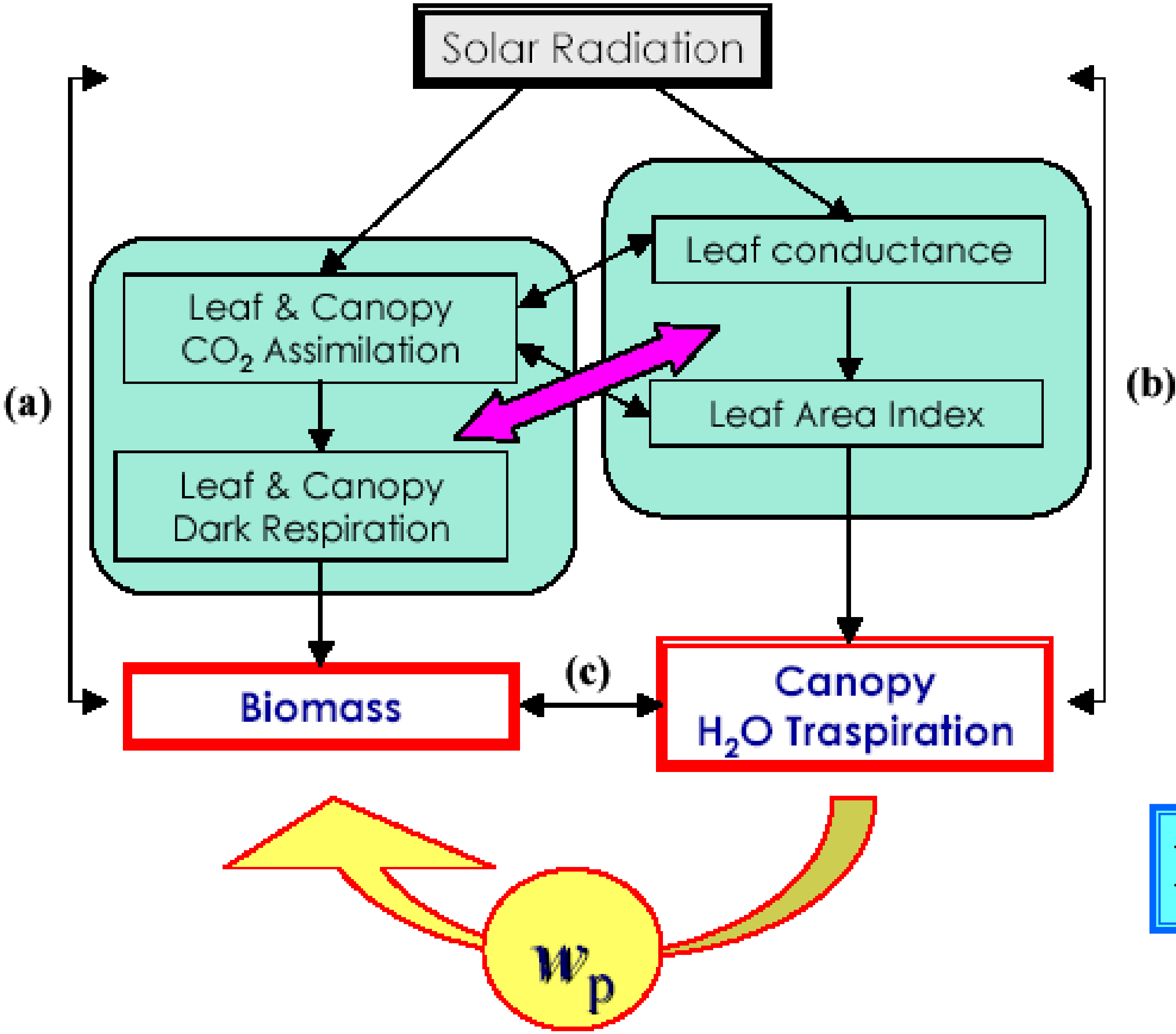
AQUACROP approach

(features, data and calibration)

Mladen Todorovic
CIHEAM-IAMB
mladen@iamb.it

AQUACROP
Water-driven crop growth engine



Biomass=w_p*Σ(E)T

Source: Steduto 2005

AQUACROP approach –
Crop Water Productivity approach

- ❑ *Linear relationship between water transpired and above-ground biomass produced is adopted*
- ❑ *AQUACROP uses the water productivity term normalized for the ETo calculated by the standard FAO P_M approach*
- ❑ *Daily above-ground biomass production (BM_i expressed in g/m^2 or t/ha) is calculated from the constant normalized water productivity term (w_p^*), the daily crop transpiration for that day (Ta_i) and reference evapotranspiration (ETo_i) for that day*

$$BM_i = w_p^* \left(\frac{Ta_i}{ETo_i}\right)$$

➢ *Kc_{top} is the crop coefficient when the canopy cover is complete (CC=1)*

Description | Development | Production | Calendar

Crop production (no water and fertility limits)

Crop Water Productivity | Harvest Index

Crop Water Productivity (normalized for ETo and CO2)

