

# POTENTIAL OF USING PHYSIOLOGICAL PARAMETERS TO ENHANCE SUGARCANE SELECTION

ZHOU M

*Zimbabwe Sugar Association Experiment Station, Private Bag 7006, Chiredzi, Zimbabwe*  
[399021@ecoweb.co.zw](mailto:399021@ecoweb.co.zw)

## Abstract

Considerable knowledge has been gained about the physiology of yield formation in crops, and it is now possible to quantitatively estimate limits to crop yield based on physiological and environmental constraints. The two main components of sucrose yield are biomass and sucrose fraction, and increasing one or both of these will increase sucrose yield. Maximising radiation interception and the efficiency of its conversion will increase biomass. Yield of sugarcane is determined by the efficiency in the production of biomass and the proportion of the biomass partitioned to stalks. Biomass production depends on radiation interception and radiation use efficiency. The greatest challenge faced by plant breeders is the accurate identification of superior genotypes in unreplicated early selection stages. With a combined strategy of family and individual selection, a high proportion of superior genotypes are still being missed. It is now known that canopy development parameters can be used in modelling canopy development of sugarcane. Clonal differences in the yield components of harvest index (HI), intercepted radiation (I) and radiation use efficiency (RUE) are not clear, and whether the variation is sufficient for use in the selection process is also not clear. Tiller development parameters define the potential sink available, while leaf development parameters define the photosynthetic capacity of the crop. There is need to identify tiller and leaf development parameters that influence yield or its components (HI, I, RUE). There is also need to determine the heritability of yield components (HI, I, RUE) and test the ability of selected parameters in identifying superior genotypes in unreplicated stages.

*Keywords:* canopy, physiology, sugarcane breeding, harvest index, solar radiation, radiation use efficiency

## Introduction

In various crops, it has been suggested that selection criteria include underlying physiological and morphological characters such as photosynthetic efficiency, leaf area (Watson, 1952) and leaf angle. Donald (1968) suggested the breeding of crop ideotypes - plants with model characteristics known to influence photosynthesis and productivity. George (1965) investigated physiological characters as aids to selection in sugarcane. Although this approach appears promising in theory, it has been disappointing in practise (Skinner *et al*, 1987).

The plant breeder exposes numerous genotypes to a wide range of environmental conditions, and selects genotypes with characteristics that make them productive. Presently, the physiological explanation for the behaviour of genotypes has come long after the genotypes have been produced. The theory of physiology has not yet been developed to the point where it can be applied to define effective selection methods and criteria. With an incomplete knowledge of physiology, selection based on results (productivity) has been more effective than selection based on underlying physiological processes (Skinner *et al*, 1987).

A number of studies have considered the potential role of plant physiology in plant breeding (Shorter *et al*, 1991; Lawn and Imrie, 1994; Hammer *et al*, 1996; Cooper and Hammer, 1996). Jackson *et al*, 1996 noted that the small amount of progress on the use of physiological understanding in plant breeding to date was not unusual, as modelling took 20 years before it was used in crop management. Plant physiology could assist in defining the roles of certain traits in improving plant types and linking physiological parameters to molecular genetics.

Jackson *et al*. (1996) noted that results from physiological research should be linked to breeding programmes. Identification of selection criteria and traits could be done using physiological understanding. Physiological research to identify key genetic parameters should be done on representative breeding populations. Some areas requiring special attention for successfully interfacing physiology research with breeding include (i) the need to work with relevant genetic populations, (ii) close integration of the physiological research with active breeding programmes, (iii) avoiding narrow focus in the physiological research, and (iv) identifying methods of selection that are relatively quick and cost effective for use in large populations, and identifying those traits with sufficient heritability.

There has been considerable discussion in the literature on the role of physiological understanding for assisting plant breeding. While some studies (Shorter *et al*, 1991) have discussed the integration of plant breeding with physiology, the majority of studies (Passioura, 1983; Blum, 1988; Ludlow and Muchow, 1990; Lawn, 1989; Lawn and Imrie, 1993; Evans, 1993b) have taken a largely 'physiological' perspective of the topic, focusing mostly on the role and potential merits of particular physiological attributes. Most physiological studies only suggest possible better methods that can be used by breeders, such as selection criteria. There are no objective comparisons with selection criteria and current methods used in breeding programmes (Jackson *et al*, 1996). Little effort was devoted to evaluating and developing outputs and ideas from physiological research in the context of active breeding programmes. Very few researchers have attempted to develop physiological research linked to challenges faced by plant breeders.

