The WOFOST model,

simulated processes, main parameters, and limitations and calibration needs

Kees van Diepen and Allard de Wit

http://www.wofost.wur.nl / http://wofost.wikispaces.com

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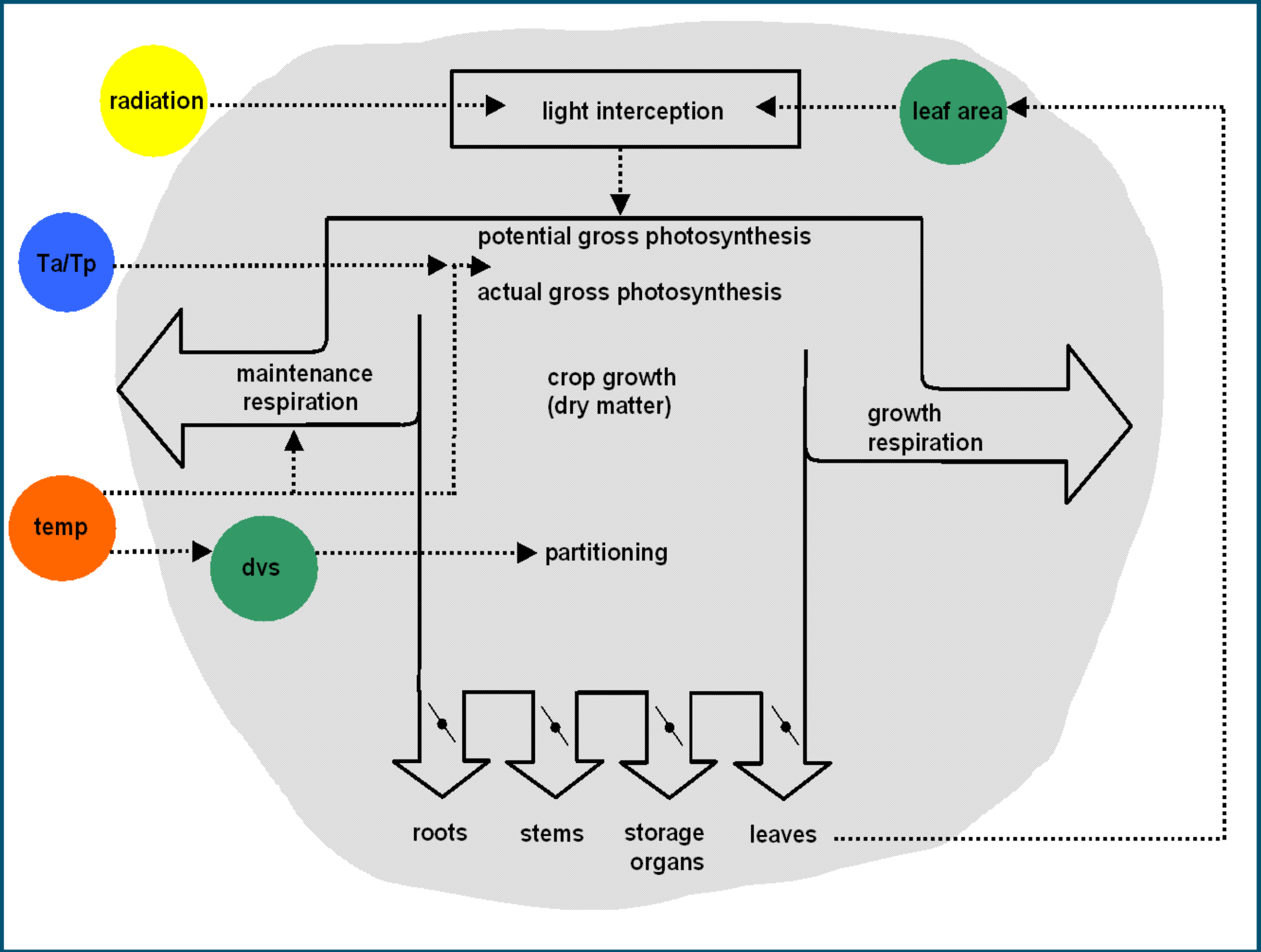
WOFOST profile