WP* = **11.0** **g/m2**

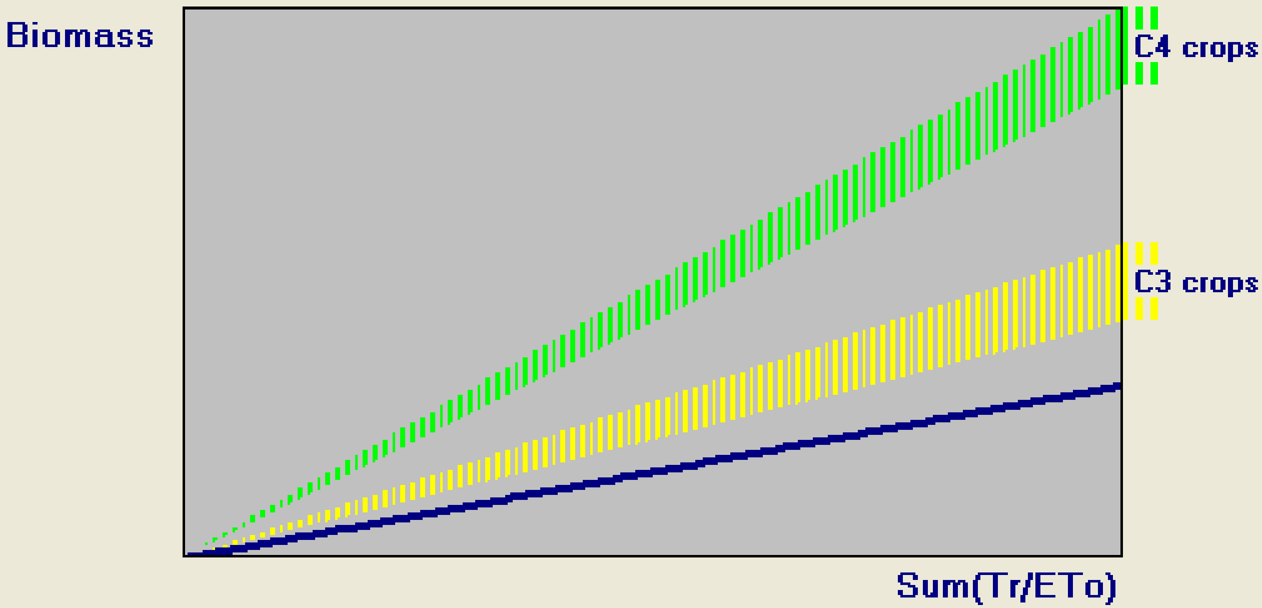
0.110 **ton/ha**

Adjustment for yield formation

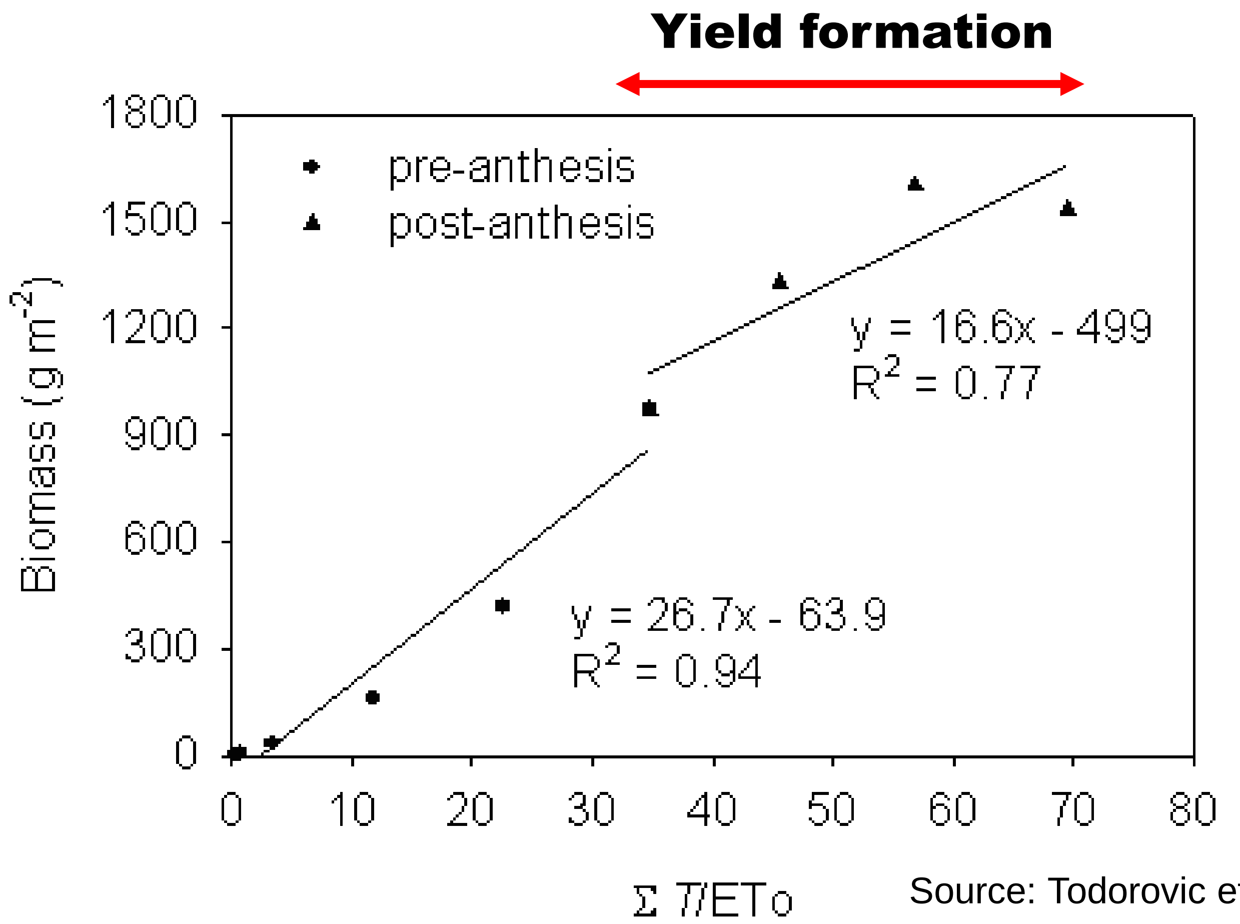
Indicative ranges :

