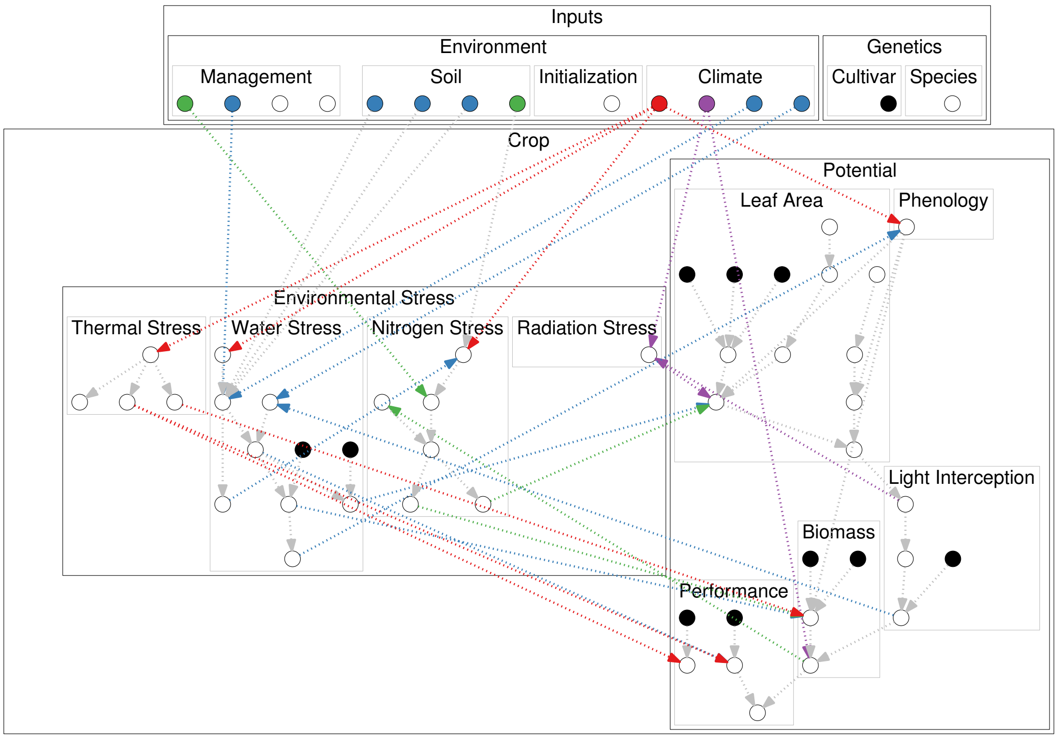
Documentation for the SUNFLO crop model

January 5, 2015

Contents

Model overview



Inputs

Climate

label	description	unit
TemperatureAirMin	Minimum air temperature	°C
TemperatureAirMax	Maximum air temperature	°C
Radiation	Global incident radiation	MJ.m-2
PET	Reference evapotranspiration	mm
Rainfall	Rainfall	mm

Soil

label	description	value	unit	reference
RootingDepth	Potential rooting depth	1000.00	mm	(Lecoeur et al., 2011)
WaterCapacity	Water content at field capacity (0-30 cm)	19.69	%	NA
WaterCapacity	Water content at wilting point (0-30cm)	9.69	%	NA
WaterCapacity	Water content at field capacity (30 cm-rooting depth)	19.69	%	NA
WaterCapacity	Water content at wilting point (30 cm-rooting depth)	9.69	%	NA
SoilDensity	Soil bulk density (0-30cm)	1.30	g.cm-3	NA
SoilDensity	Soil bulk density (30 cm-rooting depth)	1.30	g.cm-3	NA
StoneContent	Stone content (0-rooting depth)	0.10	[0 ; 1]	NA
MineralizationRate	Potential nitrogen mineralization rate	0.50	kg/ha/day (normalized)	(Valé et al., 2007)

