A SIMPLE MODEL OF UNSTRESSED SUGARCANE CANOPY DEVELOPMENT

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Abstract

Growth and water use of sugarcane are largely determined by the amount of radiation intercepted by the crop canopy. An accurate model of canopy development is therefore a prerequisite for useful predictions of growth and water use.

Canopy development of three varieties grown in different seasons and localities were measured by the way they intercepted photosynthetically active radiation. An existing empirical model based on the Canegro simulation model was tested against data measured in an experiment at Pongola. This model calculates canopy cover as a function of thermal time and does not account for variety differences, row spacing or ratoon stage. An improved model was calibrated on the Pongola data set. Model parameters include base temperature, half canopy thermal time (both variety specific), a row spacing factor and a universal shape constant. Values for the base temperature were determined for the three varieties using an iterative process. The model was then validated against independent sets of data from La Mercy.

Results show that the base temperature for all varieties was higher than previously documented values and that it varied between some varieties. NCo376 and N25 had a value of 16°C, while N26 had a value of 17°C. The new model predicted canopy cover for widely varying temperature regimes with a mean absolute error (MAE) of approximately 10% compared to a MAE of 24% for the existing model. Besides being used to support research in sugarcane, the model will assist management and planning of irrigation and weed control.

Keywords: Canopy cover, base temperature, thermal time, variety, model, accuracy

Introduction

Knowing the time it takes for a variety to form a full canopy makes for better selection of starting time to maximise the yield potential of a range of varieties on a farm. For example, Inman-Bamber, (1994) suggested that N12 be ratooned in winter because it develops a canopy relatively slowly compared with NCo376. Accurate predictions of the time when canopies shade out weed growth in crops started throughout the milling/harvesting season will be valuable for selecting appropriate weeding programmes. The time and amount of canopy cover during early stages of crop growth were very different for two varieties studied by Inman-Bamber (1994). These factors should be quantified for other varieties as they also have implications for irrigation practices that could improve water use efficiency. Since biomass production is dependant on the amount of radiation intercepted by the canopy, the ability of models to accurately predict yields of different varieties may largely hinge on accurate descriptions of canopy development.

The Canegro model (Inman-Bamber, 1991) simulates canopy cover through a mechanistic approach on a tiller and leaf level. Leaf expansion is calculated from temperature and adjusted for water stress. Leaf and tiller appearance rates are calculated as functions of thermal time using base temperatures of 10 and 16°C, respectively. Singels et.al. (1998) simulated canopy cover as a non-linear function of days after emergence and starting month. The model was based on data generated by the Canegro model for numerous irrigated situations in the S.A sugar industry.

The aim of this paper is to report on the calibration and validation of an existing and a new model for predicting unstressed sugarcane canopy cover. The Canesim canopy model was developed and calibrated using simulated data from the Canegro model and was validated on measurements from a field trial in Pongola. The second model, named the Hill model, was calibrated on data from the Pongola trial and validated with data from two field trials at La Mercy.

Methods

Experiment methods

Pongola 98/99

A growth experiment was initiated in March 1997 at Pongola (27°25' S, 31°36' E). Ten plots of several varieties including NCo376, N25 and N26 were planted in a deep sandy clay loam soil. Growth in two plots of each variety was re-started by cutting back previous growth in March, April, May, August and December of 1998. Plots (23m by 12 rows spaced at 1.4m) were cleared of trash, fertilized (167 kg/ha N, 34 kg/ha P and 167 kg/ha K) and sprayed with a mixture of Sencor (3L/ha) and diuron (2L/ha) immediately after cutback. Hoeing and a further spraying of MCPA (3L/ha) and Gesapax (3L/ha) mixture were needed to suppress late emerging weeds. Plots were also sprayed with Zinc sulphate and then side dressed with fertilizer that provided a further 77 kg/ha N, 44 kg/ha P and 1.5 kg/ha Zn per hectare) when the crop was 3-5 months old. The Canesim model was used to schedule irrigation that was delivered through dripper lines placed in alternate interrows. On most occasions 50 mL/ha of water were applied during 48 hours to keep growth free of moisture stress.

A ceptometer (1m line quantum sensor, Li-Cor, Lincoln, NE, USA) was used to measure the amount of photosynthetically active radiation (PAR) intercepted by the green leaf canopy. At each plot a reference above canopy reading was taken before taking eight below canopy readings. The ceptometer was held just below the bottom green leaves at an angle so that the tip was in the centre of the row and the recording unit was mid way between rows. The instrument was levelled before accepting a recording. Data for NCo376, N25, N26 from the March, April, May and August cycles were used because only these varieties were present in all these cycles, while the December cycle had no measurements during partial canopy.