C4 crops 30 - 35 g/m2

C3 crops 15 - 20 g/m2

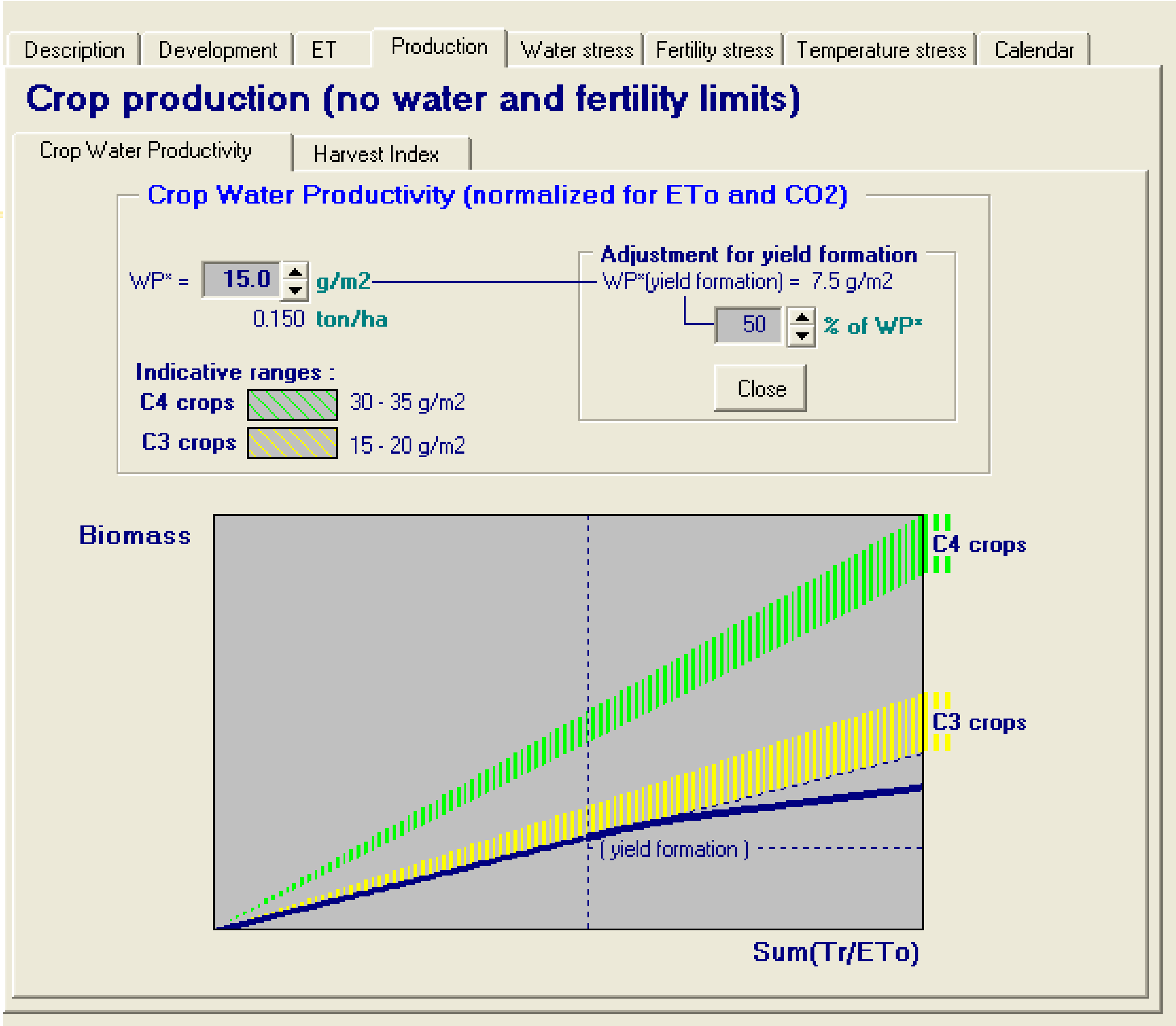


Above-ground biomass growth in relation to Transpiration normalized for ETo: the case of adjustment of WP for yield formation phase



Source: Todorovic et al., 2009

If products that are rich in lipids or proteins are synthesized during yield formation, considerable more energy per unit dry weight is required than for the synthesis of carbohydrates (Azam-Ali and Squire, 2002).



