Process-level comparison of approaches to simulating environmental and genetic effects

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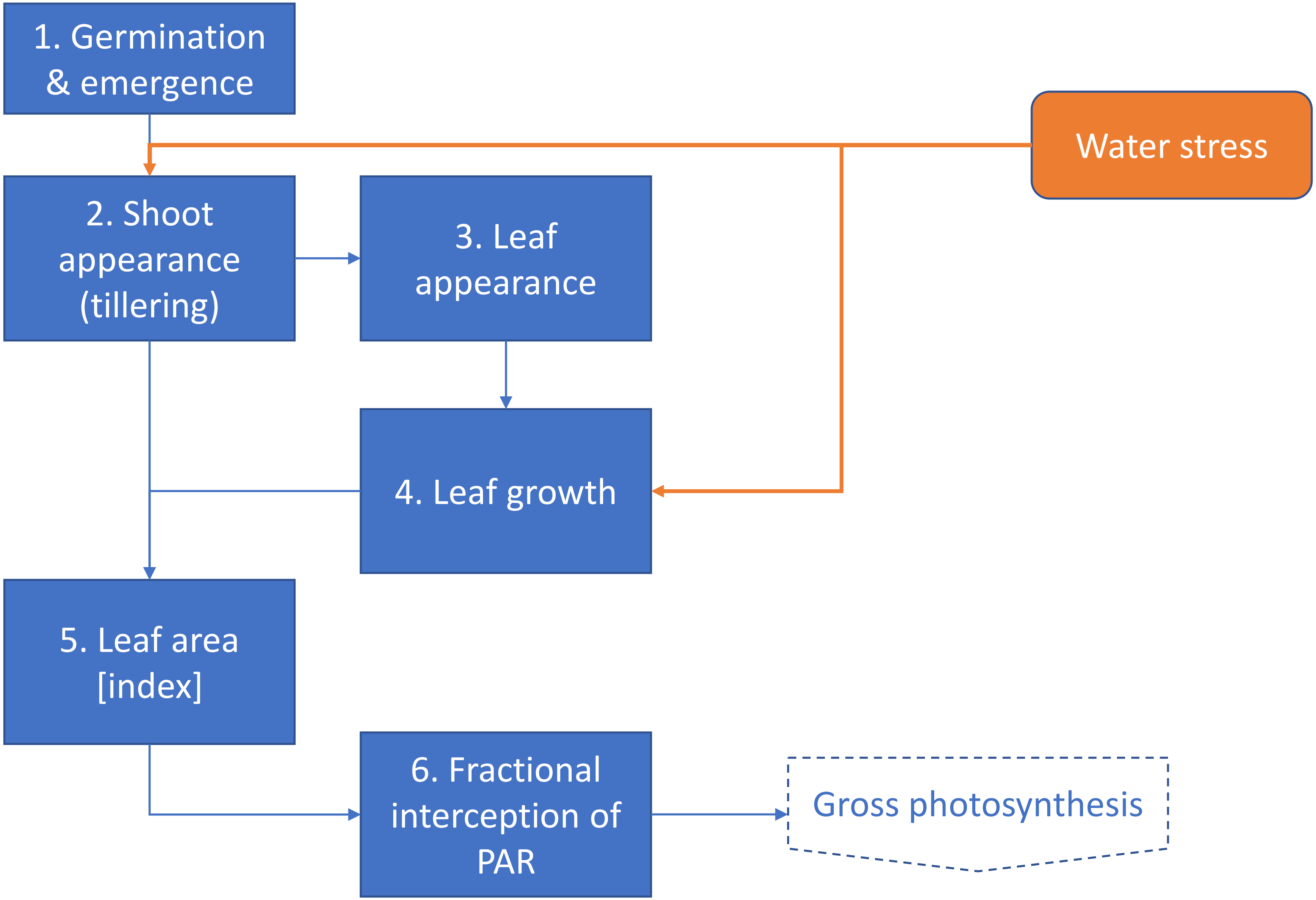
DSSAT-Canegro model structure

Canegro process structure: crop development



1. Germination & emergence

2. Shoot appearance (tillering)

3. Leaf appearance

4. Leaf growth

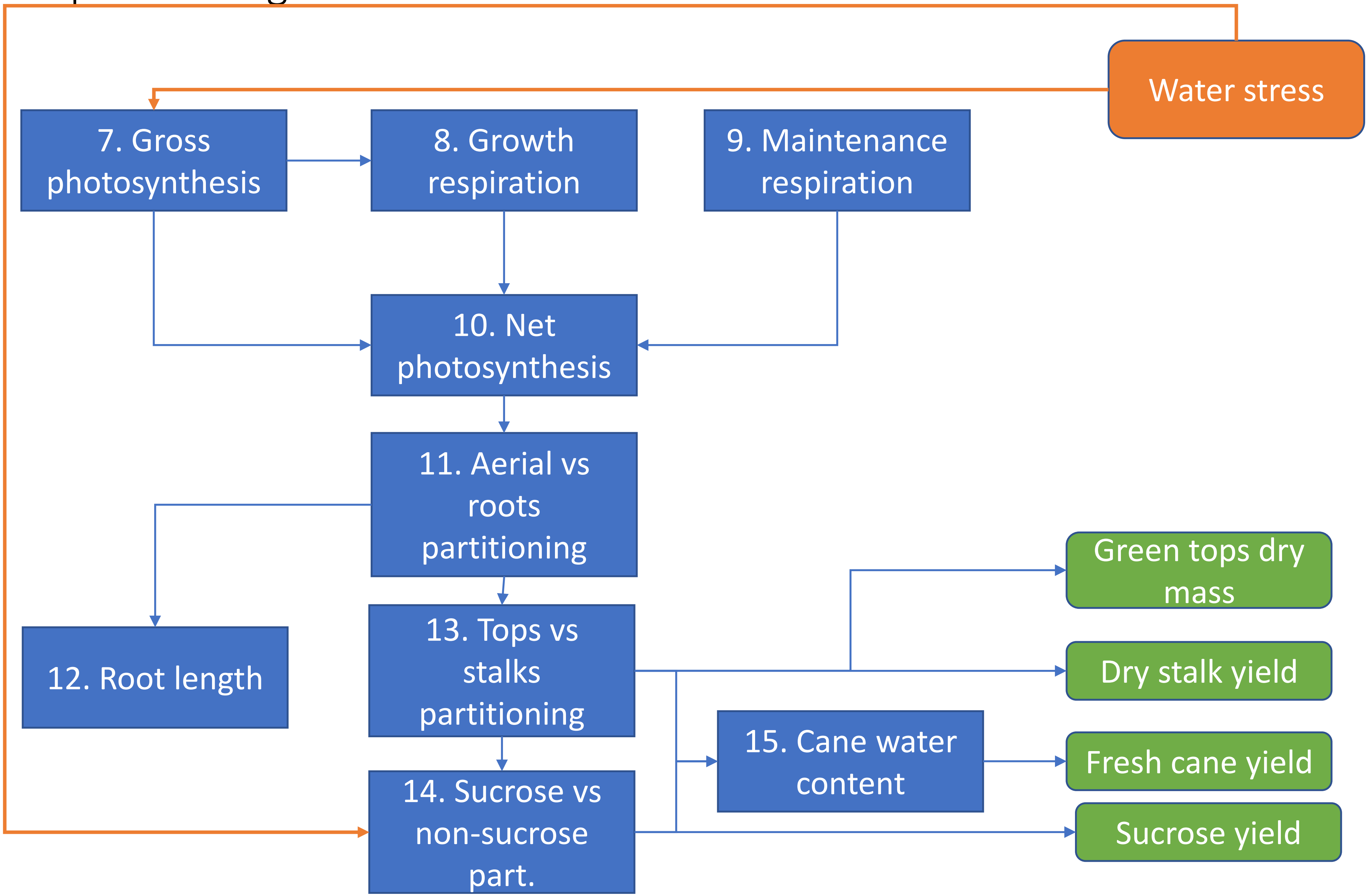
5. Leaf area [index]

6. Fractional interception of PAR

Water stress

Gross photosynthesis

Canegro process structure: biomass accumulation and partitioning


Water stress

7. Gross photosynthesis

8. Growth respiration

9. Maintenance respiration

10. Net photosynthesis

11. Aerial vs roots partitioning

12. Root length

13. Tops vs stalks partitioning

14. Sucrose vs non-sucrose part.

15. Cane water content

Green tops dry mass

Dry stalk yield

Fresh cane yield

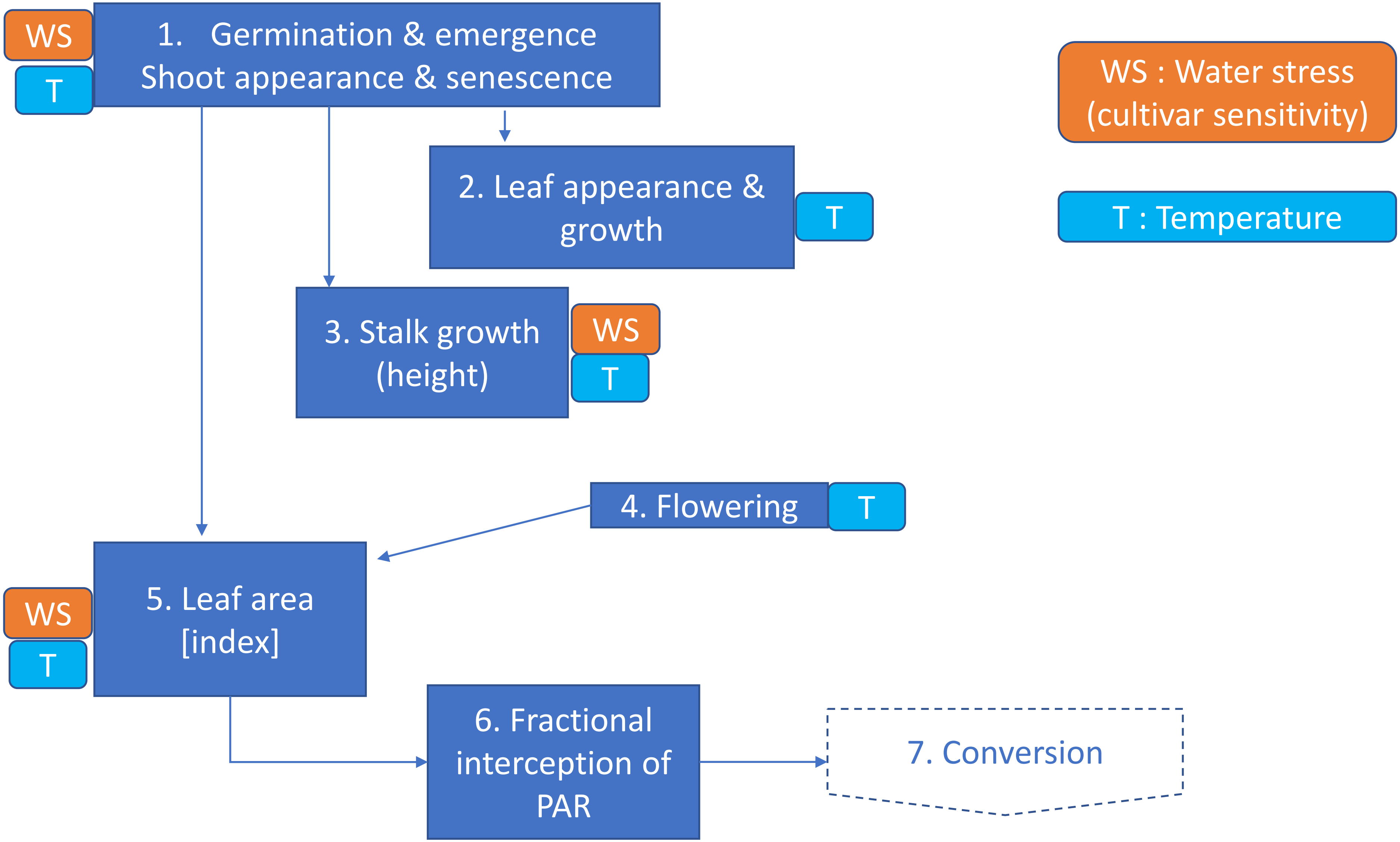
Sucrose yield

DSSAT-Canegro parameterisation philosophy

- Crop development (timing, LAI, canopy cover) should be calibrated first.
- Then consider changing RUE (ParceMax), but within a narrow range (5-10% of default value)
- Division of parameters between species, ecotype and cultivar files.
- Development versions of Canegro usually have more cultivar params.
- There are about 25 cultivar parameters that can be changed, in practice about half of these might be modified.
- Some params are effectively lookup functions.
- Quadratic parameters are very difficult to calibrate, so usually ignored.

