DSSAT v4.5 - Canegro Sugarcane Plant Module

Scientific documentation

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1. Introduction

The Canegro sugarcane model (Inman-Bamber, 1991, Singels and Bezuidenhout, 2002) simulates sugarcane crop growth and development from daily weather data, cultivar and soil properties, and management input data. It simulates:

- Canopy development at the tiller and leaf level
- Radiation capture from leaf area index
- The water balance using soil-plant-atmosphere continuum principles
- Biomass accumulation following a radiation use efficiency/respiration approach
- Biomass partitioning to different plant components, including stalk sucrose, using a source-sink approach and affected by physiological age, temperature and water stress.

The Canegro model can be regarded as one of the leading sugarcane crop growth models that has been used extensively in research and management. An early Canegro version (Inman-Bamber and Kiker, 1997) was included in version 3.5 (Tsuji *et al*., 1994) of the Decision Support System for Agrotechnology Transfer (DSSAT), Since then, amendments by different research groups resulted in different Canegro versions that were never integrated, nor incorporated into DSSAT. Simultaneously, DSSAT (version 4.0) adopted a modular structure (Jones *et al*., 2002), and many utilities were added.

The International Consortium for Sugarcane Modelling (ICSM), established by leading sugarcane industries and research groups in May 2006, recognised the above-mentioned problem and launched a project to incorporate an up-to-date version of Canegro into DSSAT v4. SASRI-Canegro was taken as the starting point. The project entailed:

- Restructuring of the Canegro code to the DSSAT v4 framework and the generic modules for management, soil, weather and the energy balance.
- Verification of model results against the current Canegro for a predetermined set of simulation runs.
- Sensitivity analysis of key processes such as canopy development, crop water uptake, biomass accumulation and partitioning, to changes in soil, weather, management and variety traits.
- Evaluation of the new DSSAT Canegro model with datasets from Zimbabwe, Australia, USA and South Africa.
- Documentation of code and concepts, as well as of the model evaluation experiments.
- Compiling a user manual.

This document is a description of model concepts and of the initial validation of the DSSAT 4.5 Canegro model. A companion document (Jones & Singels, 2008) provides guidance to the user on the setup, execution and interpretation of DSSAT v4.5 Canegro model runs and the calibration of the model for different cultivars.

2. Overview of the model

A schematic outline of the new modular structure of Canegro, and how it fits within the DSSAT v4 framework is given in Figure 1.1. Each submodule is further explained in subsequent sections.

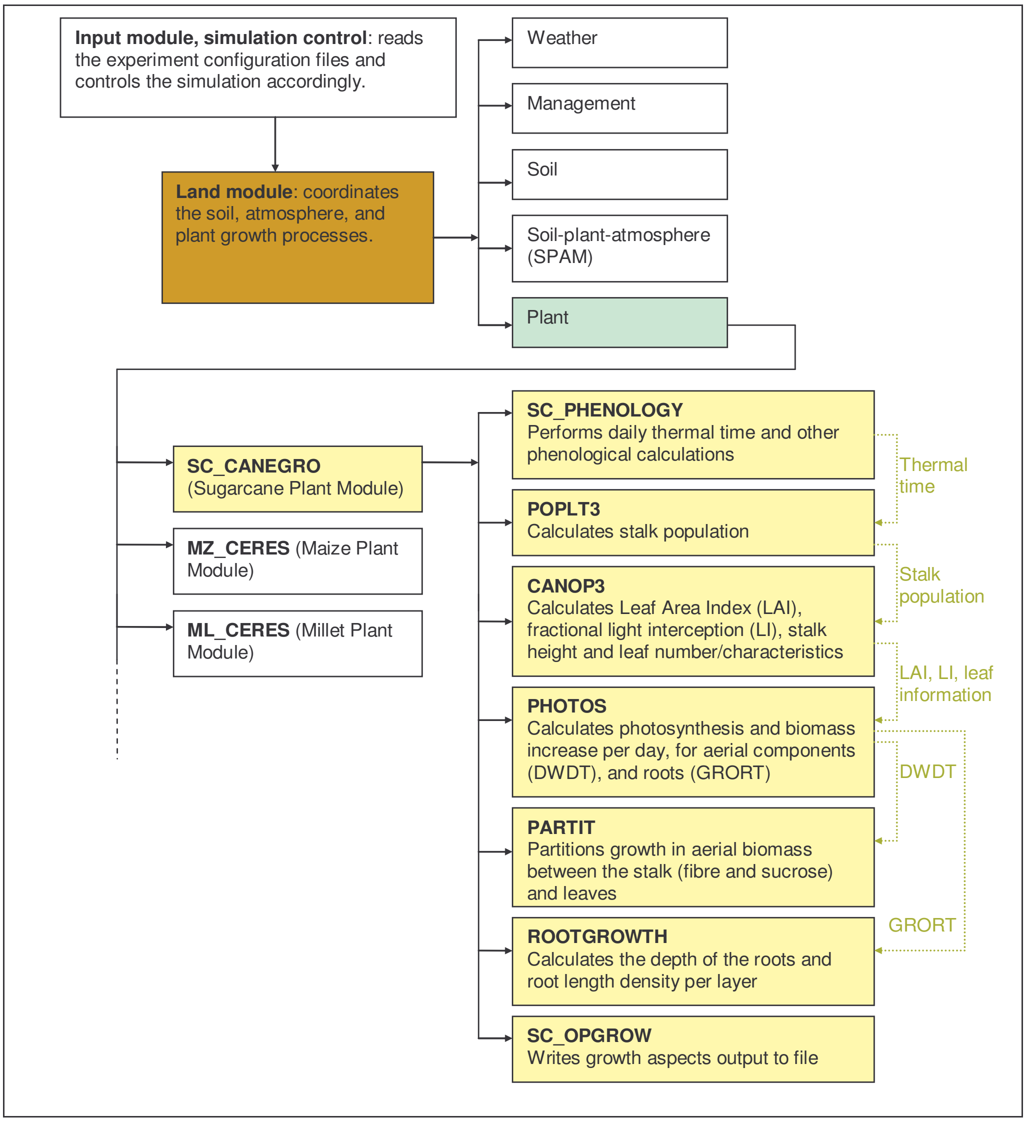

Figure 1.1. Diagrammatic representation of CANEGRO, as a module within the DSSAT Cropping System Model (CSM).

2.1. Phenological phases

The germination phase lasts from planting or ratooning to the emergence of primary tillers. Primary tiller emergence is simulated when a specified period of thermal time has accumulated from planting (TTPLNTEM) or ratooning (TTRATNEM) (Table 3.3). For the standard South African reference cultivar NCo376, these values are 428 and 203 ^{o}Cd respectively using a base temperature of 10 ^{o}C.

Start of stalk elongation is simulated when a cultivar-specific thermal time period (CHUPIBASE in Table 3.3) has elapsed since primary tiller emergence (NCo376 value 1050 ^{o}Cd with an associated base temperature of 10 ^{o}C.

Peak tiller population occurs when a cultivar-specific amount of thermal time has accumulated since emergence (NCo376 value 600 ^{o}Cd, base 10 ^{o}C) (TT_POPGROWTH in Table 3.3).

The tillering phase lasts from the emergence of primary tillers to the occurrence of peak tiller population, while the stalk elongation phase lasts from the start of stalk elongation up to harvest. The tiller senescence phase commences after peak tiller population is reached and continues until harvest. Flowering is not simulated.

2.2. Canopy development

Two options of simulating the progression of fractional interception of radiation are provided in DSSAT-Canegro, namely (1) a simple thermal time-driven method at whole canopy level (Canesim) and (2) a method using leaf area index derived from thermal time-driven development of individual leaves and tillers (Canegro). These methods are described below.

2.2.1 Canesim canopy model

The Canesim canopy model for unstressed crops is fully described by Singels & Donaldson (2000). The model calculates the interception of radiation as a function of thermal time and row spacing. The coefficient that determines the shape of the canopy curve for sugarcane is the species parameter (Hillpar1 in Table 3.1). The function includes cultivar specific parameters for (1) the thermal time requirement to reach 50 % canopy cover at 1.4 m row spacing (*Tthalfo,* Table 3.3), (2) the base temperature for calculating thermal time and (3) the response in *Tthalfo* to a change in row spacing from the standard 1.4 m.

Canopy cover is reduced by water stress as a function of the duration of severe stress (net relative stress duration) and an ecotype-specific limit on the maximum reduction possible (CS_CNREDUC in Table 3.2, default value: 0.3). Net relative stress duration is the stress duration expressed as fraction of the period required to effect the maximum reduction. The latter is considered an ecotype parameter (CS_CNPERIOD in Table 3.2, default value: 21 days). Stress duration is calculated as the number of days that the growth stress factor (zero to unity) has been below 0.5 (indicating severe stress), minus the number of days that the growth stress factor exceeded 0.5 (indicating conditions favourable for recovery). Canopy cover is reduced when net relative stress duration is increasing from one day to the next and the canopy recovers when the net relative stress duration decreases from one day to the next. The model is partially based on the findings of Smit and Singels (2006).

DSSAT requires values for total leaf area index (TLAI) and green leaf area index (GLAI) to calculate evaporation from the soil and an FAO-56 evaporation coefficient respectively (the ratio between evaporation from fully canopied, unstressed sugarcane and evaporation from a reference crop). In the Canesim canopy model leaf area is not calculated. GLAI was therefore back calculated from Beer's law of radiation extinction in plant canopies.

$$FI = 1 - \exp(-Kc*GLAI)$$

where Kc is the extinction coefficient calculated by the Canegro model. TLAI was set equal to GLAI for the interim. This needs further refinement.

2.2.2 Canegro canopy model

The original model is fully described by Inman-Bamber (1991). It simulates the development of individual leaves and shoots. Shoot leaf area is then scaled up to a canopy level by multiplying leaf area per shoot by the number of shoots per unit area. Interception of photosynthetically active radiation (PAR) is then calculated according to Beer's law, as described in section 2.2.1.

2.2.2.1 Tiller development

Shoot population density is simulated using ecotype parameters POPCF1, POPCF2 and POPDECAY (see Table 3.2) and cultivar parameters MAX_POP and POPTT16 (in Table 3.3). The ecotype parameters determine the unstressed rate of tiller production and senescence as a function of thermal time. The cultivar parameters determine the peak and mature tiller population.

Row spacing and water stress modify shoot appearance and senescence. Shoot production rate is inversely proportional to row spacing and therefore assumes a direct relationship with bud density in the ground. Shoot density is not allowed to exceed MAX_POP and final shoot density is fixed at POPTT16. Shoot cohorts are phased in (and out) to account for the range in shoot age at a given point in time (see Inman-Bamber, 1991). No distinction is made between plant and ratoon crops apart from the thermal time requirement for emergence of primary shoots (user specified - TTPLNTEM and TTRATNEM in Table 3.3).

2.2.2.2 Leaf development

Leaf emergence

The algorithm for leaf appearance in Canegro is based on the phyllochron concept, using a “broken stick” approach, as suggested by Inman-Bamber (1994a). The phyllochron interval (PI) is defined as the thermal time elapsed (^{o}Cd) between the emergence of subsequent leaves on a tiller, and is regarded as a cultivar-specific parameter. Two phyllochron values (PI1 and PI2, Table 3.3) apply to leaves below and above a cultivar-specific threshold (PSWITCH, Table 3.3) respectively. The concept is illustrated in Figure 2.1. Thermal time is calculated using a process-specific base temperature (TTBASELFEX, an ecotype parameter in Table 3.2, default value 10 ^{o}C).

