The WOFOST model,

simulated processes, main parameters, and limitations and calibration needs

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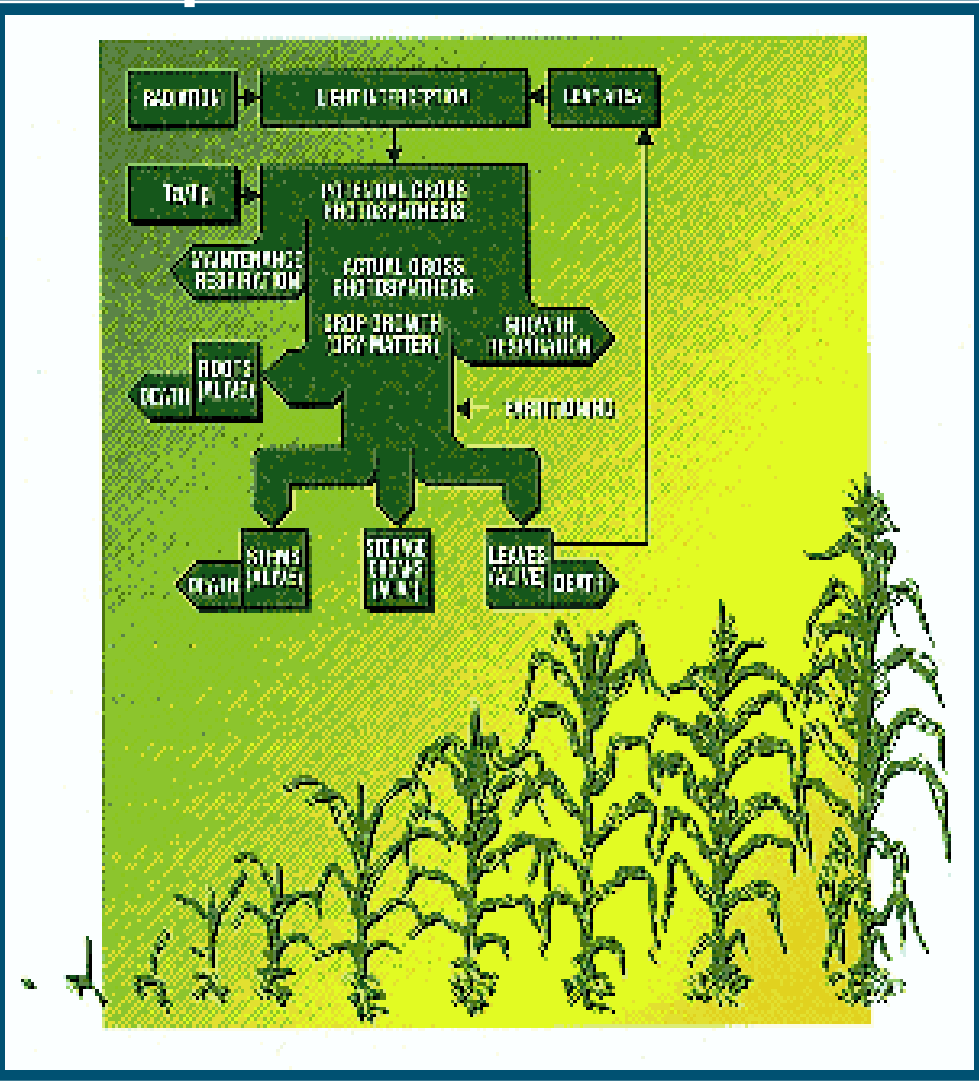
WOFOST Crop Model



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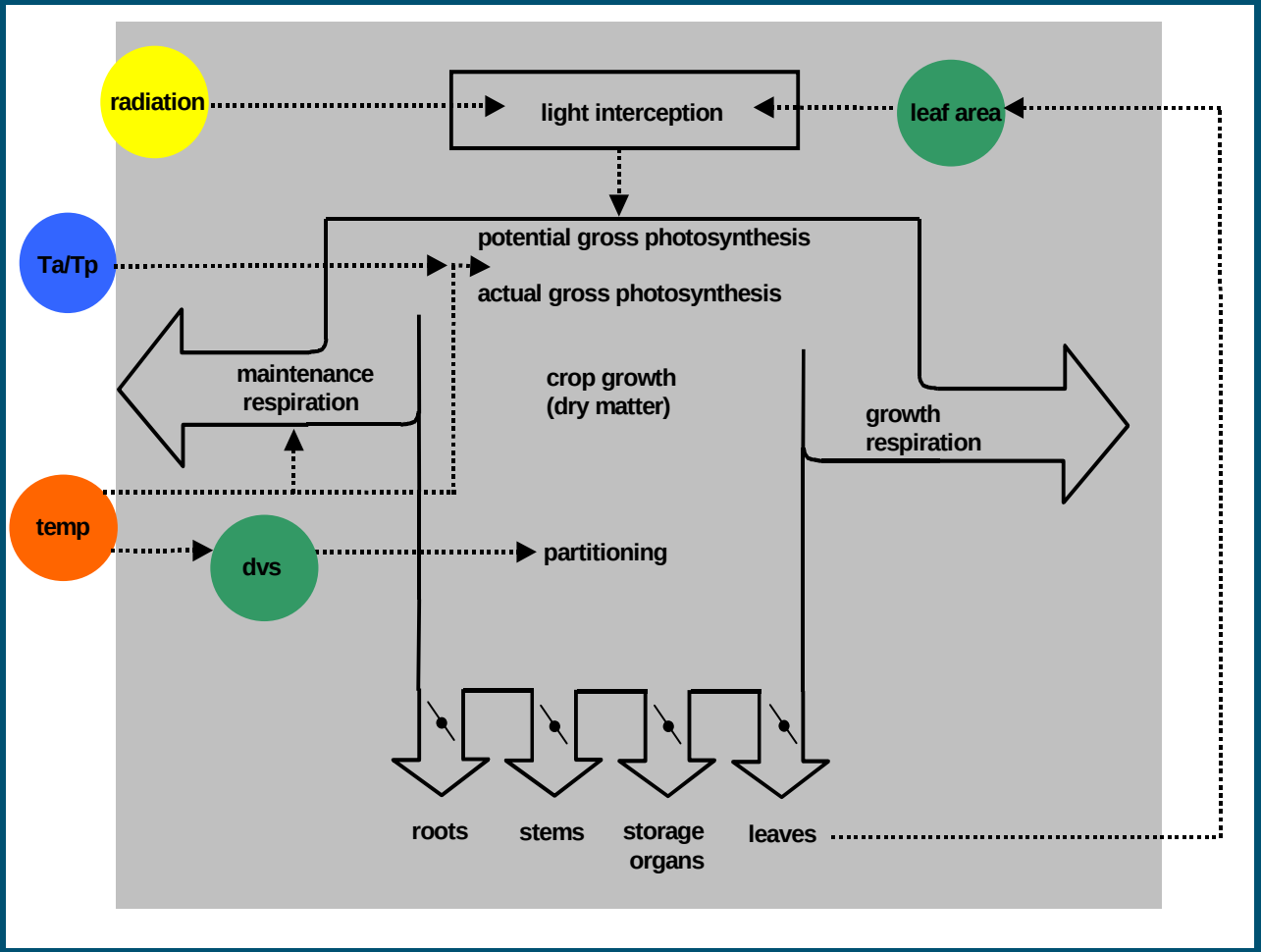
Growth in biomass: daily flow of dry matter