Mosicas process summary

Process structure: crop development Mosicas



WS

T

1. Germination & emergence
Shoot appearance & senescence

2. Leaf appearance & growth

T

3. Stalk growth (height)

WS

T

4. Flowering

T

WS

T

5. Leaf area [index]

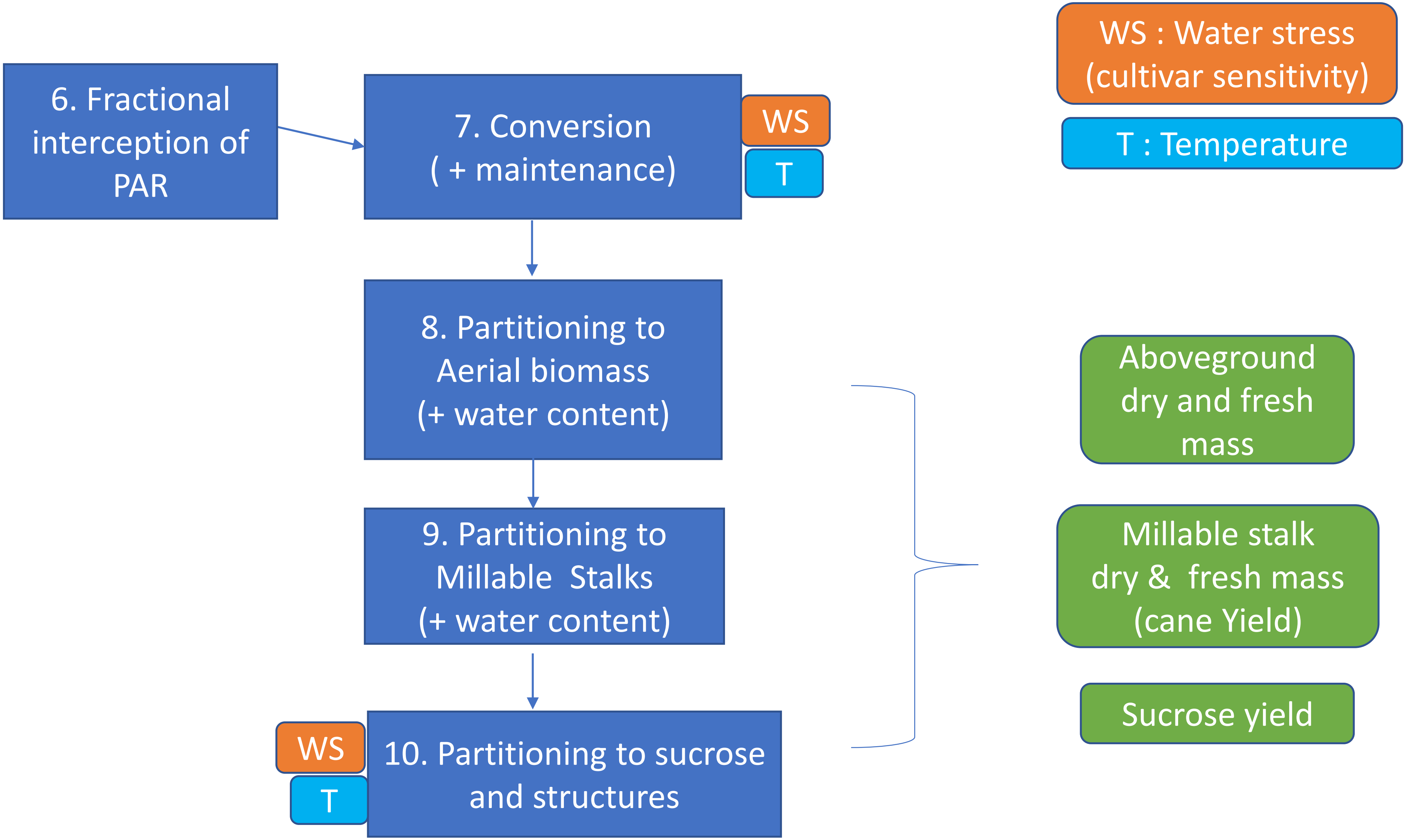
6. Fractional interception of PAR

7. Conversion

WS : Water stress (cultivar sensitivity)

T : Temperature

Process structure: biomass accumulation and partitioning Mosicas



WS : Water stress (cultivar sensitivity)

T : Temperature

6. Fractional interception of PAR

7. Conversion (+ maintenance)

WS

T

8. Partitioning to Aerial biomass (+ water content)

9. Partitioning to Millable Stalks (+ water content)

WS

T

10. Partitioning to sucrose and structures

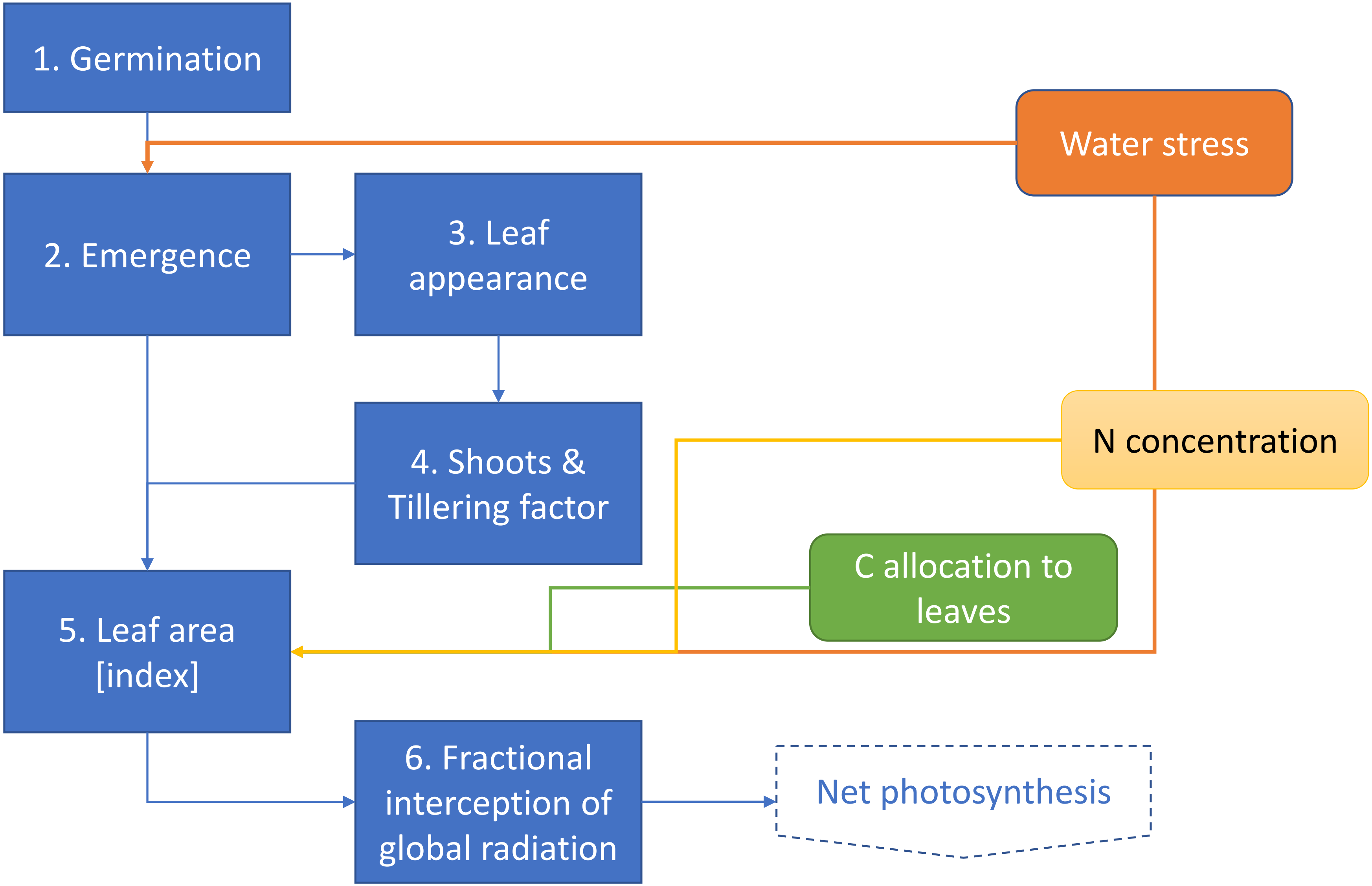
Aboveground dry and fresh mass

Millable stalk dry & fresh mass (cane Yield)