The plant breeding role of physiological understanding should be matched with a breeding programme. The constraints associated with the use of physiological parameters and possible solutions should be highlighted.

There was a range of potential technical limitations in the conduct of physiological research. Some physiological studies did not account for key influences on yield. The range of genotypes or environments used in physiological research are too limited (Zhou *et al*, 2003a). Any studies aimed at determining the physiological traits and their genetic parameters (genetic variation, heritability, genetic correlations, repeatabilities), must utilise genotypes representative of breeder's populations (Jackson *et al*, 1996).

Heritability is the ratio of genetic variance to total variance (Allard, 1960; Stevenson, 1965). Repeatability refers to the ratio of genetic variance and general environmental variance to the phenotypic variance. Clonal repeatability is used when the correlation refers to different plants of the same sugarcane genotype, usually planted at two different locations (Falconer, 1989).

Considerable knowledge has been gained about the physiology of yield formation in crops, and it is now possible to quantitatively estimate limits to crop yield based on physiological and environmental constraints (Sinclair, 1993, 1994; Muchow *et al*, 1997). The two main components of sucrose yield are biomass and sucrose fraction, and increasing one or both of

these will increase sucrose yield. Maximising radiation interception and/or the efficiency of its conversion or both could increase yield by increasing the total biomass partitioned to stalks. Singels and Donaldson (2000) showed that the amount of photosynthetically active radiation (PAR) intercepted by a canopy determined the amount of biomass produced by the canopy. It is known that genotypes exhibit different canopy development (Zhou, 2003b). An appropriate framework for considering sucrose production was to break the process into (i) interception of solar radiation, (ii) conversion of intercepted radiation to biomass and (iii) the partitioning of biomass to the various plant components.

Inman-Bamber (1991, 1994) and Zhou (2003b) described the patterns of tiller population development among sugarcane genotypes in their studies of canopy development. Zhou (2003b) and Zhou *et al.* (2003) showed that there were significant differences in canopy development among sugarcane genotypes and these differences could be described using physiological parameters. Zhou *et al.* (2003) showed that these parameters could be used for modelling differences in tiller development of a sugarcane canopy between genotypes.

The objectives were to outline the challenges faced by plant breeders during the unreplicated stages of sugarcane selection, review the potential of physiological parameters in sugarcane selection, define some potential physiological parameters and highlight potential research areas that may improve the use of physiological parameters in sugarcane selection.

### **Challenges faced by plant breeders during unreplicated stages of sugarcane selection**

The greatest challenge faced by plant breeders is the accurate identification of superior genotypes in unreplicated early selection stages (single stools and single lines) (Berding *et al.*, 1997). With a combined strategy of family and individual selection, a high proportion of superior genotypes (Table 1) can be missed and therefore discarded (Kimbeng *et al.*, 2001b). To reduce the number of superior genotypes discarded, the selection rate has to be increased (Cox *et al.*, 1996; Kimbeng *et al.*, 2000). Increasing the selection rate has resulted in poor clones being selected (Kimbeng *et al.*, 2001a) and in the increased cost of testing poor clones that would be discarded. The data of Kimbeng *et al.* (2001b) also showed that the greatest gain from selection was for cane and sugar yield, and sucrose content had the least gain at the early selection stages (Table 1). These data show the inefficiencies in the selection systems. Although this data was for family selection, high percentages of elite clones are being discarded at selection in the unreplicated stages of most selection programmes. There is a need to identify selection criteria that would increase the identification of superior genotypes.

The low gain for sucrose content at the early stages of selection indicates that selection should focus primarily on cane yield. Zhou (2003a, 2004) concluded that at the early stages, cane could be selected for yield alone, and for sucrose content later in the replicated stages after a study on the effect of stalk population on yield and quality at early selection stages.

Developments in experimental design and analysis since 1987 have made little impact on selection efficiency for cane yield at early selection stages, with the exception of analysis of genotype x environment interaction (Berding *et al.*, 1997). Harvest index has been overlooked, or maybe misunderstood in sugarcane breeding. Sugarcane is unique among field crops in that the structural part of the plant is the harvested product, and in terms of harvest index, requires special consideration of selection objectives for cane yield (Moore, 1989; Evans, 1993a).