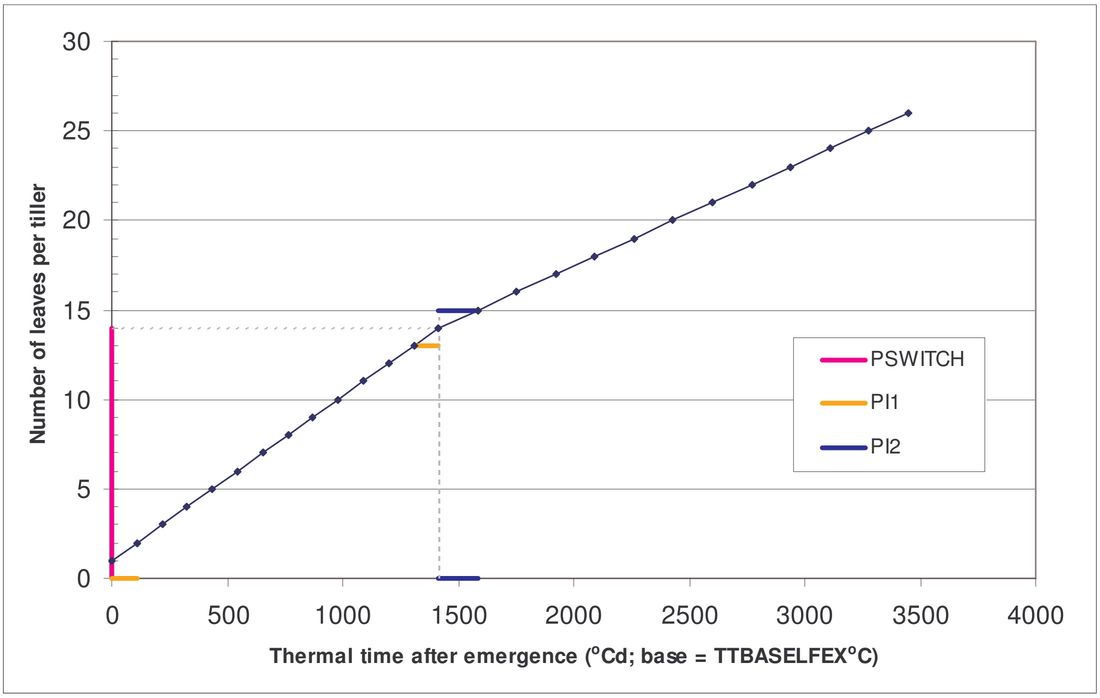

Figure 2.1. Illustration of ‘broken stick’ approach for leaf appearance as used in Canegro.

Values for PI1 and PI2 for a few South African varieties are indicated in Table 2.1.

Table 2.1 Indicative phyllochron intervals for a few South African varieties (Inman-Bamber, 1994a; Inman-Bamber and Kiker, 1997). The values were determined for a TTBASELFEX value of 10°C and PSWITCH value of 14 leaves.

Cultivar	**PI1 (°Cd)**	**PI2 (°Cd)**
NCo376	109	169
N12	118	200
N14	109	169
R570	119	119

2.2.2.3 Leaf senescence

The senescence of green leaves in Canegro is based on the assumption that a healthy, adequately-watered plant cannot have more than a variety-specific number of green leaves (LFMAX in Table 3.2). Once this has occurred, each new leaf formed is accompanied by the senescence of the oldest green leaf on the tiller. The rate of leaf senescence is accelerated under drought stress.

2.2.2.4 Leaf expansion

The basic variable used in Canegro to calculate leaf and plant dimensions is the plant elongation rate (PER, cm/day). PER can be visualised as the elongation rate of the whole shoot, including the longest leaf tip. PER depends on air temperature (Inman-Bamber, 1994b) as well as water availability. The equation used in Canegro is:

PER = SWDF2 * dPERdT * MAX(0., TMEAN-TBASEPER) * 24/10

where dPERdT is unstressed plant extension rate (mm $^{o}C^{-1}$ h^{-1}) and TBASEPER is the base temperature for plant elongation (°C). Both are regarded as ecotype parameters (See Table 3.2). SWDF2 is the water stress factor for expansive growth (see section 2.5). The term 24/10 is needed to convert the units of PER to cm/day.

Increases in leaf length and leaf width are derived from PER, hence allowing for the calculation of leaf area expansion, which is done for individual leaves on a tiller. Leaves stop expanding once they reach a maximum allowable blade area. This value increases for subsequent leaves (Inman-Bamber and Kiker, 1997) until a specific number of leaves MXLFARNO has formed. After this, the maximum allowable blade area remains at a constant value MXLFAREA.

2.2.2.5 Leaf area index and light interception

The fraction of light intercepted by the crop is determined by the green leaf area index (GLAI). GLAI is calculated as the product of the mean area of green leaves per tiller and the tiller population.

The interception of photosynthetically-active radiation (IPAR) by the canopy is calculated by making use of Beer's law as described in section 2.2.1. The value of the extinction coefficient (Kc) changes during the development of the crop. In Canegro, this is calculated as a function of the total number of leaves per tiller (as determined in the model for primary tillers), as illustrated in Figure 2.2.

This function is determined by three parameters (EXTCFN, EXTCFST, and LFNMXEXT, as explained in Figure 2.2 and Table 3.2)

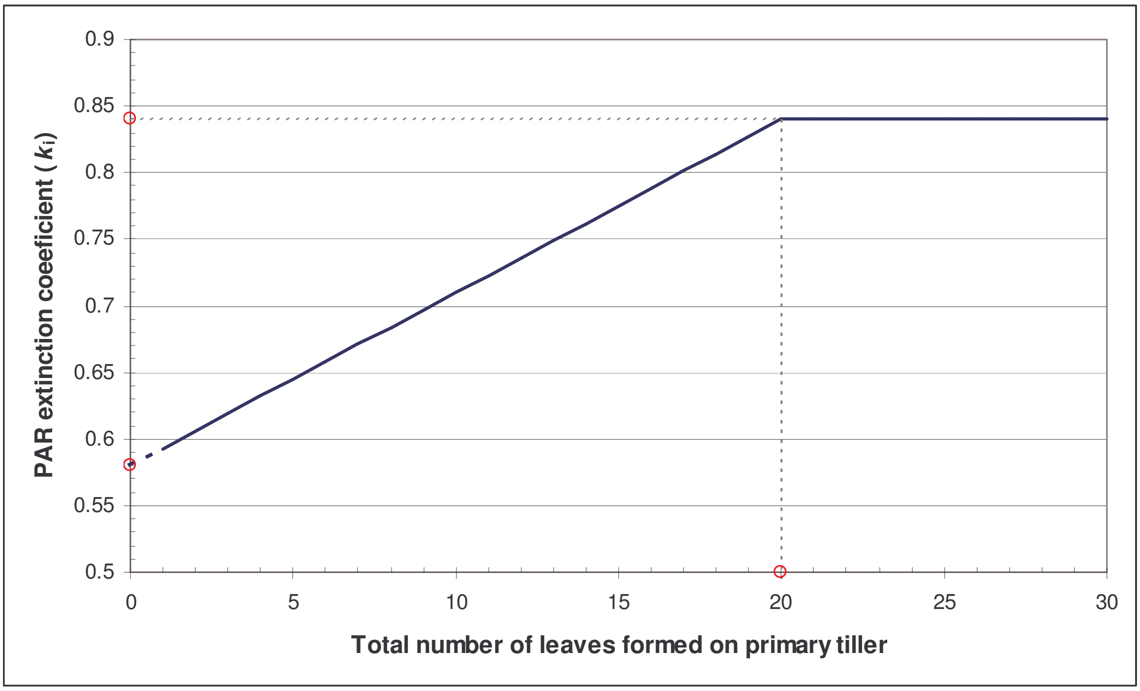

Figure 2.2. Determination of light extinction coefficient (for PAR) in Canegro (according to Inman Bamber, 1991). In this example, LFNMXEXT = 20; EXTCFST = 0.58; and EXTCFN = 0.84.

2.2.2.6 Stalk height and canopy height

Stalk height (SHGT, cm) is assumed to increase at a rate that is proportional to PER:

SHGT = SHGT + (PER * PERcoeff)

Canopy height (CANHEIGHT, cm) is calculated as:

CANHEIGHT = (SHGT + LMAX(LFN(1)) * CHTCoeff) / 100

where LMAX(LFN(1)) is the length of the longest leaf in the first tiller cohort group (cm) and PERcoeff and CHTcoeff are species parameters (Table 3.1).

2.3. Biomass accumulation and partitioning

The simulation of biomass accumulation and partitioning is fully described by Singels & Bezuidenhout (2002). Briefly, the model calculates daily increments in total biomass (dTOT/dt in t/ha/d) using photosynthetically-active radiation (PAR) conversion efficiency (PARCE in g/MJ) according to eq. 1 (derived from Inman-Bamber, 1991). The size of biomass increments depends on the amount of intercepted PAR (IPAR in MJ/ha), the size of the crop (TOT in t/ha) and the level of crop water stress (expressed by the SWDF1 factor as described by Ritchie et. al., 1986).

$$dTOT/dt = (1 – RespGcf)(PARCE.10^{-6} . IPAR – Rm .TOT) SWDF1$$

where RespGcf is the coefficient for growth respiration (considered a species parameter of 0.242 t/t; see Table 3.1) and Rm is the maintenance respiration rate.

PAR conversion efficiency and maintenance respiration depend on temperature, as described by Singels *et al.* (2005):

PARCE = PARCEmax (1 – exp (-0.08 (Tmean – Tbasephotos)) where PARCEmax is the theoretical maximum PAR-to-biomass conversion efficiency at an optimal temperature (considered a cultivar parameter, listed in Table 3.3) and Tbasephotos is the base temperature for photosynthesis (7^{o}C; considered a species parameter, listed in Table 3.1)

The fraction of biomass increments consumed by maintenance respiration (Rm) is calculated as an exponential function of temperature:

$$Rm = RespQ10 ^{((Tmean-10.0)/ 10.0)} * Respcon$$

where RespQ10 is the fractional increase in respiration rate per 10^{o}C rise in temperature (Q10 coefficient, considered as a species parameter, see Table 3.1), and Respcon is the value of Rm at the reference temperature of 10^{o}C (species parameter). This equation was derived from results reported by Liu and Bull (2001).

Daily partitioning of assimilate between roots and aerial parts is simulated as a non-linear function of total biomass. A large fraction (Max_rootpf = 0.95, see Table 3.1) is partitioned to roots early in the life of the plant but this decreases rapidly as the plant ages. The maximum fraction of daily biomass increments that is partitioned to aerial parts (in a mature crop) is specified in the cultivar file (NCo376 value = 0.88, APFMX in Table 3.3).

A temperature-dependent fraction of aerial dry mass is partitioned to stalk (see Singels *et al*., 2005) and is limited to a cultivar-specific maximum value (NCo376 value: 0.65, STKPFMAX in Table 3.3) when thermal time since emergence exceeds a cultivar-specific threshold (Nco376 value = 1050^{o}Cd, CHUPIBASE in Table 3.3).

The rate of dry matter partitioning to stalk is regarded as the source strength. Partitioning of stalk dry matter between sucrose and stalk structure is regulated by sink capacity for stalk structural growth and the source-to-sink ratio. Sink capacities for structural growth and sucrose storage are dictated by current growing conditions (temperature, water status), current stalk mass and cultivar characteristics (SUCA, TBFT in Table 3.3). The sucrose accumulation component of the model is based on a framework of sucrose distribution within stalks as it is affected by temperature and water stress (see Figure 2.3).