Sucrose yield

APSIM-Sugar process summary

APSIM process structure: crop development



1. Germination

2. Emergence

3. Leaf appearance

4. Shoots & Tillering factor

5. Leaf area [index]

6. Fractional interception of global radiation

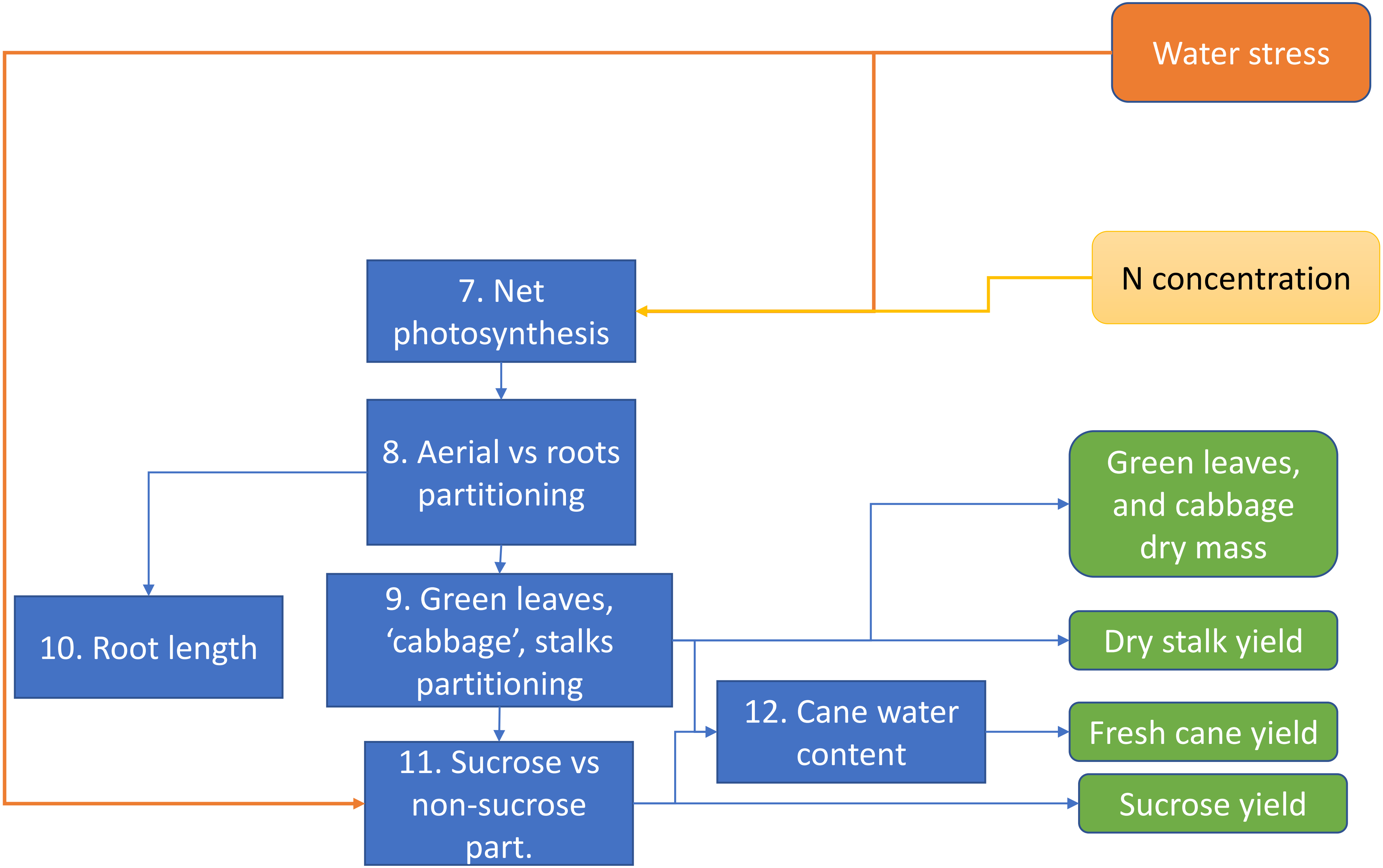
Water stress

N concentration

C allocation to leaves

Net photosynthesis

Canegro process structure: biomass accumulation and partitioning



Water stress

N concentration

7. Net photosynthesis

8. Aerial vs roots partitioning

9. Green leaves, 'cabbage', stalks partitioning

10. Root length

11. Sucrose vs non-sucrose part.

12. Cane water content

Green leaves, and cabbage dry mass

Dry stalk yield

Fresh cane yield

Sucrose yield

APSIM Parameter value philosophy

- **RUE** is “like the speed of light” (P. Thorburn) – should not be changed for sugarcane cultivars.
- A large number of model parameters are specified.
- A **small number (+-10)** of model parameters are specified / overridden **per cultivar**.
- **Plant and ratoon** crops appear as different cultivars in the xml file.
- Many parameters are specified as **lookup table parameters** – i.e. a set of x values (e.g. leaf number) and a set of y values (e.g. max leaf area). MUCH easier to work with than e.g. quadratic coeffs.
- Emphasis on parameters being **measurable**. E.g. soil kL (fraction of soil water content that can be taken up by roots each day) can be measured, but measuring k (soil conductivity) and ‘L’ (root water conductivity) by themselves is more difficult.

Process comparison summary: crop development

Process	DSSAT-Canegro	Mosicas	APSIM-Sugar
Germination & emergence	Thermal time	Thermal time	Thermal time delay; soil water content; shoot elongation from depth
Shoot population	Primary shoots with secondary shoots, driven by thermal time, limited by SWC. Shoots are assigned to cohorts with independent timing.	No effect	Primary shoot population = “seed” density. Leaf number-driven tillering factor adjusts LAI.
Leaf appearance	Phyllocron intervals (thermal time)	No effect.	Phyllocron interval lookup function (thermal time)
Leaf area	Leaf growth determined by temperature and water stress, limited by leaf size profile. Summed per shoot, across all shoots within each tiller cohort.	Continuous function of thermal time and water stress.	Leaf growth determined by temperature, water stress, N stress; limited by leaf size profile.
Radiation interception	FiPAR determined by LAI and a radiation extinction coeff.	FiPAR determined by LAI and a radiation extinction coeff.	FiSRAD determined by LAI and a radiation extinction coeff.

Process summary: biomass accumulation and partitioning

Process	DSSAT-Canegro	Mosicas	APSIM-Sugar
Biomass accumulation	Gross photosynthesis determined by FiPAR, temperature, PAR. Growth respiration (33% of expansive growth). Maintenance respiration determined for roots, leaves and sucrose by temperature and mass.	Gross photosynthesis determined by FiPAR, temperature, PAR. Maintenance respiration = fraction of total dry mass.	Net above-ground photosynthesis determined by SRAD, FiSRAD and temperature.
Root partitioning	Fraction varies by total biomass	Fraction varies with thermal time	Root allocation is a multiple of net photosynthesis, depending on crop stage.
Stalk partitioning	Weakly temperature-dependent stalk fraction after thermal time delay.	Aerial dry mass threshold, stalk fraction increases with aerial dry mass.	Fixed stalk fraction after thermal time delay.
Sucrose partitioning	Allocation determined by stalk dry mass, temperature and water stress.	Allocation determined by stalk dry mass, temperature and water stress.	Allocation determined by water stress, surplus carbohydrates.

Process details

DSSAT Canegro
Germination and emergence

Management inputs:

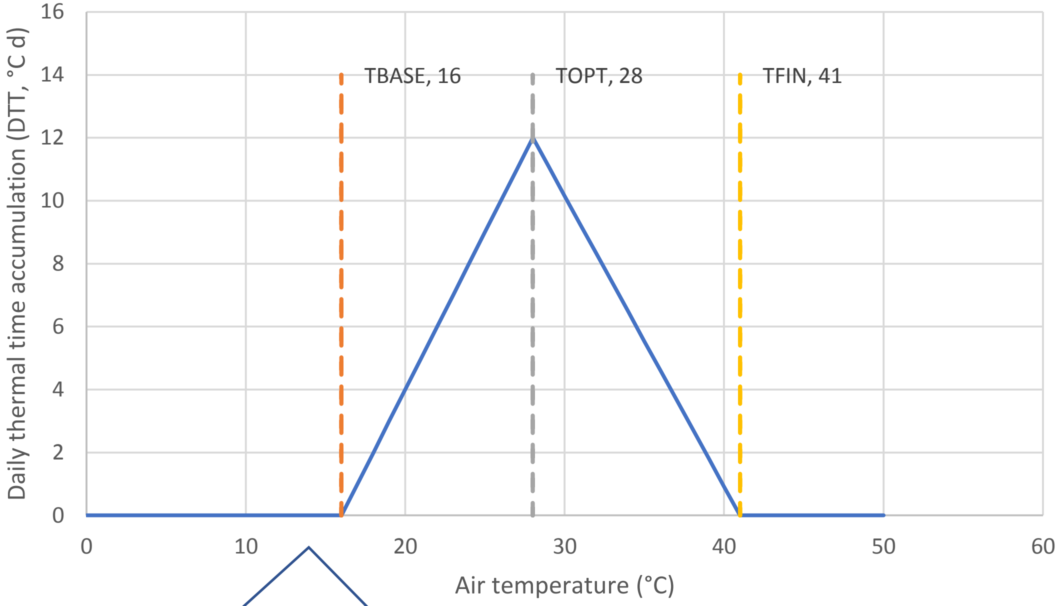
- Plant or ratoon crop choice

Environment inputs:

- Temperature (thermal time)

Genetic inputs:

- **TTPLNTEM**, **TTRATNEM**: thermal time to emergence of first primary stalk (plant and ratoon crops), °C d
- TBASE_GE_EM: base temperature for emergence (°C)
- TOPT_GE_EM: optimal temperature for emergence (°C)
- TFin_GE_EM: final cutoff temperature for emergence (°C)



A similar thermal time (“Effective temperature”) model is used in most model processes.

$$G = \begin{cases} FALSE, TT_C < TTPLNTEM \\ TRUE, TT_C \geq TTPLNTEM \end{cases}$$

For plant crops, where TTc is cumulative thermal time since crop start.

Similarly TTRATNEM for ratoon crops.

DSSAT Canegro
Primary shoot population

Management inputs:

- Bud population at crop start (N_BUDS)
- Row-spacing

Environment inputs:

- Temperature (thermal time, TT_EM)

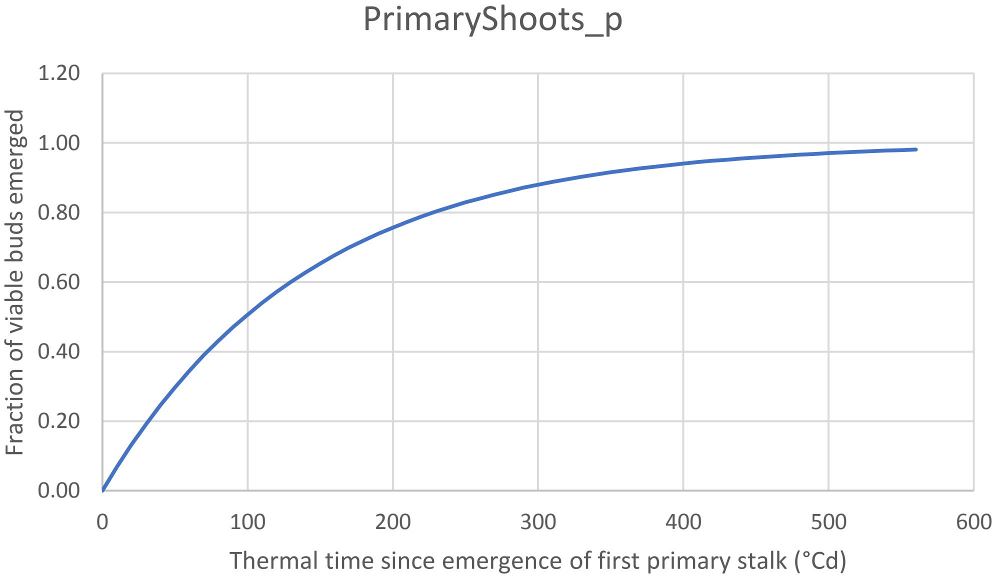
Genetic inputs:

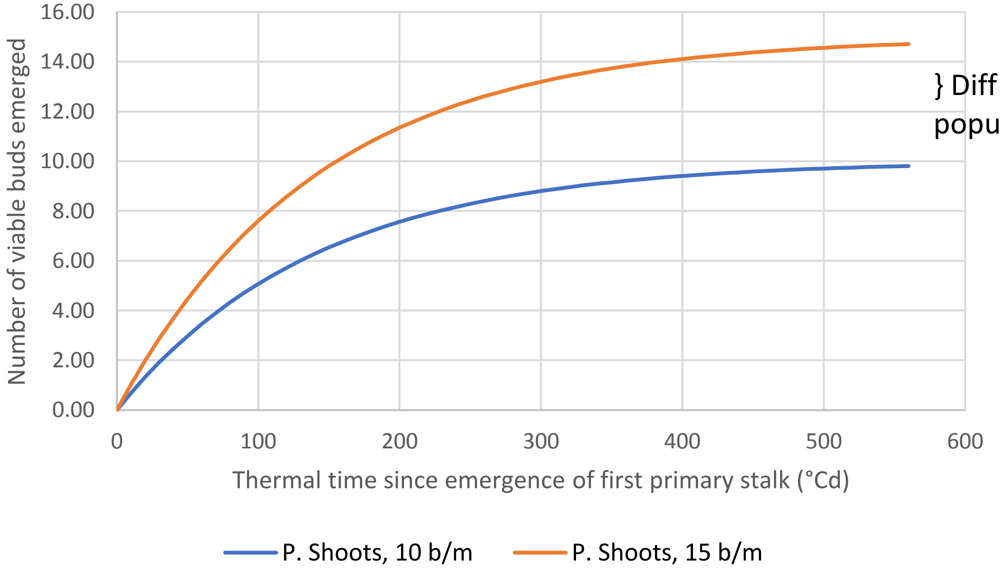
- **[hard-coded]:**

$$P = N_{BUDS} * (1. - e^{-0.0916 * \frac{TT_{EM}}{12.96}})$$

Weaknesses:

- Does not take into account water stress.
- No provision for genetic differences
- Based on single setts in pots; might be different in field situation, particularly for ratoon crops.