**Table 1. The effect of rate of family selection on the gain from selection for cane t/ha, ERC % cane, ERC t/ha and net merit grade (NMG) and elite clones that would have been discarded (adapted from Kimbeng *et al*, 2001).**

Rate of family selection in stage 1 (%)	Gain from selection (%)				Elite clones that would have been discarded (%)
	Cane (t/ha)	ERC % cane	ERC (t/ha)	Net merit grade	
10	12.68	0.64	13.40	15.15	77.03
20	8.82	0.86	9.60	10.90	66.22
30	7.75	0.80	8.58	9.82	51.35
40	5.80	0.94	6.79	8.15	40.54
50	2.82	0.91	3.77	4.87	35.81
60	3.12	0.93	4.04	5.17	24.32
70	2.90	0.65	3.52	4.34	18.24
80	2.38	0.66	3.00	3.76	9.46
90	1.73	0.45	2.17	2.70	2.70
100	0.00	0.00	0.00	0.00	0.00

### Potential of physiological parameters in sugarcane selection

It is now known that canopy development parameters can be used in modelling canopy development of sugarcane (Zhou *et al*, 2003; Donaldson *et al*, 2003). Yield of sugarcane is determined by the efficiency in the production of biomass and the proportion of the biomass partitioned to stalks. Biomass production depends on radiation interception (Singels and Donaldson, 2000) and radiation use efficiency (Sinclair, 1997).

Cane yield ( $\text{g/m}^2$ ) can be described by the following equation (Sinclair, 1997):

$$\text{Cane Yield} = HI \sum_0^D (I \times RUE) \quad \text{Equation 1}$$

where

- $HI$  = harvest index (g/g)
- $D$  = duration of growing season (days)
- $I$  = daily intercepted solar radiation ( $\text{MJ/m}^2/\text{d}$ )
- $RUE$  = radiation use efficiency (g/MJ)

Maximising each term in Equation (1) allows peak crop yields to be achieved. Physical and physiological knowledge has progressed so that considerable understanding exists concerning the factors that influence each term in Equation (1). Starting from the right with RUE, experimental and theoretical evidence have converged to describe the amount of solar radiation required in the accumulation of crop mass. Experimentally, RUE can be measured for a given time period as the accumulated crop mass ( $\text{g/m}^2$ ) divided by the amount of solar radiation intercepted by the crop ( $\text{MJ/m}^2$ ). The total biomass produced by a crop canopy is dependant on the amount of radiation intercepted and RUE. Harvest index (HI) is the fraction of total biomass that forms the harvestable portion of crop, and for sugarcane, it is the stalk component. Partitioning more biomass to the stalks can increase HI and cane yield.

However, what is not clear is whether there are varietal differences in the yield components of HI, I and RUE, how much of the variation is genetic, and whether the variation is

sufficient for use in the selection process. Such data is expensive to collect and that probably explains why it is not available. It is known that canopy development controls radiation interception (Zhou *et al*, 2003). Research has shown that RUE increased with wider row spacing, and that wider row spacing resulted in more biomass partitioned to stalks (Singels and Smit, 2002). However, there is no report on the varietal differences in RUE and the potential use of RUE in selecting high cane yield varieties.

From Equation (1), the three channels of increasing cane yield in a selection programme are increasing RUE, increasing interception of solar radiation and increasing the harvest index. For plant breeders, it is expensive to determine HI, RUE and I for large numbers of genotypes and therefore the use the HI, RUE and I for selection purposes will be limited. However the sugarcane crop canopy influences HI, RUE (Singels and Smit, 2002) and I (Zhou *et al*, 2003). The tiller development parameters will affect HI while I will also be influenced by the tillering process through the spatial arrangement of leaves on the stalks. Therefore canopy development is likely to play a greater influence on HI, RUE and I. Zhou *et al*. (2003) and Zhou (2003b) showed that canopy development can be described and predicted using canopy development parameters. Therefore canopy growth and development parameters can potentially be used to describe and predict HI, RUE and I. The potential exists to use these canopy growth and development parameters that can predict HI, RUE and I as selection criteria for cane varieties with high HI, RUE and I and such varieties may produce high cane yield.

The greatest challenge is to identify which of the canopy development parameters would predict HI, RUE and I. For these parameters to be useful as selection criteria, they should have high heritabilities and repeatabilities between selection stages and should be able to predict or be used to identify high yielding genotypes.