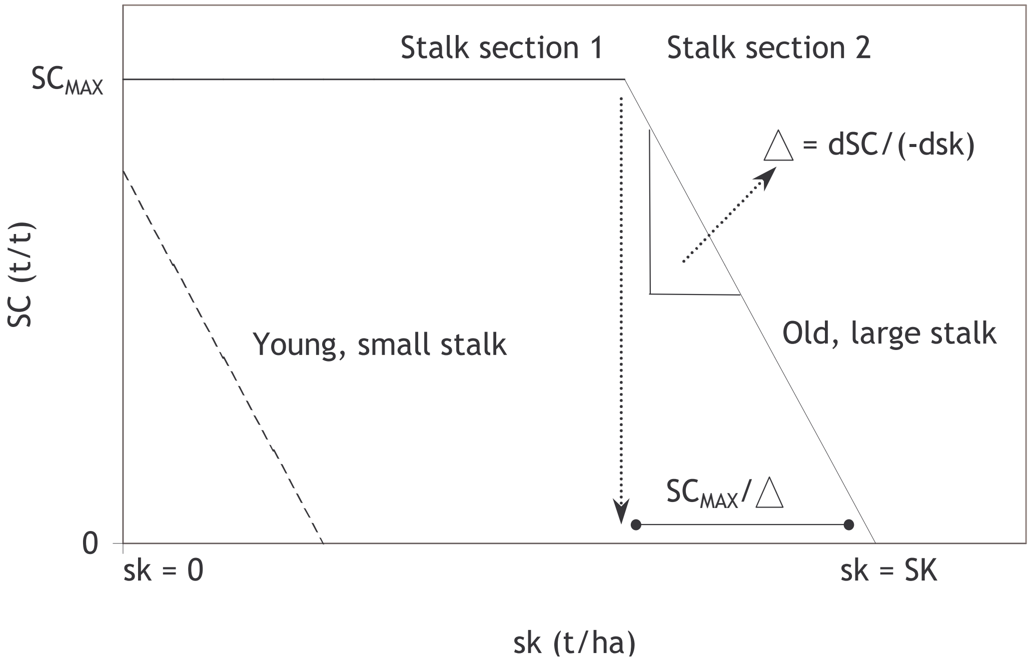

Figure 2.3. Schematic diagram of sucrose distribution within a single big stalk (SC - sucrose content, sk - cumulative stalk mass measured from the base (sk=0) to the top (sk=SK)) (from Singels & Bezuidenhout, 2002).

Sucrose accumulation response to temperature is determined by the FTCON species parameter (Table 3.1) and the TBFT cultivar parameter (Table 3.3) ; the higher the value of FTCON, the higher the sucrose partitioning response to temperature. High sucrose cultivars will tend to have higher TBFT values, reflecting their ability to partition more assimilate to sucrose at any given temperature. Sucrose partitioning response to water stress is captured in the SWDF2AMP ecotype parameter (Table 3.2).

2.4. Root growth

Root growth is expressed in terms of the extension of the rooting depth, as well as the increase of root mass and root length per soil layer. The latter, together with soil water status, determine the potential crop water uptake used to calculate the level of water stress (see section 2.5).

Root length density (RLV) is increased by converting daily biomass increments partitioned to roots (GRORT) to total root length per unit ground area (RLNEW, cm/cm^2), assuming a constant specific root length of RTcmpg (species parameter in Table 3.1, in cm/g):

$$RLNEW = GRORT * 0.0001 * RTcmpg$$

RLNEW is then apportioned to the rooted soil layers, according to the weight factors WR indicated in the soil file. It is assumed that 0.5 % of root length density (RLV) is lost each day (due to respiration and/or senescence). The value of RLV for a given layer is not allowed to be lower than the reference root length density (RLVo) for that layer. For plant crops, RLVo is initialised to a default value of 0.02 cm/cm^3 (RLVmin, a species parameter in Table 3.1) for all soil layers, while for ratoon crops it is set to 0.2 cm/cm^3 for the top soil layer and is reduced as a function of depth for deeper layers:

$$RLVo_i = 0.2 - 0.005 * [Cumdepth (i)]$$

where Cumdepth is the depth from the surface to the base of soil layer i (cm)

Daily potential increase in rooting depth is calculated assuming a 2.2 mm penetration per unit thermal time (base 16) for that day, until the maximum rooting depth is reached. Actual rooting depth increase is reduced below the potential when water stress occurs. Rooting depth is initialized at zero for a plant and "stand-alone" ratoon crop, while initial value for a ratoon crop following a preceding crop, is set to the final rooting depth of the preceding crop.

2.5. Water stress

The Canegro sugarcane model simulates the impact of water stress by regulating different plant processes (carbon assimilation, expansive growth) by different water stress factors ($SWDF_i$) according to an approach proposed by Singels & Bezuidenhout (2002). These stress factors, which represent the rate of the different processes (i) relative to the unstressed rate, are determined by potential water supply and demand using the approach of the CERES model (Jones & Kiniry, 1986) used in DSSAT 4.5 and shown below:

$$SWDF_i = f_i.\ WS_p/T_{max}\ [\text{bound by } 0.0 \leq SWDF_i \leq 1.0]$$

where f_i is a process-specific parameter, usually with a value between 0.0 and 1.0; WS_p is potential root water uptake from the soil (i.e. potential supply) and T_{max} is maximum transpiration (i.e. demand). Currently in Canegro, f_2=0.5 (the inverse of the value of the RWUEP2 species parameter in Table 3.1) for the calculation of the water stress impact on expansive growth and f_1=1.0 (Inverse of RWUEP1 = 1.) for the calculation of the impact on carbon assimilation. This implies that expansive growth rate is reduced when WS_p drops below 2 times $T_{max.}$,and carbon assimilation is reduced when WS_p drops below T_{max}. It is assumed that once WS_p/T_{max} drops below Critsw (Species parameter in Table 3.1, value of 0.2 for NCo376) , photosynthesis can only gradually recover from water stress. The thermal time taken for full recovery is specified by HuRecover (specie parameter in Table 3.1, value of 150 ^{o}Cd for NCo376.

T_{max} is calculated from the atmospheric evaporative demand (based on the FAO-56 short grass reference evaporation) modified by a crop coefficient (EORATIO species parameter with a value of 1.15, Table 3.1) and the canopy cover coefficient. The latter is calculated from leaf area index following Beer's law. .

Actual water uptake is calculated in the DSSAT water balance module following the CERES maize approach (Jones & Kiniry, 1986). The RWUMX species parameter, (Table 3.1) limits daily water transport by the sugarcane root system to a maximum value of 0.07 cm^3/cm

2.6. Lodging

The model simulates partial or full lodging of cane stalks when the mass of above-ground plant parts (fresh mass) plus the water retained on it, exceeds a cultivar-specific threshold (LG_AMBASE, the aerial mass at which lodging commences when other lodging factors such as water and wind are absent, see Table 3.3). The extent of lodging is proportional to the magnitude of the extent to which the threshold is exceeded. For NCo376, simulated lodging commences as soon as the above ground fresh plant plus water mass exceeds 220 t/ha and is completely lodged at 250 t/ha. Lodging thresholds are reduced by 7.5 t/ha when daily windrun exceeds 200 km/d or when runoff occurred, indicating a saturated topsoil. The effects of these two factors on lodging are additive. Lodging is simulated as an incremental process as each event occurs. Note: Mass of intercepted rainfall not calculated in DSSAT-Canegro v4.5

The model simulates the impact of lodged cane on the interception of radiation and on photosynthetic efficiency. These processes are reduced by 10 and 28% respectively for fully lodged cane (according to Singh *et al.*, 1999). Partially lodged cane has a proportional impact. The simulated impacts can be altered by adjusting parameters in Table 3.2 (LG_GP_REDUC, LG_FI_REDUC).

3. Cultivar, ecotype and species parameters

Although a validation workshop held in August 2007 provided some clarification regarding plant parameters, some uncertainty remains about the allocation of parameters to the species, ecotype and cultivar categories due to a lack of knowledge. The approach was to make more, rather than fewer, parameters available for adjustment by the end user and therefore the ecotype (Table 3.2) and cultivar (Table 3.3) files contain large numbers of parameters, compared to other crops. Cultivar parameters relate mainly to biomass partitioning, canopy (leaf and tiller) development and phenological phasing and these are expected to vary between cultivars. Ecotype parameters are expected to vary less with cultivars and are more difficult to adjust because data would not be readily available. Parameters for different tillering types are contained here. Species parameters (see Table 3.1) relate to photosynthesis, respiration, biomass partitioning, root growth, plant response to water stress and lodging.

Table 3.1. Species parameters for sugarcane.

Name	**Value**	**Category**	**Description**	**Reference**
Tbasephotos	7.0	Photosynthesis	Base temperature (°C) for photosynthesis	Singels *et al*., 2005
Critsw	0.2	Photosynthesis	Water stress threshold for prolonged impact from severe water stress on photosynthesis	
HuRecover	150	Photosynthesis	Thermal time required for photosynthesis to recover fully after a severe water stress event (°Cd)	
RespQ10	1.68	Photosynthesis	Fractional increase in respiration rate per 10 °C rise in temperature (Q10 coefficient)	Inman-Bamber, 1991
RespGcf	0.242	Photosynthesis	Fraction of gross photosynthesis lost to growth respiration	Inman-Bamber, 1991
PCB	0.6	Biomass partitioning	Partitioning coefficient: extinction coefficient of fraction of dry mass increments allocated to above ground biomass	Parameter 'B' in Singels & Bezuidenhout, 2002
Max_rootpf	0.95	Biomass partitioning	Maximum partition fraction of daily mass increments to roots	
FTCON	0.32	Sucrose accumulation	Temperature response shape parameter	Singels & Bezuidenhout, 2002
SURCON	0.99	Sucrose accumulation	Sucrose partitioning parameter that determines the response time of shifts in partitioning between sucrose and fibre in the stalk due to environmental changes (varies between 0 and 1)	
RTcmpg	500	Root growth	Root length per mass of roots (cm/g)	
Wrk	-0.01	Root growth	Root length density extinction coefficient by depth	
RLVmin	0.02	Root growth	Minimum root length density in soil layers (cm/cm^3)	
SenesF	5	Canopy	Number of leaves per shoot senesced per 100 stress days	
Reset	5	Canopy	Rainfall required to reset stress day counter (mm)	
Percoeff	0.16	Canopy	Fraction of plant elongation attributable to stalk elongation	Inman-Bamber, 1991
CHTCoeff	0.864	Canopy - height	Coefficient determining canopy height as a function of stalk height and number of leaves (cm/cm)	
Hillpar1	2.453	Canesim canopy	Empirical function shape parameter	Singels & Donaldson (2000)
EORATIO	1.15	Water balance	Ratio of potential ET from fully canopied unstressed sugarcane canopy to grass reference ET (Kc from FAO-56)	Allen *et al*. (1998)
RWUEP1	1	Water balance	Soil water supply/potential evaporation ratio threshold below which evaporation and photosynthesis are limited	Jones & Kiniry (1986)
RWUEP2	2	Water balance	Soil water supply/potential evaporation ratio threshold below which expansive growth is limited	Jones & Kiniry (1986)
RWUMX	0.07	Water uptake	Maximum root water uptake per unit length of root (cm^3 water/cm RLV)	Jones & Kiniry (1986), van Antwerpen (1998)
LG_RATING	8	Lodging	Lodging score when crop is fully lodged	Singels 2007 (Pers comm.)
LG_CRIT_WIND	200	Lodging	Wind run (km/d) threshold for lodging	

Table 3.2. Ecotype parameters. Parameter names shown in italics are optional depending on choice of canopy model.