} Diff bud populations

DSSAT Canegro
Secondary shoot population (tillering)

Environmental inputs:

- Temperature (thermal time, TT_EM)
- Water stress (SWDF30)
- Fractional interception of PAR (FiPAR)

Genetic inputs:

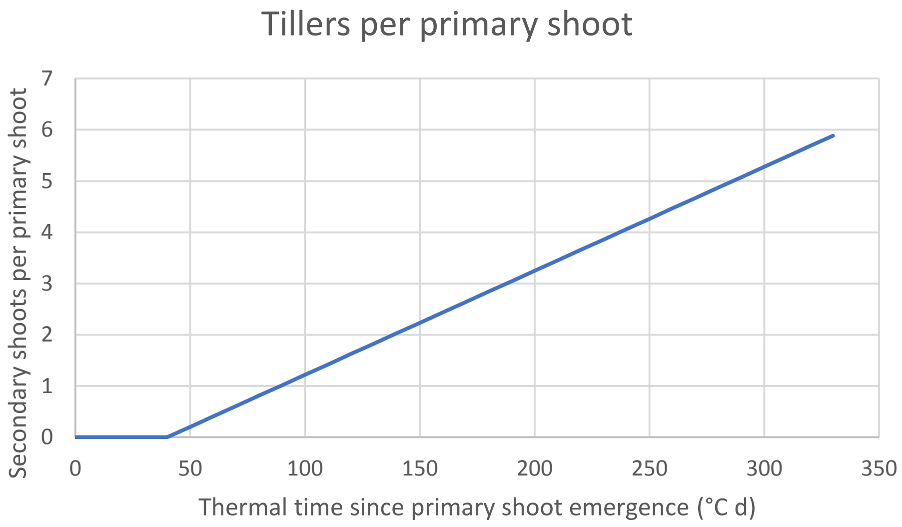
- **TDELAY:** delay from appearance of primary shoot to start of tillering
- **TAR0:** tiller appearance per unit thermal time, per primary shoot

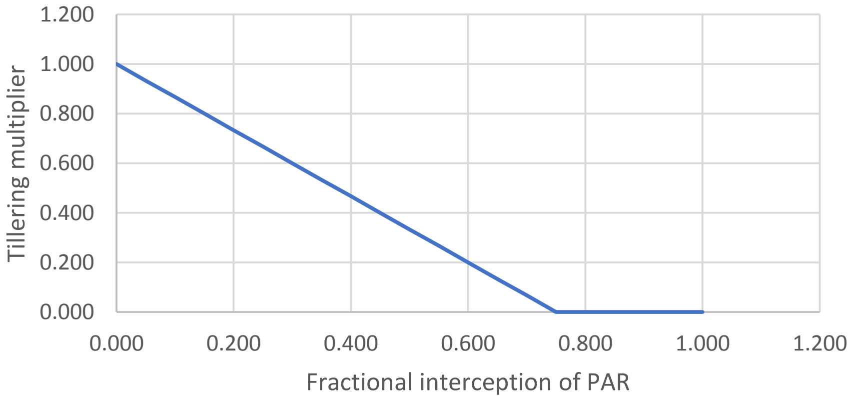
$$\Delta T = \mathrm{DTT_{tillers}} * \mathrm{TAR0} * \left(1 - \frac{\mathrm{FiPAR}}{0.75}\right) * \mathrm{SWDF30} \ * \mathrm{P_c}$$

where P_C is the number of prima shoots in shoot cohort c

Weaknesses:

- Not well-tested
- Bug in implementation
- The FiPAR at which till TP? Or a non-linear functi
- Short TDELAY appea c





This term causes a change from exponential increase to zero slope as FiPAR increases from 0.75 to 1.0. The characteristic parabolic shape of the tillering curve is an **emergent consequence of lower-level processes** (and their genetic controls) determining tillering and leaf area

Mosicas Shoot Appearance & Senescence

Management inputs:

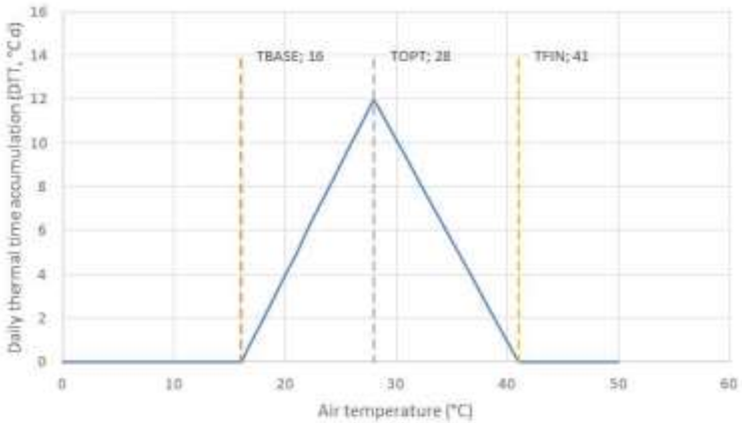
- Plant or ratoon crop choice

Environment inputs:

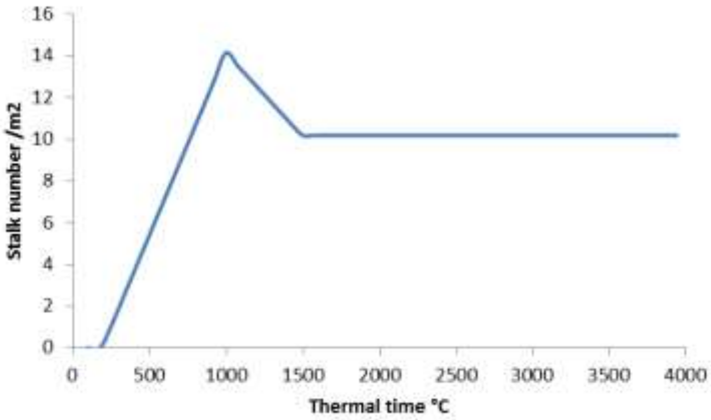
- Temperature (thermal time)

Genetic inputs:

- **Taldeb**: Thermal time from plantation/harvest to emergence, °C
- Talfinval Final value of alive stalks at harvest (/m2).
- Talpeaktt Thermal time to reach tillering peak, °C
- Talpeakval: Number of stalks at tillering peak, /m2
- **Taltb**: base temperature for stalk appearance, °C



General effect of Air temperature (x) on daily thermal time accumulation. (y)



Description:
Approach of the effect of air temperature on organs appearance and growth is the same whatever the organ. Thermal time for a stalk appearance then sennescence allows calculations of stalk emergence, tillering to a peak then senecence to a stable final value of the stalks number. According mosicas approaches for canopy development & mass accumulation, only emergence stage is taken into account (genetic inputs Taltb, Taldeb)

APSIM
Germination and emergence

Management inputs:

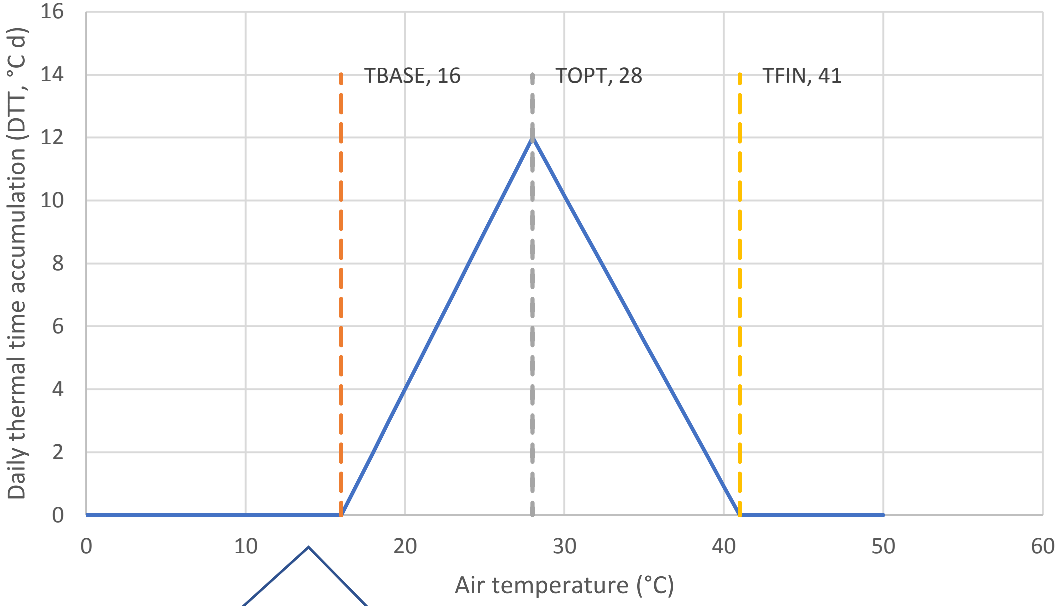
- Plant or ratoon crop.
- Planting depth.

Environment inputs:

- Temperature (thermal time)
- Soil water content

Genetic inputs:

- **Germination delay** of 250 °C d, followed by
- **shoot elongation** to the soil surface at 0.8 mm/°C d, thus accounting for planting depth.
- **Base temperature** of 9 °C for all processes
- **Optimal and final temperatures** of 32 and 45 °C.



A similar thermal time model is used in most model processes.

Thermal time is calculated in 3-hourly, based on interpolated hourly weather data.

APSIM Shoot (stalk) population

Primary shoots

Management inputs:

- **Bud population** at crop start (=number of harvested stalks)

Weaknesses:

- Only primary shoots become harvested stalks.