Description
Development
ET
Production
Water stress
Fertility stress
Temperature stress
Calendar
Crop production (no water and fertility limits)
Crop Water Productivity
Harvest Index
Crop Water Productivity (normalized for ETo and CO2)
WP* = 15.0 g/m2
0.150 ton/ha
Adjustment for yield formation
WP*(yield formation) = 7.5 g/m2
50 % of WP*
Close
Indicative ranges :
C4 crops 30 - 35 g/m2
C3 crops 15 - 20 g/m2
Biomass
C4 crops
C3 crops
(yield formation)
Sum(Tr/ETo)

Adjustment of Wp for atmospheric CO_2 concentration

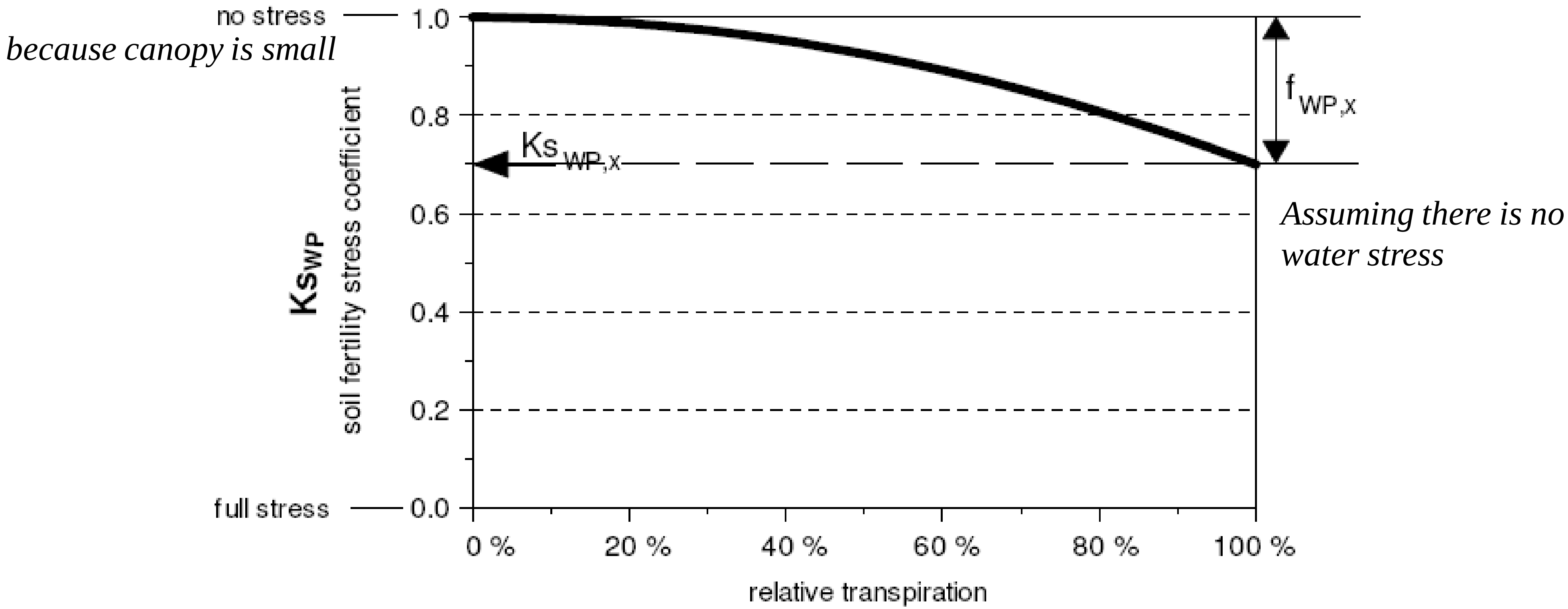
- $WP_{adj} = f_{CO2} * WP$

$$f_{CO2} = \frac{(C_{a,i} / C_{a,o})}{1 + 0.000138(C_{a,i} - C_{a,o})}$$

- f_{CO2} correction coefficient for CO_2
- $C_{a,o}$ reference atmospheric CO_2 concentration (369.41 ppm)
- $C_{a,i}$ atmospheric CO_2 concentration for year *i* (ppm)

Adjustment of WP for soil fertility

- $WP_{adj} = Ks_{WP,x} * WP$
- $Ks_{WP,x}$ soil fertility stress coefficient for water productivity (<=1)



The variation of the soil fertility stress coefficient throughout the season. During the season, Ks_{WP} will gradually decline as the relative transpiration increases.