Management

label	description	value	unit	reference
SowingDate	Sowing date	NA	dd/mm	NA
HarvestDate	Harvest date	NA	dd/mm	NA
SowingDensity	Plant density	7	pnt/m2	NA
Fertilization	Fertilization (date 1)	NA	dd/mm	NA
Fertilization	Fertilization (amount 1)	0	kg/ha eq. mineral nitrogen	NA
Fertilization	Fertilization (date 2)	NA	dd/mm	NA
Fertilization	Fertilization (amount 2)	0	kg/ha eq. mineral nitrogen	NA
Irrigation	Irrigation (date 1)	NA	dd/mm	NA
Irrigation	Irrigation (amount 1)	0	mm	NA
Irrigation	Irrigation (date 2)	NA	dd/mm	NA
Irrigation	Irrigation (amount 2)	0	mm	NA
Irrigation	Irrigation (date 3)	NA	dd/mm	NA
Irrigation	Irrigation (amount 3)	0	mm	NA

Species

Cultivar

label	description	value	unit	reference
ThermalTimeVegetative	Temperature sum to floral initiation	482.000	°Cd	(Lecoeur et al., 2011)
ThermalTimeFlowering	Temperature sum from emergence to the beginning of flowering	836.000	°Cd	(Lecoeur et al., 2011)
ThermalTimeSenescence	Temperature sum from emergence to the beginning of grain filling	1083.000	°Cd	(Lecoeur et al., 2011)
ThermalTimeMaturity	Temperature sum from emergence to seed physiological maturity	1673.000	°Cd	(Lecoeur et al., 2011)
PotentialLeafNumber	Potential number of leaves at flowering	29.000	leaf	(Lecoeur et al., 2011)

label	description	value	unit	reference
PotentialLeafProfile	Potential rank of the plant largest leaf at flowering	17.000	leaf	(Lecoeur et al., 2011)
PotentialLeafSize	Potential area of the plant largest leaf at flowering	448.000	cm2	(Lecoeur et al., 2011)
ExtinctionCoefficient	Light extinction coefficient during vegetative growth	0.880	-	(Lecoeur et al., 2011)
WaterResponseExpansion	Threshold for leaf expansion response to water stress	-4.420	-	(Casadebaig et al., 200
WaterResponseConductance	Threshold for stomatal conductance response to water stress	-9.300	-	(Casadebaig et al., 200
PotentialHarvestIndex	Potential harvest index	0.398	-	(Casadebaig et al., 201
PotentialOilContent	Potential seed oil content	55.400	% dry matter	(Casadebaig et al., 201

Phenology

label	description	value	unit	reference
ThermalTimeVegetative	Temperature sum to floral initiation	482.00	°Cd	(Lecoeur et al., 2011)
ThermalTimeFlowering	Temperature sum from emergence to the beginning of flowering	836.00	°Cd	(Lecoeur et al., 2011)
ThermalTimeSenescence	Temperature sum from emergence to the beginning of grain filling	1083.00	°Cd	(Lecoeur et al., 2011)
ThermalTimeMaturity	Temperature sum from emergence to seed physiological maturity	1673.00	°Cd	(Lecoeur et al., 2011)
SowingDepth	Sowing depth	30.00	mm	NA
Germination	Temperature sum from sowing to germination	86.20	°Cd	(Casadebaig et al., 2011)
ElongationRate	Reciprocal of hypocotyl elongation rate	1.19	°Cd/mm	(Villalobos et al., 1996)

Emergence

$Emergence = Germination + ElongationRate \cdot SowingDepth$
with:

- $Germination = 86$, Thermal time for germination (°C.d);
- $ElongationRate = 1.19$, Hypocotyl elongation rate (°Cd/mm)
- $SowingDepth = 30$, Sowing depth (mm).