Tillers

Environment inputs:

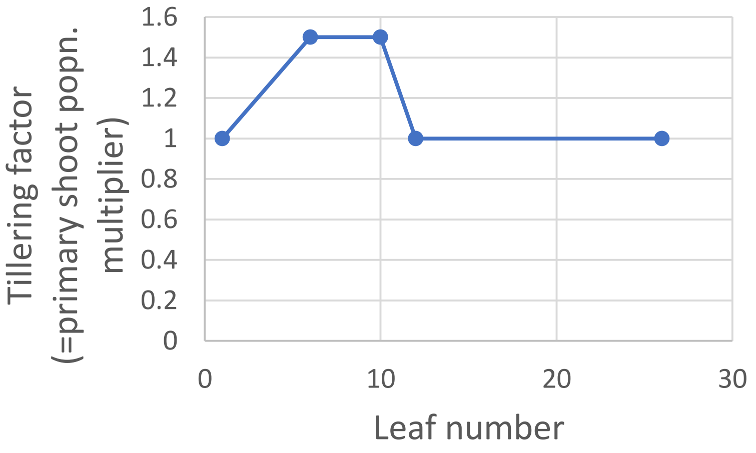
- Leaf number

Genetic inputs:

- Tillering lookup function (**primary stalk multiplier** x leaf number)

Weaknesses:

- Simplistic tillering function.
- Limited ability to capture stalk population ‘plasticity’ of sugarcane – i.e.



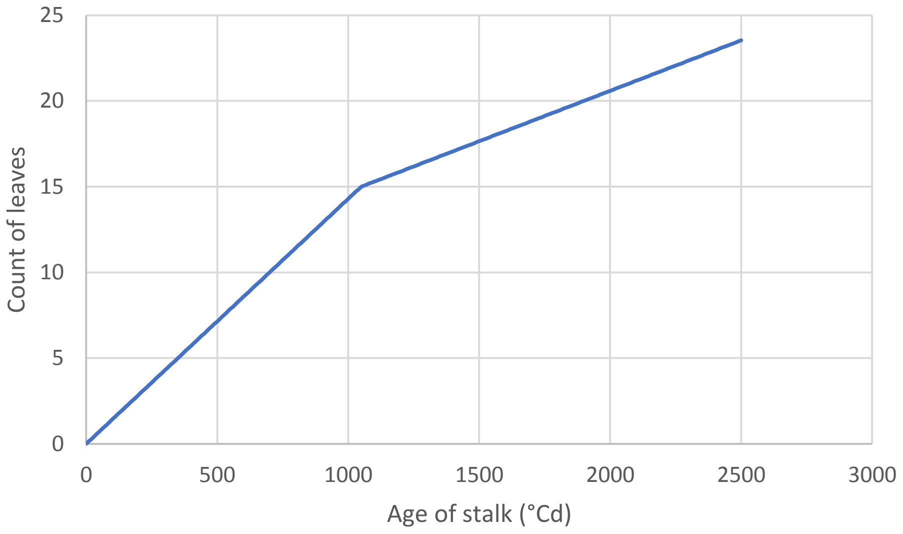
DSSAT Canegro
Leaf appearance

Environmental inputs:

- Temperature (via thermal time)

Genetic inputs:

- **Cardinal temperatures thermal time accumulation** for leaf appearance
- **PI1**: phyllocron interval 1, the thermal time between consecutive leaf tip appearance up to PSWITCH leaves have appeared.
- **PI2**: phyllocron interval 2, the thermal time between consecutive leaf tip appearance after PSWITCH leaves have appeared.
- **PSWITCH**: leaf number at which phyllcron interval changes from PI1 to PI2.



Weaknesses

- There is some evidence (e.g. Bonnett 1998) to suggest that leaf appearance rate slows continuously over the course of the crop.
- Unintuitive to calibrate – increasing the parameter results in fewer rather than more leaves.

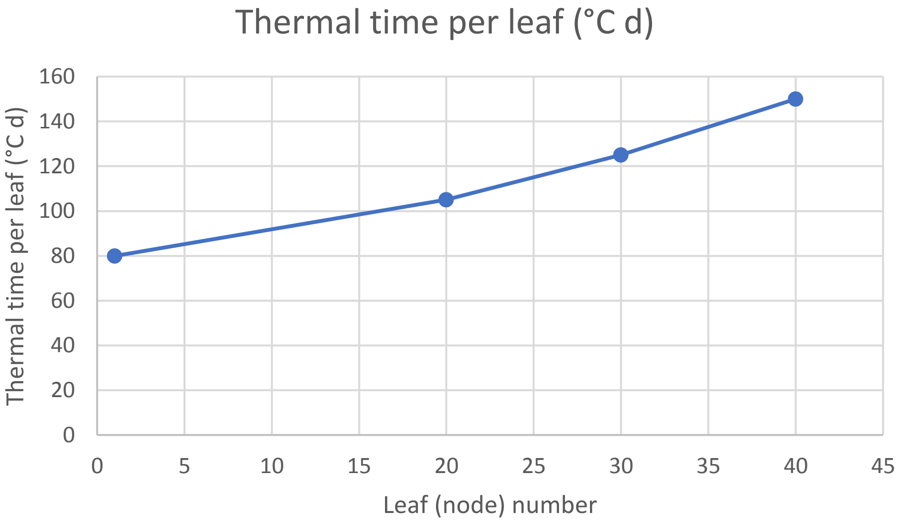
APSIM Leaf appearance

Environmental inputs:

- Thermal time

Genetic inputs:

- **Number of nodes x thermal time** lookup function
- **Maximum number of green leaves**



- Green leaf number limited by water stress; light competition when Fi > 0.85; frost 10-100% of green LAI per day, 0 to -5°C)

DSSAT Canegro
Leaf area growth

Environmental inputs:

- Temperature (daily thermal time, DTT)
- Water stress (SWDF2)
- Number of leaves

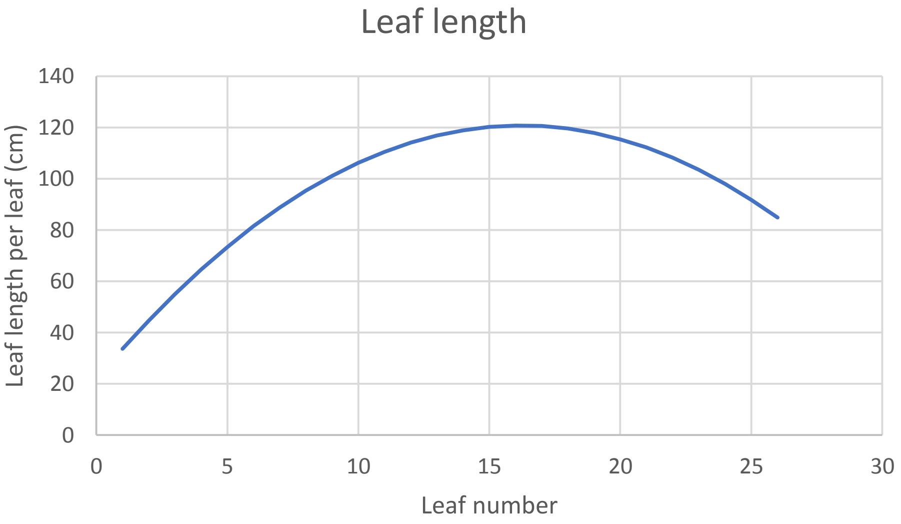
Genetic inputs:

- **MXLFAREA**
- MXLFARNO
- LER0
- ECO parameters, quadratic coeffs for max leaf length, width and area per leaf. Overriden by MXLFAREA and MXLFARNO.

Weaknesses:

- Ecotype parameters very complicated to measure
- Not linked to carbohydrate availability
- Are there physiological (genetic) links between leaf phyllocron, leaf length, leaf, and leaf width?

- Leaf elongation rate drives increase in area: triangle (50% of max leaf length) + rectangle for each leaf
- Max leaf length, width and area per leaf are limited to maximum values described by quadratic equation
- Total leaf area is the sum of leaf per leaf per shoot cohort * number of shoots in each cohort.



Mosicas Development and growth of Lai

Management inputs:

- Plant or ratoon crop choice
- Plantation date

Environment inputs:

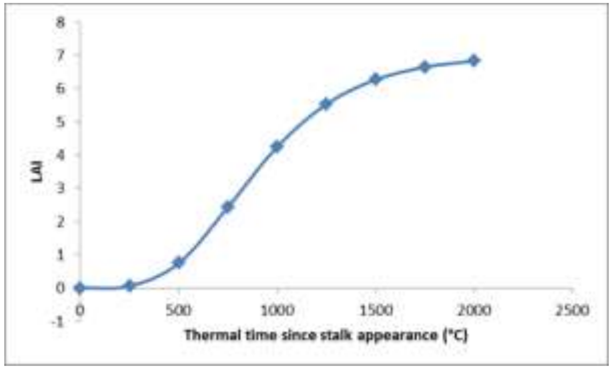
- Temperature (thermal time)
- Water stress

Driving plant status:

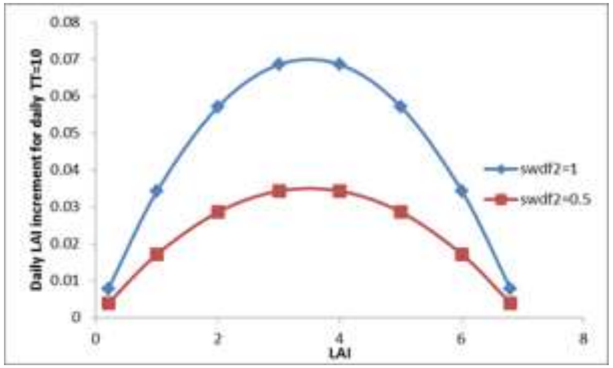
- Emergence, Lai (Source) and Lai/Laimax (Competition)
- Flowering

Genetic inputs:

- ***laitb*** : base temperature for lai growth calculation
- ***laicroi*** : growth rate of lai
- ***laiwksen*** : sensitivity of lai to water stress



Cumulative effect of thermal time (x) on Lai (y)



Lai effect (x) on Lai growth (y) according to water stress level

Description: Mosicas simulates green leaves area index (LAI) without linking with appearances and growths of stalks and leaves. Mosicas uses a "Big Leaf" approach in which LAI is calculated as a whole leaf blade. The daily increase in green Lai (gLAI) starts when stalks emergence (nbtigv), is affected by the thermal growth rate of LAI (*laicroi*), by the thermal time of current day (dttLai) derived from temperature compared with base temperature (laitb), by the level of lai (source) compared with laimax(competition) , and by flowering. The daily decrease of LAI due to water stress is affected by the water satisfaction index (swdf2).

Flowering affects LAI. At the end of initiation phase and if a crop state is reached, dGLAI occurs only on non-flowering stalks (100-pflst) where pflst is the flowering potential parameter of the cultivar.

