was arranged in order to bring together the most significant sugarcane physiologists world wide in Australia in order to update our knowledge at several levels of plant organization and to investigate way of integrating this knowledge. Recent literature was scanned to ensure that we had included all the major players world wide. Understandably not everyone could come but we do not think that the anyone was missing who could have significantly influenced the outcome of the workshop.

The workshop was planned over a period of two years with the help of a committee drawn from CSIRO Plant Industry and Sustainable Ecosystems. Four top international scientists were identified to provide leading papers and to help direct discussion at the workshop. Of the four that were invited one could not attend (Prof Frikkie Botha). The others, Dr Paul Moore, Dr Richard Richards and Dr Brian Keating provided valuable input to the workshop in the form of papers and discussion. In addition to their three invited papers, 20 papers were presented and most were of a very high standard. After negotiations with a reputable international journal (Field Crops Research = FCR) the workshop committee was invited to form an editorial panel to review all papers in preparation for a special issue dealing with the workshop proceedings. The committee has undertaken to deliver reviewed and revised papers to FCR by mid 2004 ready for publication.

We asked a leading scientist (Dr Brian Keating), a leading R&D funding person (Dr Russell Muchow) and a leading grower (Mr Andrew Barfield) to address delegates at the outset of the 3-day workshop. These speakers set the challenges ahead for the workshop. One of the main challenges was to integrate all levels of physiology and to make our work as physiologists relevant to the objectives of raising yields and reducing resource use in the sugar industry.

Leslie J.K and Byth D.E. An analysis of sugar production issues in the Ord River Irrigation Area. SRDC Technical Report No 01/2000,

Welcome and aims of workshop – Geoff Inman-Bamber

I would guess that in this room we have a large proportion of the worlds knowledge on the physiology of sugarcane either directly through your own work or indirectly through your knowledge of the work of others.

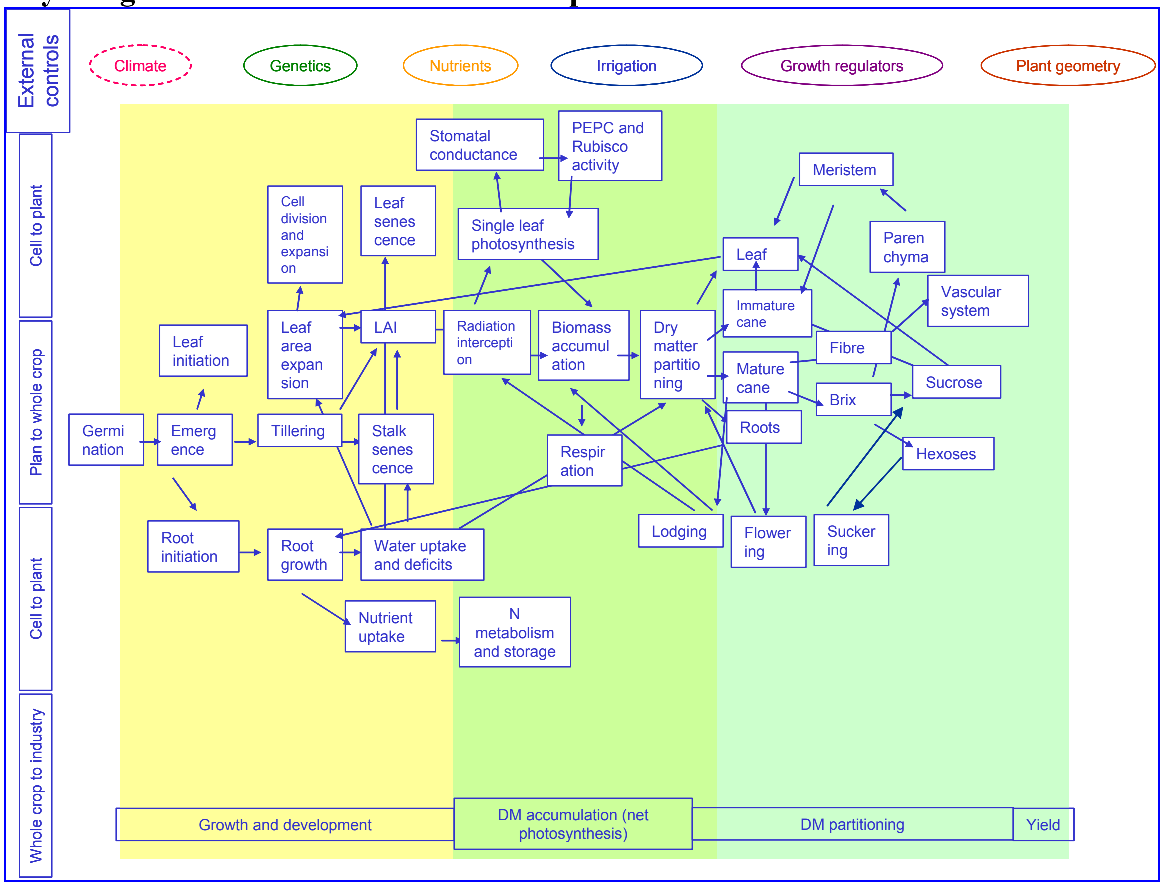
We welcome also our overseas guests from the USA, Colombia, Mauritius and South Africa. Welcome also to all the Aussies some who have also traveled a long way. Many of you have put in a large number of hours into preparing papers and presentations. I am sure that you efforts will be rewarded this week.

This is a unique opportunity to focus on what makes the sugarcane plant tick and how we can manipulate these working to benefit all those whose livelihoods depend on it including our own. Thanks to SRDC for the funds to make this meeting possible at a time when long term solutions are not popular, at least not in Australia where quick fixes are required to help an industry under many threats, not least the competition from Brazil.

In this workshop we have several aims:

1) Audit or summarize what is known about sugarcane physiology
2) Establish new links
    a. Across levels of organisation (hence the subtitle of the workshop, integrating from the cell to the crop)
    b. Across processes, from N and C assimilation to water relations and DM partitioning
    c. Across research groups with in our respective countries
    d. Across nations represented here
3) Identify where sugarcane physiology has been relevant in various growing regions, as a lesson to ourselves and funding bodies on the impact of this discipline
4) Identify the critical gaps in our understanding sugarcane physiology that if addressed by research can lead to advances in the economic and environmental sustainability of sugarcane production

Physiological framework for the workshop



The above framework was used to derive a program for the workshop based on four themes, integration, growth and development, assimilation and partitioning. The framework represents sugarcane physiology mainly at the cell to whole crop levels. It captures most of the components of these levels that were discussed at the workshop but does not include the molecular level or the crop to mill level which were discussed in some detail at the workshop.

Workshop program

Time	No	Paper/Event	Author/Chair
		Monday 1st September	
6:30		Pre-dinner drinks	
7:00		Dinner; Informal challenges to the workshop by a prominent grower, a scientist and a funding provide	Russell Muchow, Brian Keating, Andrew Barfield
		Tuesday 2nd September	
8:30		Welcome and aims of workshop	Geoff Inman-Bamber
		Explanation of process	Bill Andrew
		Integration across molecular to crop levels	**Chair: Graham Bonnett**
	1	Integration of Sucrose Accumulation Processes across Hierarchical Scales: Towards Developing an Understanding of the Gene to Crop Continuum – Keynote paper.	Paul H. Moore,
10:00		*Tea*	
	2	The historical and future contribution of crop physiology and modelling research to sugarcane production systems	Shaun Lisson, Mike Robertson, Brian Keating and Geoff Inman-Bamber
	3	A perspective from other crops on how research in genetics and plant physiology has brought about practical benefits to industry	Richard Richards
12:20		*Lunch*	
1:05		Breakout session 1, Integration across molecular to crop levels	Bill Andrew
		Development	**Chair: Geoff Inman-Bamber**
	4	Shoot and stalk dynamics, dry matter partitioning and the yield of sugarcane crops in tropical and subtropical Queensland, Australia	Allan Garside and Mike Bell
	5	Physiology of shoot architecture.	Christine Beveridge, Prakash Lakshmanan
	6	Flowering, lodging, and suckering, physiological-based traits affecting cane and sugar yield. What do we know of their control mechanisms and how do we manage them?	Nils Berding and Graham Bonnett
3:20		*Tea*	
	7	Root initiation, growth and distribution and water uptake, in relation soil water deficits and soil environment.	Mark Smith and Geoff Inman-Bamber
		Breakout session 2, Development	Bill Andrew
		Plenary, integration of key issues of the day	Committee, Mike Robertson
5:25		Close of day	