WOFOST profile

WOFOST is a semi-deterministic crop simulation model of physiological processes (daily time steps),

- phenology (sowing- flowering- maturity)
- Light interception
- Photosynthesis
- Respiration
- Assimilate partitioning
- Leaf area dynamics
- Decay
- Evapotranspiration
- Soil water balance
- *Soil fertility (seasonal nutrient supply) (not in CGMS)*

Simulation runs from sowing to maturity and is based on response of crop to weather (all Prod levels) and soil moisture conditions (Wat-lim Prod)

Major processes in WOFOST: growth and water

Growth:

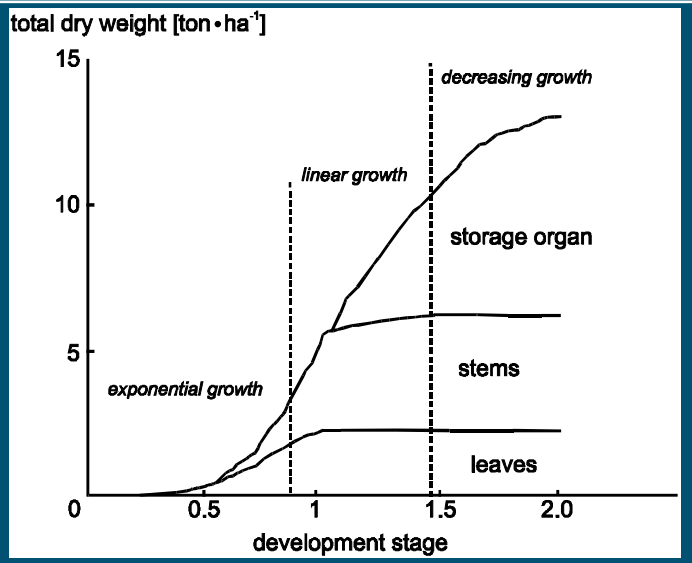
- Accumulation of biomass and its partitioning to plant organs
- Phenological development (crop life cycle, ageing)

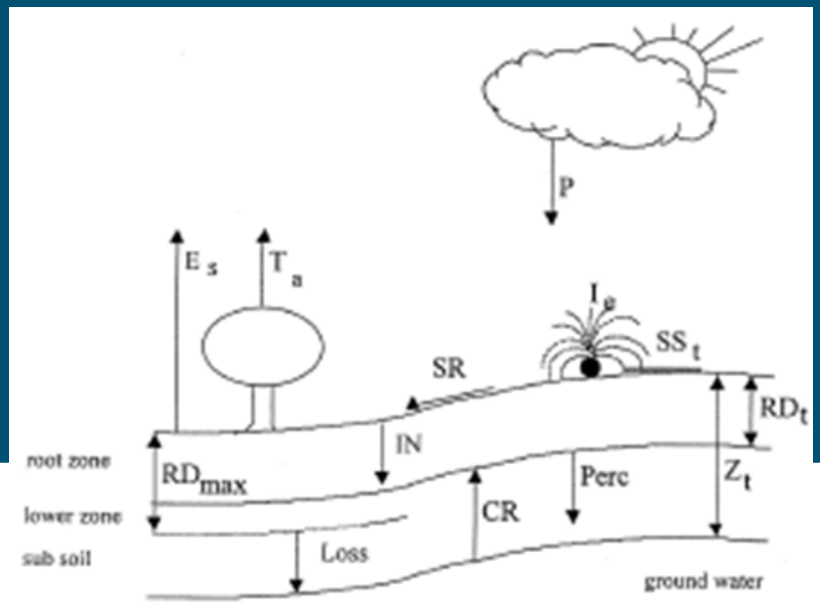
and

- death of plant organs
- leaf area development

Water supply and water use

- Exchange with atmosphere
  - Rainfall
  - Transpiration
  - Evaporation
- Soil water movements
  - Soil water in rootzone
  - Percolation, deep drainage
  - Capillary rise, phreatic water
  - Runoff





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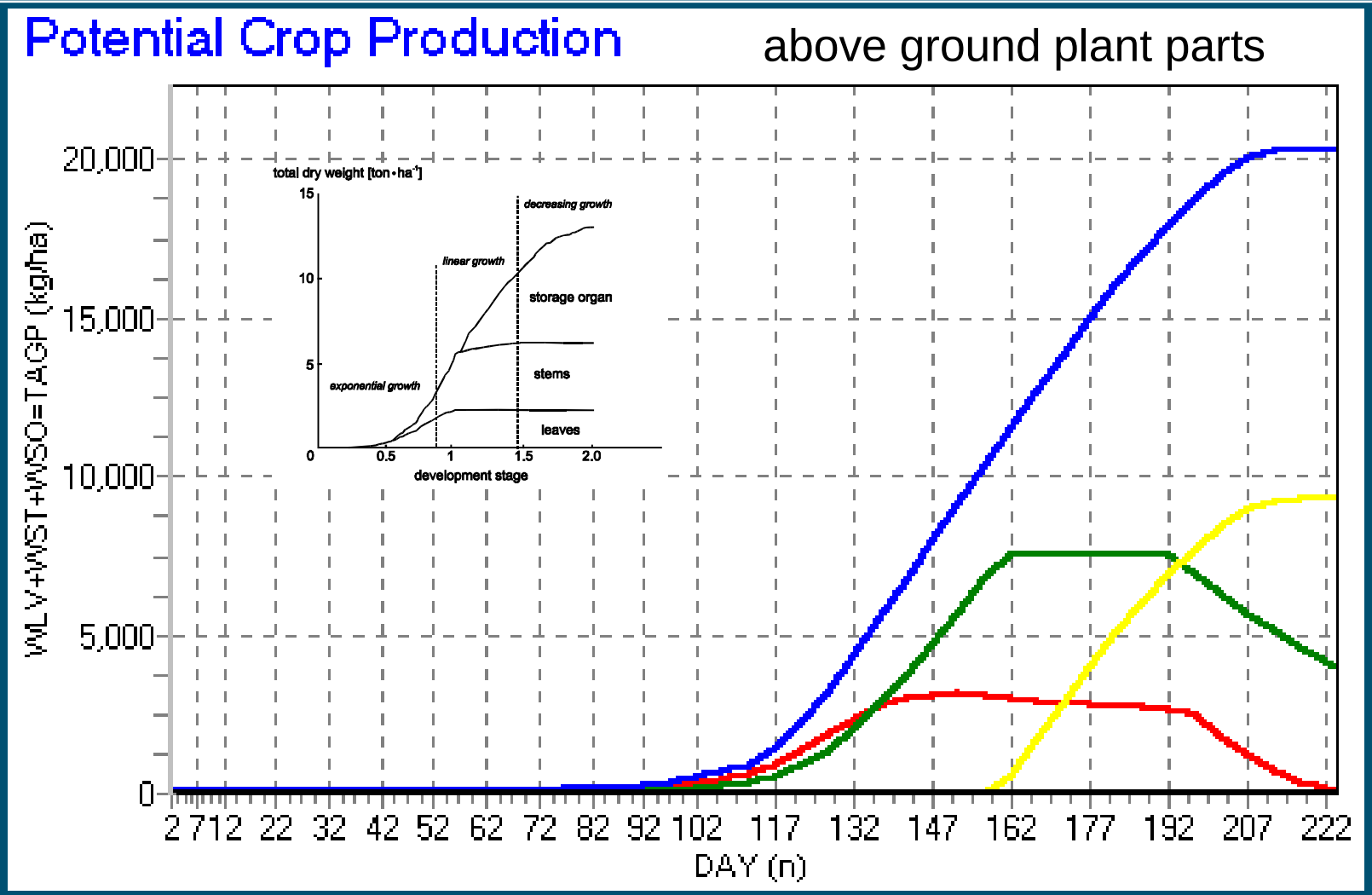
Pot Prod - Growth curve over season incl decay