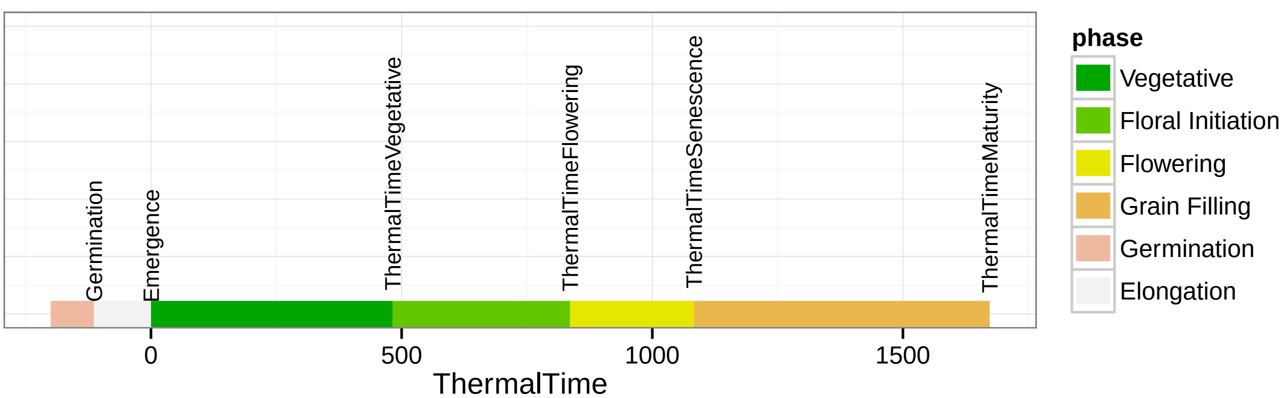
ThermalTime

$$ThermalTime_d = \begin{cases} \int_0^d (T_m - T_b) \cdot (1 + WaterStressPhenology) \cdot dt & \text{if } T_m > T_b \\ 0 & \text{else} \end{cases}$$

with:

- T_m, Daily mean air temperature (°C);
- $T_b = 4.8$, Basal temperature (°C) (Granier and Tardieu, 1998);
- $ThermalStressPhenology$ Water stress effect on plant heating

PhenoStages



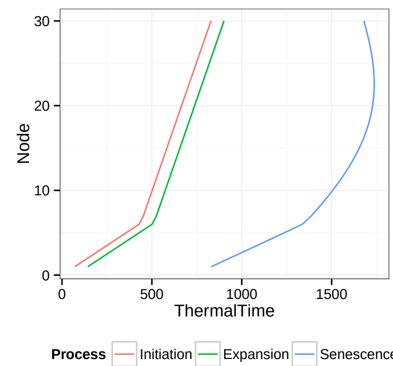
In the software model, phenostages are computed as integers $\in [0, 7]$ corresponding to duration between key stages:

- **0**, begining of simulation - sowing (bare soil)

- **1**, sowing (A0) - emergence (A2)
- **2**, emergence (A2) - floral initiation (E1)
- **3**, floral initiation (E1) - flowering (F1)
- **4**, flowering (F1) - onset of senescence (M0)
- **5**, onset of senescence (M0) - maturity (M3)
- **6**, maturity (M3) - harvest
- **7**, harvest - end of simulation (bare soil)

LeafArea

label	description	value	unit	reference
PotentialLeafNumber	Potential number of leaves at flowering	29.00	leaf	(Lecoeur et al., 2011)
PotentialLeafProfile	Potential rank of the plant largest leaf at flowering	17.00	leaf	(Lecoeur et al., 2011)
PotentialLeafSize	Potential area of the plant largest leaf at flowering	448.00	cm2	(Lecoeur et al., 2011)
Phyllotherm_1	Phyllotherm (leaf <= 6)	71.43	°Cd	(Rey, 2003)
Phyllotherm_7	Phyllotherm (leaf > 7)	16.34	°Cd	(Rey, 2003)
PotentialLeafDuration	Thermal time between expansion and senescence	851.33	°Cd	(Casadebaig, 2008)



LeafInitiationTime, LeafExpansionTime, LeafSenescenceTime

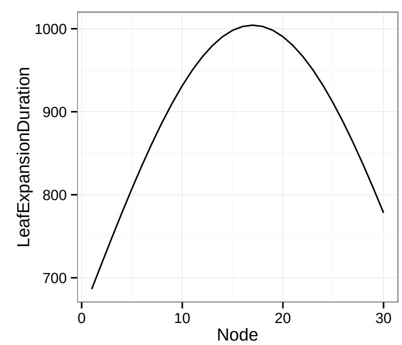
$$LeafInitiationTime_i = \begin{cases} i \cdot Phyllotherm_1 & \text{if } i \leq 6 \\ (i-5) \cdot Phyllotherm_7 + a & \text{if } i \leq LeafNumber \end{cases}$$

with:

- $Phyllotherm_1 = 76.43$ (°C.d)
- $Phyllotherm_7 = 16.34$ (°C.d)
- $a = 400$ (°C.d)

$$LeafExpansionTime_i = LeafInitiation_i + 1/a$$

with $a = 0.01379$.