Soil fertility stress

Calibration soil fertility

Calibration

for 50 % fertility stress

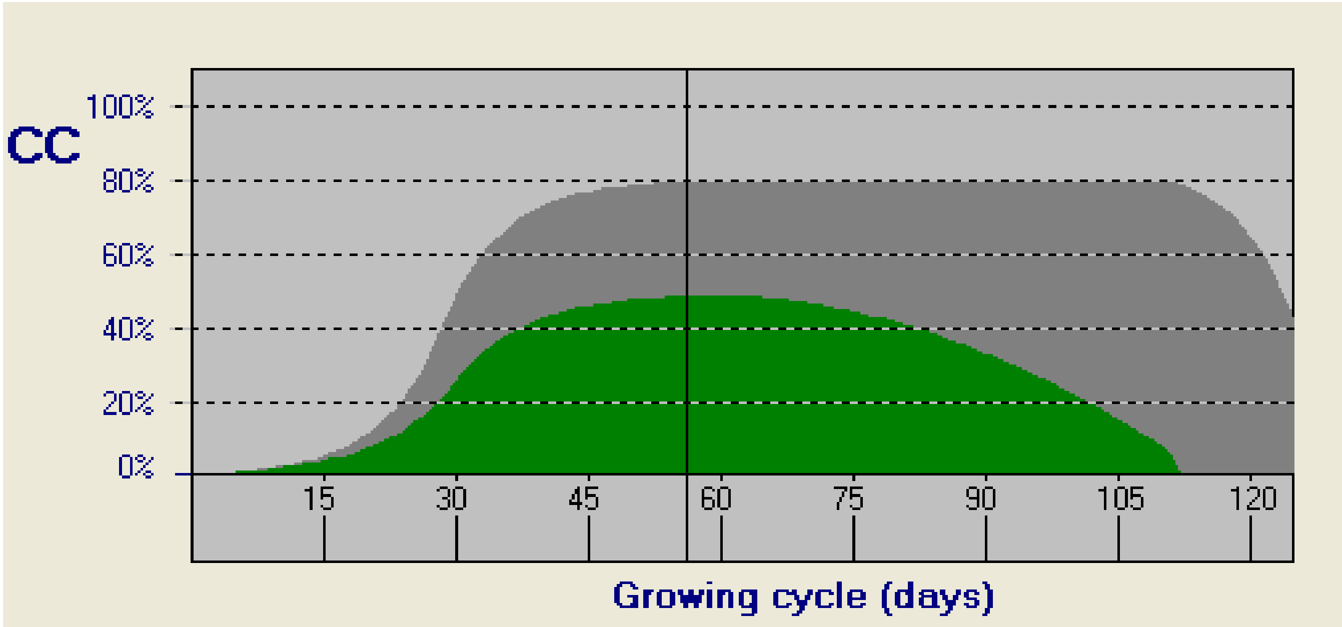
Effect of soil fertility

Reduction

- Canopy growth coefficient......... 18 %
- Maximum canopy cover.... 38 %
- Crop water productivity........ 8 %
- Average canopy cover decline..... 0.78 % day

Canopy | Water Productivity | Biomass | Ks coefficient | Crop parameters

Soil Fertility Class	Average seasonal Kc	Maximum canopy
Non limiting	0.72	at........50 days
Stress (calibration)	0.38	at........56 days



Close

AquaCrop input data – Main items

- Climate
  - precipitation, air temperature, ETo, CO_2 concentration
- Crop
  - Start growing cycle, Crop development, Production, ET, Water stresses, Fertility stress, Temperature stress, Calendar of growing cycle (for no stress conditions)
- Soil
  - soil horizons – thickness, texture (PWP, SAT, FC, WP, TAW, Ksat, tau);
  - soil surface – CN, REW;
  - restrictive soil layer
- Management
  - Irrigation
  - Field (soil fertility, mulches, field surface practices – runoff control, soil bunds)

Crop parameters

Crop Development

1. Initial canopy data:
    1. Type of planting method (sowing/transplanting)
    2. Planting density (plants/m2)
    3. Initial canopy cover (%)
2. Canopy Development
    1. Emergence, maximum canopy, senescence, maturity as a f(time)
    2. Canopy Growth Coefficient CGC (%/day) starting after emergence
    3. Maximum Canopy Cover (%)
    4. Canopy Decline Coefficient CDC (%/day) starting at senescence
3. Flowering and Yield Formation
    1. Flowering starting time as a f(time) and duration (days)
    2. Yield formation (days)
    3. Length building up HI (days)
    4. Determinancy – potential vegetative growth linked with flowering (yes/no)
4. Root deepening
    1. Minimum and maximum effective root depth (m)
    2. Maximum depth as a f(time) after sowing
    3. Root development shape factor
5. Temperatures
    1. Base temperature and cutoff (upper) temperature (for GDD approach)

Crop parameters

Crop Production

1. Crop Water Productivity (normalized for ETo and CO_2)
    1. WP (g/m^2) with the possibility of adjustment for yield formation
2. Harvest Index HI
    1. Reference HI (%)

Crop Evapotranspiration

1. Crop Coefficients
    1. Ke – soil evaporation from wet soil surface
    2. Kcb – crop transpiration from well watered crop
    3. Effect of canopy shelter in late season (%)
2. Water Extraction Pattern
    1. % of extraction for 4 soil horizons corresponding to the effective root depth
    2. Maximum root extraction (mm/day)

Crop parameters

Water Stresses

1. Canopy expansion
    1. p_upper – no stress (fraction of TAW), values from 0 to 0.5
    2. p_lower – full stress (fraction of TAW), values from 0.3 to 0.8
    3. *Curve shape factor*
    4. *Adjustment for ETo*
2. Stomatal closure
    1. p_upper – no stress (fraction of TAW)
    2. Curve shape factor
3. Early Canopy Senesence
    1. p_upper – no stress (fraction of TAW)
4. Aeration stress
    1. No sensitive to water logging – deficient aeration conditions Sat - 0%vol
    2. Very sensitive to water logging – deficient aeration conditions Sat – 15%vol
5. Harvest Index
    1. Before flowering
    2. During flowering
    3. During yield formation