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

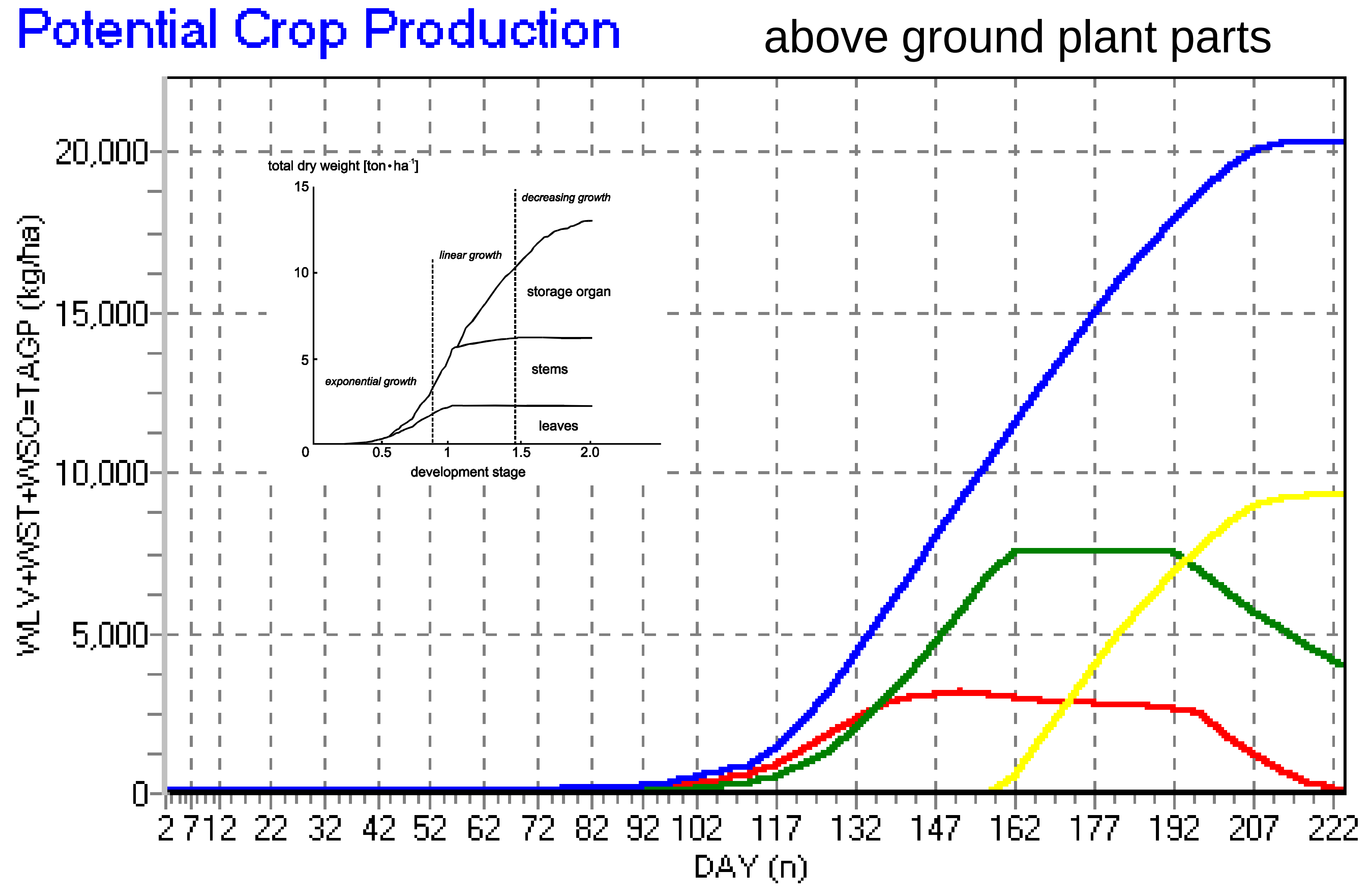
1. phenology (sowing- flowering- maturity)
2. Light interception
3. Assimilation (Photosynthesis)
4. Respiration
5. Assimilate partitioning
6. Leaf area dynamics (growth and decay)
7. Evapotranspiration
8. Soil water balance and drought response
9. *Soil fertility (seasonal nutrient supply) (not in CGMS)*

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)

Growth in biomass: daily flow of dry matter



Pot Prod - Growth curve over season incl decay



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WOFOST parameter types

- Single value parameters
  - A single value defining the shape of a functional relationship (ex: LAIEM, Q10) or a switch (ex: IDSL, IOX)
- Tabular parameters
  - The parameter is a function of another variable, usually temperature or development stage.
  - Its value is found by interpolation given DVS or TEMP
  - This is done with the AFGEN function

1: Phenology – terminology

Phenological development and model stage (DVS):

- 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

1: Phenology – parameters

Appearance organs controlled by heat sums:

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

! Phenological development may be influenced by day length

Controlling parameters:

- TBASEM
- TSUMEM
- TEFFMX
- DTSMTB
- TSUM1
- TSUM2
- DLO
- DLC

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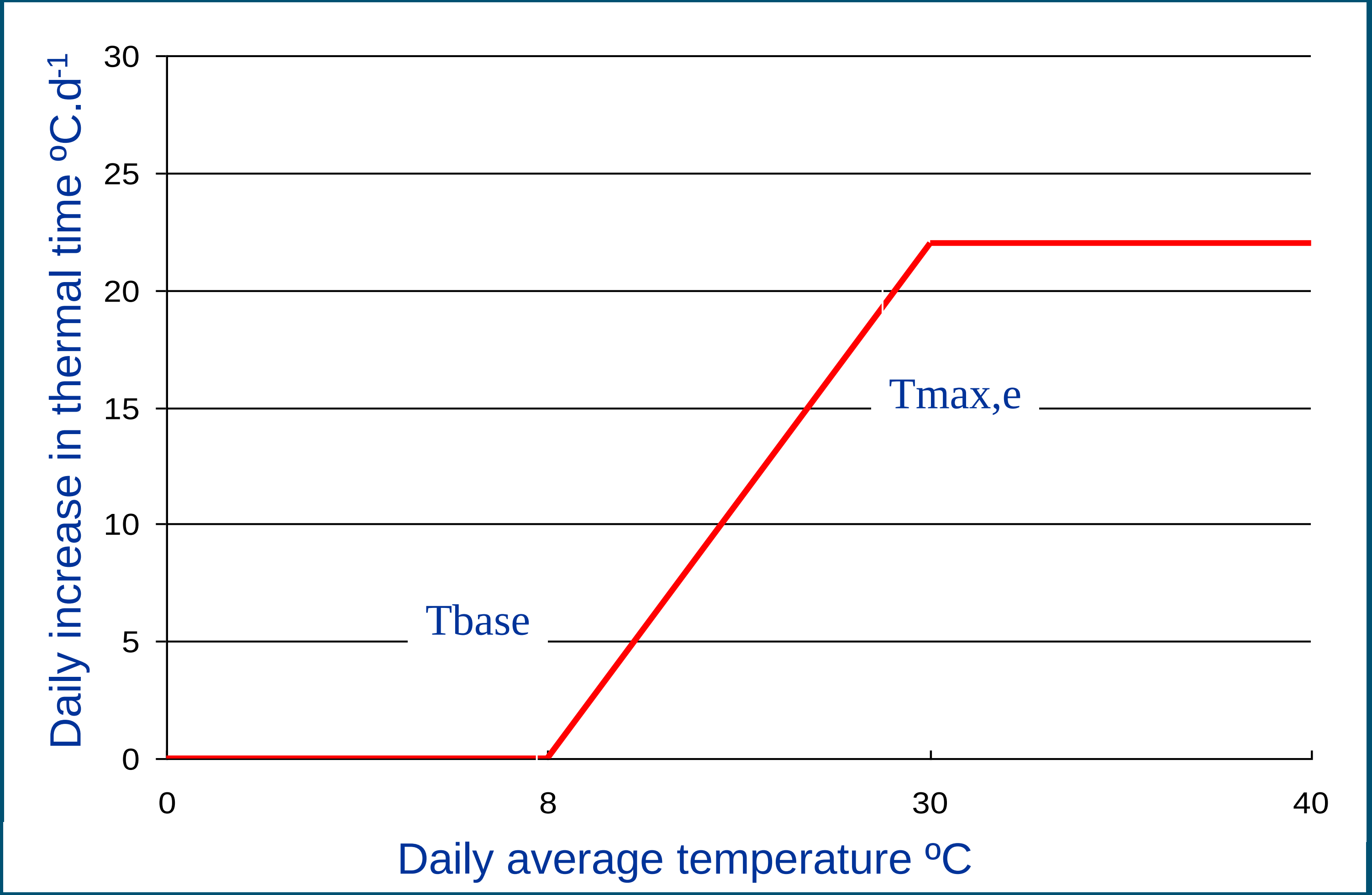
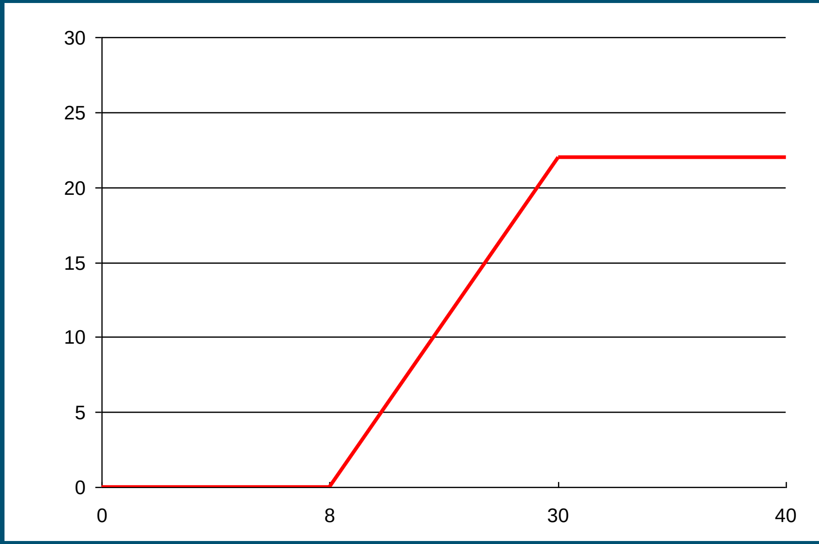
1: Phenology – daily TSUM increase



1: Phenology – DTSMTB parameter



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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2: Light interception - principles

Interception of sunlight:

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

2: Light interception – Top of Canopy

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)

2: Light interception – Within Canopy

Solar radiation within canopy

- LAI total
- LAI shaded and sunlit
- reflection
- leaf angle distribution, scattering (implicit assumptions in WOFOST)
- extinction coefficient (KDIFTB)

$\Rightarrow$ requires modeling of LAI

Controlling parameters:

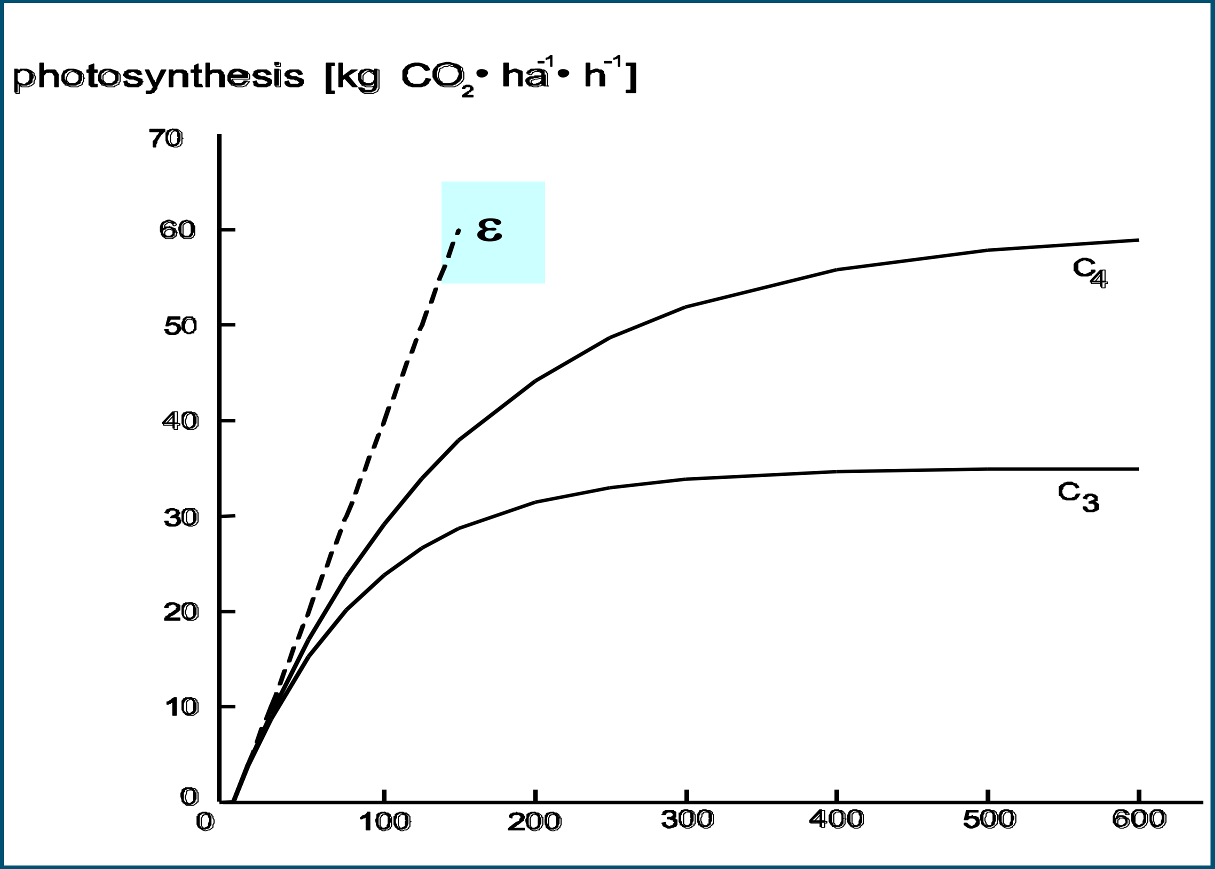
•KDIFTB

2: Light interception – Implementation

- Principle: detailed modeling over the day: changing solar elevation, diffuse/direct radiation, etc (= tedious!)
- Simplified procedure in WOFOST:
  - 3-point Gaussian integration over the day
    - 3 points in depth in leaf canopy
  - 3 x 3 points per day (three solar elevations * three canopy depths)
- Potential assimilation rate calculated

3. CO2 assimilation: principles

Photosynthesis light response curve (per unit leaf area)



Absorbed radiation PAR J $m^{-2}s^{-1}$

Controlling crop parameters

EFF (epsilon)
Initial Light use Efficiency
= 0.45

AMAXTB
C4: 30-90
(default 70)
C3: 15-50
(default 40)