APSIM Leaf area (index)

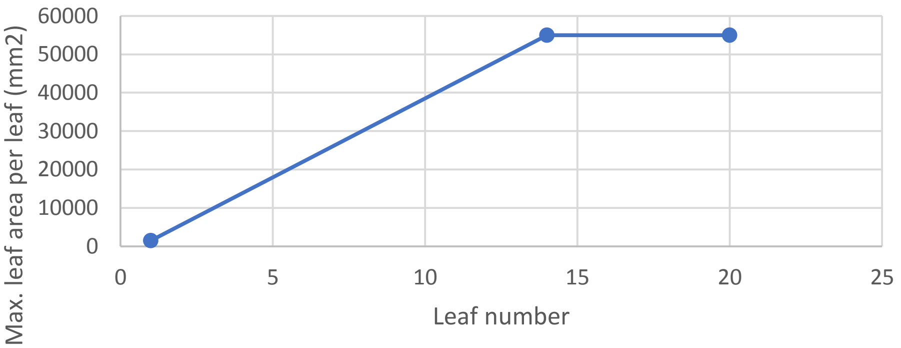
Environmental inputs:

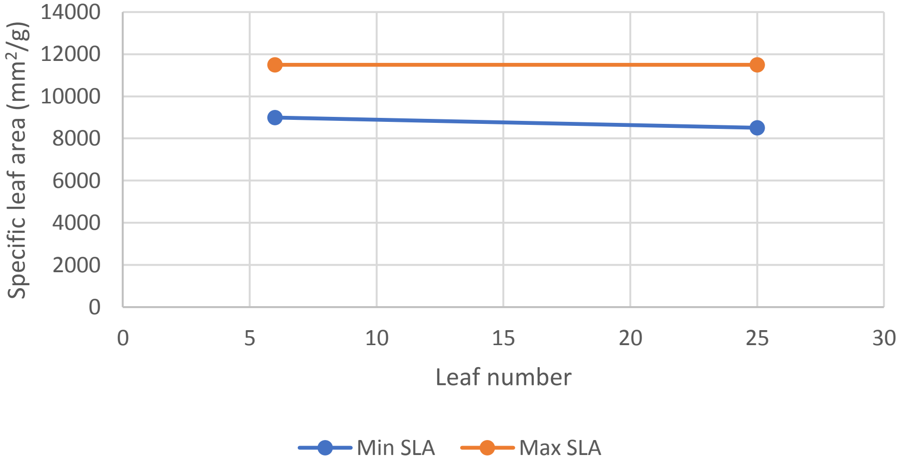
- Thermal time
- Carbohydrate availability
- Water stress
- Nitrogen stress
- Stalk population (via tillering factor)

Genetic inputs:

- **Area of leaf #1**
- **Specific leaf area** (max and min by leaf number)
- **Correction factor** for area of actively-growing leaves
- **Maximum leaf area per leaf** (lookup function by leaf number)

- Area of first leaf is a sensitive parameter, because subsequent leaves are limited by C availability


Leaf size profile for Q117



DSSAT Canegro
Radiation interception

Environmental inputs:

- Leaf area index

Genetic inputs:

- EXTCFN – (maximum) radiation extinction coefficient, at LFNMXEXT number of leaves = 0.84.
- EXTCFST – minimum radiation extinction coeff = 0.58.

Weaknesses:

- Is it necessary to have two extinction params? One might be enough.
- Does not account for diffuse radiation (some evidence to suggest that it underestimates under cloudy conditions)

Mosicas Interception of Radiation

Management inputs:

- Plant or ratoon crop choice

Environment inputs:

- Radiation

Driving plant status:

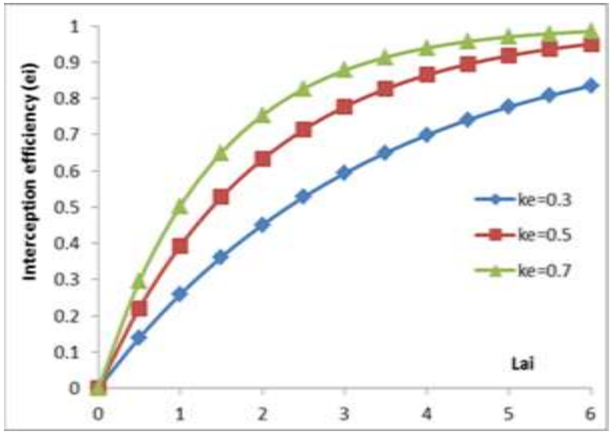
- Lai

Genetic inputs:

- **Ke**: extinction coefficient

Weaknesses:

- No effect of row spacing, lodging
- ei observations when aged and lodged



Lai effect on ei according to ke level

Description: The interception efficiency (ei) depends on LAI and a parameter, the extinction coefficient (ke), using Beer's law approach. Intercepted photosyntatically active radiation (PARi) depends on ei and the incident photosyntatically active radiation (PAR) which is half the incident solar radiation (SOLRAD)

APSIM Radiation interception

Environmental inputs:

- Leaf area index

Genetic inputs:

- **Global** radiation extinction coefficient (0.38)

Weaknesses:

- Global radiation is not quite right for photosynthesis, but more accurate for shading → soil surface evaporation.

DSSAT Canegro Photosynthesis and respiration

Environmental inputs:

- Temperature, PAR
- FiPAR
- Water stress (SWDF1)
- Green leaf, root and sucrose pool dry masses

Genetic inputs:

- PARCEMax: max RUE
- Species params for maintenance respiration reference rate for green leaves and roots, sucrose

Weaknesses:

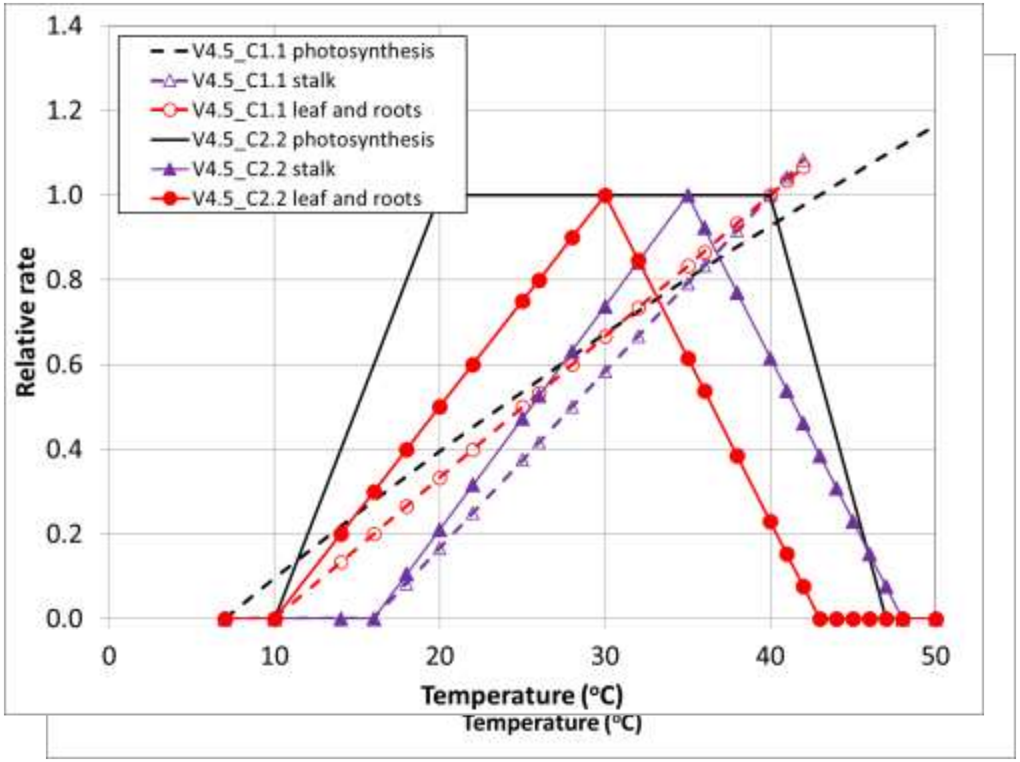
- Difficult to measure Rm.
- Should Pg effective temperature be skewed to Tmax, Rm eff. temp skewed to Tmin?

- Photos:

$$Pg = PAR * Parce_{eff} * FiPAR * SWDF1$$

- Maintenance respiration:

$$Rm_x = RCoeff_x * \left(RespQ10^{RmEffTemp}\right) * Mass_x$$



Mosicas Conversion and Partition to Above ground Biomass

Management inputs:

- Plant or ratoon crop choice / Irrigation

Environment inputs:

- Temperature , Radiation, Water stress

Driving plant status:

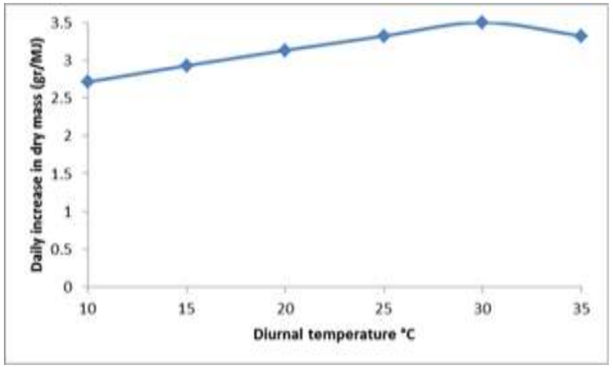
- **Interception efficiency (ei)**
- Dry mass (maintenance)

Genetic inputs:

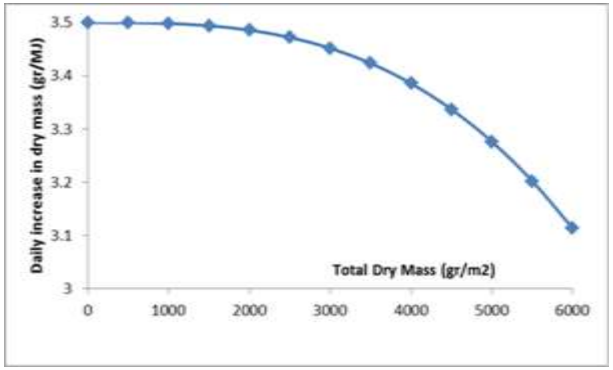
- ***ruemax***: conversion coefficient of intercepted PAR into total dry mass (gr/MJ)
- **P01:** coefficient for maintenance respiration effect on conversion

Weaknesses:

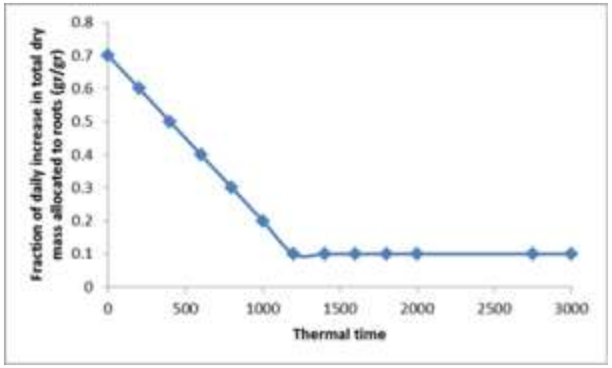
- Maintenance, root observations



Conversion: Temperature effect



Conversion: Dry mass effect (maintenance)



Partition: Daily fraction allocated to roots

Description:

Conversion: Mosicas converts the daily intercepted PAR (PARi) into daily gain in total dry mass (dTBDM). This conversion process is affected by temperature (ktemp) and water (swdf1) satisfaction coefficients, maintenance respiration coefficient (p01) and the cultivar maximum radiation conversion efficiency (ruemax).