Wednesday 3rd September			
Time	**No**	**Paper/Event**	**Author/Chair**
		N,K and water uptake and stress	**Chair: Mark Smith**
8:00	8	Nitrogen metabolism and biochemistry in sugarcane.	Ian Biggs
	9	Potassium: A pivotal role in sugar production in Australia	Bernard Schroeder
	10	Modelling nitrogen dynamics in sugarcane systems: Recent advances and applications	Peter J Thorburn, Elizabeth Meier and Merv Probert
	11	Water relations in sugarcane and response to water deficits.	Geoff Inman-Bamber and Mark Smith
10:00		*Tea*	
		Breakout 3, N and water uptake and stress	Bill Andrew
		Radiation interception and Radiation use efficiency	**Chair: Peter Thorburn**
	12	Effect of time of harvest/ratooning on growth and partitioning	Lisa McDonald
	13	Biomass accumulation and dry matter partitioning in different ideo type cultivars of sugarcane.	Graham Kingston
	14	Examination of the reduced growth phenomenon in sugarcane	Sarah Park and Geoff Inman-Bamber
	15	Opportunities for improved radiation interception by sugarcane: theory and practice	Abram Singels, Michiel Smit, Rob Donaldson & Kerry Redshaw
1:05		*Lunch*	
		Breakout session 4 Radiation interception and Radiation use efficiency	Bill Andrew
		Physiology, breeding and selection	**Chair: Nils Berding**
	16	Using industry information to identify key agronomic and economic problems in the Sugar Industry	Roger Lawes
	17	Regional and genetic variation in CCS	Scott Chapman
3:35		*Tea*	
	18	Progress and prospects in genetic improvement in sucrose accumulation	Phillip Jackson
		Breakout session 5. Physiology, breeding and selection	Bill Andrew
		Plenary, integration of key issues of the day	Committee, Mike Robertson
5:40		Close of day	

Thursday 4th September			
Time	**No**	**Paper/Event**	**Author/Chair**
		Sucrose accumulation and genetics	**Chair: Paul Moore**
8:30	19	An examination of sucrose metabolism and accumulation from the laboratory to the field.	Peter Albertson
	20	Discovery of the important genes responsible for sucrose accumulation in maturing stem	Rosanne Casu and John Manners
	21	Increasing the utility of genomics in unravelling sucrose accumulation.	Derek Watt, Deborah Carson, Mike Cramer, Alistair McCormick, Barbara Huckett and Frikkie Botha
10:00		*Tea*	
		Breakout session 6. Sucrose accumulation and genetics	Bill Andrew
		Partitioning of photo-assimilate	**Chair: Graham Bonnett**
	22	Defining the path of sucrose transport and compartmentation of sucrose accumulation in the stem and its control points	Anne Rae and Chris Grof
	23	Opportunities for improved biomass production and partitioning in sugarcane: theory and practice	Abram Singels, Rob Donaldson & Michiel Smit
		Breakout session 7. Partitioning	Bill Andrew
12:50		*Lunch*	
		Plenary, integration of key issues of the day	Committee, Mike Robertson
		Workshop synopsis	**Brian Keating, Paul Moore and Richard Richards**
3:30		Close of workshop	

Delegates

Organisation	Des.	First name	Last Name	Organisation	Des.	First name	Last Name
BSES	Dr	Nils	Berding	Facilitator	Mr	Bill	Andrews
BSES	Dr	Alan	Garside	CSIRO-PI	Dr	Graham	Bonnett
BSES	Dr	Prakash	Lakshmanan	CSIRO-CSE	Dr	Geoff	Inman-Bamber
BSES	Dr	Bernard	Schroeder	CSIRO-CSE	Dr	Shaun	Lisson
CSE	Mr	Ian	Biggs	USDA Hawaii	Dr	Paul	Moore
CSE	Dr	Roger	Lawes	CSIRO-CSE	Mr	Razak	Nayamuth
CSR	Dr	Lisa	McDonald	CSIRO-CSE	Dr	Sarah	Park
CSR	Mr	Terry	Morgan	CSIRO-PI	Dr	Richard	Richards
DPI	Dr	Mike	Bell	CSIRO-CSE	Dr	Mark	Smith
Cenicana Colombia	Dr	Alvaro	Amaya	CSIRO-CSE	Dr	Peter	Thorburn
SASEX, S Africa	Dr	Abram	Singels	CSIRO-CSE	Dr	Brian	Keating
SASEX, S Africa	Dr	Michiel	Smit	BSES	Dr	Graham	Kingston
SASEX, S Africa	Dr	Derek	Watt	SRDC	Dr	Russell	Muchow
CSIRO-PI	Dr	Peter	Albertson	CSIRO-PI	Dr	John	Manners
CSIRO-PI	Dr	Rosanne	Casu	BSES	Dr	Mathew	Purnell
CSIRO-PI	Dr	Scott	Chapman	UQ	Dr	Christine	Beveridge
CSIRO-PI	Dr	Phil	Jackson	UQ	Dr	Christa	Critchley
CSIRO-PI	Dr	Anne	Rae	UQ	Dr	Susanne	Schmidt
SRDC	Mr	Andrew	Barfield	CSIRO-CSE	Dr	Mike	Robertson
SRDC	Dr	Robert	Troedson				

Workshop technical report

A more detailed report will be available in the form of the special issue in Field Crops Research to be published after July 2004. However this issue will not contain all the papers presented at the workshop. Abstracts of all presentations are provided in this report which follows the outline of the workshop program. Notes taken during breakout sessions are reported under the relevant sections.

A. Integration across molecular to crop levels

1. Integration of Sucrose Accumulation Processes across Hierarchical Scales: Towards Developing an Understanding of the Gene-to-Crop Continuum, Paul H. Moore, Plant Physiologist, USDA, ARS, Pacific Basin Agricultural Research Center, Aiea, Hawaii, USA

Abstract
Although we have a working knowledge of the general biology of sugarcane and are fairly efficient in crop production, we are only beginning to produce the detailed biochemical and genetic information that will be needed to develop technologies necessary for long-term success of the sugarcane industry. An understanding of the biological constraints on sucrose accumulation will arise neither from purely intuitive assaults nor from traditional physiology experiments that try to explain observable phenomena by reducing them to interplay of elementary units that are then investigated independently of each other. A true understanding of sucrose accumulation will be achieved only through a combination of experimental and computational analyses of comprehensive datasets to gain information on the underlying molecules and processes. Currently, systems-level approaches towards understanding biology are gaining momentum primarily because of the rapid progress that is being made in molecular biology, particularly in genome sequencing, proteomics, and high-throughput measurements. Large-scale sequencing projects have not only provided complete sequence information for a number of genomes, but they are also facilitating the development of integrated pathway-genome databases that provide organism-specific connectivity maps of metabolic and, to a lesser extent, other cellular networks. To date, the processes that generate mass, energy, information transfer, and cell-fate specification have been analyzed only at the cell or microorganism levels, where they are shown to be seamlessly integrated through a complex network of cellular constituents and reactions. Despite the key role of these networks in sustaining cellular functions, their large-scale structure is essentially unknown. Fifty years of sugarcane research have identified and characterized a suite of physiological processes and enzymes involved in sucrose accumulation. More recently, genes encoding these enzymes have been isolated, cloned, and used in experiments to transform sugarcane to increase or decrease expression of the enzyme with the goal of altering sucrose accumulation. However, results of this reductionist approach towards understanding sucrose accumulation have fallen short of expectations, apparently because of the complex interactions among the multitude of simultaneous processes. Recent rapid expansion of sugarcane molecular datasets and the beginning of a systems approach to metabolic modeling of sucrose accumulation point the way for future research efforts to integrate processes from gene to crop performance.

2. The historical and future contribution of crop physiology and modelling research to sugarcane production systems, S.N. Lisson, N.G. Inman-Bamber, M.J. Robertson and B.A. Keating. CSIRO Sustainable ecosystems, Brisbane and Townsville

Abstract
International sugarcane farming practice has been significantly influenced by crop physiology research, both directly, and indirectly via process based, simulation growth

models. These models not only operationalise our basic physiology understanding but also serve to identify knowledge gaps and priority research areas. This paper explores the integration between basic field research, model development and application and on-ground impact. It explores the historical mutual dependency between basic sugarcane physiology research and model development through a description of the key sugarcane models and the seminal published field and controlled environment studies on which they are based. Examples are given of applications of this understanding and modelling capability that have led to significant impacts on sugarcane farming system design, practice and policy. Finally, the paper identifies current gaps in our understanding of sugarcane physiology and the potential applications and impacts to be gained from an improved understanding in these areas.