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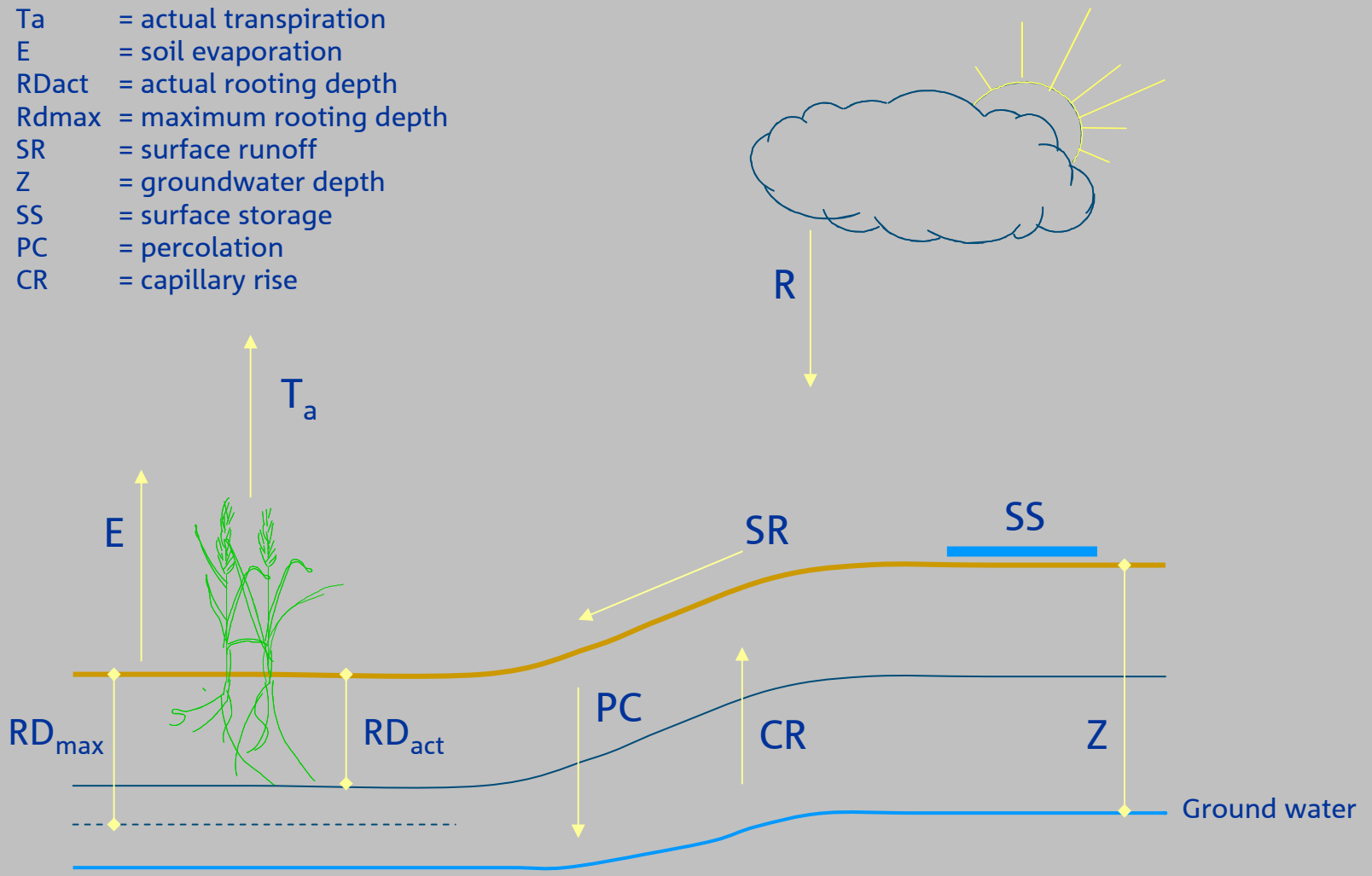
Water-limited growth influenced by transpiration

Ta = actual transpiration
E = soil evaporation
RDact = actual rooting depth
Rdmax = maximum rooting depth
SR = surface runoff
Z = groundwater depth
SS = surface storage
PC = percolation
CR = capillary rise