Name	Value	Category	Description	Reference	Guide for determination
DELTTMAX	0.07	Sucrose accumulation	Max. change in sucrose content per unit change in stalk mass in the unripenened section of the stalk (/t)	'DELTAMAX' in Singels & Bezuidenhout, 2002	Range between .06 and 0.08. High sucrose varieties will have high value. Calibrate against irrigated seasonal sucrose curve
SWDF2AMP	0.5	Sucrose accumulation	Sucrose partitioning sensitivity to water stress parameter	‘FWCON' in Singels & Bezuidenhout, 2002	
CS_CNREDUC	0.3	Canopy - CANESIM	Maximum fractional canopy reduction due to water stress		
CS_CNPERIOD	21	Canopy - CANESIM	Water stress period required to effect maximum canopy reduction (days)		
Tthalfa	125	Canopy - CANESIM	Half canopy thermal time adjustment for row spacing (^{o}Cd/m)		
dPERdT	0.176	Canopy - height	Change in plant extension rate (mm/h) per unit change in effective temperature (^{o}C)	Originally from Inman-Bamber (1991), since adjusted	
EXTCFN	0.84	Canopy - light extinction	Maximum canopy light extinction coefficient	Inman-Bamber (1991)	See Figure 2.2
EXTCFST	0.58	Canopy - light extinction	Minimum canopy light extinction coefficient	Inman-Bamber (1991)	See Figure 2.2
LFNMXEXT	20	Canopy - light extinction	Leaf number (including dead leaves still attached) at which maximum light extinction occurs		
AREAMX_CF(1)	0	Canopy - leaves	Cultivar parameter for quadratic equation defining maximum leaf area	Inman-Bamber (1991)	Regress quadratic equation to leaf area (cm^2) vs leaf no data: $y= cf_1+cf_2*x+cf_3*x^2$
AREAMX_CF(2)	27.2	Canopy - leaves	Cultivar parameter for quadratic equation defining maximum leaf area	Inman-Bamber (1991)	
AREAMX_CF(3)	-20.8	Canopy - leaves	Cultivar parameter for quadratic equation defining maximum leaf area	Inman-Bamber (1991)	
WIDCOR	1	Canopy - leaves	Parameter affecting the width of leaves	Inman-Bamber (1991)	Used to determine area of expanding leaves
WMAX_CF(1)	-0.0345	Canopy - leaves	Cultivar parameter for quadratic equation defining max leaf width per leaf number	Inman-Bamber (1991)	Used to determine area of expanding leaves
WMAX_CF(2)	2.243	Canopy - leaves	Cultivar parameter for quadratic equation defining max leaf width per leaf number	Inman-Bamber (1991)	Used to determine area of expanding leaves
WMAX_CF(3)	7.75	Canopy - leaves	Cultivar parameter for quadratic equation defining max leaf width per leaf number	Inman-Bamber (1991)	Used to determine area of expanding leaves

Table 3.2. Ecotype parameters (continued)

Name	Value	Category	Description	Reference	Guide for determination
LMAX_CF(1)	-0.376	Canopy – leaves	Parameter for quadratic equation defining max leaf length per leaf number		
LMAX_CF(2)	12.2	Canopy – leaves	Parameter for quadratic equation defining max leaf length per leaf number		
LMAX_CF(3)	21.8	Canopy – leaves	Parameter for quadratic equation defining max leaf length per leaf number		
MAXLFLENGTH	100	Canopy – leaves	Absolute max leaf length (overrides LMAX_CF-calculated values)		
MAXLFWIDTH	3.5	Canopy – leaves	Absolute max leaf width (overrides LMAX_CF-calculated values)		
POPCF(1)	1.826	Tiller population	Stalk population coefficient, in ideal conditions (no stress), as function of thermal time		
POPCF(2)	-0.00201	Tiller population	Stalk population coefficient, in ideal conditions (no stress), as function of thermal time		
POPDECAY	0.004	Tiller population	Fraction of tillers above the future mature tiller population (at a thermal time of 1600 °Cd), that senesce per unit thermal time		Adjust by comparing simulated and observed tiller population. Varies from 0.003 to 0.005
TTBASEEM	10	Phenology	Base temperature (°C) for emergence and start of stalk elongation		
TTBASELFEX	10	Phenology	Base temperature for leaf phenology (°C)		
TTBASEPOP	16	Phenology	Base temperature for stalk phenology (°C)		
TBASEPER	10.57	Phenology	Base temperature for plant extension (°C)		
LG_AMRANGE	30	Lodging	Range in aerial mass from the start to the end of lodging (t/ha)		
LG_GP_REDUC	0.28	Lodging	Reduction in gross photosynthesis due to full lodging, as a fraction	Singh *et al.*, (1999)	
LG_FI_REDUC	0.1	Lodging	Reduction in fractional interception by the canopy due to full lodging		

Table 3.3. Cultivar parameters. Parameter names shown in italics are optional depending on choice of canopy model.

Name	**Value**	**Category**	**Description**	**Reference**	**Rough guide for determination**
PARCEmax	9.9	Biomass accumulation	Maximum (no stress) radiation conversion efficiency expressed as assimilate produced before respiration, per unit PAR. (g/MJ)	Singels *et al.*, 2005	
APFMX	0.88	Biomass accumulation	Maximum fraction of dry mass increments that can be allocated to aerial dry mass (t/t)	'ADMPFmax' in Singels & Bezuidenhout, 2002	
STKPFMAX	0.65	Biomass partitioning	Fraction of daily aerial dry mass increments partitioned to stalk at high temperatures in a mature crop (t/t on a dry mass basis)	Singels *et al.*, 2005 derived from Liu and Bull (2001)	
SUCA	0.58	Sucrose accumulation	Sucrose partitioning parameter: Maximum sucrose contents in the base of stalk (t/t)	'Scmax' in Singels & Bezuidenhout, 2002	
TBFT	25	Sucrose accumulation	Sucrose partitioning: Temperature at which partitioning of unstressed stalk mass increments to sucrose is 50% of the maximum value (^{o}C)	"T50" in Singels & Bezuidenhout, 2002	Range between 22 and 28. Early season high sucrose have high values. Calibrate against irrigated seasonal sucrose curve
Tthalfo	250	Canopy - CANESIM	Thermal time to half canopy (^{o}Cd)		Range between 200 and 300. Quick canopy variety will have low value. Calibrate against multiple data sets of canopy cover *vs* thermal time
Tbase	16	Canopy - CANESIM	Base temperature for canopy development (^{o}Cd)		Ranges between 14 and 18. Quick canopy variety will have low value. Calibrate against multiple data sets of canopy cover *vs* thermal time
LFMAX	12	Canopy – leaves	Maximum number of green leaves a healthy, adequately-watered plant will have after it is old enough to lose some leaves		
MXLFAREA	360	Canopy – leaves	Max leaf area assigned to all leaves above leaf number MXLFARNO (cm^2)	Inman-Bamber (1991)	Size of biggest leaf on primary stalk
MXLFARNO	14	Canopy – leaves	Leaf number above which leaf area is limited to MXLFAREA	Inman-Bamber (1991)	Leaf no of biggest leaf on primary stalk

Table 3.3. Cultivar parameters (continued)

Name	Value	Category	Description	Reference	Rough guide for determination
PI1	69	Leaf phenology	Phyllocron interval 1 (for leaf numbers below Pswitch, ^{o}C.d (base TTBASELFEX))	Inman-Bamber (1991)	Compare simulated and observed leaf number over thermal time
PI2	169	Leaf phenology	Phyllocron interval 2 (for leaf numbers above Pswitch, ^{o}C.d (base TTBASELFEX))	Inman-Bamber (1991)	Compare simulated and observed leaf number over thermal time
PSWITCH	18	Leaf phenology	Leaf number at which the phyllocron changes.	Inman-Bamber (1991)	Compare simulated and observed leaf number over thermal time
MAX_POP	30	Tiller phenology	Maximum tiller population (stalks/m2)		Obvious. Ranges from 20 to 80
POPTT16	13.3	Tiller phenology	Stalk population at/after 1600 degree days (/m2)		Obvious. Ranges from 7 to 15
TTPLNTEM	428	Phenology	Thermal time to emergence for a plant crop (degree C days, base TTBASEEM)		Obvious
TTRATNEM	203	Phenology	Thermal time to emergence for a ratoon crop (degree C days, base TTBASEEM)		Obvious
CHUPIBASE	1050	Phenology	Thermal time (baseTTBASEEM) from emergence to start of stalk growth	'TTskp' in Singels & Bezuidenhout, 2002	Obvious
TT_POPGROWTH	600	Phenology	Thermal time from emergence to peak tiller population (^{o}Cd, base TTBASEPOP)		Obvious. Ranges from 400 to 800.
LG_AMBASE	220	Lodging	Aerial mass (fresh mass of stalks, leaves, and water attached to them) at which lodging starts; t/ha		Ranges from 180 to 300

4. Differences between the DSSAT4.5 and DSSAT3.5 versions of the Canegro model

In effect, the DSSAT v4.5 version of Canegro differs from the DSSAT v3.5 version primarily with regard to the calculation of biomass accumulation and partitioning.

The dependence of photosynthesis and growth respiration on temperature is now accounted for (following Liu & Bull, 2001). The equations used to simulate these relationships are fully described by Singels *et al*. (2005). The DSSAT v3.5 version assumed (1) a constant photosynthetically-active radiation use efficiency, independent of temperature, and (2) growth respiration rate as a constant proportion of photosynthesis rate after subtraction of maintenance respiration, also regardless of temperature.

In the DSSAT v3.5 version of Canegro, root and stalk mass were simulated as fractions of total dry matter and aerial dry matter respectively. Partitioning of daily increments was not simulated. Sucrose content was determined empirically from crop age, time of year and irrigation (fully described by O'Leary, 2000) and applied to only one cultivar (NCo376). The approach was based on states rather than rates and was therefore incapable of simulating the changes in partitioning ratios that occur in response to environmental changes, or to cultivar characteristics.

The DSSAT v4.5 version of Canegro simulates daily partitioning of biomass increments to roots and stalk as functions of total biomass. It simulates the partitioning of stalk mass increments to stored sucrose and stalk structure using a source-sink approach. It also accounts for genotypic variation by allowing user adjustment of cultivar traits related to partitioning. See section 2.3 and Singels & Bezuidenhout (2002) for a more detailed description.

Biomass accumulation and partitioning of the DSSAT v4.5 version of the model is therefore more responsive to environmental and genotypic variation that that of the DSSAT v3.5 version. The model should provide more robust predictions of cane stalk and sucrose yields for situations where it has not been calibrated or applied before.

A slightly different method of calculating tiller senescence has also been introduced in the DSSAT v4.5 version. Originally, the model by Inman-Bamber (1991) used three empirical parameters to simulate the senescence of tillers after peak population has been reached. A new, more robust, method of simulating tiller senescence was introduced which uses only one parameter (POPDECAY). POPDECAY is defined as the tiller senescence rate per unit thermal time, expressed as the fraction of tillers above the future mature tiller population (at a thermal time of 1600 ^{o}Cd).

In terms of model implementation, the DSSAT v4.5 version of Canegro differs substantially from the DSSAT v3.5 version. The latter is a standalone model, while the DSSAT v4.5 version uses a modular approach (Cropping System Model (CSM) – Jones *et al*. (2003)), so only the plant growth and development aspects of the current SASRI Canegro model are reflected in the DSSAT v4.5 Canegro. All other model aspects are handled by common (to all crops in the DSSAT CSM) modules. This modular approach is beneficial in a number of ways, at the occasional cost of having to use common routines where Canegro-specific ones have been developed and are possibly more appropriate (see section 5 below).

5. Differences between DSSAT4.5 Canegro and the standalone SASRI Canegro

5.1. Potential evapotranspiration

The SASRI Canegro model uses a modified Penmon-Monteith algorithm (McGlinchey & Inman-Bamber, 1996) to calculate sugarcane reference evaporation directly, as opposed to the more conventional way of calculating grass reference evaporation and then applying a crop coefficient as prescribed by the FAO-56 method (Allen et. al., 1998).