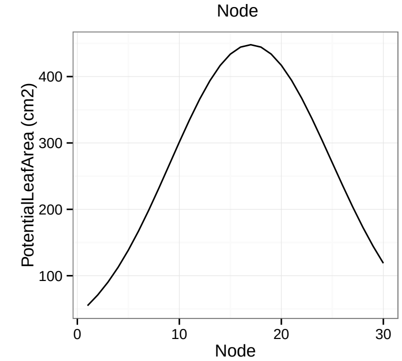
LeafExpansionDuration

$$LeafExpansionDuration_i = a + PotentialLeafDuration \cdot exp^{\frac{-(i-PotentialLeafProfile)^2}{(c \cdot PotentialLeafNumber)^2}}$$

with:

- $PotentialLeafDuration = 851.3$ (°C.d)
- $a = 153$ (°C.d)
- $b = 0.78$

$$LeafSenescenceTime_i = LeafExpansionTime_i + LeafExpansionDuration_i$$



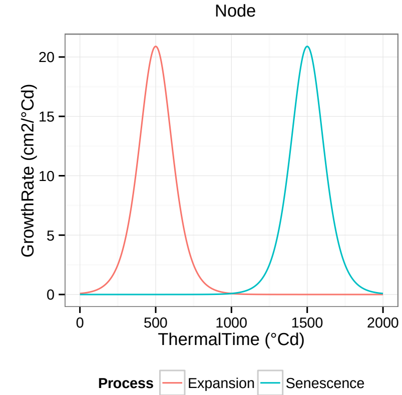
PotentialLeafArea

$$PotentialLeafArea_i = PotentialLeafSize \cdot exp^{a \cdot (\frac{i-PotentialLeafProfile}{PotentialLeafProfile-1})^2 + b \cdot (\frac{i-PotentialLeafProfile}{PotentialLeafProfile-1})^3}$$

with: * $a = -2.05$ and $b = 0.049$, shape parameters * $PotentialLeafSize$ (cm2) and $PotentialLeafProfile$ (node), genotypic parameters.

LeafGrowthRate, LeafSenescenceRate, LeafArea

$$LeafGrowthRate_i = (T_m - T_b) \cdot PotentialLeafArea_i \cdot a \cdot \frac{exp^{-a(ThermalTime - LeafExpansionTime_i)}}{(1 + exp^{-a(ThermalTime - LeafExpansionTime_i)})^2}$$



$$LeafSenescenceRate_i = (T_m - T_b) \cdot LeafArea_i \cdot a \cdot \frac{exp^{-a(ThermalTime - LeafSenescenceTime_i)}}{(1 + exp^{-a(ThermalTime - LeafSenescenceTime_i)})^2}$$

with:

- $T_m = 25$, mean air temperature (°C)
- $T_b = 4.8$, base temperature (°C)
- $a = 0.01379$

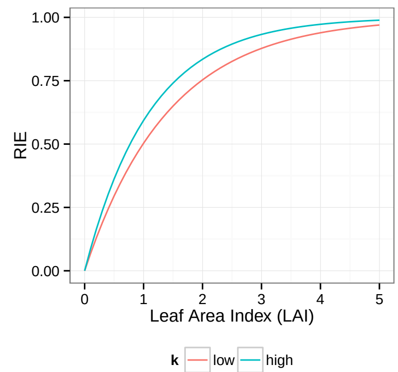
The illustration uses $i = 10$ as values for $PotentialLeafArea_i$, $LeafExpansionTime_i$ and $LeafSenescenceTime_i$