TMPFTB
Tmean response

TMNFTB
Tmin response

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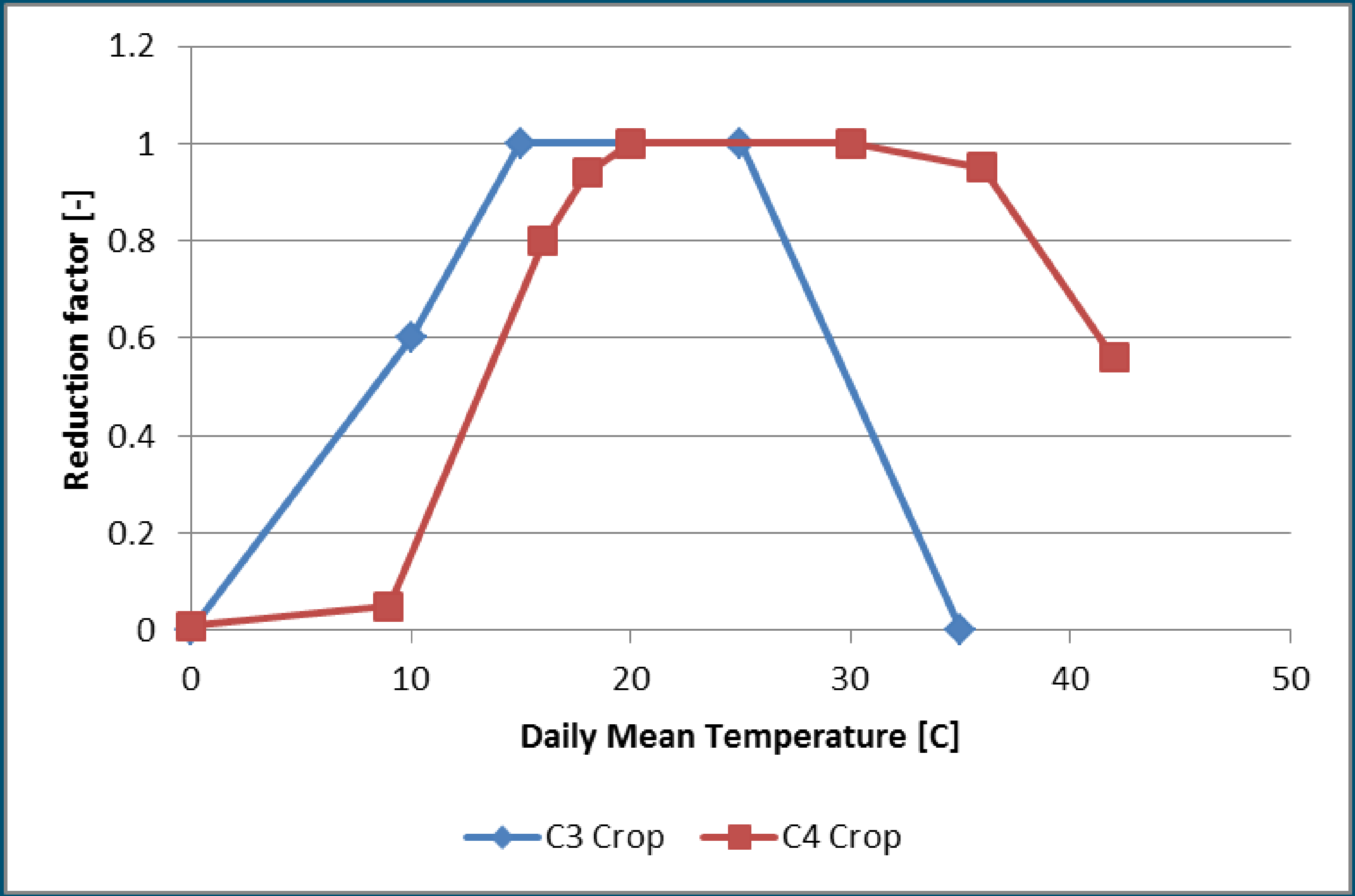
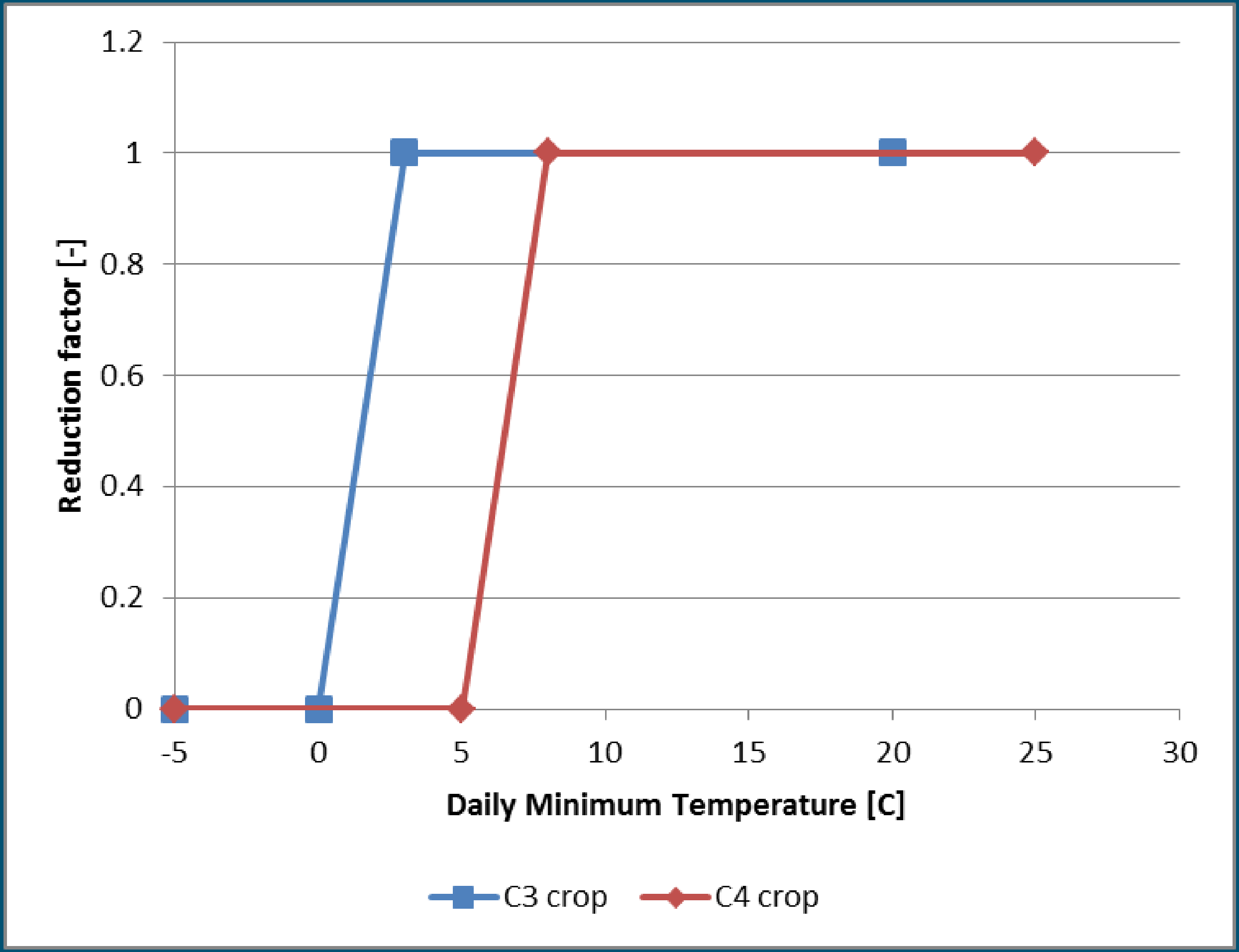
3. CO_2 assimilation: mean temp. reduction (TMPFTB)



3. CO_2 assimilation: min temp reduction (TMNFTB)



4. Respiration: plant maintenance

Maintenance respiration proportional with:

- Biomass of living plant organs
- Maintenance coefficient per plant organ (RMO, RMS, RML, RMR)
- Q10 specifies relative increase with each 10 ºC increase in daily maximum temperature
- Maintenance respiration increases rapidly with temperature!!