The latter method is one of the options provided in DSSAT v4.5. In DSSAT v4.5, this option uses dew point as the measure of humidity, regardless of whether dew point or relative humidity is provided or not. If dew point temperature is not provided, DSSAT assumes that dew point temperature (Tdew) equals minimum temperature (Tmin), an assumption that may produce questionable estimates of reference evaporation for arid and semi-arid climates.

During our implementation of the DSSAT v4.5 Canegro model, the DSSAT CSM weather input module was modified such that it is now assumed that if a single value of humidity is provided in the weather input file, it represents maximum daily humidity, which is also assumed to occur at the coldest (Tmin) time of the day (DSSAT only allows for a single input relative humidity value per day). If dew point temperature is not provided as input, it is calculated using these humidity and temperature values following a method described by Campbell & Norman (1998).

DSSAT assumes that Tdew is equal to Tmin when relative humidity is not provided in the weather input file. In such a case, the FAO-56 method for calculating grass reference evaporation can be inaccurate when this is assumption is not valid. The Priestley-Taylor method can be specified in these situations. However, it is highly recommended that maximum relative humidity (and windspeed), or pre-determined Tdew, be included in the weather data input and that the FAO-56 method be specified.

In DSSAT v4.5, the grass reference calculated by the FAO-56 (or Priestley-Taylor) method is modified by a factor that is derived from sugarcane leaf area index (LAI) and a crop coefficient specified in the species file (EORATIO). Sugarcane potential evapotranspiration will increase by this factor as LAI increases from 0 to 6. EORATIO was calibrated by comparing evapotranspiration for ten well-watered crops simulated by the DSSAT v4.5 and SASRI (standalone) versions of Canegro.

5.2. Soil evaporation

Potential soil evaporation (EOS) is now calculated identically in the two models. EOS in DSSAT was originally calculated as a function of healthy (green) leaf area index (XHLAI). This is not a problem in most crops, as senesced leaves usually fall off the plant. With sugarcane, however, the leaf area of dead leaves attached to the stalk affects light transmission through the canopy and will therefore impact on potential soil evaporation. Hence, a new measure of leaf area index was introduced into the DSSAT CSM, namely total LAI (green plus dead). This variable is used to calculate potential soil evaporation, while healthy LAI is still maintained for calculating potential transpiration.

5.3. Runoff

SASRI Canegro uses a variable runoff curve number approach to model runoff (Schmidt & Schulze, 1987), whereas DSSAT4.5 uses a constant runoff curve number specified in the soil input file. When the curve number in DSSAT4.5 was set to the average value calculated by SASRI Canegro, minimal differences in runoff between the models were noted.

5.4. Root growth

An inconsistency in the root partitioning code in SASRI Canegro was identified and fixed. For a plant crop, root length density (RLV) is initialised in SASRI Canegro to 0.02 cm/cm^3 in all layers in the soil profile. For a ratoon crop, RLV is initialised using an exponential function (decreasing with depth), resulting in values of RLV close to zero for layers below a depth of 40 cm. In the DSSAT 4.5 Canegro this function was kept, but RLV values of below 0.02 cm/cm^3 were set equal to 0.02 cm/cm^3, for consistency. This did not affect aboveground partitioning, because no mass balance was in place. The effect of this change was to reduce overall biomass increase allocated to root system, particularly later in the season. It seems to have had little effect on model output.

5.5. Water stress in topsoil layers

Water stress is calculated in the top 30 cm of the soil profile for modelling stress effects on tiller population. In SASRI Canegro, only layers that are fully included in the top 30 cm are taken into account when calculating water stress, resulting in unintended variation in water stress calculation when compared to a soil with a different layer configuration. In DSSAT, this problem does not occur because the set soil layer configuration fits neatly into 30 cm, but the algorithm was corrected anyway, taking account of partial layers if necessary.

5.6. Tiller senescence

Originally, the model by Inman-Bamber used three empirical parameters to simulate the senescence of tillers after peak population has been reached. A new more robust method of simulating tiller senescence was introduced which uses only one parameter (POPDECAY). POPDECAY is the defined as the tiller senescence rate per unit thermal time, expressed as the fraction of tillers above the future mature tiller population (at a thermal time of 1600 ^{o}Cd).

6. Remaining coding issues that need attention

6.1. LAI calculation with the Canesim option for canopy development

The back calculation of leaf area index from fractional interception (FI) as simulated with the Canesim canopy option (see section 2.2.1) needs further refinement. The method estimates green LAI (GLAI). Total LAI (TLAI) was set equal to GLAI for the interim. This will have an impact on soil evaporation and transpiration, as TLAI is used to determine potential soil evaporation and the crop coefficient that related relates potential sugarcane transpiration to potential transpiration from a grass crop. Soil evaporation is expected to be slightly higher than that simulated with the Canegro canopy option, while transpiration is expected to be slightly lower. This will be addressed in a future release by estimating TLAI from GLAI and total and dead leaf number.

6.2. Root growth

We believe that in the model, roots penetrate the soil (in depth) far too quickly in plant crops. This has a limited effect because root length density (RLV)) increases at a realistic rate and water uptake is affected much more by RLV than by rooting depth. While the RLV error has been corrected (see 5.4), the root depth coding error has not yet been corrected in DSSAT4.5.

7. Model validation

7.1. Introduction

DSSAT-Canegro behaves differently to the stand-alone Canegro as a result of differences in non-plant routines, such as the water balance, so it is important to establish the usefulness of the new model by evaluating its performance against measured data.

Validation involves the comparison of simulated and measured data for certain variables. The differences are described statistically. This provides a measure of the accuracy of the model, which feeds into the decision making process where the model is applied. It should be noted that these validations were performed with no calibration of model parameters (except the reference evaporation crop coefficient, EORATIO) since the incorporation of the Canegro model into DSSAT (i.e. parameter values are the same as a those used in SASRI Canegro). It is possible that calibration of species/cultivar parameters may be required as a result of interactions between the plant growth and development routines and (different to Canegro) features of the DSSAT water balance.

The statistical parameters used for quantifying model performance are:

- the coefficient of determination (R^2),
- slope and intercept of the linear regression between simulated and observed values,
- root mean square error (RMSE). The error in RMSE refers to the difference between the simulated and observed value.
- the average difference between simulated and observed values (APE).

7.2. Validation data sets

Two South African experiments have been chosen, namely (1) a dryland experiment conducted at La Mercy, South Africa (described by Inman-Bamber, 1994a, b) and (2) an irrigated experiment conducted in Pongola, South Africa (described by Rostron, 1972 and Inman-Bamber, 1994b).

7.2.1 La Mercy experiment

The Agrowth7 trial (dryland) was conducted at La Mercy (29^{o} 34'S, 30^{o} 8'E) in coastal Kwazulu-Natal, South Africa. Cultivar NCo376 was ratooned and harvested at 8 different dates (Table 7.1) during the period from 1989 to 1991. Row spacing was 1.2 m. (DSSAT4.5 experiment name - SATO8902). Soil profile information is listed in Table 7.2. It should be noted that the soil was somewhat difficult to describe, and can be considered a fairly ‘extreme’ soil in terms of clay content. Initial soil moisture conditions were assumed to be 50% of available water content.

Table 7.1. Trial treatments

Treatment	Crop type	Start	Harvest	Harvest Age (days)
1	Ratoon	01 Jun 1989	02 Oct 1990	488
2	Ratoon	01 Aug 1989	05 Dec 1990	491
3	Ratoon	01 Oct 1989	05 Feb 1991	492
4	Ratoon	01 Dec 1989	03 Apr 1991	488
5	Ratoon	01 Feb 1990	04 Jun 1991	488
6	Ratoon	01 Apr 1990	31 Jul 1991	486
7	Ratoon	01 Jun 1990	01 Oct 1991	487
8	Ratoon	01 Aug 1990	03 Dec 1991	489

Table 7.2. Soil profile information

Layer thickness	Lower limit (cm^3/cm^3)	Drained upper limit (cm^3/cm^3)	Saturated water content (cm^3/cm^3)	Rooting weight	Bulk density (g/cm^3)	Saturated water conductivity cm/h
5	0.102	0.255	0.387	1.0	1.3	0.8
10	0.102	0.255	0.329	0.8	1.61	0.8
15	0.102	0.237	0.316	0.7	1.63	0.8
15	0.131	0.228	0.319	0.6	1.59	0.8
15	0.132	0.238	0.345	0.5	1.48	0.7
15	0.142	0.258	0.359	0.45	1.46	0.6
15	0.221	0.329	0.390	0.40	1.48	0.5
15	0.307	0.349	0.385	0.37	1.56	0.5
15	0.346	0.375	0.391	0.35	1.6	0.5
45	0.357	0.405	0.413	0.32	1.56	0.05

7.2.2 Pongola experiment

The AgrowthHR trial was conducted in Pongola (27°24'S, 31°35'E) in Northern Kwazulu-Natal, South Africa from 1967 to 1970. Cultivar NCo376 was ratooned and harvested at 8 different times (Table 7.3). Row spacing was 1.5 m and crops were irrigated to avoid water stress. Soil profile information is listed in Table 7.4. Initial soil moisture conditions were assumed to be 50% of available water content. (DSSAT4.5 experiment name- SXPG6801).

Table 7.3. Trial treatments

Treatment	Crop type	Start	Harvest	Harvest age (days)
1	Ratoon	17 Dec 1968	05 May 1970	504
2	Ratoon	11 Feb 1969	30 Jun 1970	504
3	Ratoon	08 Apr 1969	25 Aug 1970	504
4	Ratoon	03 Jun 1969	20 Oct 1970	504
5	Ratoon	29 Jul 1969	15 Dec 1970	504
6	Ratoon	23 Sep 1969	09 Feb 1971	504
7	Ratoon	18 Nov 1969	06 Apr 1971	504
8	Ratoon	13 Jan 1970	29 May 1971	501

Table 7.4. Soil profile information

Layer thickness	Lower limit (cm^3/cm^3)	Drained upper limit (cm^3/cm^3)	Saturated water content (cm^3/cm^3)	Rooting weight	Bulk density (g/cm^3)
5	0.101	0.261	0.368	1.0	1.39
12	0.101	0.261	0.368	0.82	1.39
15	0.101	0.261	0.368	0.64	1.39
15	0.160	0.282	0.371	0.47	1.43
15	0.160	0.282	0.371	0.35	1.43
30	0.151	0.304	0.399	0.22	1.34
30	0.151	0.304	0.399	0.12	1.34
30	0.151	0.304	0.399	0.07	1.34
30	0.151	0.304	0.399	0.03	1.34
90	0.151	0.304	0.399	0.01	1.34

Note: Saturated hydraulic conductivity per layer is unknown for this soil; the soil is classified as draining 'moderately well' in the DSSAT Sbuild program, which corresponds with an overall profile drainage rate of 0.4 $cm.h^{-1}$.

7.3. Results

7.3.1 La Mercy experiment

Simulated and observed values of aerial dry mass, stalk dry mass, sucrose mass and leaf area index are compared in Figures 7.1 to 7.4. Corresponding statistical comparisons are given in Tables 7.5 to 7.8.