Maximum and minimum temperatures as well as global incoming radiation totals were measured during the course of the experiment at a weather station 100 m from the experiment.

La Mercy 90/91

Ceptometer readings were recorded on a second ratoon crop of variety NCo376 at La Mercy. Data from crops started on the following times were used: December 1990, February 1991, April 1991, June 1991 and July 1991. These crops were not irrigated and the row spacing was 1.2 m. Data from cycles that did not include partial canopy cover readings, or data from cycles that showed a clear reduction in canopy cover as a result of water stress, were excluded. The full details of the experiment are given by Inman-Bamber (1994).

La Mercy 97/98

Ceptometer readings were carried out on a first ratoon crop of variety NCo376 started in November 1997. The crop was irrigated fully to prevent any water stress and the row spacing was 1.4 m. Details of the experiment are fully described by Singels et. al. (1998) and McGlinchey and Inman-Bamber (1996).

Details of the crops from which data were used to calibrate and validate the models, are summarized in Table 1.

Model descriptions

It has been shown that canopy development of unstressed sugarcane is determined largely by temperature (van Dillewijn, 1952; Inman-Bamber, 1994). To confirm this, measured canopy cover values below 80% for the different cycles of NCo376 at Pongola were compared with accumulated radiation and accumulated temperature above given thresholds. The coefficient of determination was determined for these comparisons, using the different thresholds. The r^2 value for temperature at a threshold of 16°C was 0.968 whilst that for radiation was 0.82 with a threshold of 14MJ/d. This clearly shows that temperature, and not radiation, explains most of the variation in canopy cover.

Canesim canopy model

The Canesim model is represented by eq. 1.

$$CC = 100/(1 + e^{(-a * [TT-b])}) \quad \text{Eq. 1}$$

where CC - canopy cover (%)

TT - thermal time accumulated since previous cut (°C.d)

a & b - empirical constants

and $TT = S\,(Tmax + Tmin) / 2 - Tbase$ Eq. 2

where Tmax – daily maximum temperature (°C)

Tmin – daily minimum temperature (°C)

Tbase - base temperature (°C)

This model does not cater for variety differences, the effect of row spacing, or ratoon stage on canopy cover.

Hill model

The model is named after the Hill equation (Haefner, 1996) and is shown in eq. 3

$$CC = 100 * TTI^k / (.5^k + TTI^k) \quad \text{Eq. 3}$$

where CC – canopy cover (%)

TTI – thermal time index

k – empirical shape constant

and $TTI = TT / (TThalf)$ Eq. 4

where TT - accumulated thermal time since emergence (°C.d)

TThalf - TT required to half canopy (°C.d)

and $TThalf = TThalf_{1.4} - r * (1.4 - RS)$ Eq. 5

where RS - row spacing (m)

$TThalf_{1.4}$ - half canopy thermal time at row spacing of 1.4 m

r - response in TThalf to unit change in row spacing (°C.d/m)

For this model it was assumed that emergence was completed after 100 °C.d (base 10) had accumulated from the time of the previous cut following the relationship used in the APSIM sugarcane model (Keating et.al, 1999).

Table 1. Details of crops used for model calibration and validation.

Experiment	Starting time	Varieties	Ratoon stage	Row spacing	Data use
Pongola 97/98	March, April, May, August	NCo376, N25,N26	1	1.4 m	Validate Canesim Calibrate Hill
La Mercy 90/91	December, February, April, June, July	NCo376	2	1.2 m	Validate Hill
La Mercy 97/98	November	NCo376	1 and 2	1.4 m	Validate Hill

Model calibration

Canesim

Model parameters were determined through a process of iteration with the objective of finding the best fit of eq. 1 to CC vs. TT data. The data were generated by using the Canegro model (Inman-Bamber, 1991) to simulate CC for numerous climatic scenarios in the northern irrigated areas of the S.A industry. Stress free crops grown at 1.2m spacing starting each month of the year were simulated from 1968 to 1994 for Pongola and TenBosch and from 1967 to 1991 for Mtubatuba. These scenarios were selected because of the availability of climatic data and because the original aim was to use this model to assist irrigation management.

Values for a, b and Tbase (in eq. 1) of -0.00425$^{o}C^{-1}$, 915 ^{o}C.d and 10^{o}C respectively, gave the best fit to the data (r^2=0.994, n=4960).