(uses 15-30 percent of all assimilates)

Controlling crop parameters

RMO, RMS, RML, RMR

Q10
(usually Q10=2.0 at Tref=25 ºC)

4. Respiration: growth (conversion losses)

Growth respiration dependent on:

- Conversion coefficient per plant organ
- Partitioning of assimilates over organs
- Not explicitly modelled by WOFOST but implicit in the conversion coefficients

Controlling crop parameters

CVO, CVS, CVL, CVR

Uses 30-40 percent of all assimilates

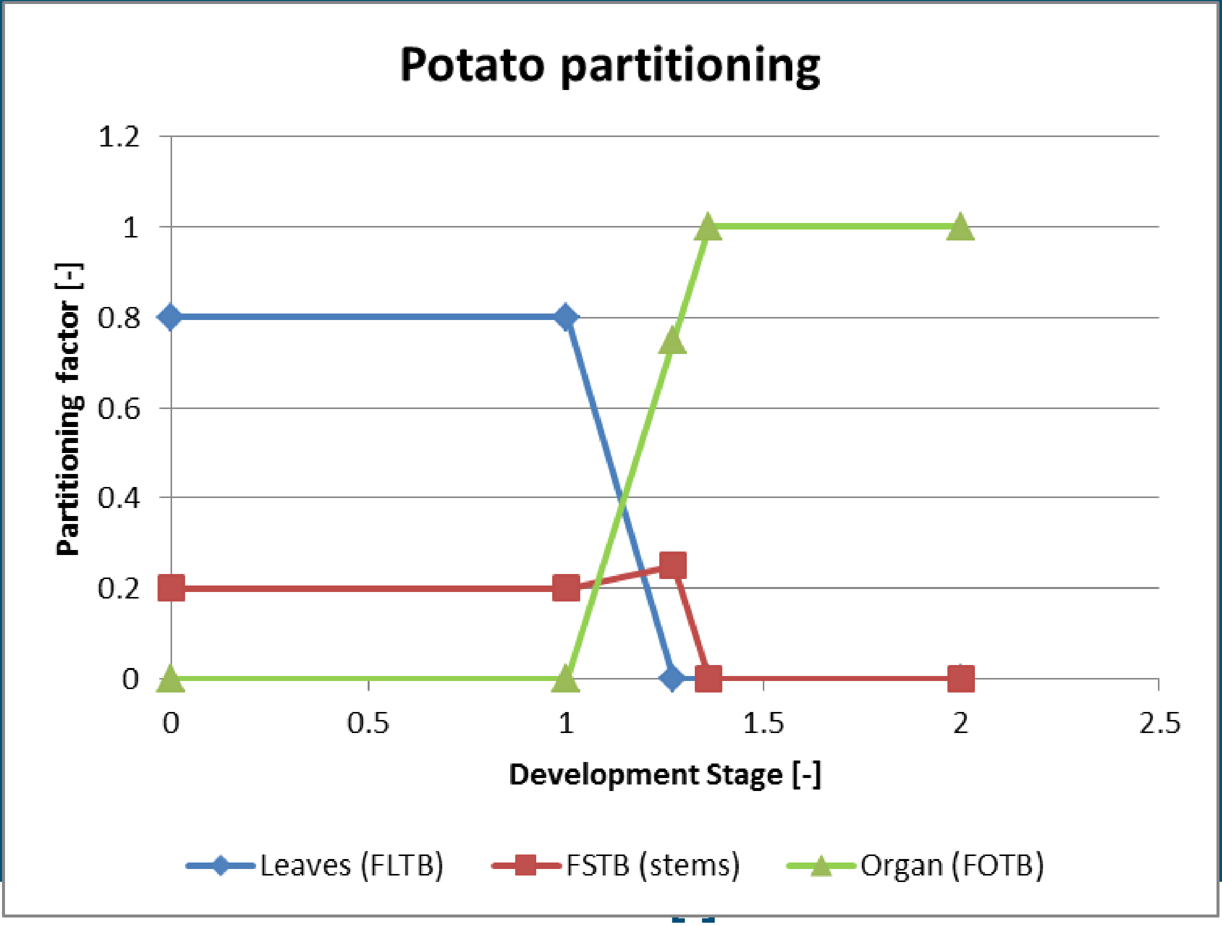
5. Partitioning: principles

- Assimilates are distributed over different plant organs (leaves, stems, roots, storage organs)
- Depending on development stage
- Two stage partitioning in WOFOST:
  - Below-ground e.g. roots (FRTB)
  - Above-ground (1 – FRTB):
    - Leaves (FLTB)
    - Stems (FSTB)
    - Storage organs (FOTB)

must add up to 1.0

5. Partitioning: implementation

Rigid partition tables as function of development stage (DVS)



Controlling crop parameters

FRTB, FSTB, FLTB, FOTB

6. Leaf area dynamics: principles

- Leaf growth:
  - driven by increase in leaf biomass
  - Conversion to leaf area through specific leaf area (SLA = m^2 of leaf per kg biomass)
  - Leaf area growth can be source or sink-limited
- Leaf decline (senescence):
  - Aging of leaves
  - Drought stress or self-shading
- Stems and pods can also contribute to the leaf area
- Requires book-keeping of leaf age classes for biomass, SLA and leaf age!