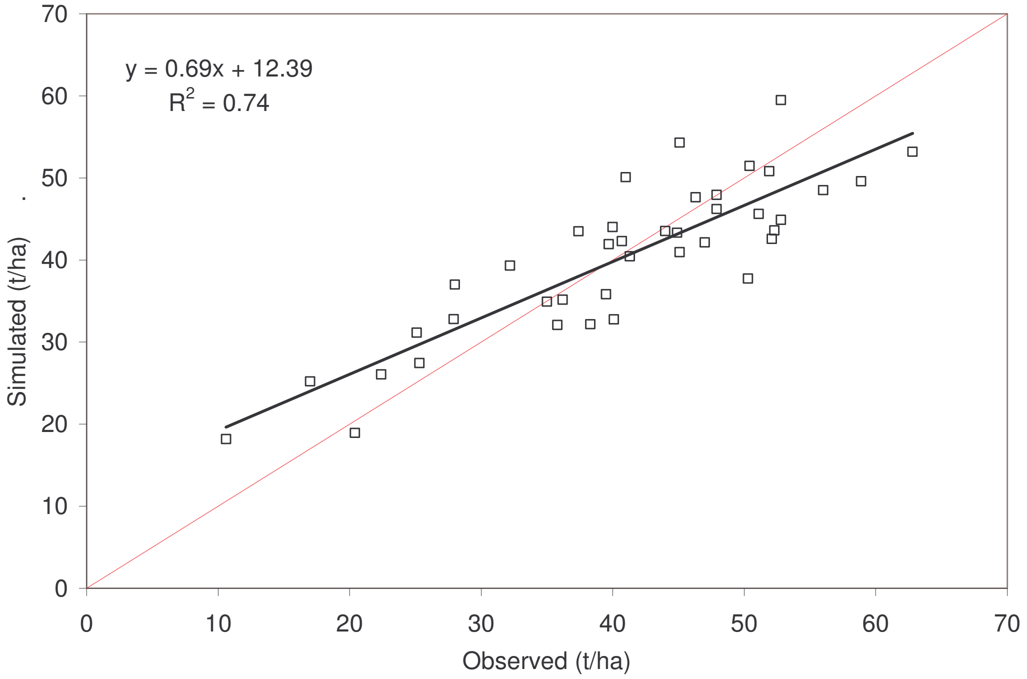

Figure 7.1. Simulated and observed aerial dry mass for the La Mercy experiment.

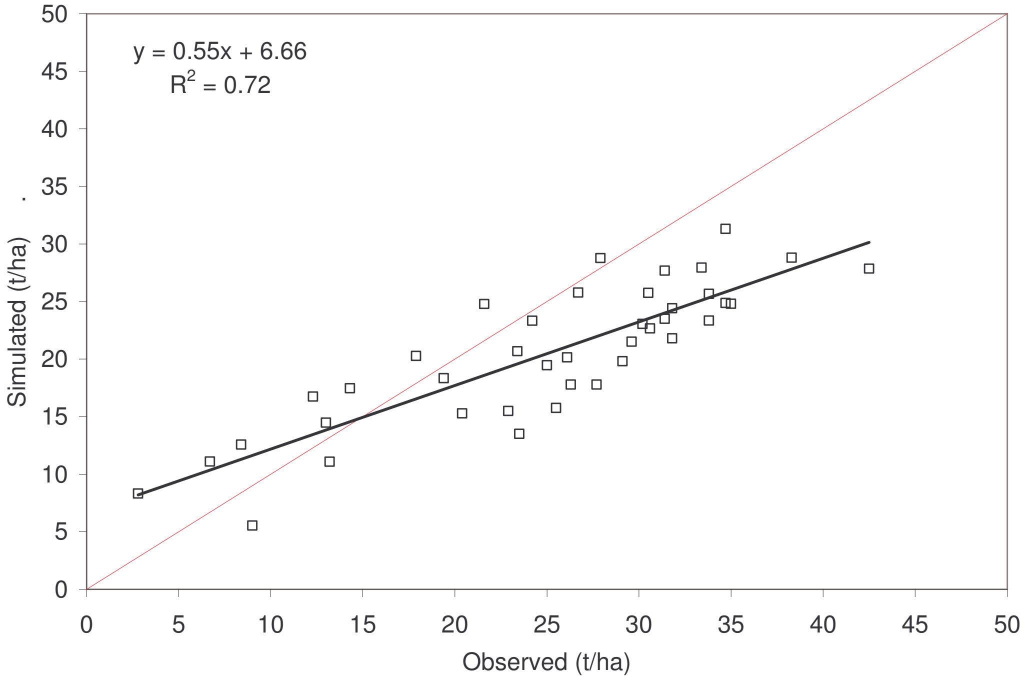

Figure 7.2. Simulated and observed stalk dry mass for the La Mercy experiment.

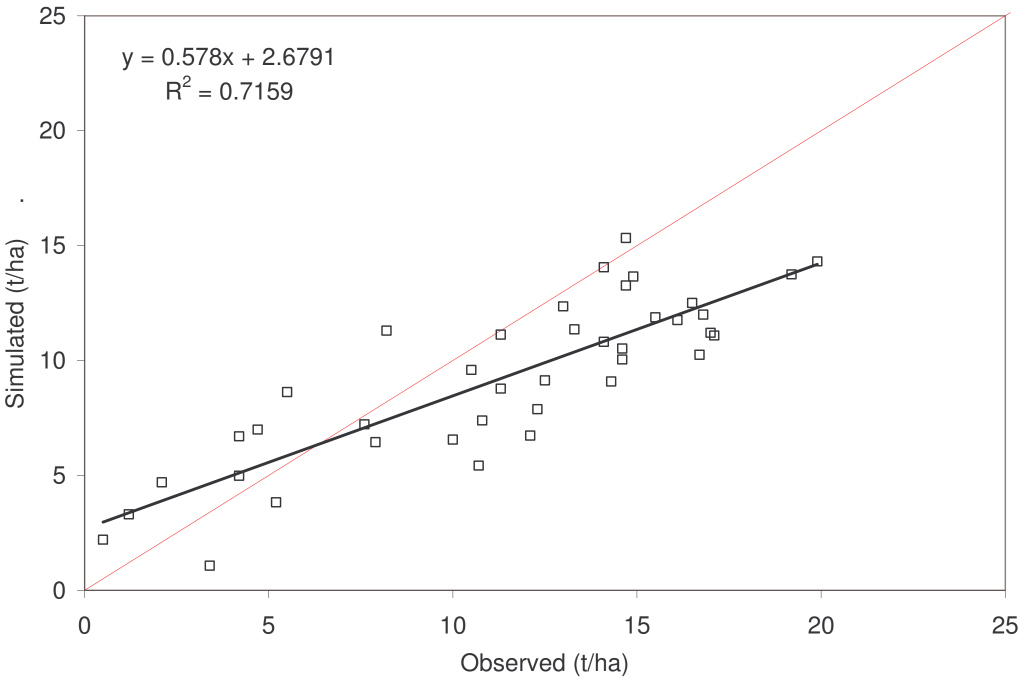

Figure 7.3. Simulated and observed sucrose mass for the La Mercy experiment.

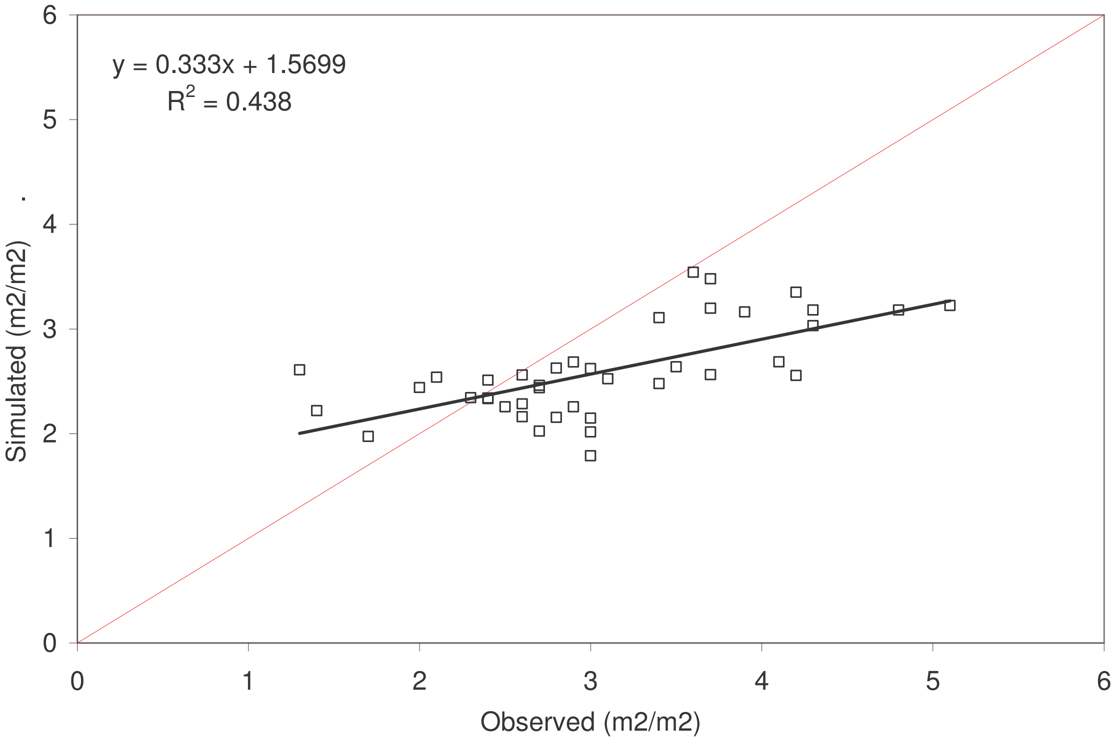

Figure 7.4. Simulated and observed green leaf area index (m^2/m^2) for the La Mercy experiment.

Table 7.5. Validation statistics for aerial biomass (t/ha) for La Mercy experiment

Trt	APE%	APE	RMSE%	RMSE	R^2	No of obs	Mean Observed	Mean Simulated	Ratio
1	-8.94	-3.74	14.73	6.17	0.98	5	41.86	38.12	0.91
2	4.27	1.70	12.53	4.99	0.47	5	39.86	41.56	1.04
3	-7.22	-3.04	9.76	4.11	0.94	5	42.14	39.10	0.93
4	0.03	0.01	9.49	4.17	0.89	5	43.98	43.99	1.00
5	-13.48	-5.79	18.40	7.90	0.95	5	42.96	37.17	0.87
6	5.81	2.09	18.33	6.60	0.93	5	35.98	38.07	1.06
7	8.15	3.04	15.44	5.76	0.91	5	37.32	40.36	1.08
8	4.73	2.01	16.57	7.06	0.35	5	42.60	44.61	1.05
Pooled	*-1.14*	*-0.46*	*14.65*	*5.98*	*0.74*	*40*	*40.84*	*40.37*	*0.99*

Table 7.6. Validation statistics for stalk dry mass (t/ha) for La Mercy experiment

Trt	APE%	APE	RMSE%	RMSE	R^2	No of obs	Mean Observed	Mean Simulated	Ratio
1	-19.19	-4.86	29.32	7.42	0.99	5	25.30	20.44	0.81
2	-18.11	-4.47	24.68	6.09	0.56	5	24.68	20.21	0.82
3	-26.99	-7.35	27.78	7.57	0.86	5	27.24	19.89	0.73
4	-24.73	-6.97	25.95	7.32	0.92	5	28.20	21.23	0.75
5	-31.65	-8.06	36.52	9.31	0.98	5	25.48	17.42	0.68
6	-0.06	-0.01	26.93	5.73	0.93	5	21.28	21.27	1.00
7	-5.61	-1.25	20.40	4.53	0.93	5	22.22	20.97	0.94
8	-12.85	-3.31	23.30	6.00	0.41	5	25.76	22.45	0.87
Pooled	*-18.13*	*-4.54*	*27.51*	*6.88*	*0.72*	*40*	*25.02*	*20.48*	*0.82*