Crop parameters

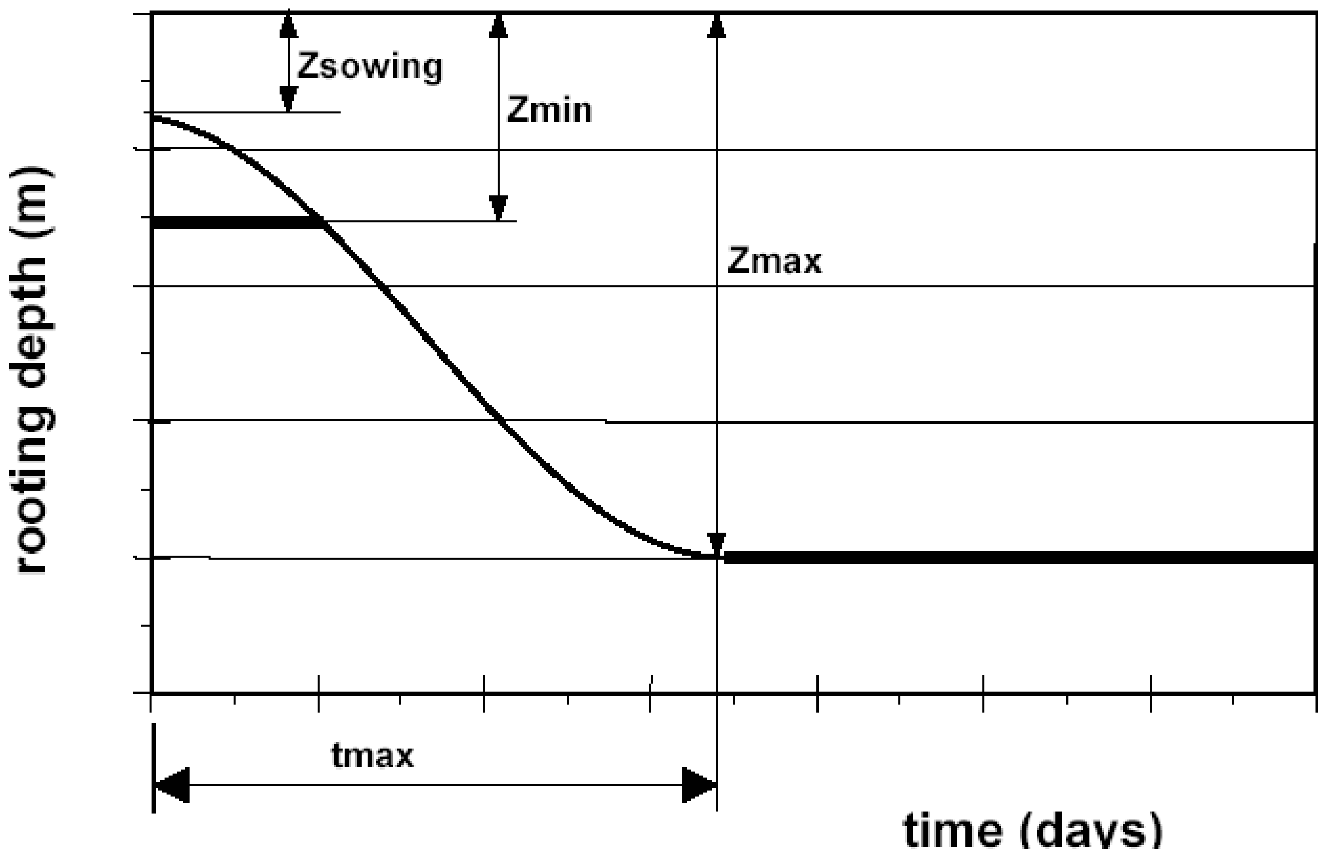
Fertility Stress

1. Reduction of Canopy Growth Coefficient CGC (%)
2. Reduction of Maximum Canopy Cover CC (%)
3. Reduction of Reference Water Productivity (%)
4. Average decline Canopy Cover (%)