$$LeafArea_i = \int LeafGrowthRate_i - \int LeafSenescenceRate_i$$

Light interception

LAI

$$LAI = SowingDensity \cdot \sum_{i=1}^{LeafNumber} LeafArea_i$$



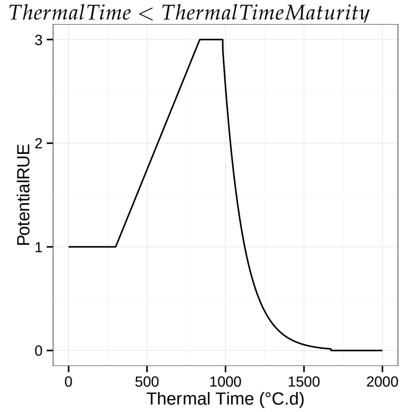
RIE

$$RIE = 1 - exp^{(-ExtinctionCoefficient \cdot LAI)}$$

Biomass production

RUE

$$PotentialRUE = \begin{cases} r_0 & \text{if } ThermalTime < 300 \\ r_0 + 2 \cdot \frac{ThermalTime - 300}{ThermalTimeFlowering - 300} & \text{if } 300 < ThermalTime < ThermalTimeFlowering \\ r_{max} & \text{if } ThermalTimeFlowering < ThermalTime < ThermalTimeSenescence \\ a \cdot exp^{b \cdot (1 - \frac{ThermalTime - ThermalTimeMaturity}{ThermalTimeMaturity - ThermalTimeSenescence})} & \text{if } ThermalTimeSenescence < ThermalTime < ThermalTimeMaturity \\ 0 & \text{else} \end{cases}$$



with:

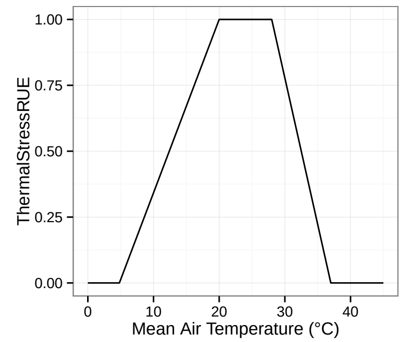
- $r_0 = 1$, vegetative RUE
- $r_{max} = 3$, maximum RUE
- $a = 0.015$, final RUE
- $b = 4.5$, slope of RUE decrease in grain filling stage

CropBiomass (Monteith, 1977)

$$dCropBiomass = Radiation \cdot 0.48 \cdot RIE \cdot RUE \cdot dt$$

CropPerformance

Thermal stress

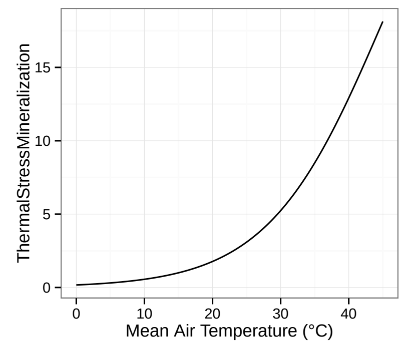


ThermalStressRUE (Villalobos et al., 1996)

$$ThermalStressRUE = \begin{cases} T_m \cdot \frac{1}{T_{ol}-T_b} - \frac{T_b}{T_{ol}-T_b} & \text{if } T_b < T_m < T_{ol} \\ 1 & \text{if } T_{ol} < T_m < T_{ou} \\ T_m \cdot \frac{1}{T_{ou}-tc} - \frac{tc}{T_{ou}-tc} & \text{if } T_{ou} < T_m < tc \\ 0 & \text{else} \end{cases}$$

with:

- $T_b = 4.8$, base temperature (°C)
- $T_{ol} = 20$, optimal lower temperature (°C)
- $T_{ou} = 28$, optimal upper temperature (°C)
- $T_c = 37$, critical temperature (°C)