Partition: The partitioning of total dry mass gain to root and aboveground dry mass gain is regulated by dynamic allometric fractions that depend on thermal time

APSIM Net Photosynthesis

Environmental inputs:

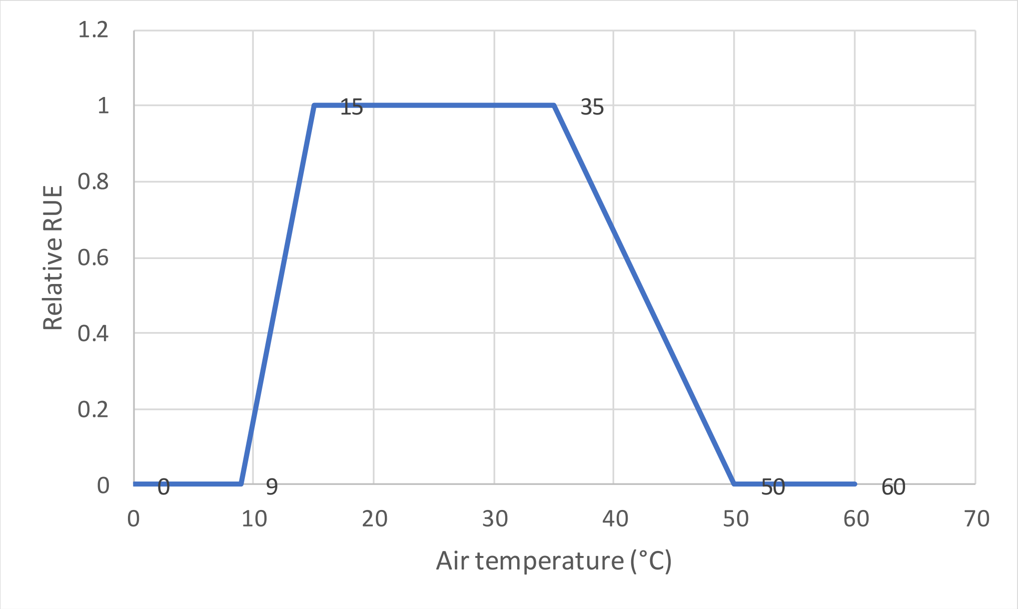
- Fractional interception of radiation
- Temperature
- Water stress (SWDF1)
- N availability / stress

Genetic inputs:

- **RUE** – fixed for all sugarcane varieties. 1.80 g/MJ/m2 for plant crops, 1.65 g/MJ/m2 for ratoon crops.

Weaknesses:

- Perhaps sugarcane RUE does vary?
- Physiological basis for plant/ratoon crop differences in RUE?



- Represents above-ground biomass.
- Respiration is not simulated
- Daily biomass increase drives transpiration via transpiration efficiency.

DSSAT Canegro

Biomass partitioning: roots, stalks, canopy

Environmental inputs:

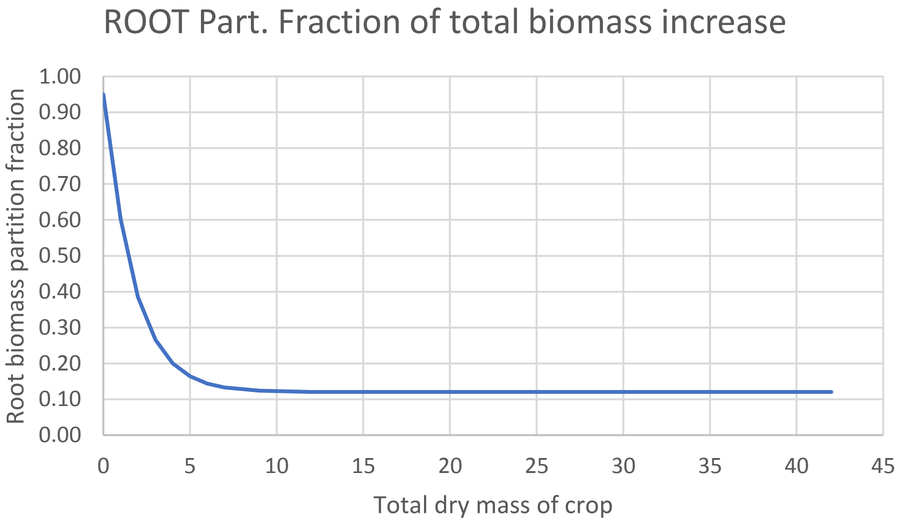
- Temperature
- Total dry mass

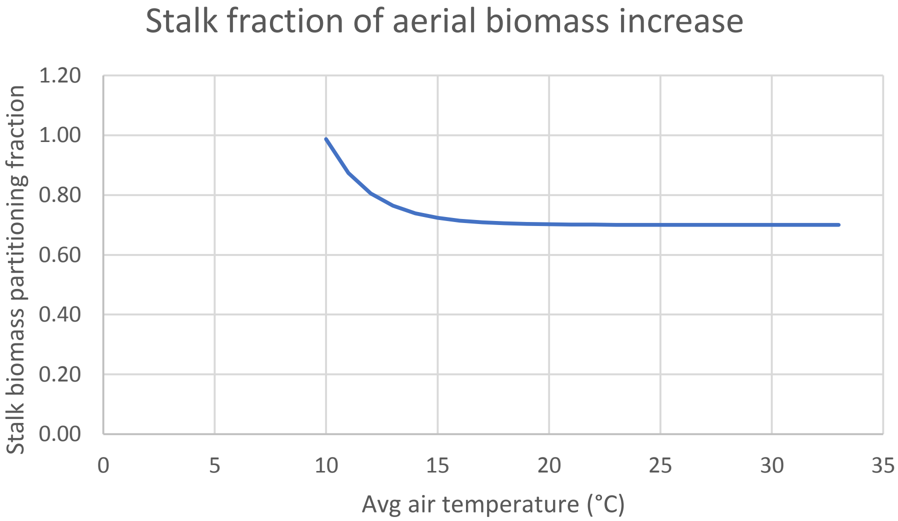
Genetic inputs:

- **APFMX** – maximum fraction of biomass allocated to aerial biomass. (0.88)
- Max root fraction hard-coded at 0.95. PCB = extinction coeff = 0.6.
- **STKPFMAX** – max fraction of aerial biomass increment allocated to stalks

Weaknesses:

- Temperature relationship favours stalk mass accumulation under cool conditions – but stalk growth is more temperature-sensitive?
- Not very dynamic.





Mosicas Partition into Millable stalk

Management inputs:

Environment inputs:

Driving plant status:

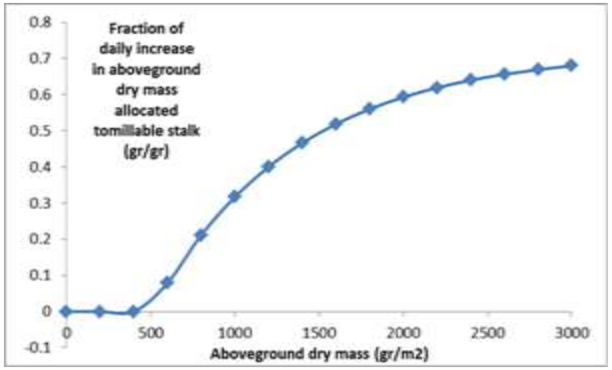
- Above ground biomass

Genetic inputs:

- ***ptigdeb***: Above ground biomass level when millable stalk dry mass appears ((g/m2)
- ***ptigdec***: Attenuation coefficient of daily fraction of aboveground dry mass allocated to millable stalk
- ***ptigfin*** Final daily fraction of aboveground dry mass allocated to millable stalk

Weaknesses:

- No environmental effects



Partition: Daily fraction allocated to millable stalk mass according to aboveground mass

<u>**Description**</u>: The partitioning of daily increase in aboveground dry mass to daily increase in millable stalk dry mass is regulated by dynamic allometric fractions that depend on the amount of aboveground biomass

APSIM Biomass partitioning: roots, stalks, canopy, sucrose

Environmental inputs:

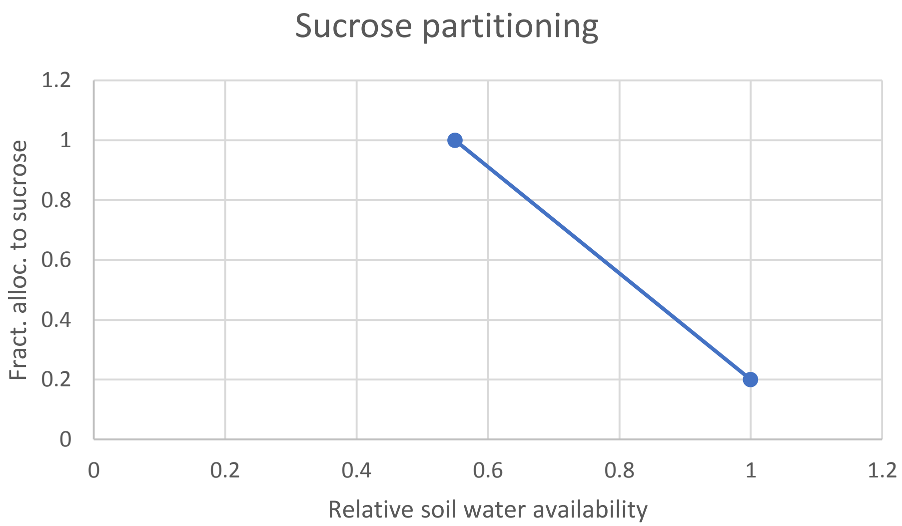
- Temperature (thermal time)
- Fractional interception of PAR (FiPAR)
- Relative soil water content

Genetic inputs:

- **Root growth** fraction multiplier (0.3 at emergence to 0.2 at flowering; lookup parameters?)
- Thermal time delay from emergence to **start of stalk growth** (1200-1800 °C d)
- **Stalk fraction**: usually 70%.
- **Leaf:cabbage** ratio, 1.7:1
- **Sucrose delay**: usually 0.0
- **Sucrose allocation stress factor** lookup

Weaknesses:

- Temperature impact on sucrose allocation?
- Empirical, not very dynamic



- Excess source to leaves increases SLA to an allowable max, after which remainder goes to sucrose.

DSSAT Canegro
Sucrose accumulation

Environmental inputs:

- Temperature
- Water stress (growth)
- Stalk dry mass

Genetic inputs:

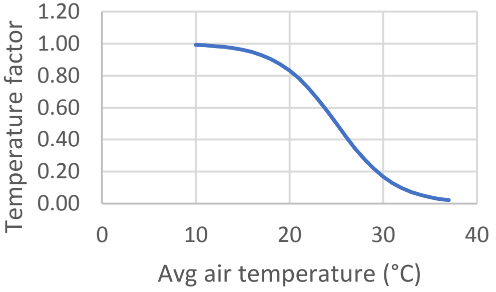
- **SUCA** – maximum sucrose content in the stalk
- ECO params.

Weaknesses:

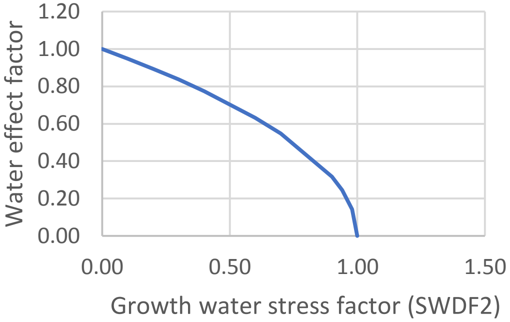
- Multi-dimensional and complicated, making it difficult to understand

- Sucrose accumulation partition based on temperature, water stress and existing sucrose content.