### **The relationship between tiller population development parameters and cane yield**

In a study of tiller population development parameters of sugarcane by Zhou (2005), the data for individual genotypes studied showed that the parameter's thermal time to peak tiller population (TTTP), thermal time per tiller (TTPT), peak tiller population (PTP) and tiller survival rate were highly positively correlated to cane yield, while final tiller population (FTP) was poorly correlated to cane yield (Table 2). However, combined trend lines for all genotypes for TTTP and TSR showed poor correlations to cane yield. PTP appeared the most likely parameter with potential for use in cane yield selection, as it was highly correlated to cane yield and was quicker and easier to measure than the other parameters.

**Table 2 Correlations ( $R^2$ ) of peak tiller population (PTP), final tiller population (FTP), thermal time to peak tiller population (TTTP), thermal time per tiller (TTPT) and tiller survival rate (TSR) to cane yield.**

Variety	PTP	FTP	TTTP	TTPT	TSR
ZN6	0.81	0.64	0.99	0.98	0.96
ZN7	0.84	0.69	0.83	0.98	0.99
N14	0.99	0.48	0.78	0.91	0.90
NCo376	0.91	0.02	0.74	0.98	0.88

### Potential parameters

For parameters to be useful for simulating cultivar response to the environment, the value should be stable across environmental conditions, significant differences in the value should exist between different cultivars and the parameters should have some physiological meaning (Zhou *et al*, 2003). The tiller development parameters (Table 3) would be defining the potential sink available while the leaf development parameters (Table 4) define the photosynthetic capacity of the crop.

**Table 3. Description of tiller population development parameters.**

Parameter name	Parameter description	Units
TTE	Thermal time to 50 % shoot emergence. Tbase = 16°C	°C.day
TTTP	Thermal time to peak tiller population. Tbase = 16°C	°C.day
TTPTt	Thermal time per tiller, tillering phase.	°C.day
PTP	Peak tiller population	number
PARTT	PAR transmission threshold at start of tiller senescence	fraction
TTPTs	Thermal time per tiller, senescence phase	°C.day
TTTSTP	Thermal time to stable tiller population	°C.day
TSR-STP	Tiller survival rate at stable tiller population	fraction
STP (TT1600)	Stable tiller population at TT1600	number
TDR	Tiller death rate = TTTSTP/PTP-STP	°C.day
TTFTP	Thermal time to final tiller population	°C.day
FTP	Final tiller population at harvest	number
TSR-FTP	Tiller survival rate at FTP	fraction
TSR-FTP/STP	Tiller survival rate between FTP and STP	fraction

**Table 4. Description of leaf development parameters.**

Parameter name	Parameter description	Units
TTL	Thermal time requirement (base 10°C) for the appearance of a leaf, called a phyllochron	°C.day
PG	Phyllochron gradient	Number
LAMAX	Surface area of the youngest biggest leaf of anunstressed crop	cm <sup>2</sup>
TTLMAX	Thermal time requirement (base 10°C) for the appearance of the biggest youngest leaf	°C.day
LNO	Leaf number of the youngest biggest leaf	Number
LAngle	Angle of the leaf where it subtends to the stalk	Degrees
ELADP	Elipsoidal leaf angle distribution parameter	Number
GLN/stalk	Number of green leaves per stalk	Number
SFL	Size of first leaf	cm <sup>2</sup>

### Potential research areas into the use of physiological parameters in sugarcane breeding

There is need to identify canopy development parameters that influence cane yield or its components (HI, I and RUE). These studies could focus on the tiller development and leaf development parameters. Those parameters that are highly correlated with cane yield or its components are likely to be useful in predicting potentially high yielding varieties during the early stages of sugarcane selection.

There is need to determine the heritability and repeatability of the yield components (HI, I, RUE) and selected canopy development physiological parameters in the early stages of selection. The yield components and the physiological parameters will only be useful if they are correlated and highly heritable.

There is need to test the identified and selected canopy development physiological parameters for their accuracy as selection criteria for high cane yield varieties in unreplicated stages of selection. Those that can predict cane yield more accurately and are cheaper and quicker to measure would be ideal for use as selection criteria.