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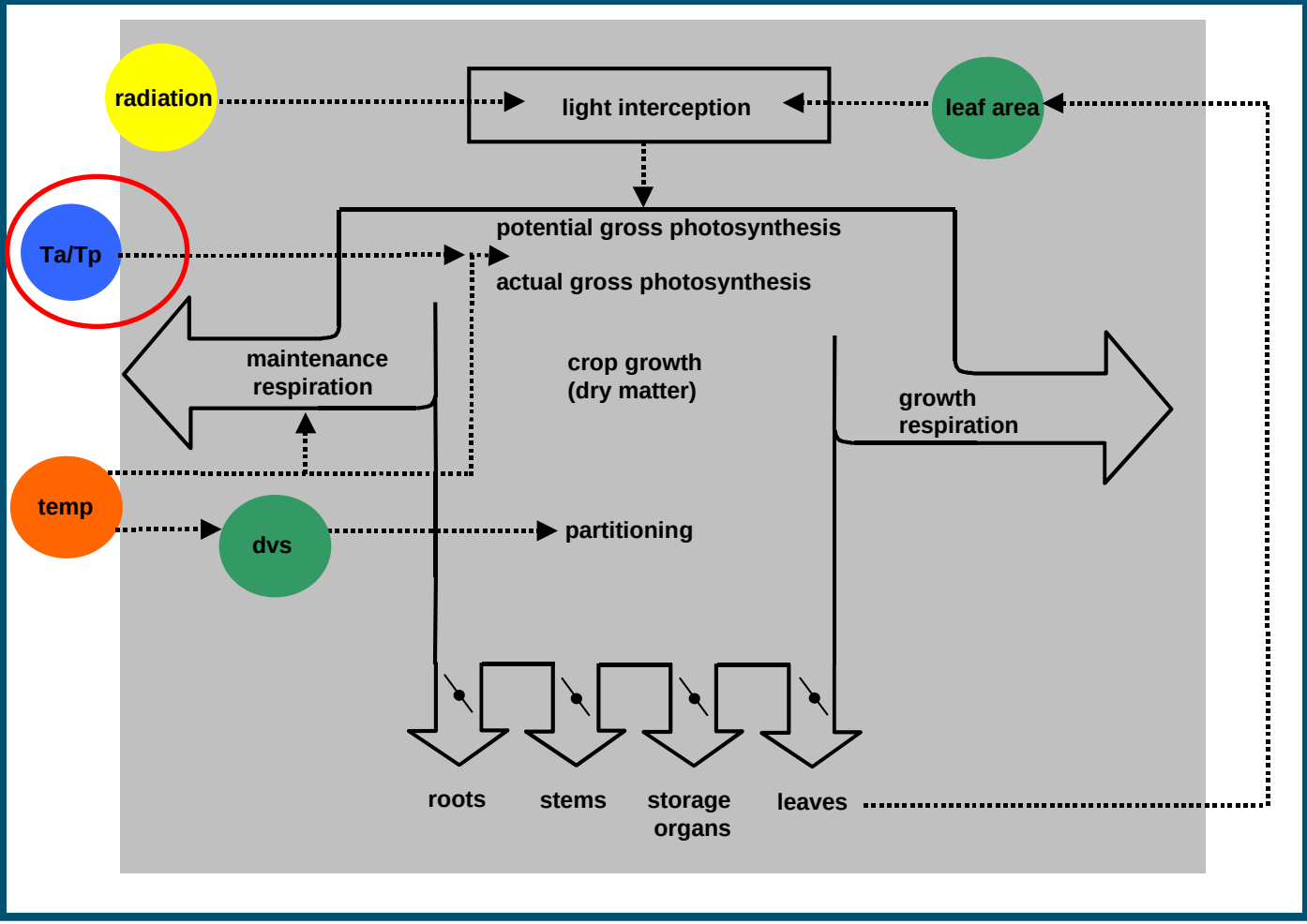
Water limited growth defined by reduction in transpiration :



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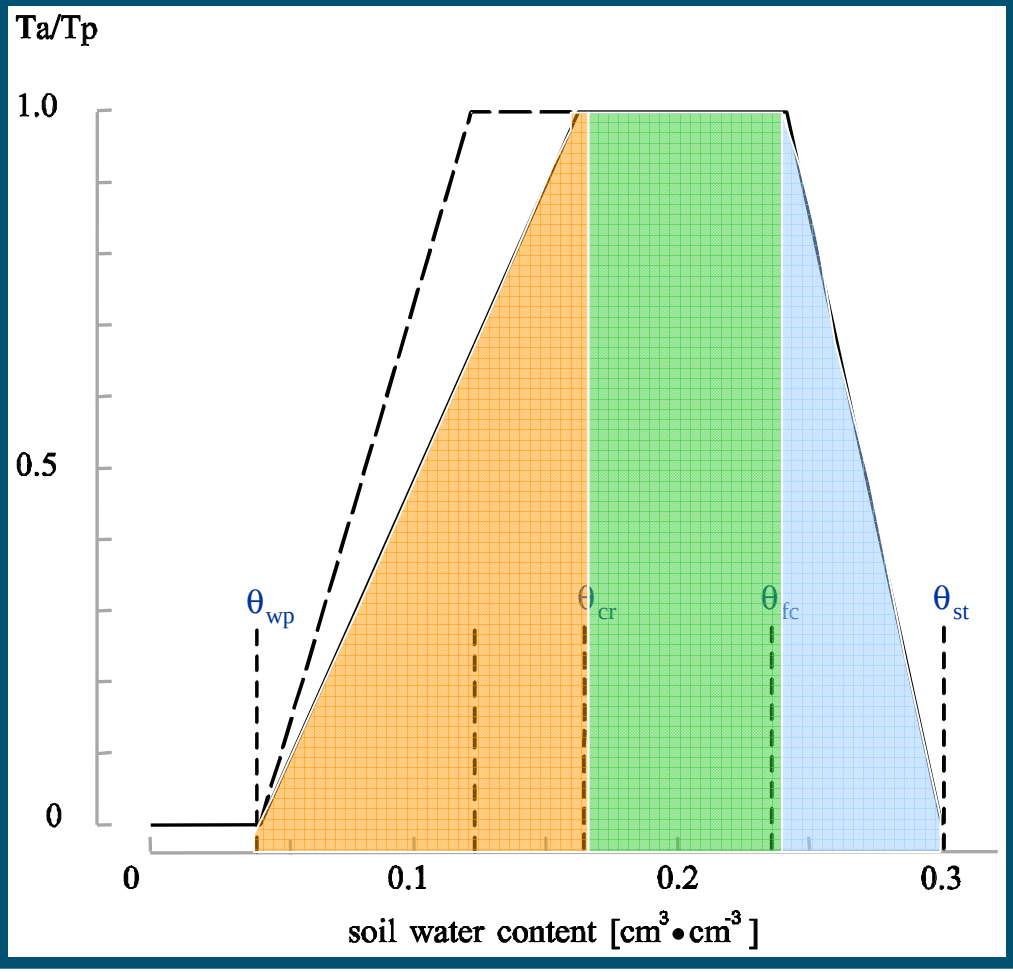
WOFOST – water-limited growth growth

Transpiration reduction factor:



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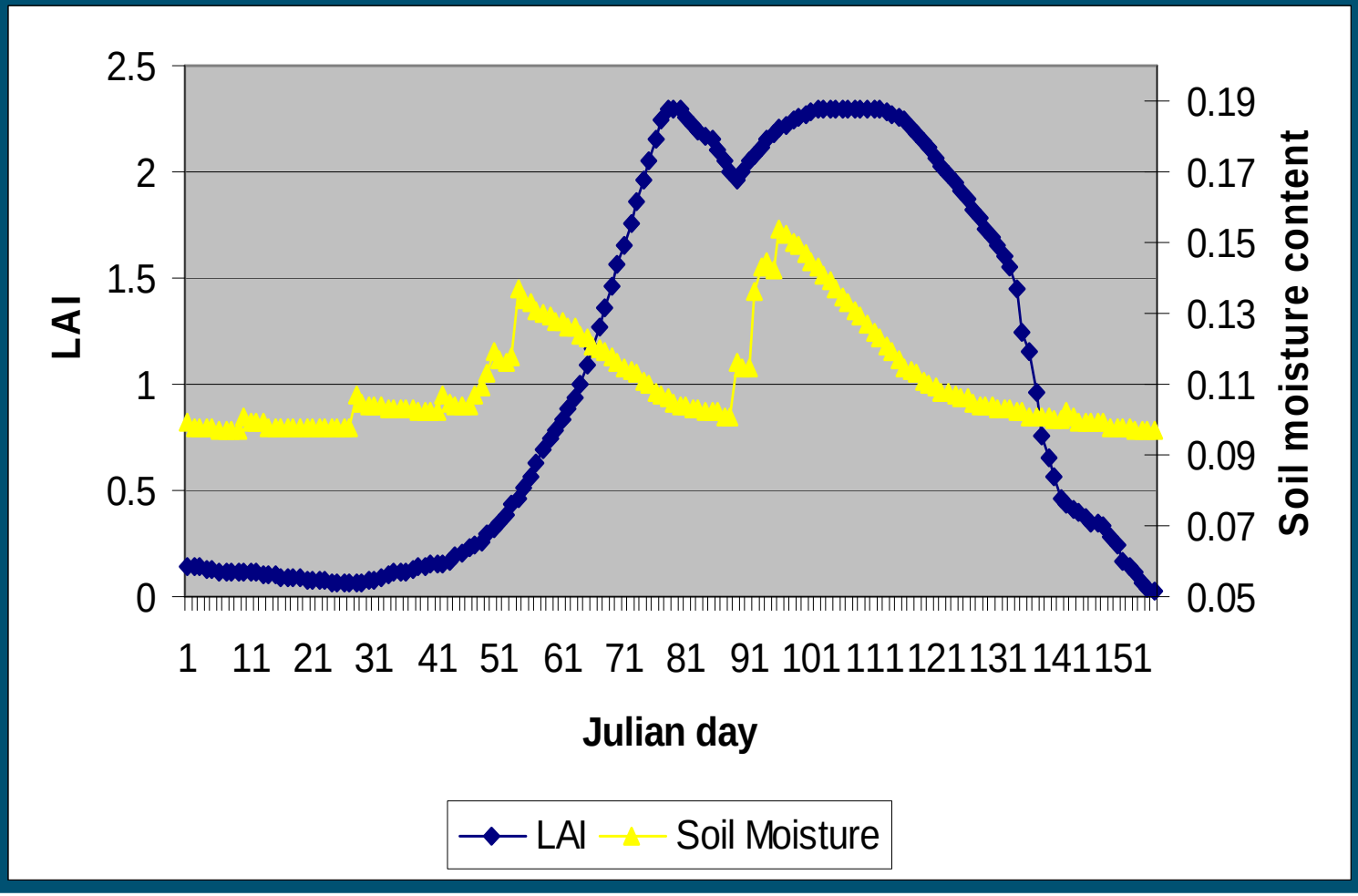
WOFOST – water-limited growth

Simulated soil moisture content and effect on LAI:



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WOFOST – growth processes - 3

Interception of sunlight:

- Solar radiation at top of canopy
- Solar radiation within canopy
- Intercepted radiation
- CO_2 assimilation

WOFOST – growth processes - 4

Solar radiation at top of canopy:

- daily amount (measured or derived)
- clear sky radiation (Angot)
- atmospheric transmission
- 50% = PAR 400-700 nm
- direct and diffuse light ratio
- solar elevation as f(date, hour, latitude)

WOFOST – growth processes - 5

Solar radiation within canopy

- LAI total
- LAI shaded and sunlit
- reflection
- leaf angle distribution, scattering
- extinction coefficient

$\Rightarrow$ requires modeling of LAI

WOFOST – growth processes - 6

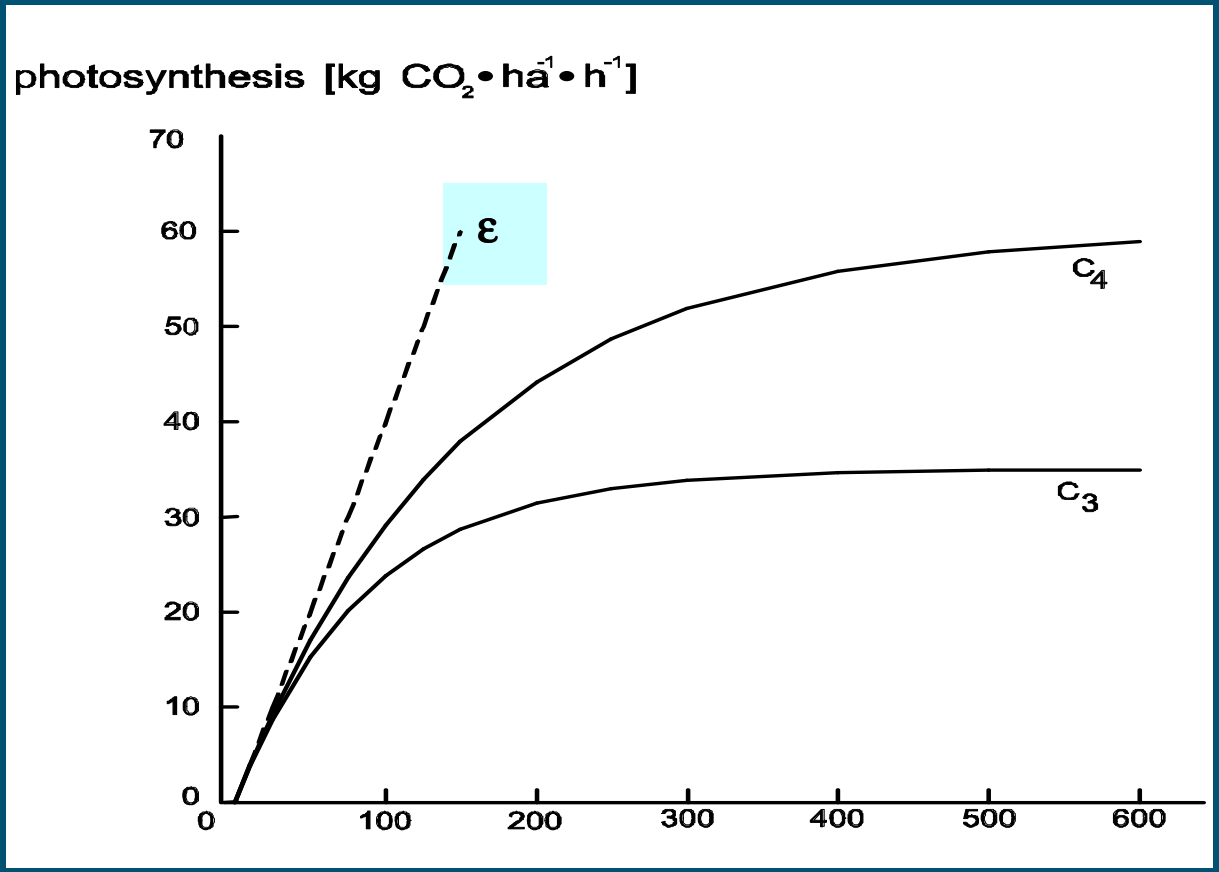
- Integration daily interception
  - 3-point Gaussian integration
  - 3 points in depth in leaf canopy
  - 2 x 3 points in time per day (three solar elevations)
- CO_2 assimilation