Temperature Stress

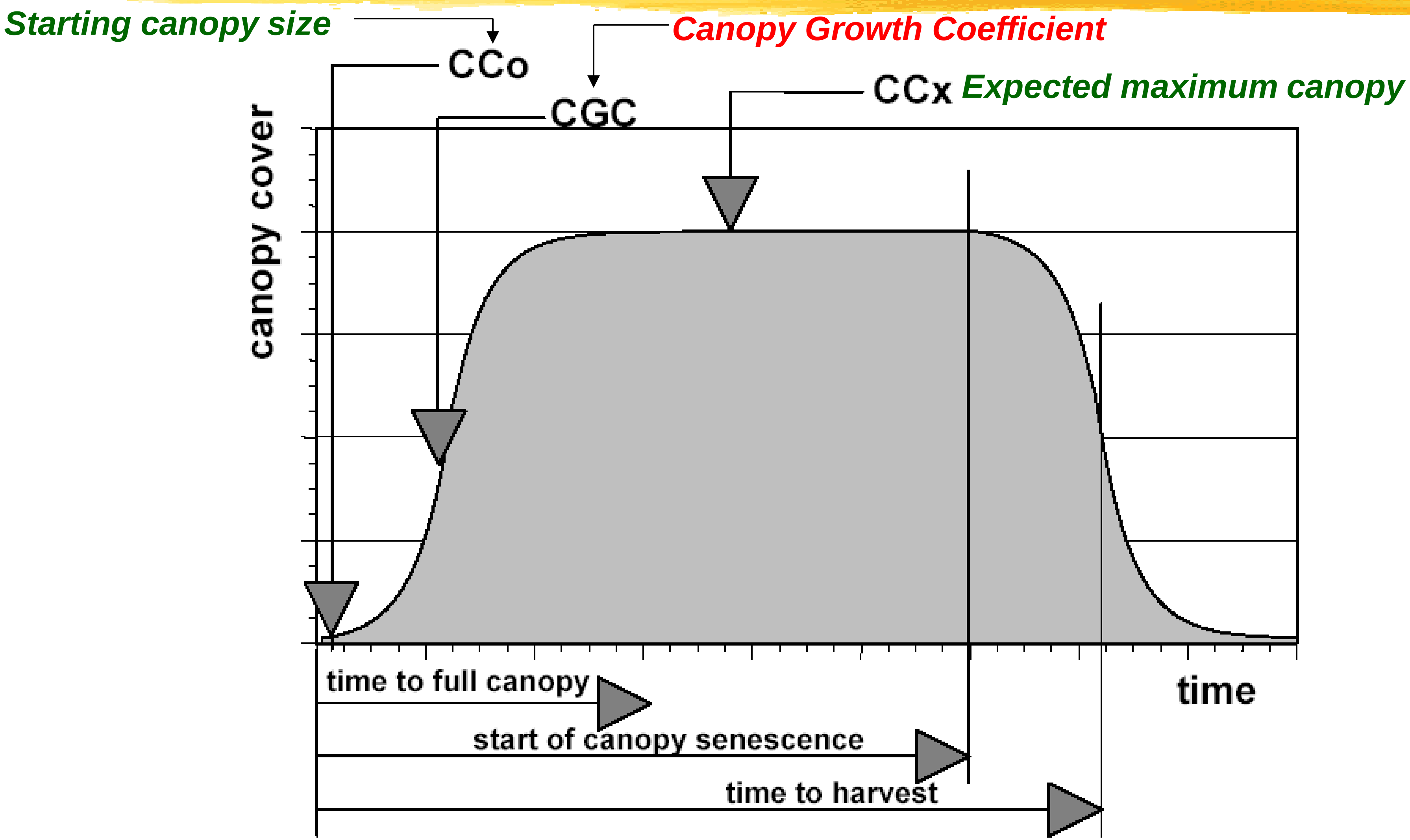
1. Biomass production affected by cold stress (°C)
2. Pollination affected by cold stress (°C)
3. Pollination affected by heat stress (°C)

AQUACROP approach –
rooting depth of annual crops (sigmoidal function)



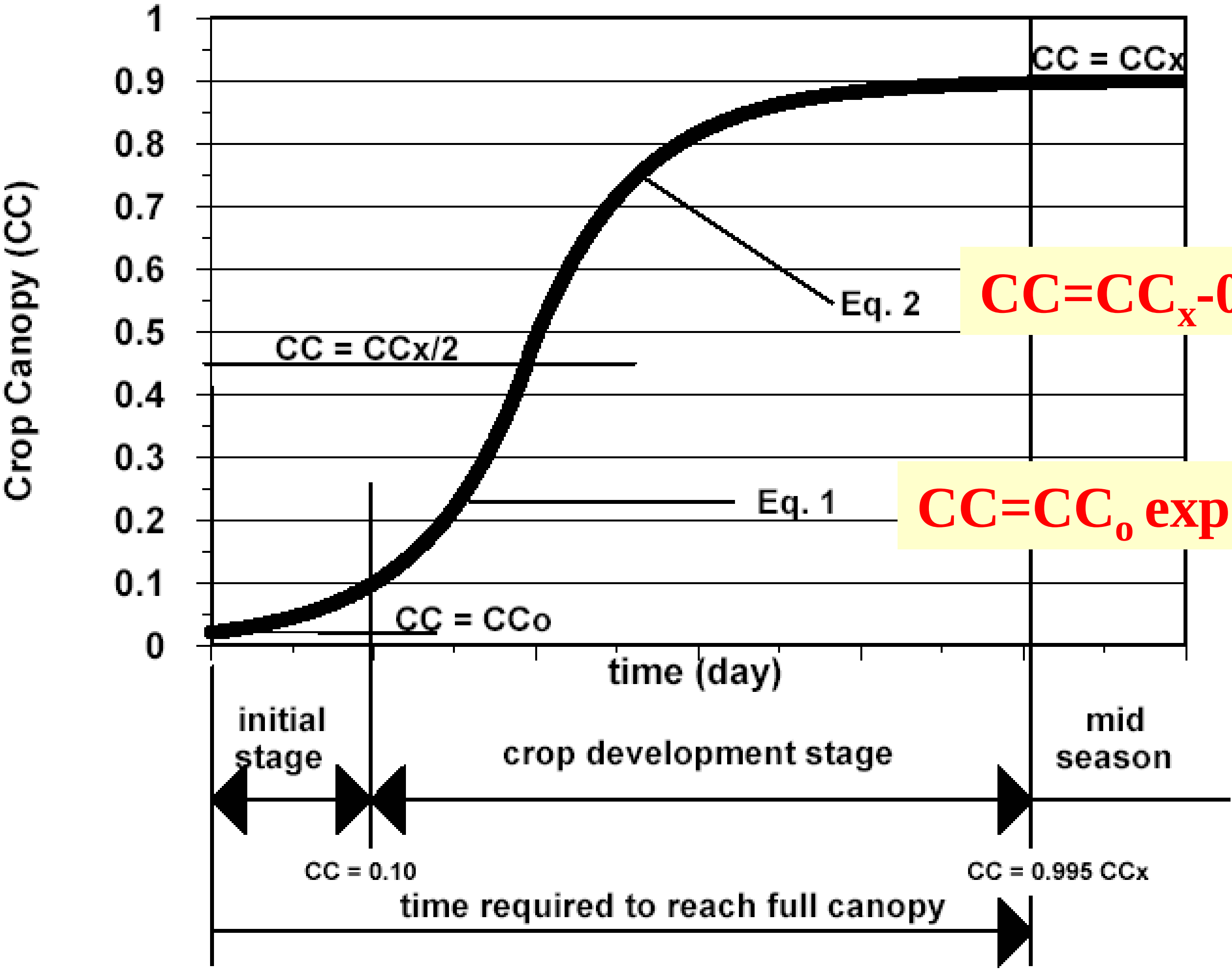
$$Z_{r,i} = Z_{sowing} + (Z_{\max} - Z_{sowing})\left[0.5 + 0.5\sin\left(3.03\frac{t_i}{t_{\max}} - 1.47\right)\right]$$