3. Understanding the physiology of winter cereals – scope for genetic improvement, Richard Richards, CSIRO Plant Industry, Canberra

Abstract
Before looking at the physiological traits required for wheat or any other crop we need to look at the environment. Then we need to consider other limitations such as disease. Then we need to develop a framework for crop improvement such as:

Biological Yield = Incident Radiation x Radiation Intercepted x Radiation Use Efficiency

Grain Yield = Water Use x Water-use Efficiency x Harvest Index

Yield in winter cereals is limited largely by water. Transpiration efficiency (g biomass per mm water transpired), varies through the year depending on vapour pressure deficit. In southern Australia 50% of potential biomass is often lost due to evaporation from the soil surface. Priorities for winter cereal improvement in a water-limited environment are to make use of the full growing season, reduce evaporation of precious rainfall from soil surface, increase water use efficiency and increase C allocation to grain. Spring wheats selected for dry conditions feature, Australian hard quality, high yield, high water use efficiency, triple rust resistance and broad spectrum disease resistance. High WUE was developed using a new isotope selection technique which makes use of the phenomenon of ^{13}C discrimination during photosynthesis. Yields have been improved substantially by improvement in these traits. Spin-offs from physiological understanding of wheat have been an appropriate breeding program and new varieties for growers, molecular markers for use in breeding and molecular and genetic understanding of traits.

Breakout session 1. Discussion of 'Integration across molecular to crop levels'

Areas of agreement

- A yield framework is necessary to identify key areas that need to be targeted.
- Commonality exists between crops and this allows us to learn from studies in different crops and their application to sugarcane.
- All speakers highlighted a need for further physiological knowledge in specific areas.
- The value of models is not purely as decision support tools for growers, but as a research tool also.

- In wheat there is a good linkage of improved physiology knowledge to increased yield but this is yet to be shown in sugarcane.
- We need to integrate. We already have a large knowledge-base that we could use, but we need to think of ways of bridging levels of information from the farmer to the scientist and vice-versa (e.g. simplified models could help transfer knowledge as farm management tools).
- Adoption is low in the sugar industry compared to other industries.
- Each level needs to be informed by neighbouring levels – this will lead to integration across entire scale.
- The system is enormously complex! Crop models may not be comprehensive enough, but they are useful research tools. When the data don't fit the model it shows where the gaps in our understanding are.
- Richards's talk was a good example of using physiology and developmental genes to improve yield.
- Complexity can be simplified by a suitable framework.
- Diversity of traits – what traits have been selected inadvertently currently and historically.
- There is scope for more physiological targeted breeding – why isn't there more of it?

Areas of disagreement

- Doubt about use of models at the farm level despite increased level of computerisation in industry.
- Concern about the impact of selection against suckering and its impact on ratoonability.

Knowledge gaps

- There was general agreement with list of gaps presented by Shaun Lisson.
    - Improved understanding of the aging process
    - Sucrose accumulation
    - Physiology of water retention
    - Water stress physiology
    - Understanding the reasons for crop class RUE differences
- Richard's frame work can be used to prioritise the "wish list".
- Soil health is an issue. How do we model this.
- Knowledge in industry differences between attainable and actual yield.
- How realistic is the theoretical yield produced by APSIM?
- Is there a case for a trait based breeding program?
- How to produce ideotype of perfect variety? (Must contain reduced lodging, low flowering % in the tropics, reduced rate of tillering, erectness).
- Can we link gene expression (or models) to breeder selection traits.
- Models could be improved by a greater contribution from other researchers – a broader information base to feed in (e.g. –omics' information).
- Morphological traits are very useful, but basic physiological, biochemical and morphological traits are not well understood in sugarcane.
- Physiology of lodging important.
- Root systems not well understood, particularly C partitioning, interactions between cultivars, soil conditions and climate
- Physiology of shoot architecture – it is important to understand stress mechanism impacts on bud growth, what is the cost of excessive tillers.
- How to weight selection index for flowering and lodging?

What is the contribution of physiology research to the sugar industry

- Lodging / suckering / flowering – trait identification/quantification
- Photoperiod for controlled flowering
- Ripeners
- Competition effects – structure of breeding plots.

B. Growth and Development

4. Shoot and stalk dynamics, dry matter partitioning and the yield of sugarcane crops in tropical and subtropical Queensland, Australia, M.J. Bell and A.L. Garside, *Sugarcane Yield Decline Joint Venture, [a]Agency for Food and Fibre Sciences (Farming Systems), Queensland Department of Primary Industries, Kingaroy, Qld 4610, Australia [b]Bureau of Sugar Experiment Stations, Davies Laboratory, Aitkenvale, Qld 4814, Australia.*

Abstract

The yield plateau experienced by the Australian sugar industry for most of the period from the early 1970's suggests that yield constraints have become an important feature of sugarcane farming systems in Australia. The Sugarcane Yield Decline Joint Venture (SYDJV) has shown that significant yield increases can be obtained by manipulating components of the farming system (e.g. crop rotation, controlled traffic and reduced tillage). However, in order to identify key crop targets for any new farming system an improved understanding of the physiological mechanisms mediating these yield responses is required. Data collected from SYDJV experiments investigating the impact of crop rotation, plant population, tillage and trash management have been analyzed to determine the impact of treatments on shoot and stalk dynamics and crop yield.

Crop rotation or soil fumigation cause a reduction in detrimental soil biota that results in significantly improved crop establishment, with production of greater numbers of both primary and higher order shoots. Manipulation of soil N status with N fertiliser was also shown to have a positive impact on initiation of secondary tillers, but effects were small for the limited range of N levels investigated. Survival of tillers until final harvest was strongly influenced by the density of established primary shoots and the growing conditions during the latter part of the growing season. Avoidance of water stress and provision of N fertiliser were shown to increase tiller survival, but establishment of a high density of primary shoots was seen as the most effective method of maximising crop yield – especially under suboptimal conditions.

Experimental treatments had limited impact on partitioning of dry matter to stalks, but large differences were observed between crop varieties and environments. The relative importance of final stalk numbers and individual stalk dry weights to variation in yield in each experiment varied widely. Experiments using the variety Q117 in northern regions (Mackay, Burdekin and Tully) achieved relatively low final stalk densities (4-8 stalks m^{-2}) and yield variation was primarily due to the impact of treatments on this parameter. Experiments at Bundaberg used a number of varieties (Q124, Q141, Q188), and all achieved higher stalk densities (9-12 stalks m^{-2}) with yield variation primarily affected by individual stalk weight.

Plant population trials at Bundaberg and Mackay extended the range of plant densities studied and allowed the yield components from the agronomic studies to be put in a wider perspective. Negative relationships between individual stalk weight and stalk density were observed in these experiments, and also in an experiment where stalk density was manipulated by

thinning. These data show that treatments that increase stalk density without also increasing rates of dry matter accumulation during stalk filling are unlikely to result in yield improvements. Improvements in soil health afforded by crop rotation and soil fumigation achieve yield benefits by achieving both these prerequisites.

5. Molecular Physiology of Bud Outgrowth and Shoot Architecture in Higher Plants,

Christine Beveridge, Prakash Lakshmanan and Chuong Ngo

Abstract

Shoot architecture is an important agronomic trait and is major determinant of crop yield. It plays a significant role in resource acquisition and utilization and in competition and environmental adaptation. Shoot architecture is also an important factor impacting management practices for many crops. Axillary bud formation and its further development (branching) are the key factors controlling shoot architecture. Axillary bud formation and outgrowth are determined by genetic make-up, the environment, endogenous factors and the growth phase of the whole plant and the bud. In sugarcane bud outgrowth is important for germination, tillering, suckering, rationing and shoot architecture. The old concept was that auxin inhibits bud outgrowth and cytokinin promotes it and that auxin may act indirectly through cytokinin. This concept was supported by a classical experiment with garden pea in which decapitation of the apical bud promoted bud outgrowth due to removal of the apically supplied auxin. Exogenous auxin can inhibit bud outgrowth and auxin level drops after decapitation. Where the early experiments proof of a role for auxin or just a correlation? What happens if we do the same experiment with a bigger plant? On bigger plants, visible bud outgrowth occurs before the depletion of endogenous auxin level in the stem. In this case a basipetal signal that moves faster than auxin must be required to stimulate bud outgrowth. We propose a new hypothesis: Auxin acts to inhibit growth of buds that have already entered the first stage of bud outgrowth (transition stage). Meristem initiation is required for the formation of an axillary bud. The bud enters a transition stage where it may cycle between transition states or reach sustained dormancy or growth. In order to achieve sustained growth, a dormant bud is induced to pass through the transition stage and if not subsequently inhibited will pass to a sustained growth stage. Genetics can help us test whether auxin and/or cytokinin are involved. Several ramosus (*rms*) mutants have been identified in pea. These mutants can branch at nearly every vegetative node along the stem. Mutant *rms* shoots are not deficient in auxin and do not have elevated cytokinin levels compared with wild types. Grafting studies show that two RMS genes act mostly in the shoot. Three RMS genes, RMS1, RMS2, and RMS5 control the level of two novel hormone-like signals. Photoperiod has a substantial effect on the outgrowth position of lateral branches along the stem. Low nutrient decreases tendency to branch, whereas high levels promote it. Crowding can decrease branching. For example cotton plants in the field show little branching, whereas a single cotton plant can show extensive branching. Photoperiod affects branching. In pea this is shown best at basal nodes. Many other plants show affects at basal and aerial nodes. RMS mutants in pea show response to photoperiod at basal and aerial nodes. Therefore the branching and flowering/photoperiod systems are "interwoven". Mutants have been identified with branching at basal nodes only (RMS6 and RMS7) and with decreased branching where axillary meristem initiation is prevented (suppressed axillary meristems; sax).