Photosynthesis as function of absorbed light

Photosynthesis light response curve (per unit leaf area)

controlling crop parameters

ebsilon Initial Light use Effic = 0.45



AMAXTB C4 range 30-90 Classic 70

AMAXTB C3 range 15-50 Classic 40

TMPFTB reduced AMAX at low temp

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WOFOST – growth processes - 8

Leaf area dynamics **controlling crop parameters**

$RGRLAI_c$, $TDWI_c$

- Leaf canopy formation
  - Young crop: sink or source limited
  - Full growth: source limited

  - Source-limited = supply assimilates & partitioning
  - Sink-limited = maximum leaf area expansion rate

- Daily Leaf Age Classes with biomass & thickness => leaf area

SLATB

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WOFOST – growth processes - 9

- Maximum leaf class age defined by heat sum ‘span’ at constant 35 ºC

SPAN

- Leaf canopy decay
  - regular according to life span
  - accelerated due to drought stress
  - accelerated due to self shading

WOFOST – growth processes - 10

Maintenance respiration proportional with:

- Biomass of living plant organs
- Maintenance coefficient per plant organ
- Temperature (Q10 factor: doubling with 10 ºC)

(uses 15-30 percent of all assimilates)

WOFOST – growth processes - 11

Growth respiration dependent on:

- Conversion coefficient per plant organ
- Partitioning of assimilates over organs

Uses 30-40 percent of all assimilates

WOFOST – growth processes - 12

Phenological development and model DVStage:

- sowing
- Emergence ⟶ DVS=0
- tiller formation
- floral initiation or double ridge appearance
- spikelet formation
- stem elongation
- anthesis (flowering) ⟶ DVS = 1
- grain set
- grain dehydratation (ripening)
- dead-ripe (maturity) ⟶ DVS=2

WOFOST model use and output

WOFOST simulates for theoretical production situations Pot and WatLim

WOFOST is designed to fit available regional data sets as input data

- Crop
- Soil, site
- Weather

Farm management factors limited to crop cultivar choice and average sowing date

Model output

- Crop growth curves: crop stage, biomass, LAI and harvestable part under potential and water-limited conditions
- Soil moisture evolution

- Monitoring based on tracking differences with normal conditions
- Model output can be used as yield predictors

Limitations of WOFOST

Inherent to simulation technique:

- Multi-parameter model, difficult to calibrate and validate
- Sensitive for initial state of soil and crop

Chosen generalizations

- Growth is source driven, not sink limited (except early leaf expansion)
- No crop architecture (except leaf angle distribution, no plant height, no branching, no individual leaves, no number of grains)
- Homogeneous canopy, no effect of rows, N-S orientation)
- No translocation of assimilates between organs. No temporary reserves.

Chosen system boundaries

- Single field crop oriented,
- No crop rotations, no permanent crops, no fallow,
- no continuous simulation (limited presowing, no post harvest)

Limited knowledge of crop response relations

- Empirical relations, e.g. partitioning, mechanism not well understood
- Best for near optimum growth conditions
- Severe stress difficult to quantify
- Recovery mechanisms unknown

Limitations of WOFOST

Model: not simulated:

- Winter dormancy, vernalization
- Frost damage, winter kill
- Cold stress, heat stress
- Damage by hail and strong winds
- **Sensitive stages for drought stress**
- **Damage from excess water, flooding**
- Management response (e.g. resowing)
- Effect of weeds, diseases, animals
- Yield quality
- Harvest losses

Data: not all crops sufficiently calibrated for all regions

WOFOST – crop input data reflects complexity

- Crop (choice from 8 field crops)
- Standard crop file
  - 46 crop parameters including
  - 34 single parameters
  - 12 multiple parameter tables (dynamic parameters function of crop age or temperature)
- Variety (regional cultivars with some parameters modified)
- Crop calendar
  - start of season
  - end of season

Origin of crop parameter values

Borrowed from other models in the family and regional inventories

and originally from

- Laboratory measurements
- Crop physiological field trials
- Agronomic field trials
- Crop cultivar specifications
- Farm field observations
- Agricultural handbooks,
- Info agric extension services etc
- General literature

Crop data overviews from MARS Project

Agromet crop inventories JRC Agriculture project Action 3 (1990-1994)

- Hough, 1990 UK
- Falisse 1992 Benelux
- Narciso, Ragni, Venturi 1992 It Sp Gr (Mediterranean)
- Russell and Wilson 1994 wheat EU12
- Bignon 1990 Mais Grain EU12
- Russell 1990 barley EU12
- Boons-Prins et al. 1993 Ten crops EU12 for CGMS,

Complexity of crop parameter input

Number of crop input parameters for simulation of biomass			
	scalarV	ArrayV	total
Storage organs	2	1	3
Stems	2	2	4
Roots	4	2	6
Leaves	9	3	12

Note: TAGP Total Above Ground Biomass is not a state variable ss, but an output variable

Phenology controlling crop parameters

Appearance organs controlled by heat sums:

dvs (scale)	tsum	stage	
-	-	sowing	TBASEM, TEFFMX, TSUMEM
0	+ TSUMEM	emergence	DTSMTB()
1	+TSUM1	anthesis (flowering)	TSUM1
2	+TSUM2	maturity/harvest	TSUM2