Table 7.7. Validation statistics for sucrose mass (t/ha) for La Mercy experiment

Trt	APE%	APE	RMSE%	RMSE	R^2	No of obs	Mean Observed	Mean Simulated	Ratio
1	-20.60	-2.38	33.97	3.92	0.98	5	11.54	9.16	0.79
2	-21.19	-2.43	28.99	3.33	0.69	5	11.48	9.05	0.79
3	-27.20	-3.35	30.19	3.72	0.64	5	12.32	8.97	0.73
4	-23.78	-3.02	28.33	3.59	0.79	5	12.68	9.66	0.76
5	-27.95	-2.90	31.20	3.24	0.96	5	10.38	7.48	0.72
6	0.96	0.09	33.68	3.21	0.87	5	9.54	9.63	1.01
7	-6.49	-0.66	30.93	3.13	0.88	5	10.12	9.46	0.94
8	-17.30	-2.18	32.00	4.03	0.49	5	12.60	10.42	0.83
Pooled	*-18.56*	*-2.10*	*31.21*	*3.54*	*0.72*	*40*	*11.33*	*9.23*	*0.81*

Table 7.8. Validation statistics for green leaf area index (m^2/m^2) for La Mercy experiment

Trt	APE%	APE	RMSE%	RMSE	R^2	No of obs	Mean Observed	Mean Simulated	Ratio
1	-21.94	-0.70	24.03	0.77	0.74	5	3.20	2.50	0.78
2	-5.43	-0.16	14.54	0.42	0.80	5	2.90	2.74	0.95
3	-9.71	-0.28	14.20	0.41	0.66	5	2.86	2.58	0.90
4	-10.28	-0.30	13.63	0.40	0.64	5	2.90	2.60	0.90
5	-32.88	-1.25	35.55	1.35	0.63	5	3.80	2.55	0.67
6	-15.28	-0.47	24.94	0.77	0.54	5	3.10	2.63	0.85
7	-22.64	-0.73	31.42	1.02	0.92	5	3.24	2.51	0.77
8	2.74	0.07	34.32	0.88	0.60	5	2.56	2.63	1.03
Pooled	*-15.56*	*-0.48*	*26.56*	*0.82*	*0.44*	*40*	*3.07*	*2.59*	*0.84*

7.3.2 Pongola experiment

Simulated and observed values of stalk dry mass and sucrose massfor the Pongola experiment are compared in Figure 7.5 and 7.6. Statistical comparisons are given in Tables 7.9 and 7.10.

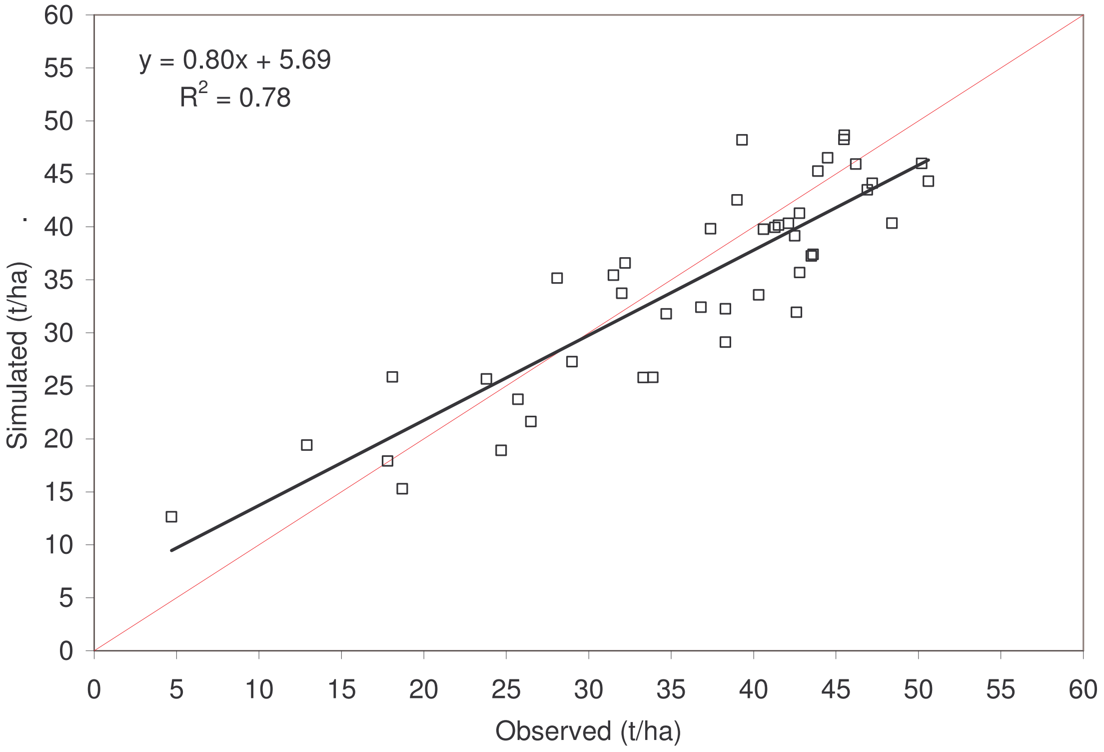

Figure 7.5. Simulated and observed stalk dry mass for Pongola experiment.

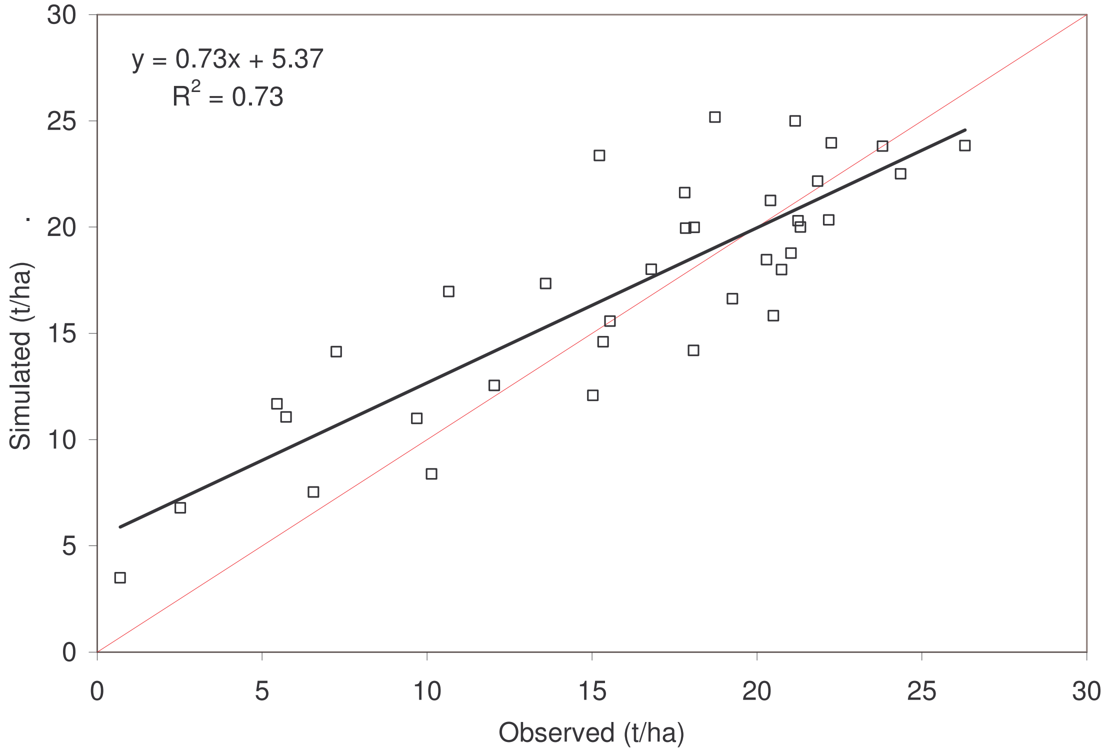

Figure 7.6. Simulated and observed sucrose mass for Pongola experiment.

Table 7.9. Validation statistics for stalk dry mass for Pongola experiment.

Trt	APE%	APE	RMSE%	RMSE	R^2	No of obs	Mean Observed	Mean Simulated	Ratio
1	-5.05	-1.75	17.69	6.13	0.79	5	34.64	32.89	0.95
2	2.36	0.82	8.25	2.87	0.95	6	34.75	35.57	1.02
3	12.92	3.72	19.19	5.52	0.96	6	28.76	32.48	1.13
4	-1.18	-0.42	13.91	4.95	0.93	5	35.62	35.20	0.99
5	-11.41	-4.86	14.26	6.07	0.51	5	42.56	37.71	0.89
6	-11.44	-4.69	15.97	6.55	0.65	6	41.02	36.33	0.89
7	-6.84	-2.62	12.24	4.69	0.94	6	38.27	35.65	0.93
8	-6.72	-2.26	10.30	3.47	0.95	5	33.66	31.40	0.93
Pooled	*-3.97*	*-1.43*	*14.31*	*5.17*	*0.78*	*44*	*36.12*	*34.69*	*0.96*

Table 7.10. Validation statistics for sucrose mass for Pongola experiment.

Trt	APE%	APE	RMSE%	RMSE	R^2	No of obs	Mean Observed	Mean Simulated	Ratio
1	12.18	1.87	29.64	4.56	0.66	6	15.39	17.26	1.12
2	7.52	1.23	15.29	2.49	0.91	6	16.30	17.52	1.08
3	22.33	2.85	30.62	3.91	0.90	6	12.76	15.61	1.22
4	10.04	1.52	23.23	3.51	0.91	6	15.13	16.65	1.10
5	-0.17	-0.03	16.26	2.87	0.79	6	17.62	17.59	1.00
6	-6.79	-1.32	16.13	3.13	0.60	6	19.41	18.09	0.93
7	0.51	0.09	15.54	2.72	0.88	6	17.49	17.58	1.01
8	-3.81	-0.64	10.44	1.75	0.95	6	16.75	16.11	0.96
Pooled	*4.26*	*0.70*	*19.70*	*3.22*	*0.74*	*48*	*16.35*	*17.05*	*1.04*

7.4. Discussion

Although overall model performance was reasonable, the model consistently underestimated high values of green LAI, stalk mass and sucrose mass at La Mercy. Aerial dry mass at La Marcy was calculated accurately, as was stalk dry mass and sucrose mass at Pongola. As can be expected, simulation accuracy was best for aerial dry mass, followed by stalk dry mass and then sucrose mass. The accuracy achieved for this validation (RMSE values for stalk dry matter of 6.88 and 5.17 t/ha for the La Mercy and Pongola experiments respectively, and RMSE values for sucrose mass of 3.54 and 3.22 t/ha for the La Mercy and Pongola experiments respectively) is better than that quoted by O'Leary (2000) for the same data sets (RMSE value of 11.11 t.ha for stalk dry mass and 6.07 t/ha for sucrose mass respectively). Simulation accuracy also compares well with that found in a more comprehensive validation conducted by Singels & Bezuidenhout (2002). They found RMSE values for aerial dry mass, stalk dry mass and sucrose mass predictions of 6.94, 5.48 and 2.6 t/ha respectively.

Further investigation is required to identify reasons for the simulation bias observed for the La Mercy experiment. The soil input used indicates a poorly drained soil with very low conductivity in the bottom layer. This amounts to the presence of a water table most of time, the impacts of which are difficult to simulate.

7.5. Performance comparison of DSSAT v3.5 and v4.5 versions of Canegro

Simulations by the DSSAT v3.5 and DSSAT v4.5 versions of Canegro are compared with observed values in Figures 7.7 to 7.10. In the following graphs, mean values are displayed. In each season, measurements were taken on a number of occasions. The observed and simulated values on these days have been averaged and plotted.