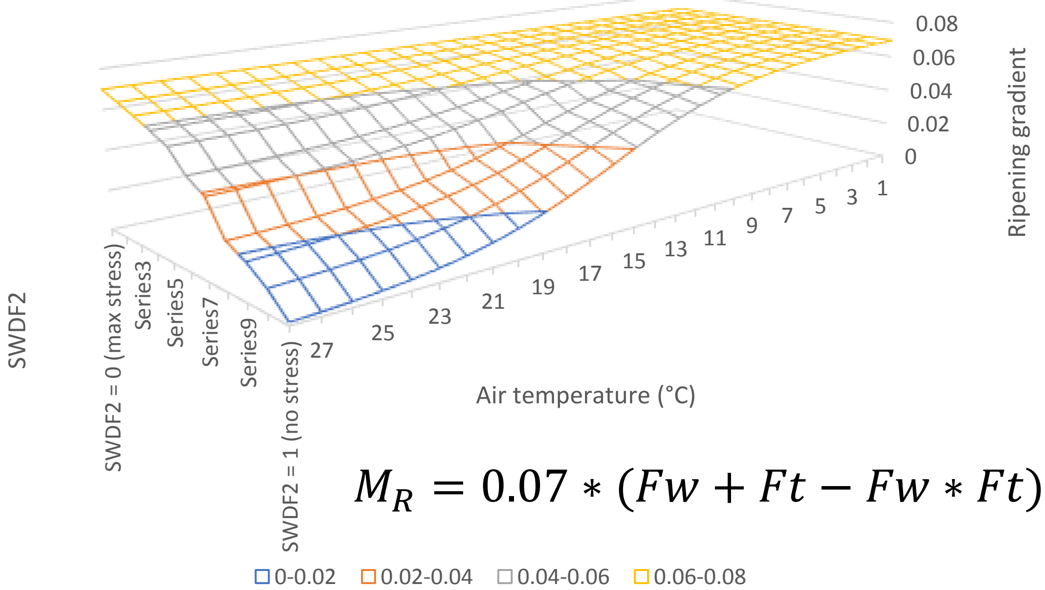
Temperature effect (Ft)



Water stress effect (Fw)



- Based on the concept of a ripening gradient, which is steeper in mature stalks and under conditions unfavourable for expansive growth.



$$M_R = 0.07 * (Fw + Ft - Fw * Ft)$$

Mosicas Partition of stalk mass to Structures & sucrose

Management inputs:

- Irrigation

Environment inputs:

- Temperature
- Water stress differentials (growth, accumulation)

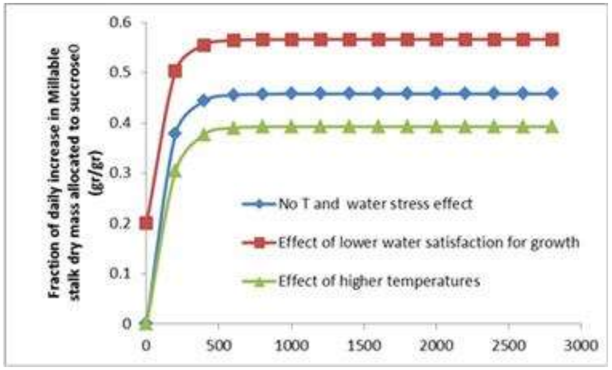
Driving plant status:

- Millable stalk dry mass

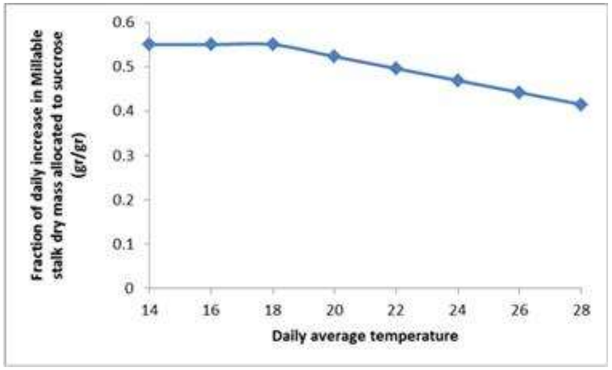
Genetic inputs:

- ***pstrudec*** : Attenuation coefficient of daily fraction of millable stalk dry mass allocated to structures
- ***pstrufin*** : Final daily fraction of millable stalk dry mass allocated to structures (g/g)
- ***pstrutb***: Temperature treshold from which fraction of stalks dry mass allocated to structures is decreasing
- ***pstrutcroi***: Temperature effect on daily fraction of millable stalks dry mass allocated to structures (/°C)

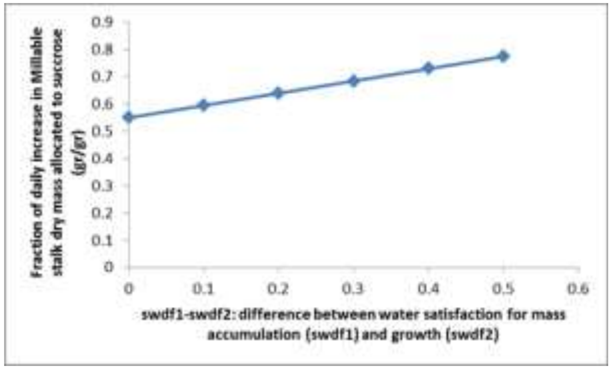
Weaknesses:



Effect of stalk dry mass (x) on daily fraction (y) allocated to structures



Effect temperature (x) on daily fraction (y) allocated to structures



Effect water stress (x) on daily fraction (y) allocated to structures

__Description__: The partitioning of daily increase in millable stalk mass to daily increase in structures is regulated by dynamic allometric fraction that depends on the amount of existing millable stalk mass. temperature and water stress indexex. The remaining biomass not allocated to structures is stored as stalk sucrose.

DSSAT Canegro
Water uptake

Environmental inputs:

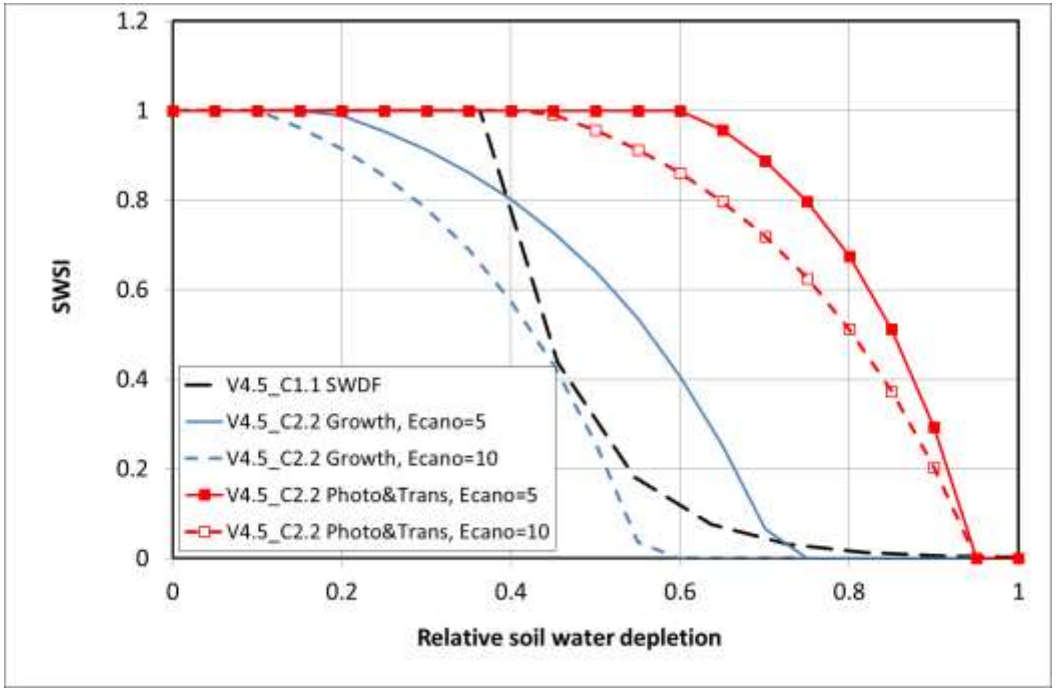
- Sugarcane reference evaporation
- Soil water content

Genetic inputs:

- AQP_UP5 – **relative soil water depletion level at which stress starts**, for ETp=5mm/day.

Weaknesses:

- Rather empirical
- Square peg in a round hole – some difficulty working it into Canegro and DSSAT CSM



- Based on FAO AquaCrop model.
- Simulates a more gradual transition to stress than CERES SWDFx approach.

Mosicas Cultivar sensitivity to water stress

Management inputs:

- Irrigation/rainfed

Environment inputs:

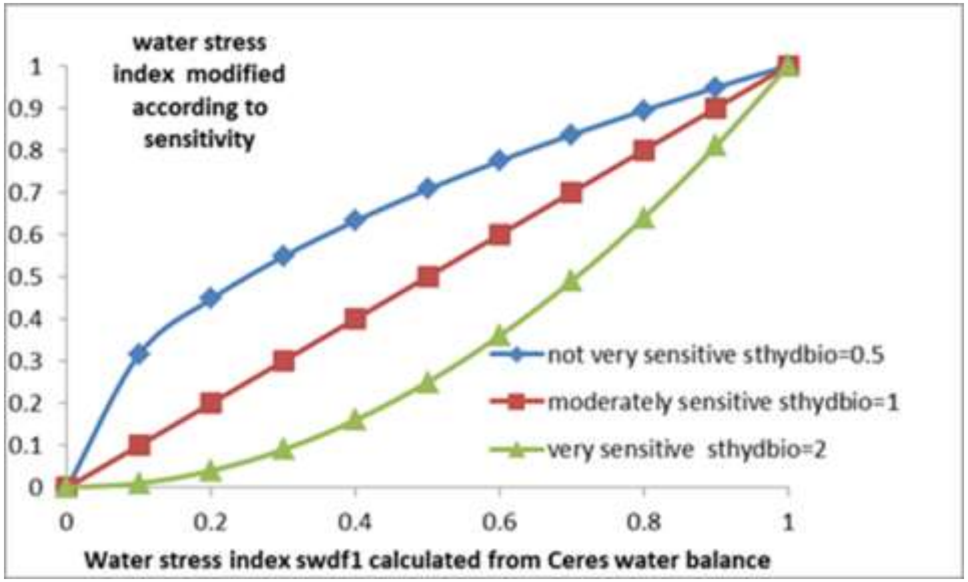
- Rain, irrigation, ETo

Genetic inputs:

- **sthydbio**: Sensitivity to water stress index (swdf1) for mass accumulation.
- **sthydcroi**: Sensitivity to water stress index (swdf2) for growth

Weaknesses:

- Need irrigation/rainfed variety Trials



effect of water sensitivity on water stress index modification

Description:

The Ceres soil water balance is used to calculate water stress coefficients for growth (swdf2) and biomass accumulation (swdf1) which are then modified according to cultivar parameters of sensitivity to water stress.

Code:

$swdf1=swdf1^{(sthydbio)}$

$swdf2=swdf2^{(sthydcroi)}$

APSIM Water uptake

Environmental inputs:

- Temperature (thermal time)
- Fractional interception of PAR (FiPAR)

Genetic inputs:

- **TEC,** transpiration efficiency coefficient lookup table: 8.7 g kPa/kg

Weaknesses:

- Conservation of water means that water and biomass are always linked, though sometimes this is not the case.
- **VPD** does not account for wind speed, aerodynamic resistance

$$Toi = R_i(1 - \exp(-E * LAI)) * RUE \ * \frac{VPD}{TEC}$$

i.e.

$$Toi = \Delta Biomass \ * \frac{VPD}{TEC}$$

Water stress is calculated as the ratio of potential root water uptake to potential supply (based on kL). Water stress is an input to the biomass increment calculation.

DSSAT Canegro
Comments

- Diffuse radiation
- Reliance on some complicated parameters, e.g. quadratic leaf profile coeffs.
- Water balance and tillering algorithms are new and less rigorously tested than others.