In summary, novel hormone-like signals act with classical hormones (auxin and cytokinin), genetic regulation of shoot architecture occurs via genes that either inhibit bud outgrowth (e.g., RMS), promote bud outgrowth or inhibit axillary meristem initiation (e.g., SAX). The regulation of bud outgrowth at different nodes is not equivalent. Genes can modify outgrowth at particular nodes or developmental stages.

6a. Agronomic impact of sucker development in sugarcane under different environmental conditions, N. Berdinga, A.P. Hurneyb, B. Saltercde and G.D. Bonnettcef.

Abstract
Sugarcane has a variable propensity to produce suckers, or late-formed tillers in mature crops. These suckers are low in sugar content but harvested with the mature stalks. This results in a dilution of the sucrose content of the mature stalks. Differences in the propensity to form suckers have been observed in crops and cultivars within the same experiment. The environmental factors promoting sucker initiation, or suckering, have however, not been elucidated. A field experiment was run in plant and first ratoon crops to investigate the factors of post-monsoonal irrigation, nitrogen, and within-row stool spacing to test the roles of moisture, nitrogen and light in suckering. The experiment tested these main effects and their interactions. Their effect on mature stalks traits was small but significant. Their effect on suckering was, by comparison, much larger. Nitrogen and moisture promoted suckering and their effects were additive. Plant density, although generating measurable differences in the light levels penetrating the canopy did not give consistent effects on suckering. The effects of suckers on reducing commercial cane sugar (CCS) was greater than previously reported, 10% of suckers by weight in the harvested material reducing CCS by 1.6 and 1.3 units in the plant and ratoon crops, respectively. Use of excessive nitrogen, in combination with post-monsoonal rain in autumn and winter, will increase suckering and reduce profitability.

6b. Environmental stimuli promoting sucker initiation in sugarcane, G.D. Bonnett[ab], B. Salter[ac], N. Berding[d], and A. P. Hurney[e]

Abstract
The presence of suckers, late-formed tillers, in mature sugarcane crops reduces the sugar concentration of harvested material to the detriment of profitability. The amount of suckering varies with cultivar and season. However, the environmental stimuli promoting suckering, i.e. number of sucker culms, are not understood. This paper describes the effects on suckering of increasing soil moisture, nitrogen, and the level of light penetrating the canopy, which was manipulated by plant spacing or removal of dead leaf from mature stalks. Increased nitrogen availability late in the crop's growth cycle promoted suckering, even in a cultivar of low suckering propensity. Higher levels of nitrogen applied at the beginning of the growing season had inconsistent effects, probably due to variation in rainfall. Increased soil moisture late in the growing season greatly increased suckering and also had a positive effect when combined with nitrogen. The effect of plant spacing on sucker number was only significant in the plant crop, and then only when expressed as sucker number per mature stalk. Removal of dead leaves had a significant effect on suckering at one site but not another. In all cases higher spacing and dead leaf removal increased light levels recorded under the canopy. The quality and quantity of light required to promote suckering still remain unknown, as does the means by which the plant perceives the light stimuli. The differences in suckering between the plant and ratoon crops suggested that not all stimuli were included in the treatments applied. All cultivars responded similarly to any significant environmental stimuli.

7. Growth and Function of the Sugarcane Root System, D.M. Smith, N.G. Inman-Bamber and P.J. Thorburn

Abstract
A literature review was undertaken in an attempt to bring a physiological perspective to bear on the question, 'How does root system growth and function influence productivity?' Sugarcane root systems are commonly depicted as comprising highly-branched superficial roots, downward-oriented buttress roots and deeply-penetrating agglomerations of vertical roots known as rope roots. It is unclear how common rope systems are in modern sugarcane varieties. Data on biomass and length distributions for sugarcane roots show the expected exponential decline with depth, with maximum values for root length density as high as 5 cm cm-3. While observations from the 1930s suggested maximum root depth could exceed 6 m, most published data on rooting depth is biased by the maximum depth of sampling, which tends to have been <2 m. There is evidence of root activity below 2 m, from use of 32P as a tracer and observed changes in soil water content. Root:shoot ratios have been found to reach a peak of ~0.5 within ~75 d of planting, but to decline thereafter to a value of 0.25 or less. There is little information available on root turnover in sugarcane, but there is experimental evidence that although die-back of the root system occurs at harvest, the root system is not completely replaced when ratooning occurs. The below-ground C budget for sugarcane is very poorly understood and, consequently, C allocation and the 'energy cost' of the sugarcane root system is unknown.

Hydraulic properties for root systems have been determined with considerable variation in conductivities found among the few varieties for which measurements have been made. Stomatal and root hydraulic conductances are correlated in sugarcane, for both pot and field-grown crops, resulting in homeostatic regulation of leaf water potential. Available evidence indicates that stomatal response to root water status is achieved by transmission of a chemical signal in xylem sap. Such mechanistic control of stomatal opening by root water status also suggests co-ordination of assimilation by root water status. However, integrated analysis of plant water relations, gas exchange and water use efficiency has not been undertaken for sugarcane. Thus, despite substantial published information on sugarcane root systems, a full description of the effect of root growth and function on sugarcane productivity is not yet possible. Such an understanding will await analysis of root system effects on integrated water, C and nutrient uptake physiology, including an assessment of the costs and benefits of C investment by the plant in the root system.

Breakout session 2. Discussion on 'Development'

Areas of agreement

- There is little knowledge of the root system because it is difficult to study especially in field.
- We are not sure how important root characters are. Intuition says they are important. They are particularly likely to be important if water limiting and in N uptake distribution.
- Partitioning of photosynthate to the root is another area that we need to know.
- It would be helpful to understand the physiology of lodging
- Plant breeders should be encouraged to get sugar up without lodging.
- Lodging is probably dependent on climatic conditions rather than on crop class.
- There is a preference for not having flowering (depending on temperatures etc), but flowering is needed for breeding purposes.

Knowledge gaps

- Is there an optimum number of stalks/m^2? And, how do we achieve this? We need to know combination of genotype, environment, quality, etc. that determine germination.
- What causes the final number of stalks?
- The crop relies on tillers to maintain stalk population. Could a way be found to rely more on viability of primary shoots.
- What are the cultivar differences in this regards (tillers / stalks).
- We have not selected for good root systems and we have super imposed heavy in-field traffic.
- Old verses newer varieties: studies are needed in relation to other traits (apart from yield and CCS).

General comments

- Systems biology - moving from molecular biology to physiological function does not require the full bore systems biology approach. We can identify traits with high heritability using gene expression and markers and then link gene presence with trait without knowing full gene function.
- Sugarcane could benefit from GTR exploration of physiological traits from other species.
- Breaking physiological yield barrier requites improving the capacity of plant to tolerate sub-optimal environmental conditions.
- Does early vigour and actually impacts on final yield or are benefits of early vigour for radiation capture lost by final harvest?
- Modelling needs to handle cultivar differences and then system elements not in models such as disease

Plenary, integration of key issues of the day
Graham Bonnett

- Models are good as a research tool, but I'm not sure if there is a future role in decision support. Is it that we need simpler models in decision support rather than no model?
- Are models limited by physiological understanding?
- Could models be improved by wider input?
- Is there a case for a trait-based breading system in Australia?
- Morphological, biochemical and molecular traits may be suitable as selection criteria rather than just yield and CCS.