Hill model

The Pongola data set was used to calibrate the Hill model. Tbase for each variety was determined through iteration using different Tbase values by maximising the r^2 value of a linear fit between CC (only values lower than 80%) and TT. Results of this are given in Table 2.

The least variation (highest r^2) was obtained when a base temperature of 16^{o}C was used for NCo376 and N25, and 17^{o}C for N26.

TThalf was determined visually from graphs depicting CC vs. TTI data. There was no evidence from this data set that the value was different between varieties. The value was found to be 250 ^{o}C.d for Tbase 16 and 17^{o}C

From results reported by Thompson & du Toit (1965) , Boyce (1968) and Bull and Bull (1996) it was concluded that the thermal time required to reach half canopy changes by 50% for each one meter change in row spacing. It was assumed that this response is linear within the range 0.5 to 1.5 m row spacing. The value of r was therefore taken to be half of $TThalf_{1.4}$, that is 125 ^{o}C.d

The value for k, the universal shape constant, was found to be 2.453 (r^2=0.987 by fitting the Hill equation to CC vs. TTI data.

Model validation

The Pongola data set was used to validate the Canesim canopy model and the La Mercy data sets were used to validate the Hill model. The following parameters were used to quantify model accuracy:

Table 2. The r^2 value (all significant at P = 0.05) of a linear fit between canopy cover of three varieties and thermal time using different base temperatures (Tbase in ^{o}C)

Tbase:	15	16	17	18
NCo376	0.961	**0.968**	0.966	0.955
N25	0.941	**0.957**	0.951	0.928
N26	0.933	0.95	**0.958**	0.956

- The slope and intercept of the linear regression between simulated and measured values. A slope of one and intercept of zero would be ideal.
- The coefficient of determination (r^2).
- Then mean absolute difference between simulated and measured values expressed as a percentage of the mean measured value (named mean absolute error, MAE).
- Then mean of the absolute difference between the corresponding simulated and measured value as a percentage of the given measured value (named mean relative absolute error, MRAE). MRAE is a more stringent test than MAE as it penalizes for erroneous estimates of small values more severely.
- The percentage of simulated values that differ by less than 20% from the measured value (named accuracy frequency, AF)

Results and discussion

Canesim

Validation results are summarized in Fig. 1. The very high MRAE of 106% and wide scatter of points are indicative of the poor accuracy of the Canesim model. Also, the inability of the Canesim model to account for the measured differences in variety (a) and crop cycles (b) are depicted in Fig. 2.

Hill model

The calibration and goodness of fit of the Hill model are illustrated in Fig 3. The test parameters show a substantial improvement over the Canesim canopy model (see Fig. 3, MRAE decreased from 106 to 22%) and indicate that the model fitted the measured data excellently.

The validation on independent data is shown in Fig.4. Apart from some outliers the model fits the measurements fairly well. The simulation error is only slightly more than that of the calibration and is still much better than for the Canesim model. This validation is very encouraging but the model must be tested under lower temperature conditions (like the Midlands of KwaZulu-Natal) as well as under narrow row spacings and later ratoon stages before it is applied more widely.

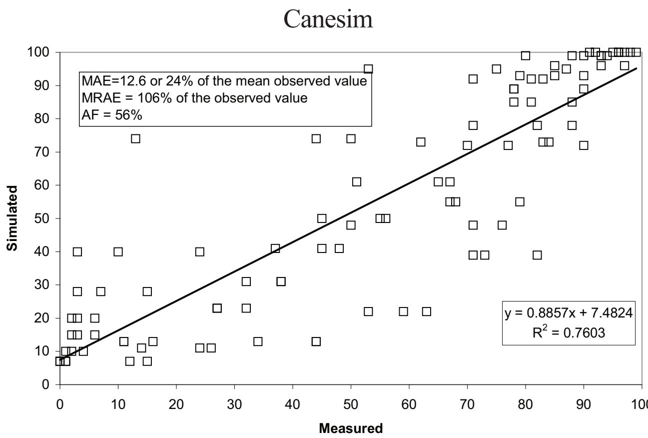

Fig.1 A scatter plot of measured and Canesim simulated canopy cover (%) with the best linear fit.

Conclusions

Results form this study indicate that:

- temperature is the most important environmental factor to predict unstressed canopy development,
- base temperatures for canopy development are much higher than previously documented and varieties may have specific base temperatures,
- a simple empirical model of sugarcane canopy development is sufficiently accurate for unstressed conditions.