! Phenological development may be influenced by day length — DLO, DLC

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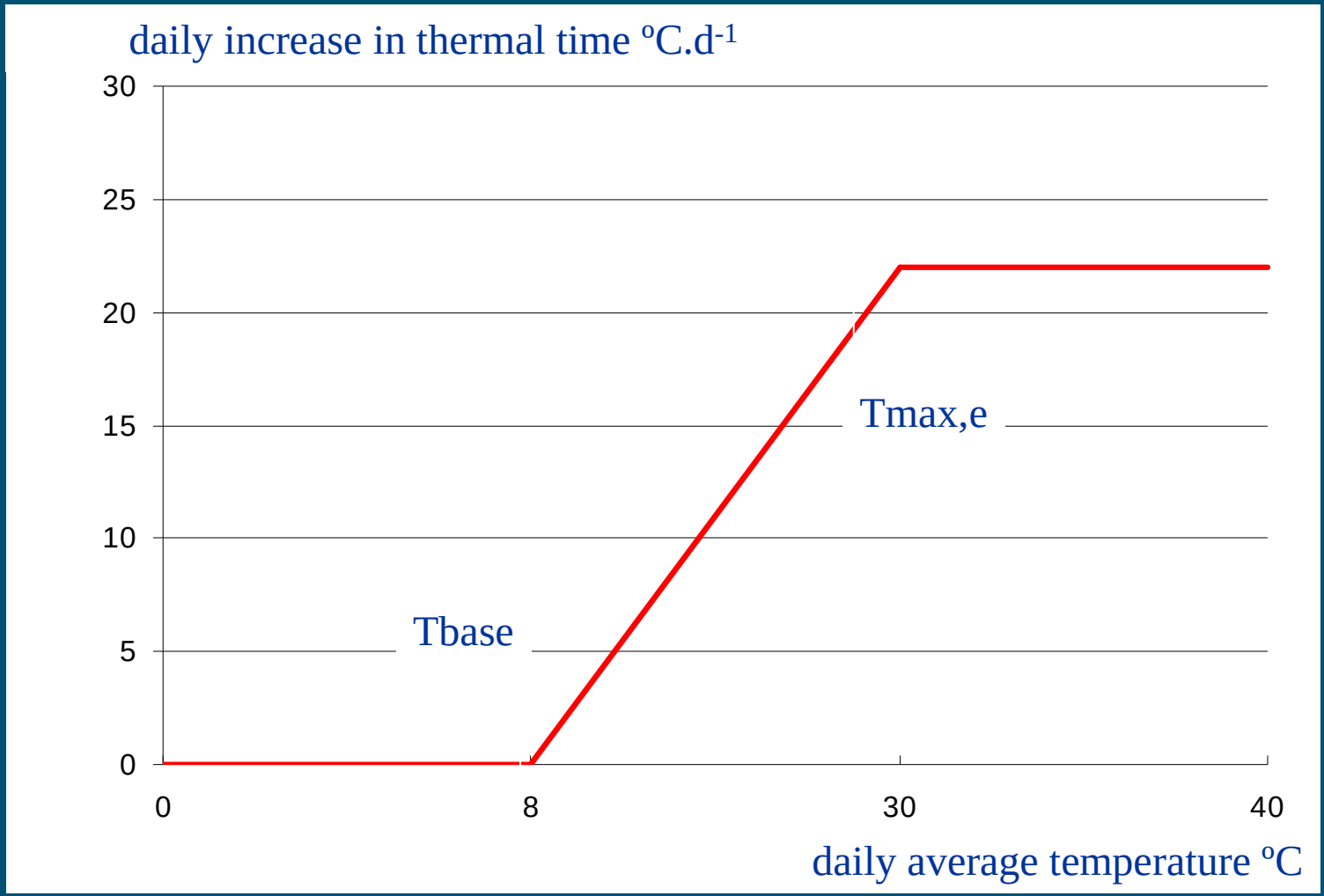
WOFOST – calculation of thermal time (Tsum)



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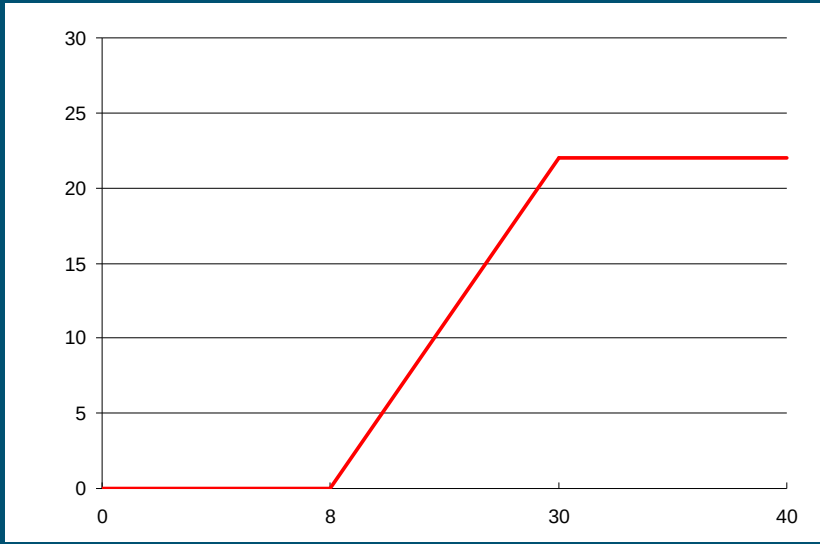
Tsum in crop data file



DTSMTB() multiple parameter

Format: Table "AFGEN function"

Value found by interpolation

- TSUM1 = 750. ! temperature sum from emergence to anthesis [cel d]
- TSUM2 = 859. ! temperature sum from anthesis to maturity [cel d]
- DTSMTB = 0.00, 0.00, ! daily increase in temp. sum
- 8.00, 0.00, ! as function of av. temp. [cel; cel d]
- 30.00, 22.00,
- 35.00, 22.00

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How to adjust which crop parameters and why?

- Aim of the model application? What was the question?
- Type and detail of observations
- Which parameters are sensitive or not ?
- Why insensitive under certain conditions?
  - Overruled by other process or parameters
  - Driving environmental factors are not effective
- Plausible range?
- Sacred value or free for fitting?
- Consistencies and interrelations with other parameters?
- Consistencies between different crop varieties (in the same regional model application).

WOFOST – adjust grain filling period of cereal

Growth periods controlled by heat sums:

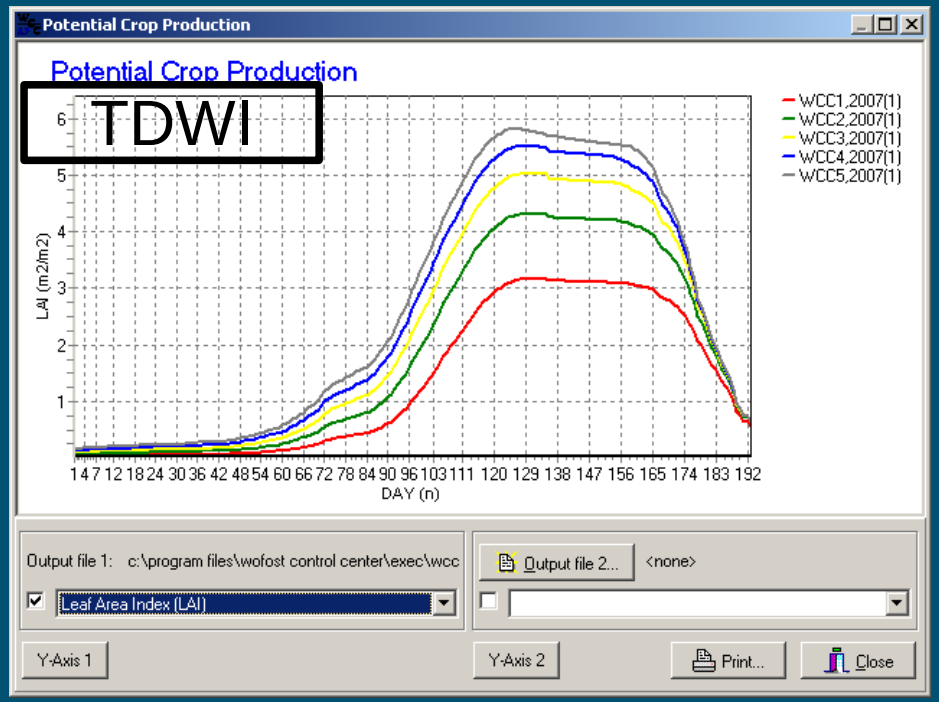
dvs (scale)	tsum	growth period
-	sowing	sowing-emergence
0	0	emergence
1	+TSUM1	vegetative growth
2	+TSUM2	grainfilling