- The knowledge gaps identified were soil health and how it can be modeled and historical understanding of how we have changed genotypes.

Geoff Inman-Bamber

- Framework was necessary for deciding on selection criteria and for modelling approach. Framework necessary for identifying key traits for selection.
- Lodging was a common them during the day. What happens in the selection process? Do lodging varieties come through breeding process because they are tall. Is the breeding process biased towards lodging.
- Once lodging is sorted out, what is the next ceiling to yield, i.e. is there a limit to sugarcane yield after lodging fixed?
- Tillers – to what extent are tillers wasteful. Can we control the wastage of tillers? Can we optimize tillering by hormonal or genetic control of buds?
- Roots – linked to soil health. Definition of soil health not yet been given – can we define soil health in terms modelling water and nutrient uptake? The effect of compaction on roots is not known but it is possible that root signals are involved. How much carbon goes below ground? Has selection for above-ground biomass and sucrose caused limited root development?

Brian Keating

- Have we got a sugarcane yield improvement framework? A lot of 90s research around radiation (Muchow etc), and partitioning (this = elements of a yield improvement prog). Where do things the likes of tillers and suckering fit into this possible framework. What are the main constraints/yield limitations? Which constraints are not being addressed?
- Are we on a model utility plateau? There has been a lot of modelling progress, is this sustainable in the next decade? Where will the systems modelling get to in the next 10 years? Are we at a physiological understanding ceiling – is this limiting modelling? Have we already harvested the lower hanging fruit? What about the other constraints to yield (i.e. soil biological issues are not modelled, but they definitely have an effect).

General discussion at the end of day 1

- Scott Chapman. It is interesting that proper studies have not been done in Australia to say where we are in terms the physiology in varieties and traits today. This is a key understanding that is needed. A trial is required using all past varieties to access the physiological components giving rise to improved yield and CCS. Whilst it might have been done in one or two regions, it needs to be industry-wide.
- Phil Jackson – this is basic knowledge, but doesn't have direct application. This possibly limits why this study has not been done.
- Russell Muchow. One problem of conducting such a study is that the Australian environment is degrading.
- Phil Jackson - We need to question today's breeding programs to see if they are masking environmental problems (compaction, soil degradation).

C. Nitrogen, potassium and water uptake and stress

8. Nitrogen metabolism and biochemistry in sugarcane, Ian Biggs

9. **Potassium: A critical physiological role in sugarcane production,** B.L.Schroeder and A.W. Wood

Abstract
Potassium is an essential nutrient for sugarcane production and adequate K nutrition is essential to ensure that the crop can withstand adverse conditions. However there are perceptions in the Australian sugar industry that the application of potassium is not always warranted because of large soil reserves and/or sources of K in irrigation water, and concerns that the addition of K will affect juice quality and the recovery of raw and refined sugar. What is not widely appreciated is the disparity between the amount of K applied and that removed by the crop. Recent modifications to the K recommendations for the Australian sugar industry ensure that reserves are maintained without affecting the cane juice quality. The ability of soil to supply K and the plant uptake characteristics also need to be taken into account. Data from field trials and pot experiments and leaf analysis trends indicate that the role of K is more complex than previously recognised. It also seems likely that the causes of high ash may be caused by factors other than K fertiliser uptake. It is important to ensure that potassium fertiliser use is optimised and takes into account the wide range of conditions in the Australian sugar industry. This will ensure that the crop can better withstand the periodic drought conditions that occur in the sugarcane growing regions.

10. Modelling nitrogen dynamics in sugarcane systems: Recent advances and applications, Peter J Thorburn, Elizabeth Meier and Mervyn E. Probert

Abstract
Substantial amounts of nitrogen (N) fertiliser are necessary for commercial sugarcane production because of the large biomass produced by sugarcane crops. Since this fertiliser is a substantial input cost and has environmental implications if N is lost to the environment, there are pressing needs to optimise the supply of N to the crops' requirements. The complexity of the N cycle and the strong influence of climate, through its moderation of N transformation processes in the soil and its impact on N uptake by crops, make simulation-based approaches to this N management problem attractive. In this paper we review the current capability for modelling soil and plant N dynamics in sugarcane systems, describing the considerable advances that have recently been made. We then illustrate insights gained into improved management of N through simulation based studies for the issues of crop residue management, irrigation management and greenhouse gas emissions. We conclude by identifying process not represented in the model, and ways in which these can be partially overcome in the short term.

11. Water relations in sugarcane and response to water deficits, N.G. Inman-Bamber and D.M. Smith

Abstract
Knowledge of water relations is fundamental to improved crop management in regions where irrigation is practiced or where dry conditions cannot be avoided. The objective of this review was to assess where knowledge of sugarcane water relations must be strengthened in order for progress to be made in irrigation management as well as genetic improvement and general management of climate and plant and soil resources. Although past research in sugarcane water relations has been piecemeal, at least some data is available for most aspects. Knowledge about evapotranspiration in sugarcane has advanced recently to allow estimates of daily water use to be obtained from hourly weather records. Evaporation from a wider range of surface conditions (mulched or lodged crops, different row configurations) needs to be determined. Physiological water stress thresholds for irrigation have been defined for a limited range of cultivars so that irrigation can be applied differentially for expansive growth and for sucrose accumulation. This work needs to be tested across a wider range of cultivars and conditions. Manipulation of dry matter partitioning through water stress clearly has large potential benefits. The mechanisms for enhanced partitioning to sucrose are documented but models need to be developed and tested to transfer this knowledge to practical irrigation management for increasing sucrose content. Responses to water stress in root and leaf conductances varied considerably between the few genotypes considered. Some genetic variation in ^{13}C discrimination was reported and this needs to be followed up. Osmoregulation on the other hand appears not to vary greatly amongst cultivars. Control of stomatal aperture by chemical signals from roots could apply to both ripening processes and to limited growth in compacted soils. This needs to be followed up.

Breakout session 3, Discussions on N,K and water uptake and stress

Agreement

- N, K, water are important industry issues.
- N and water need to be linked better in management
- Other nutrients worth considering (Si)
- Si also a soil conditioner.
- Sugarcane uses/needs surprisingly little N.
- Need to determine how best to reduce N-application to crops (how much and in what form do we really need to supply).
- Varietal evaluation of N Reductase is important for growth.
- Important gap is role of legumes.
- Useful application of modelling to evolve knowledge / hypothesis testing (Peters paper).
- We have 75% of the NUE story understood.
- K – role in drought tolerance? Compartmentation in plant.
- Need economic evaluation of alternative practices.
- Low NR in cane.
- Need better soil and plant tests for K.
- K – should not over-deplete problem with luxury consumption.
- Established plants cope extremely well with low water in terms of sugar accumulation.

Disagree

- Is it important to limit N consideration to cane production. (does approach help N management).

Knowledge gaps

- N nutrition – is enough reaching the leaves?

- Low N in leaves late seasons – what is the implications of this, what is our capability to model this, can we harvest younger crops to avoid declining growth rates?.
- We need confirmation of capacity to reduce irrigation without yield loss
- Clarify practical implications of reducing irrigation.
- K issues - understanding K dynamics, sustainability of K withdrawal, exploiting/understanding genetic differences, impact of soil health on K uptake.
- Reasons for declining growth rate in older crops could be due to low N.
- Implementation of water saving options through demonstration to growers.
- Understanding of genetic differences in NUE and WUE (and its components).
- Pathway of N released from cover crops (is information available in literature?).
- We need to ascertain the benefit (social and environmental) of reducing N-applications.
- We need to determine the role of water in plant establishment (this is very useful to tell us when to stop supplying water).
- Need to know what happens to the ratoon crop after drying the cane.
- We need to do more soil K tests in different regions.
- Optimal use of water for sucrose production is important.
- Maturation management needs more work (e.g. drying off, ripeners).
- Selection criteria for NUE (e.g. enzyme levels) needs consideration.
- K cycling in the farming system needs attention.
- ^{13}C as screening tool for increased transpiration efficiency
- Green leaf number for water management (including variety differences)
- Fine-tuning N recommendations.
- Implications of legumes in system for N recommendations.
- Match N application to crop use and soil factors – how to get growers to adopt lower N rates to match crop need. Need some incentive to help this (e.g. $, permits).
- We need information on linked N, K and water balances in irrigated areas both in spatial and temporal dimensions (whole catchment, whole season and whole ratoon cycle).