6. Leaf area dynamics: growth

- Early crop canopy growth:
  - Sink or source limited (limited by exponential growth rate LAI)
  - SLA function of DVS
  - SLA adjusted to keep leaf growth <= exponential growth rate
- Mature crop canopy growth:
  - Source limited growth (leaf biomass increase)
  - SLA function of DVS

Controlling crop parameters

RGRLAI (sink-limited growth)

TDWI (initial LAI)

SLATB (SLA as function of DVS)

6. Leaf area dynamics: senescence

- Leaves die when they reached a physiological age
  - defined by heat sum 'SPAN' at constant 35 ºC
- Additionally leaves can die from:
  - Water stress (PERDL)
  - Self-shading when $LAI>LAI_{crit}$ ($LAI_{crit} = 3.2/KDIF =\sim 5.5$)
- Oldest leaves die first in all cases

Controlling crop parameters

SPAN

PERDL

KDIFTB

6. Leaf area dynamics: implementation

- WOFOST keeps track of:
  - Living leaf biomass for each day (a leaf class)
  - Specific leaf area for each class
  - Physiologic age for each class
- How to calculate leaf area:

$$LASUM = \sum_{class=1}^{class=n} leafbiomass * SLA$$

- When leaves die:
  - Corresponding leaf biomass classes are emptied
  - Dead biomass is added to the "dead weight leaves"

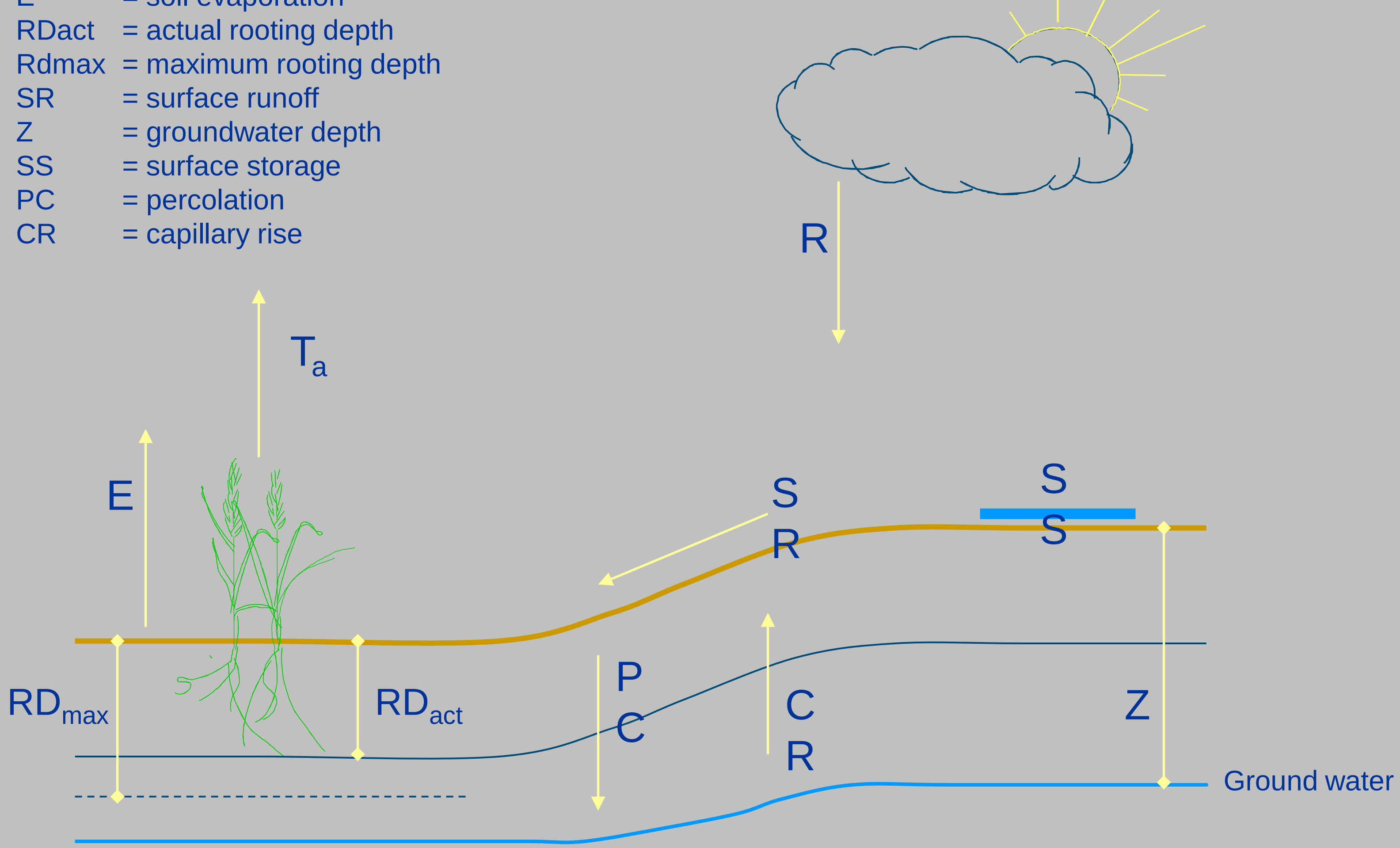
7. (Evapo)transpiration: principles

- Crop water use is calculated separately for:
  - Crop canopy (transpiration)
  - Bare soil surface (soil evaporation)
  - Soil surface with ponding (water evaporation)
- Transpiration:
  - Reference ET multiplied with correction factor (CFET)
  - Maximum ET as a function of LAI
  - Limited by soil moisture
- Soil/Water Evaporation:
  - Reference ET * shading_factor(LAI)