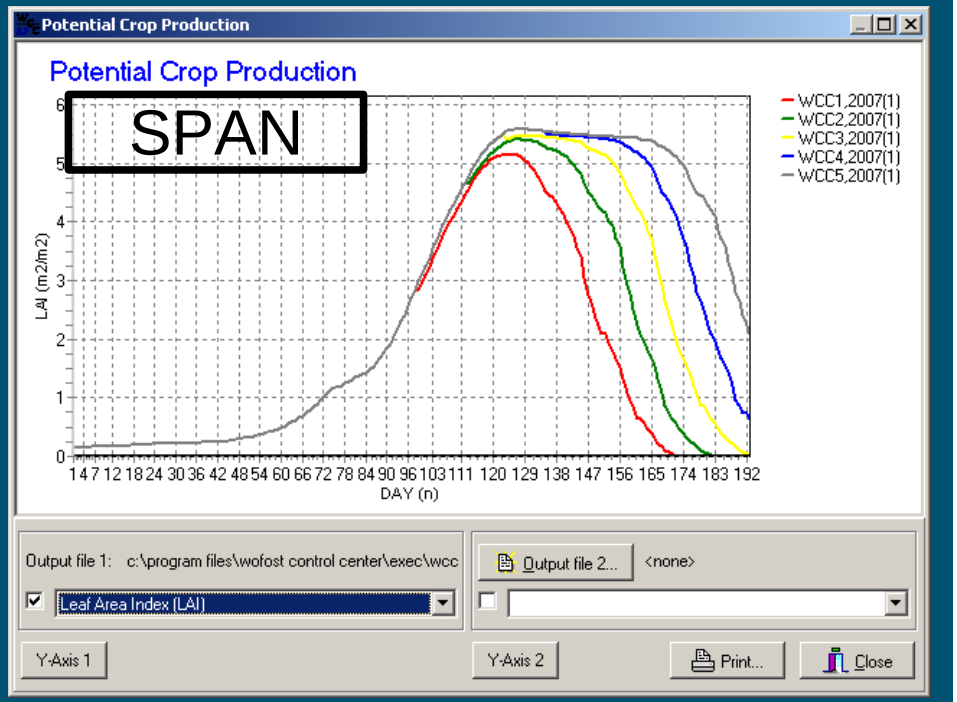
Example: Larger TSUM2 extends growing season,

1. Often linear response , but if Temp below Tbase it has no effect
2. Growing season may stop before TSUM2 is reached if LAI drops to zero, message appears: “no living leaves anymore”. In that case a longer growing season can be simulated by modifying LAI dynamics
   - by extending the period of leaf formation or
   - by increasing the life span of leaves (or both)

Optimize two important parameters

- Initial dry weight (TDWI)
- Life span of leaves (SPAN)





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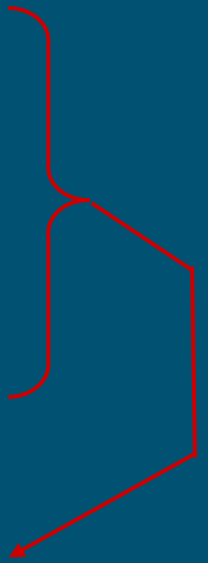
Example: mismatch of crop parameters to reality

Simulation of phenology of winter-wheat without vernalization			
	reality	simW-Eur	simCentrAsia
Sowing date	10 Oct	nil	nil
Emergence	25 Oct	1 January	1 Apr
Start dormancy	1 Dec	nil	nil
End dormancy	1 March	nil	nil
Flowering	31 May	31 May	31 May
Maturity	10 Aug	10 Aug	10 Aug



Note: Ideally simulation follows reality. The applied simulation skips early autumn growth and dormancy. The best attainable fit is that simulation of biomass is close to reality since end of dormancy. Simulation of phenological stages is distorted until flowering .
The simulated initial situation is fake, too.

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Observations needed for quick calibration of crop parameters

WOFOST	Regional calibration Regional observations	Local calibration, Observations at point locations
PHENOLOGY	**Parameters** TSUM1, TSUM2 **Necessary observations** crop calendars or dates of emergence, flowering and maturity (year specific, if not average).	**Parameters** TSUM1 detailed, TSUM2, TSUMEM, TBASEM, DLO, DLC, TEFFMX **Necessary observations** **dates of** sowing, emergence, flowering, maturity for different years
POTENTIAL YIELD LEVEL – SIMPLE	**Parameters** AMAXTB **Necessary observations** **T**otal biomass under optimal conditions (with LAI-MAX above 3) at point or NUTS level.	**Parameters** AMAXTB, SLATB, SPAN **Necessary observations** LAI-MAX and total biomass under optimal conditions.

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Process controlling parameters for advanced calibration

WOFOST	Regional calibration Observations at point or NUTS level	Local calibration Detailed observations at point locations (field experiments)
POTENTIAL YIELD LEVEL – COMPLEX	**Parameters** SLATB, SPAN, FOTB **Necessary observations** maximum LAI and total biomass and/or yield under optimal conditions	**Parameters** AMAXTB**,** SLATB, SPAN, RGRLAI, LAIEM, TDWI, partitioning factors (FLTB, FRTB, FOTB detailed), TMPFTB, RDRRTB **Necessary observations** LAI, total biomass, weights of leaves, stems, storage organs and roots over time during the growth period under optimal conditions.
WATER-LIMITED YIELD LEVEL	**Parameters** CFET, RDMCR. **Necessary observations** total biomass and/or yield level under rain fed conditions	**Parameters** CFET detailed, RDMCR detailed, PERDL, DEPNR **Necessary observations** LAI, total, biomass, weights of leaves, stems and storage organs and possibly crop transpiration, evaporation and rooting depth over time during the growth period under water-limited conditions.
		Model parameters that cannot be calibrated: See Appendix B with complete list of model parameters in CGMS/WOFOST and the model parameters that cannot be calibrated

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Conclusion

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