D. Radiation interception and radiation use efficiency

12. The effect of time of ratooning on sugarcane growth in northern Australia.
Lisa McDonald

Abstract
The industry is beginning to look at using its infrastructure more efficiently as a way of creating greater margins in a more competitive environment. Extending mill operating time is one option that would allow increased production while increasing the efficiency of the use of capital involved in harvesting and milling. To determine the effects of extending the length of the harvest season on sugarcane productivity, information is needed on the effects of harvesting and ratooning crops outside the current harvesting period. The aims of this research were: to determine the productivity of crops started and harvested outside the current harvest season in Australia (mid-June to late November), to determine whether crops started at different times show similar relationships between yield accumulation and climate as found in previous studies. Cane productivity was not reduced by ratooning crops before the start of the traditional harvest period; however, starting crops after October had reduced cane productivity. CCS, dry weight sucrose content and dry matter content were all lower for one year old crops ratooned before June than crops ratooned after June. The relationships between thermal time and stalk emergence, leaf emergence and leaf area index were similar for all times of ratooning. Crop start time and age had a significant influence on biomass yield of sugarcane. Timing of harvest influenced dry matter and sucrose content at harvest. Crop age and stem dry weight also influenced these attributes but to a lesser extent. This experiment has shown there is definitely potential to harvest high yielding cane crops prior to June, the main issue is improving the CCS of these crops to improve sugar yield and grower profitability.

13. Biomass accumulation and dry matter partitioning in different ideotype cultivars of sugarcane, Graham Kingston

Abstract
There is increased focus on opportunity for emergence of sugarcane "energy industry" based on sugar, ethanol, electricity. Will a change in focus change our perspective for cultivar features or ideotypes? What do we know about differences cane ideotypes in regard to accumulation of biomass and partitioning of yield into vegetative parts and partitioning into fibre and sugars? Currently there is limited capacity to model existing cultivar effects. Experiments were conducted at Bundaberg (24.80 S, 152.60 E) on a red ferrosol soil using commercial irrigation and fertilizer practices. Cultivar Q108 represented a high fibre, moderate sucrose type and Q111 a medium fibre and high sucrose type. The trial was conducted on a plant and two ratoon crops with two replications. Crops were planted or ratooned in March, June, September, December and harvested at 6, 9, 12 and 15 months of age (in these months). Plots of 7 rows x 10m (gross), 3 rows x 5 m (net) were harvested manually and separated into trash, leaf, top and stalk components which were then analysed for fibre, dry matter content, CCS (pol), sucrose, glucose, fructose, polymers (HPLC) and ash. Cultivar ideotypes with different fibre and sucrose content did not differ significantly in biomass production nor in the ratio of vegetative components. However they differed significantly in partitioning between fibre and C6 sugars. These partitioning effects were generally consistent between varieties across years. An extended crushing season for alcohol co-generation of electricity would be best based on harvesting of 12 & 15 month cane.

14. Decline in radiation use efficiency with age in sugarcane under high input conditions, S. E. Park, G. Inman-Bamber and M. Robertson

Abstract
In Australian sugarcane crops, growth in terms of radiation use efficiency (RUE) can slow down well before final crop harvest, despite conditions that are considered favourable for growth. In order to assess the extent and cause of this reduced growth phenomenon (RGP), 14 experiments conducted in Australia were examined. From these experiments, 34 treatments were selected with the knowledge that nutrients and water were non-limiting and that the yields obtained were limited only by temperature and radiation.

In 50% of treatments, radiation use efficiency (RUE), defined as the amount of biomass accumulated per unit radiation intercepted, significantly declined between approximately 223 and 665 days after crop start. The high incidence of RGP observed in the analyses (a) challenges the previously held assumption that a constant value of RUE can be used to adequately describe biomass accumulation in sugarcane as a function of cumulative light interception, and (b) suggests that relatively low growth rates during the later phases of the cropping season are frequently experienced throughout the Australian sugar industry.

Mean maximum RUE in the plant crop was found to be greater than in ratoon crops, although the values of 1.70 and 1.46 g/MJ which included an estimate unrecoverable senesced material, for plant and ratoon crops, respectively, are below the previously used values of 1.8 and 1.65 g/MJ. As there was no effect of location, cultivar, crop duration, ratoon crop class or fumigation treatment on RUE for the periods either before or after the onset of reduced growth, it would appear that the value of RUE is predominantly influenced by crop class. Despite the differences in RUE between the two crop classes, the difference in the number of RGP incidences was not significant different for plant and ratoon crops.
In order to gain a greater mechanistic understanding of the factors likely to be associated with the onset of the RGP, the relative time of lodging, specific leaf nitrogen (SLN), stalk number and seasonal temperature were all considered individually. Declining SLN and increasing stalk loss were associated with RGP, however other factors such as lodging, mean temperature and an increase in the number of chilling injury events cannot be discounted as contributing causal factors.

15. Opportunities for improved radiation interception by sugarcane A. Singels, M.A. Smit, KA Redshaw & R.A. Donaldson.

Abstract
The two main components of sucrose yield are the biomass and the sucrose fraction thereof and increasing one or both of these will increase yield. Biomass could be increased by maximizing radiation interception or the efficiency of its use in photosynthesis, or both. The aim of this paper is to investigate the interactions of crop start date, cultivar and crop class on canopy development and interception of radiation. A better understanding of these effects may point the way to more effective crop improvement and husbandry strategies that could enhance radiation interception.

The literature and models reviewed here suggests that there are areas where there is a lack of sufficient understanding of canopy development processes. Some of the information is contradictory, while some of the modelling concepts do not reflect the current status of knowledge adequately. Fractional interception (FI) of radiation, leaf and shoot development was measured on well-watered crops harvested at 12 months in June and December at Mount Edgecombe, South Africa.

Results show that that starting time had a significant impact on total radiation intercepted. Seasonal average FI for the June start was 80% of that of the December start. The cultivar impact on seasonal FI was less, the largest difference being 13% for the June start. Measurements of primary shoot leaf appearance support the concept of a gradually increasing phyllochron. Leaf appearance rates were similar for different crop classes and start times. Stalk profiles of leaf size were dependent on start time and shoot ranking order. The dynamic nature of leaf size profiles could be explained by source-sink concepts and the dependence of leaf area on temperature.

Shoot appearance rate was directly related to the density of buds in the ground. This explained the difference in shoot appearance rate between crop classes and row spacing. Peak shoot density occurred at a thermal time (base 16) of 600 ^{o}C.d.

Evidence presented here show that radiation interception of unstressed crops could be increased significantly by adjusting planting density to optimally match the cultivar and crop cycle, at least in theory. Increases of between 10 and 15% could be expected when cultivar and planting density is optimally matched with starting time. However, it is doubtful whether different row spacings for different cultivars and crop cycles are practically feasible for all cropping situations.

The main shortcomings of models are (1) the separation of leaf and shoot phenology from biomass dynamics and (2) inadequate representation of intra-stool shoot variation.

Breakout session 4. Discussion on Radiation interception and Radiation use efficiency

Agreement

- Modelling leaf area is difficult when leaf size varies more between stalk cohorts than between cultivars.
- There are clear benefits of extending the harvest season. Beneficiaries need to consider the current pricing systems and perhaps consider revising the pricing systems. What is the practicality of extending the harvest season in the north?

Disagreement

- Is the RUE sigmoid model an artefact of low rates especially early season ?
- If lodging is always present can plot variance and partitioning structure identify its severity.
- Why is SLN always so low at harvest and how is it distributed in the canopy?

Knowledge gaps

- Management options for season extension (ripeners, variety).
- Causes of the late season increase in RUE. What is the role of lodging, what methods do we have for dealing with gaps/uneven leaf area distribution in the canopy when considering the fraction of light intercepted?
- Why we have low RUE in ratoon crops?
- What is the role of specific leaf N and its critical value in RUE values?

E. Physiology, breeding and selection

16. Applications of industry information in sugar cane production systems, R. A. Lawes and R.J. Lawn

Abstract
The Australian sugar industry collects, during normal commercial operations, data on the production of sugar cane, although the nature and extent of the information varies considerably between regions. These data have become increasingly accessible to researchers who, through various analytical methods, have shown that this information can be used for a range of purposes. Examples include the development of regional models to predict CCS in response to rainfall, the estimation of genetic gain over an extended period across many regions, the development of alternative options to improve the efficiency of cane supply to the mill, the assessment of trends in productivity (including intra-regional spatial and temporal productivity trends), and the identification of attributes of the production system that affect productivity. Experience has shown that, while they are essentially empirical in nature, these analyses can be used to define problems within the industry and either initiate or complement more traditional agronomic and genetic research necessary to solve these problems. This paper reviews the different ways that industry information has been used to facilitate decision-making and their value in the identification of problems such as a chronic decline in CCS in the wet tropics. The merits of expanding this type of approach in the sugar industry more generally are also discussed.