8. Soil water balance: schema

WOFOST Water balance

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



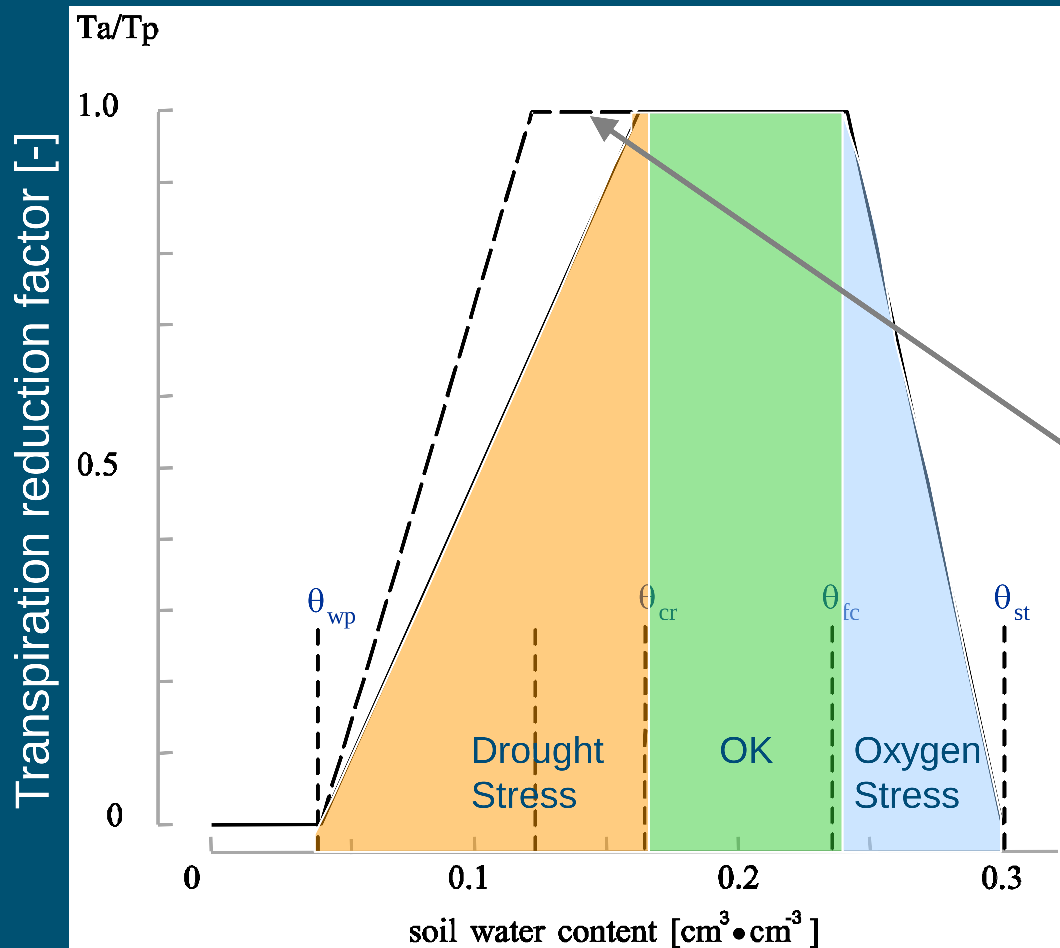
8. Soil water balance: implementation

WOFOST Water balance

- Simple 1-layer soil model with increasing rooting depth
- Bucket-type of water-balance not a Richards-equation multi-layer type of water-balance (e.g. SWAP, HYDRUS1D)
- Daily time-steps
- Limitations: instantaneous wetting of the soil profile, no root density, hysteresis, etc.

8. Soil water balance: drought response

WOFOST Water balance



θcr is variable and depends on ET0 and the crop group number DEPNR:
5 = drought resistant
1 = drought sensitive

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9. Soil fertility and nutrient limitations

- Based on the QUEFTS approach:
  - Post-processing of WOFOST biomass output (no dynamic simulation)
  - Reduction biomass based on ratio of available and necessary nutrients (NPK) given simulated biomass
- Not implemented in CGMS

WOFOST model use and output

WOFOST simulates for theoretical production situations Pot and Water-Lim
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 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 (1)

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 (2)

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 (standard files for ~25 field crops included)
- Standard crop file
  - 46 crop parameters including
  - 34 single parameters
  - 12 multiple parameter tables (dynamic parameters function of DVS or temperature)
- Variety (regional cultivars with some parameters modified)
- Crop calendar
  - start of season (emergence or sowing)
  - end of season (maturity or harvest)

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

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).

Example: 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)

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.

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.

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

Questions

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