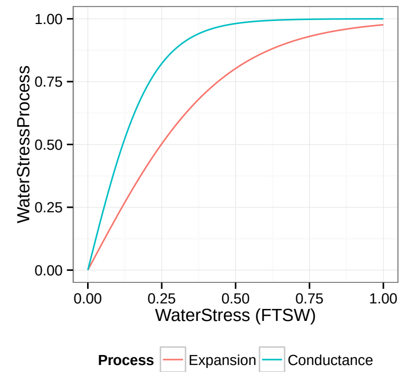
ThermalStressMineralization (Valé et al., 2007)

$$ThermalStressMineralization = \frac{T_c}{1 + (T_c - 1) \cdot exp^{(-0.119 \cdot (T_m - T_b))}}$$

with:

- $T_b = 15$, base temperature (°C)
- $T_c = 36$, critical temperature (°C)

ThermalStressAllocation



Water stress

WaterStressExpansion, WaterStressConductance

$$WaterStressProcess = -1 + \frac{2}{1 + exp^{(a \cdot WaterStress)}}$$

with $a \in [-15.6; -2.3]$, genotype-dependant response parameter

WaterStressPhenology

$$WaterStressPhenology = a \cdot (1 - WaterStressConductance)$$

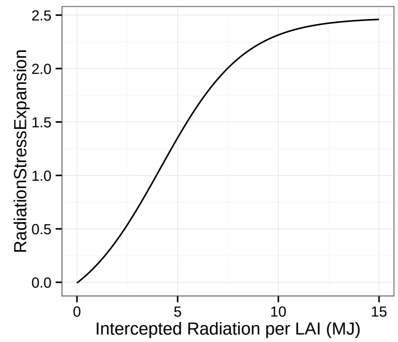
with $a = 0.1$, scaling parameter for water-stress plant heating

WaterStressMineralization

$$WaterStressMineralization = 1 - (1 - y_0) \cdot (1 - RelativeWaterContent_{layer1})$$

Nitrogen stress

Radiation stress



RadiationStressExpansion (Rey, 2003)

$$RadiationStressExpansion = s \cdot a + \frac{b}{1 + exp^{(\frac{c - IPAR/LAI}{d})}}$$

with:

- $s = 2.5$, scaling parameter for density effect;
- $a = -0.14$; $b = 1.13$; $c = 4.13$; $d = 2.09$

References

Casadebaig, P., 2008. Analyse et modélisation de l'interaction Génotype - Environnement - Conduite de culture: application au tournesol (Helianthus annuus L.) (PhD thesis). Toulouse University.

Casadebaig, P., Debaeke, P., Lecoeur, J., 2008. Thresholds for leaf expansion and transpiration response to soil water deficit in a range of sunflower genotypes. European Journal of Agronomy 28, 646–654.

Casadebaig, P., Guilioni, L., Lecoeur, J., Christophe, A., Champolivier, L., Debaeke, P., 2011. SUNFLO, a model to simulate genotype-specific performance of the sunflower crop in contrasting environments. Agricultural and Forest Meteorology 151, 163–178.

Granier, C., Tardieu, F., 1998. Is thermal time adequate for expressing the effects of temperature on sunflower leaf development? Plant, Cell & Environment 21, 695–703.

Lecoeur, J., Poiré-Lassus, R., Christophe, A., Pallas, B., Casadebaig, P., Debaeke, P., Vear, F., Guilioni, L., 2011. Quantifying physiological determinants of genetic variation for yield potential in sunflower. SUNFLO: a model-based analysis. Functional Plant Biology 38, 246–259.

Monteith, J.L., 1977. Climate and the Efficiency of Crop Production in Britain. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 281, 277–294.

Rey, H., 2003. Utilisation de la modélisation 3D pour l'analyse et la simulation du développement et de la croissance végétative d'une plante de tournesol en conditions environnementales fluctuantes (température et rayonnement). (PhD thesis). Ecole Nationale Supérieure Agronomique de Montpellier, spécialité sciences agronomiques, CIRAD-AMAP / INRA - LEPSE.

Valé, M., Mary, B., Justes, E., 2007. Irrigation practices may affect denitrification more than nitrogen mineralization in warm climatic conditions. Biology and Fertility of Soils 43, 641–651.

Villalobos, F., Hall, A., Ritchie, J., Orgaz, F., 1996. OILCROP-SUN: a development, growth and yield model of the sunflower crop. Agronomy Journal 88, 403–415.