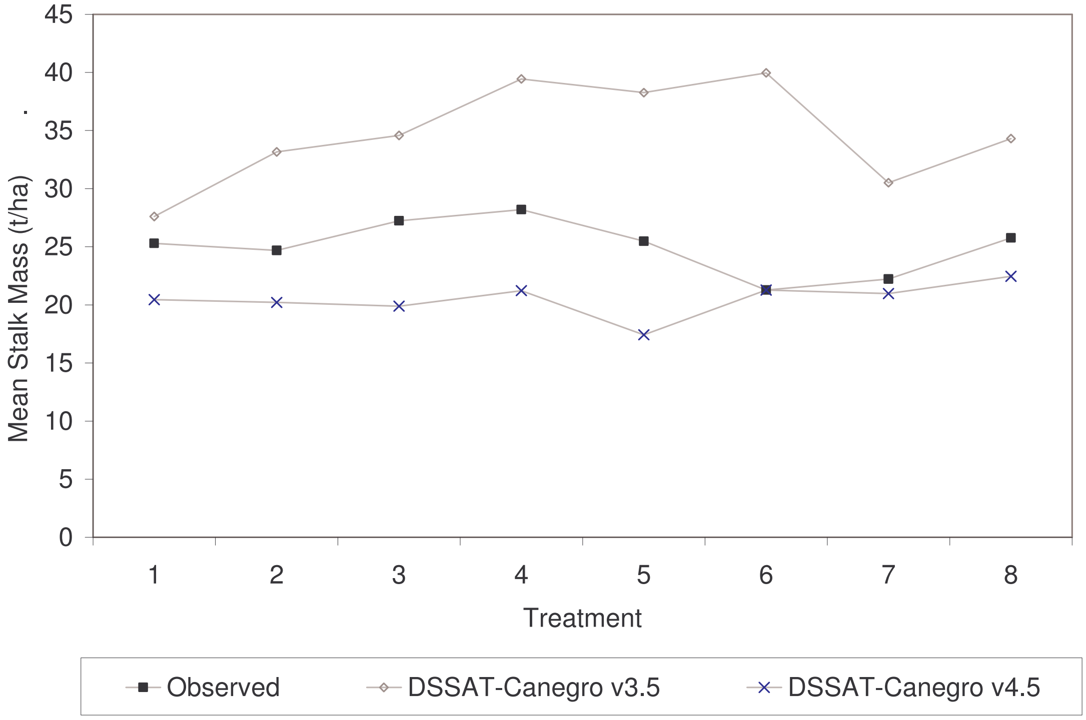

Figure 7.7. Mean stalk mass (t/ha) per treatment, simulated and observed, La Mercy 1989-90.

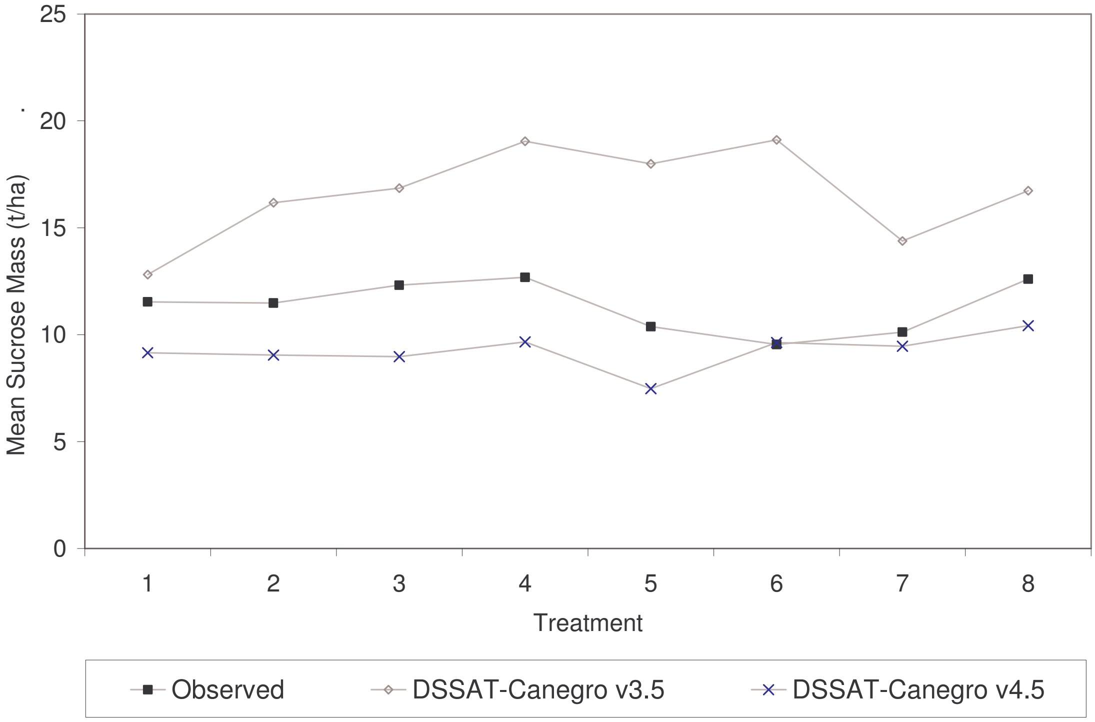

Figure 7.8. Mean sucrose mass (t/ha) per treatment, simulated and observed, La Mercy 1989-90.

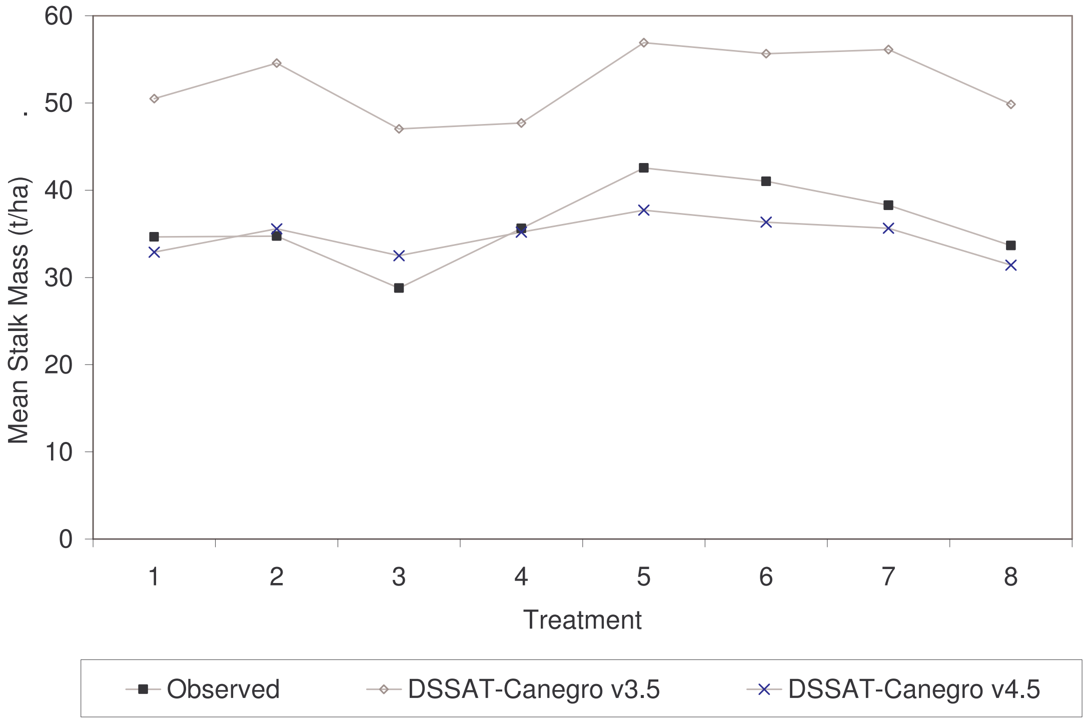

Figure 7.9. Mean stalk dry mass (t/ha), per treatment, simulated and observed, Pongola 1968-70.

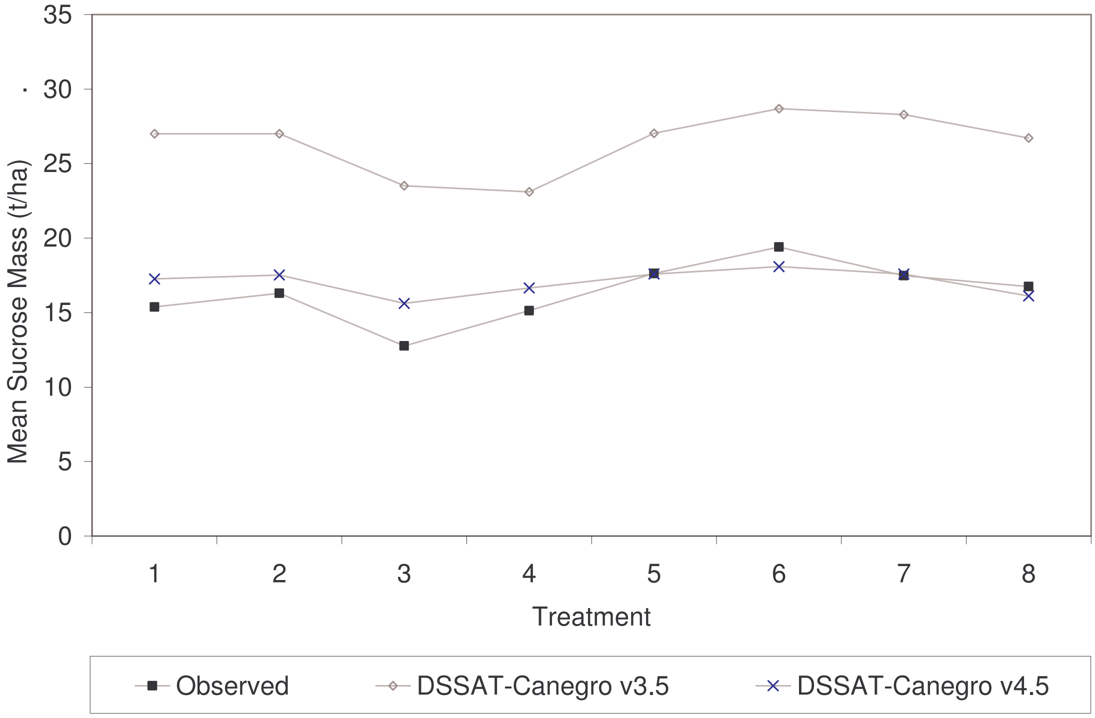

Figure 7.10. Sucrose mass (t/ha), per treatment, simulated and observed, Pongola 1968-70.

The DSSAT v4.5 version of Canegro appears to perform substantially better, overall, than the DSSAT v3.5 version. While absolute yields are closer to reality with DSSAT v4.5, DSSAT v3.5 appears to respond slightly better to seasonal variations.

8. Conclusions

An up-to-date version of Canegro with enhanced capabilities (temperature-dependent photosynthesis and radiation, source-sink approach to biomass partitioning, lodging and an option for thermal time driven canopy development) was incorporated successfully into DSSAT v4.5. A number of species, ecotype and cultivar parameters were defined and the latter are accessible to users for calibration of new genotypes. It is expected that the number of parameters will be reduced significantly as new insights are gained with respect to their impact on crop growth and the actual genotypic variability that exist in associated traits. Parameters for five ecotypes and seven real and three hypothetical cultivars are provided with the software.

The new code was verified by comparing the output of the DSSAT v4.5 version of the Canegro model with that of the SASRI stand-alone version. For well-watered scenarios the output was almost identical, while small discrepancies existed for water limited scenarios. The sources of these discrepancies were traced to differences in calculation methods in modules outside the plant module, such as reference evapotranspiration. The discrepancies were deemed acceptable.

The new model was validated by comparing simulated values with observation of LAI, aerial dry mass, stalk dry mass and sucrose mass for two South African experiment (irrigated and rainfed). The overall performance of the model was highly satisfactory and was better than that of the DSSAT3.5 version, although there was systematic under-estimation of high values of LAI, stalk dry mass and sucrose mass for the dryland experiment.

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