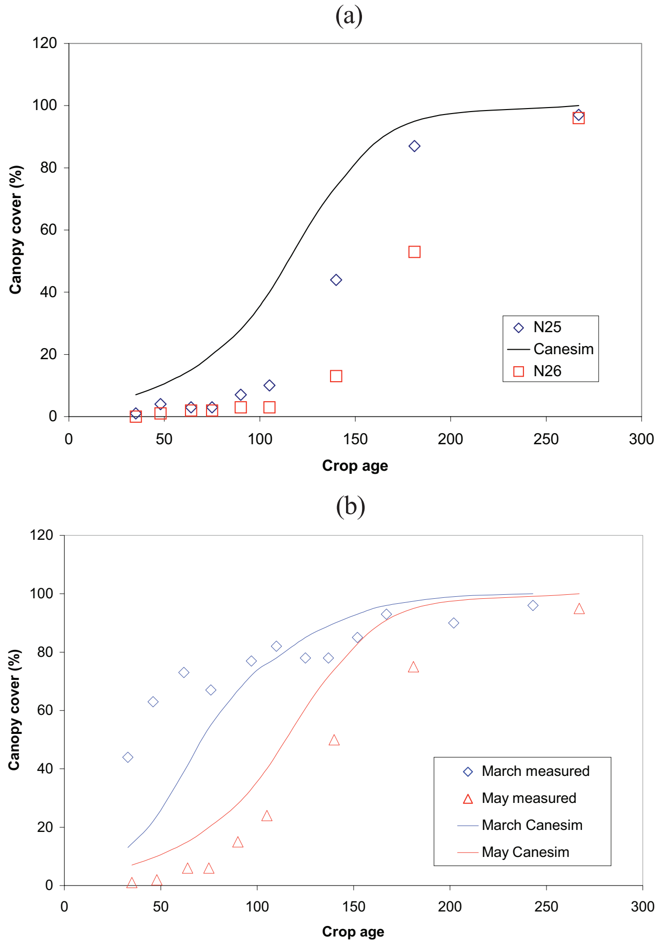

Fig. 2. Measured (symbols) and simulated (lines) canopy cover for two varieties in the May cycle (a) and for two cycles for NCo376 (b).

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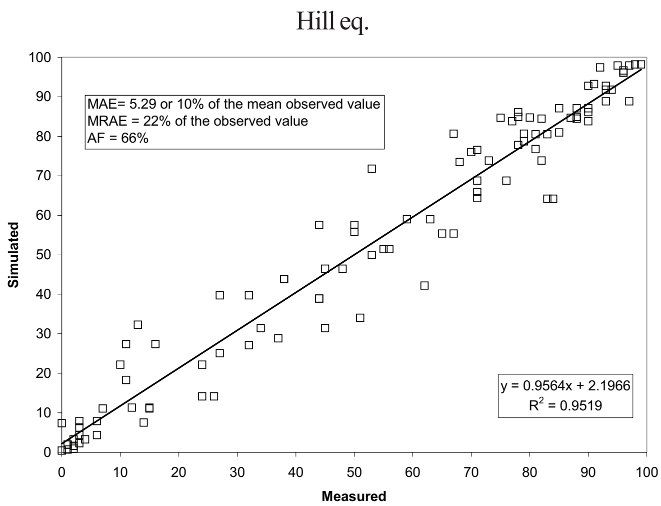

Fig. 3. Calibration scatterplot of measured and Hill simulated canopy cover for crops grown in Pongola.

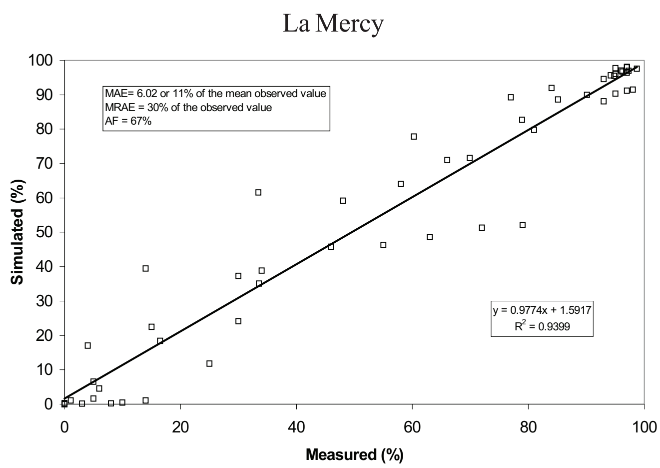

Fig 4. Validation scatterplot of measured and Hill simulated canopy cover for crops grown in La Mercy.