17. Regional and genetic variation in CCS, Scott Chapman

18. Breeding for improved sugar content in sugarcane, Phillip A. Jackson

Abstract
Improving sugar content in sugarcane increases sugar yields with only a small marginal increase in costs of production. This makes gains in sugar content economically more beneficial than corresponding increases in cane yield, and means that increased sugar content is an important objective of sugarcane breeding programs. However comparisons of cultivars released in different years indicate that sugarcane breeding programs have delivered increased sugar yields via improvements in cane yield, with much smaller contributions to sugar content. This is contrary to what might be expected given that sugar content normally has moderate to high heritability and is not substantially affected by competition effects in small plots, which should make for easy gains from selection. Possible reasons for slow rates of genetic gain in sugar content are discussed. These include: that insufficient weighting has been applied to sugar content in comparison with cane yield in selection of parents, that most favourable alleles for sugar content are fixed in current cultivars, and that gene effects contributing to levels of sugar content above current cultivars are negatively correlated with cane yield. Ways to test these hypotheses and address the associated limitations within sugar cane breeding programs are proposed.

Breakout session 5, Physiology, breeding and selection

Agreement

- General agreement between harvest time work and biomass accumulation and dry matter partitioning work.
- Sucrose /dry matter constant throughout crushing season whilst fresh weight sucrose percentage varies considerably.
- Growth reduction – keys are lodging and stalk death.

Areas of difference

- Why is RUE data low in the ratoon.

Knowledge gaps

- Late ratoon yields not adequately explained by current models.
- Physiology of water content in cane stalks is not known.
- Why is SLN in ratoons less than SLN in plant crops (is there any link to earlier leaf area in ratoon and incomplete remobilisation as tillers die).
- What governs the partitioning of photosynthate?
- Why do we loose tillers (would it made a difference if they were all retained).
- If crop were mostly primary stalks, would we end up with more sucrose or storage volume (less fibre).
- Effects of temperature on RUE (Grafton data).
- Advantages of tillering for resilience against stress. Is there a yield penalty under good conditions?
- Time of harvest, how can we disentangle age, ratoon, and time of harvest?
- Does sugarcane have too many green leaves – older ones may not be productive and lead to water loss and carbon loss.
- What is the physiological basis of poor performance in ratoon? Stool maturity? Physiological status of the stool.
- Can we have a sugarcane plant that has high CCS without ripening – all genetically programmed … please?
- Above 3 points are components of ideotype development via breeding.

Plenary, integration of key issues of the day, requiring a allocation of expenditure ($100) on different issues

Mark Smith

Knowledge gaps for growers need to be considered. Can we increase resource use efficiency. “How low can you go with N” (whilst protecting profitability – are there incentives to do this, i.e. tradable N permits???).
In regard to genetic differences for NUE and WUE. Can we control these in a cost effective manner.
Why do tillers die? Would it make any difference if less died? Can you have fewer, bigger tillers.
What CCS is achievable, what are the yield components, can we take them apart and put them together to fit better.
How do we replenish K in a long-term way.
I allocate $30 for resource use efficiencies in general, $30 for the CCS question, $20 for nutrient and water use efficiencies specifically, $10 for tillers and $10 for K issues.

Peter Thorburn

Presentations have been about what we know. We are not necessarily talking about what we don’t know. Our target is to identify gaps in knowledge. We are collating research on territories well-

covered. It would be interesting to perturb the sugarcane system and see the results. Little information was presented on the wet-tropics and lodging. If we address out-of-the-standard issues, we might throw light on the standard issues and provide better understanding of them.
I would allocate $80 in systems where we know we have made limited progress, out on a limb projects, i.e. the wet tropics, water-logging and $20 for sugar accumulation.

Nils Burden
I'm impressed by what we don't know. People are suggesting traits, K and drought tolerance, leaf N, water relations as important. WUE is the most important trait to consider in the future. Progress for cane yield is detailed but this has not been the case for CCS. We don't know the integration of the components has led to increased yield through breeding.
I allocated $50 to WUE, $30 to trying to understand the components that drive cane yield, $20 to an intensive selection program for high CCS.

Mike Robertson
I can provide a fresh set of eyes having not been in sugarcane for past 6 years. We are stuck in a paradigms with physiology of sugar accumulation modelled in a very crude way.
a) A consortium of work is required to rethink accumulation of sugar at many levels. Need to consider the theoretical physiological limits to CCS. $40
b) work on soil/crop interaction is required. Not necessarily as in the SYDJV, but also soil constraints (salinity, low pH, etc) this would benefit from a more physiology approach. $40
c) Lodging, suckering, flowering is still a serious issue in managing crop production and we still have a very crude understanding of managing these. $20

Further comment
Paul Moore
Physiology of sugar accumulation is grossly under-educated. Australia once led science in this area, but no longer today. There is no large concentrated effort, but one or two additions here and there. Today's research is industry driven (understandably) but there is no great progress in our understanding.

Mike Bell
We need an understanding of our progress and how we did it and consideration of what was compromised on the way.

Phil Jackson
This is an on-going effort in sugar accumulation research but no great progress in knowledge.

John Manners
Physiology needs to be done in the context of a large program. Past physiology has not considered genetic variation adequately. Efforts are isolated and therefore have not provided big prizes.

Scott Chapman
APSRU demonstrated well that we can predict amount of sugar in the crop level but don't know how it gets integrated over months. Compared to grains there is little knowledge in sugar.

Bernard Schroeder
Pressures in industry cause isolated research and it is refreshing to have multi-disciplines looking for the common good. More meetings of this kind are required.

Phil Jackson
One potential opportunity to go forward is for people working at different levels to be working on the same thing – the ability to reconcile analysis at all levels will provide insights into explaining things. If we are looking at the same experiment we'll find ways of integrating.

Mike Bell
The SYDJV is an example of the above. It's a big task to bring different scales and perspectives together but is very worthwhile.

Razack Nayamuth
All physiologists from 20 years ago jumped on the biotech bandwagon – we now have these gaps in our knowledge. Closure of research institutes that has exacerbated this. Secondly, farmers like to build big sinks, but these cannot be filled – why is researched aimed at building big sinks – this is something we should look into (especially in the context of water use efficiency).

F. Sucrose accumulation and genetics

19. Measurement of sucrose at an internode level rather than whole stalk CCS alone can increase our understanding of sucrose accumulation in sugarcane. P.L. Albertson and C.P.L. Grof

Abstract
The sugar industry in Australia has used an indirect measure of commercial cane sugar (CCS) to estimate sugar content and purity in cane for the past century. The measurement of CCS has proven to be a valuable industry measure of recoverable sucrose, in mature cane, at the mill. However, there are possible limitations of applying CCS as the sole measure of sugar composition and we suggest that a direct measurement would be a valuable adjunct for the investigation of the sucrose accumulation process in field grown plants as well as screening of novel Saccharum germplasm. There are several factors that influence the CCS value calculated. These include the level of soluble compounds other than sucrose in juice, stalk fibre and stalk moisture content. The subunits of sucrose, the hexoses glucose and fructose, are two soluble sugars present in cane juice, particularly in immature cane, which negatively affect CCS. Similarly, increased levels of fibre and moisture present in cane are rightly penalised in the CCS formula as they impact on the recovery of sucrose at the mill. However, these factors vary during development and between clones at any given time, evaluating clones on CCS measurements alone may not reveal all the features of the sucrose accumulating potential of an individual clone. In contrast, a direct measurement of sugars, particularly if combined with stem sectioning, gives an accurate sucrose measurement. The direct measure also enables the calculation of the sucrose to hexose ratio, a biochemical indicator of maturity that, unlike the CCS measurement, is independent of moisture content and not affected by fibre. It can also be applied to mature internodes very early in the season when whole stalk CCS is normally negative. Direct measurement of sugars, in conjunction with CCS, will provide a better understanding of the sucrose accumulation process and may provide greater scope to identify traits associated with sucrose accumulation.