### Conclusions

There is little use of physiological characters in sugarcane selection. Studies on the potential use of plant physiology in plant breeding have been disappointing, due to the limited number of genotypes studied. Studying relevant genetic populations and integrating physiological research with breeding programmes can overcome this limitation. Considerable knowledge has been gained about the physiology of yield formation in crops and it is now possible to quantitatively estimate limits to crop yield based on physiological and environmental constraints. Maximising radiation interception, radiation use efficiency and increasing partitioning of biomass to stalks could increase cane yield. The greatest challenge faced by sugarcane breeders is the accurate identification of superior genotypes in unreplicated selection stages. Physiological parameters that can predict yield or its components may offer potential as selection criteria that will improve identification of superior genotypes. Tiller and leaf development parameters offer potential as yield predictors. Therefore potential research should focus on tiller and leaf development parameters that are correlated to yield or its components. Research currently has shown a high correlation of some tiller development parameters to cane yield. The heritability of the most promising parameters should be studied. There is need to then test the promising parameters for their ability to predict yield in unreplicated selection stages.

### REFERENCES

- Allard RW (1960). *Principles of Plant Breeding*. John Wiley and Sons, New York, Chichester, Brisbane, Toronto. 485 pp.
- Berding N, More PH and Smith GR (1997). Advances in breeding technology for sugarcane. pp 189-220 In: Keating BA and Wilson JR (Eds), *Intensive Sugarcane Production: Meeting the Challenges Beyond 2000*. CAB International, Wallingford, UK.
- Blum A (1988). *Plant Breeding for Stress Environments*. CRC Press, Boca Raton, Fl, 223 pp.
- Cooper M and Hammer GL (1996). Synthesis of strategies for crop improvement. pp 591-623 In: M Cooper and GL Hammer (Eds), *Plant Adaptation and Crop improvement*. CAB International, Wallingford, UK.
- Cox MC, McRae TA, Bull JK and Hogarth DM (1996). Family selection improves the efficiency and effectiveness of a sugarcane improvement programme. pp 287-290 In: Wilson JR, Hogarth DM, Campbell JA and Garside AL (Eds), *Sugarcane: Research Towards Efficient and Sustainable Production*. CSIRO Div Tropical Crops and Pastures, Brisbane, Australia.
- Donald CM (1968). The breeding of crop ideotypes. *Euphytica* 17: 385-403.
- Donaldson RA, Redshaw KA and Singels A (2003). In search of parameters to model cultivar specific canopy development. *Proc S Afr Sug Technol Ass* 77: 605-609.
- Evans LT (1993a). *Crop Evolution, Adaptation and Yield*. Cambridge University Press, Cambridge, UK.

- Evans LT (1993b). Processes, genes and yield potential. pp 687-696 In: DR Buxton *et al.* (Eds), *International Crop Science I*. Crop Science Soc America Inc, Madison, WI, USA.
- Falconer DS (1989). *Introduction to Quantitative Genetics*. 3rd edition. Longmans Press, London, UK.
- George EF (1965). Physiological growth attributes of *Saccharum* clones and their progenies. *Annals of Botany* 29: 153-165.
- Hammer GL, Butler D, Muchow RC and Meinke H (1996). Integrating physiological understanding and plant breeding via crop modelling and optimization. pp 419-441 In: M Cooper and GL Hammer (Eds), *Plant Adaptation and Crop improvement*. CAB International, Wallingford, UK.
- Inman-Bamber NG (1991). A growth model for sugarcane based on a simple carbon balance and CERES-Maize water balance. *S Afr J Plant Soil* 8: 93-99.
- Inman-Bamber NG (1994). Temperature and seasonal effects on canopy development and light interception of sugarcane. *Field Crops Res* 36: 41-51.
- Jackson P, Robertson M, Cooper M and Hammer GL (1996). The role of physiological understanding in plant breeding: from a breeding perspective. *Field Crops Res*. 49: 11-37.
- Kimbeng CA, McRae TA and Stringer JK (2000). Gains from family and visual selection in sugarcane, particularly for heavily lodged crops in the Burdekin region. *Proc Aust Soc Sug Cane Technol* 22: 163-169.
- Kimbeng CA, Froyland D, Appo D, Corcoran A and Hetherington M (2001a). An appraisal of early generation selection in the central Queensland sugarcane improvement programme. *Proc Aust Soc Sug Cane Technol* 23: 129-135.
- Kimbeng CA, McRae TA and Cox M (2001b). Optimizing early generation selection in sugarcane. *Proc Int Soc Sug Cane Technol* 24: 488-494.
- Lawn RJ (1989). Agronomic and physiological constraints to productivity in the tropical grain legumes and opportunities for improvement. *Exp Agric* 25: 509-528.
- Lawn RJ and Imrie BC (1993). Exploiting physiological understanding in crop improvement. pp 136-146 In: BC Imrie and JB Hacker (Eds), *Focused Plant Improvement: Towards Responsible and Sustainable Agriculture*. Proc 10th Aust Plant Breeding Conf, Vol 1. Organising Committee, Aust Convention and Travel Service, Canberra, Australia.
- Lawn RJ and Imrie BC (1994). Exploiting physiology in crop improvement. *Plant Physiology Abstracts* 20: 467-476.
- Ludlow MM and Muchow RC (1990). A critical evaluation of traits for improving crop yields in water-limited environments. *Adv Agron* 43: 107-153.
- Moore PH (1989). Physiological basis for varietal improvement in sugarcane. pp 19-55 In: Mohan Naidu K, Sreenivasan TV and Premachandran MN (Eds), *Sugarcane Varietal Improvement*. Sugarcane Breeding Institute, Coimbatore, India.
- Muchow RC, Robertson MJ and Keating BA (1997). Limits to the Australian sugar industry: Climatic and biological factors. pp 37-54 In: Keating BA and Wilson JR (Eds), *Intensive Sugarcane Production: Meeting the Challenges Beyond 2000*. CAB International, Wallingford, UK.
- Passioura JB (1983). Roots and drought resistance. *Agricultural Water Management* 7: 265-280.
- Shorter R, Lawn RJ and Hammer GL (1991). Improving genotypic adaptation in crops – a role for breeders, physiologists and modelers. *Experimental Agriculture* 27: 155-175.
- Sinclair TR (1993). Crop yield potential and fairy tales. pp 707-711 In: Buxton DR *et al.* (Eds), *International Crop Science I*. Crop Science Society of America, Madison, WI, USA.
- Sinclair TR (1994). Limits to crop yield? pp 509-532 In: Boote KJ *et al.* (Eds), *International Crop Science I. Physiology and Determination of Crop Yield*. Crop Science Society of America, Madison, WI, USA.

- Sinclair TR (1997). Yield plateaus in grain crops: The topography of yield increase. pp 87-102 In: Keating BA and Wilson JR (Eds), *Intensive Sugarcane Production: Meeting the Challenges Beyond 2000*. CAB International, Wallingford, UK.
- Singels A and Donaldson RA (2000). A simple model of unstressed sugarcane canopy development. *Proc S Afr Sug Technol Ass* 74: 151-154.
- Singels A and Smit MA (2002). The effect of row spacing on an irrigated plant crop of sugarcane variety NCo376. *Proc S Afr Sug Technol Ass* 76: 94-105.
- Skinner JC, Hogarth DM and Wu KK (1987). Selection methods, criteria and indices. pp 409-453 In: DJ Heinz (Ed), *Sugarcane Improvement Through Breeding*. Elsevier Scientific Publications, The Netherlands.
- Stevenson GC (1965). *Genetics and Breeding of Sugar Cane*. Tropical Science Series, Longman, Green and Company Ltd. 284 pp.
- Watson DJ (1952). The physiological basis of variation in yield. *Adv Agron* 4: 101-145.
- Zhou M (2003a). The effect of selecting for stalk population on yield, quality, agronomic characteristics and disease and pest tolerance of sugarcane varieties. 7th ISSCT Breeding and Germplasm Workshop, 5 to 9 May 2003, Durban, South Africa.
- Zhou M (2003b). Modelling Variety differences in canopy growth and development of sugarcane (*Saccharum officinarum* L) using CANEGRO. MSc Agric Thesis, Faculty of Science and Agriculture, University of Natal, South Africa. 154 pp.
- Zhou M (2004). Stalk population control of yield, quality and agronomic traits of sugarcane populations in early selection stages. *Sugarcane International* Vol 22(5): 14-20.
- Zhou M (2005). The relationship between tiller population development parameters and cane yield of sugarcane. *Proc Int Soc Sug Cane Technol* 25: 443-451.
- Zhou M, Singels A and Savage MJ (2003). Physiological parameters for modelling differences in canopy development between sugarcane cultivars. *Proc S Afr Sug Technol Ass* 77: 610-621.