20. Genomics approaches for the identification of genes determining important traits in sugarcane, Rosanne E. Casu, John M. Manners, Graham D. Bonnett, Phillip A. Jackson, C. Lynne McIntyre, Rob Dunne, Scott C. Chapman, Anne L. Rae, and Christopher P. L. Grof

Abstract
Sugarcane is a genetically complex polyploid grass, which makes difficult the identification of associations between genes and traits. New methods are needed to accelerate this process. In recent years, a new research paradigm of genomics has emerged. Through genomics science it has become possible to characterise entire eukaryote genomes at the DNA sequence level. However, for crop plants with complex genomes such as sugarcane, gene characterisation is currently best achieved via expressed sequence tag (EST) analysis where sequence information is restricted to genes that are actually functioning in any particular tissue or situation. A further advance has been the development of DNA microarrays where expression analysis of thousands of genes can be undertaken simultaneously. Current work on EST and array analysis of gene expression in sugarcane is reviewed and insights on stem functions associated with maturation and sucrose accumulation are discussed. Furthermore, a strategy for associating gene expression with a trait is described where individuals exhibiting particular traits are selected from segregating populations of sugarcane and their gene expression profiles compared. A preliminary experiment that tests the feasibility and an experimental design for this ‘genetical genomics’ strategy on a population segregating for sugar content measured as commercial cane sugar, is described. Given the complex genetics of sugarcane, this strategy and refinements of it, represent

an attractive pathway to the identification of candidate genes that may control sugar accumulation and other traits in sugarcane.

21. Increasing the utility of genomics in unravelling sucrose accumulation, Derek Watt, Alistair McCormick, Cindy Govender, Deborah Carson, Mike Cramer, Barbara Huckett and Frikkie Botha

Abstract
Genomics research into sucrose metabolism in sugarcane has been based on the premise that cataloguing genes expressed in association with culm development would ultimately lead to the identification of genes controlling accumulation of the sugar. However, despite the compilation of extensive annotated gene lists in a number of laboratories, including our own, the identity of key regulatory genes remains elusive. One factor contributing to this situation has been a tendency for genomics-based strategies to be formulated in isolation from the extensive biochemical, enzymological and physiological data available on sucrose metabolism and carbohydrate accumulation, both for sugarcane and other organisms. It is our contention that the full analytical power of genomics will only be realised if it is focused, rather than global, and conducted as part of a multi-disciplinary research effort. Consequently, we are currently examining the expression behaviour of a suite of sucrose-metabolism related genes, within a research context that has been guided by established source-sink models.

22. Sucrose accumulation in the sugarcane stem; pathways and control points for transport and compartmentation. Anne L. Rae, Christopher P.L. Grof, Rosanne E. Casu and Graham D. Bonnett

Abstract
The accumulation of high concentrations of sucrose in the stem of sugarcane has been the subject of many studies. Although models have been constructed from the available information, many steps in the transport and accumulation pathway remain unknown. Recent advances in molecular approaches may elucidate some of these processes. Genes encoding proteins associated with sugar synthesis and storage will provide valuable tools. In particular, the use of techniques to localize the sites of expression of sugar transporters and metabolic enzymes will assist in defining possible routes of sugar movement. When combined with an analysis of metabolite concentrations and enzyme activities in cellular and subcellular compartments, these novel approaches will contribute to an integrated picture of stem function. Control points identified will provide useful tools for selection of efficient genotypes and targets for molecular manipulations.

23. Improving biomass production and partitioning in sugarcane: theory and practice, A. Singels, R.A. Donaldson and M.A. Smit

Abstract
Sucrose yields in sugarcane (Saccharum spp.) could be increased by increasing the efficiency of producing biomass per unit of intercepted radiation and/or by increasing the fraction of total biomass partitioned to stalk sucrose, or both. This could be achieved by optimally matching the physiology of genotypes to the driving environmental conditions. Quantitative knowledge of the subtle effects of climate and genotype is required to optimize cultivar choice, time of harvest, irrigation and chemical ripening. The objective of this paper is to review existing knowledge of the effect of time of harvest and cultivar on the assimilation and partitioning of biomass in sugarcane by comparing modelling theory and published literature with observations from selected experiments conducted at Pongola, South Africa. The ultimate aim is to identify

research priorities for the attainment of more efficient use of plant and natural resources in production of sugarcane.
Simulations were compared with observations for well-watered crops harvested at different times of the year at Pongola, South Africa. Crops started in April and May seem to have higher radiation use efficiencies than other crops thereby compensating for the low interception of radiation during this time of the year. Winter harvested crops partitioned a smaller fraction of final biomass to leaves and more to stalks than summer crops. This trend was not simulated by the Canegro model. Simulations were partially improved by refining the model to account for temperature control of photosynthesis and respiration. The observed seasonal peak of stalk sucrose content also occurred later than simulated, while the observed decrease in sucrose content from January to April could not be reproduced by the model. These shortcomings have serious implications for the relevance of the model as a tool for identifying crop improvement and management strategies.
Cultivars differed markedly in the partitioning of assimilate to stored sucrose. The Canegro model successfully mimicked these differences using two cultivar parameters. This approach to simulating genotypic and environmental control of sucrose accumulation seems promising.
Results suggest that there is scope for improving yields but that the optimisation process should include assessing all components of the production process including radiation capture, net photosynthetic efficiency and stalk partitioning. Sufficient understanding of the interactions between these components is lacking. There is a need for models to distinguish between photosynthesis and respiration and the strong dependence of both these on temperature should be taken into account. Sinks for leaf, stalk structure and sucrose need to be considered separately to adequately understand the effect of temperature on partitioning. Sequential observations of biomass fractions need to be backed by simulation modelling to put it into the context of the system dynamics. Measurements of stalk sucrose profiles are also essential in gaining the necessary understanding of sucrose accumulation.

Breakout session 6 Partitioning of photo-assimilate

Agreement

- Bridging the gaps between disciplines to examine physiological components and to break the ceiling for yield and CCS.
- We need a different approach to Brazil (two different ones).
- Developing frameworks required for understanding sucrose accumulation (and testable hypotheses). Framework to cover crop level through to tissue/cellular level.
- Useful to examine genetic variation. Types of variation. “Wild” versus *S. officinarum* cultivars. Very high CCS material versus current cultivars (debatable).
- We need a common language between biotechnology and crop physiologists/agronomists. Joint projects required. (Is the SYDJV a good model).

Disagree

- Hypothesis – generation at what point.

Knowledge gaps

- Ability to interpret responses and differences.
- Systems approach to prioritization of selection traits
- Higher resolution analysis of key traits
- Physiological limits to CCS – theoretical and what does recurrent selection show.
- Role of water content in CCS variation

- Historical analysis of variety differences (including parents and wild material).
- Physiological analysis of yield components
- Characterisation of wild material.
- Adding value to breeding databases – mining information.
- What is happening to the tissue water.
- Stem anatomy needs further exploration.
- Why does APSIM not have respiration?
- Molecular study of environmental impact on ESTs.
- Can the EST or microarray methods be used to push the CCS barrier.
- Reducing breeding time scales by measuring basal stem characteristics, e.g. CCS. Early season represents 'G" effects. Late season represents increasing 'E" effects.

Final Plenary, integration of key issues of the day and the workshop

New Linkages:
- Learned a lot about what others are doing.
- Have been influenced by others.
- Have identified potential links for future collaboration
- Across industries (e.g. Richard's talk)
- Enormous opportunities for integration (biotech/breeders/crop physiologists etc)
- Potential to integrate physiology with active breeding program (rather than working in isolation).

Meeting the challenges of the workshop:
- Summarised knowledge (not plant/cellular, crop physiology) – modelling.
- Good experience having discussion group together – working on common goals.
- Have identified who is doing what – who to contact/link with.
- Given us an indication about what is happening elsewhere in world – compare our situation.

How do we move forward:
- Use this as a platform to create links for cross-organisation/cross-country work.
- Successful in identifying gaping caverns in knowledge which is restricting the way forward – list top 3 or 4 – initiate work to address these (e.g. grains – key issues: call for research consortia).
- Work collaboratively across different scales and sciences. Multiple levels.
- Having genetic variables in these so can measure differences (environment/genetic variables).
- Consider different frameworks people are using and how they line up.

Voting for Key issues:
- WUE, NUE (19)
- Variability of key traits (efficiency of selection) (3)
- Comparative physiology of germplasm – historical improvement (18)
- Sucrose and CCS accumulation – pathways, plant physiology, crop/environment (24)
- Recurrent sucrose improvement (6)
- Soil/plant interactions (root biology, soil biology (12)
- Above-below ground partitioning (2)

- Breeding for diversified products/industries (2)
- Crop architecture (3)
- Reduced growth phenomenon (1)
- Adoption of knowledge management (1).

Appendix 3

Unravelling genetic, climate and management controls of CCS, yield and water use efficiency for improved selection and management of varieties.

Proposal Submitted to SRDC for 2004 Funding Round