AQUACROP approach – Green Canopy Cover (CC)



CGC is derived from the required time to reach full canopy

AQUACROP approach –
Canopy development equations for non-stress conditions



When $CC > CC_x/2$

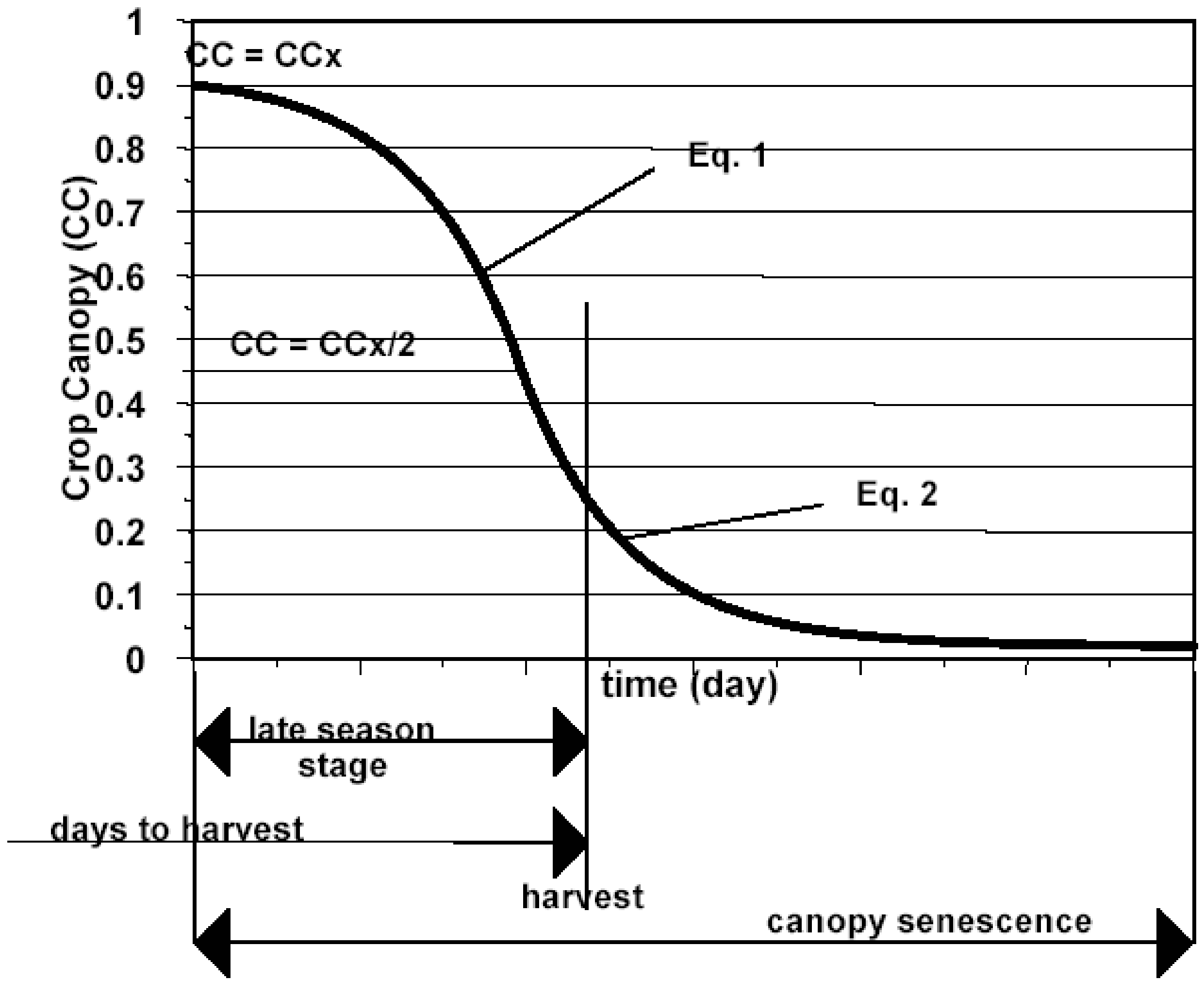
$$CC = CC_x - 0.25(CC_x^2/CC_o)\exp(-CGC(t))$$

$$CC = CC_o \exp(CGC(t))$$

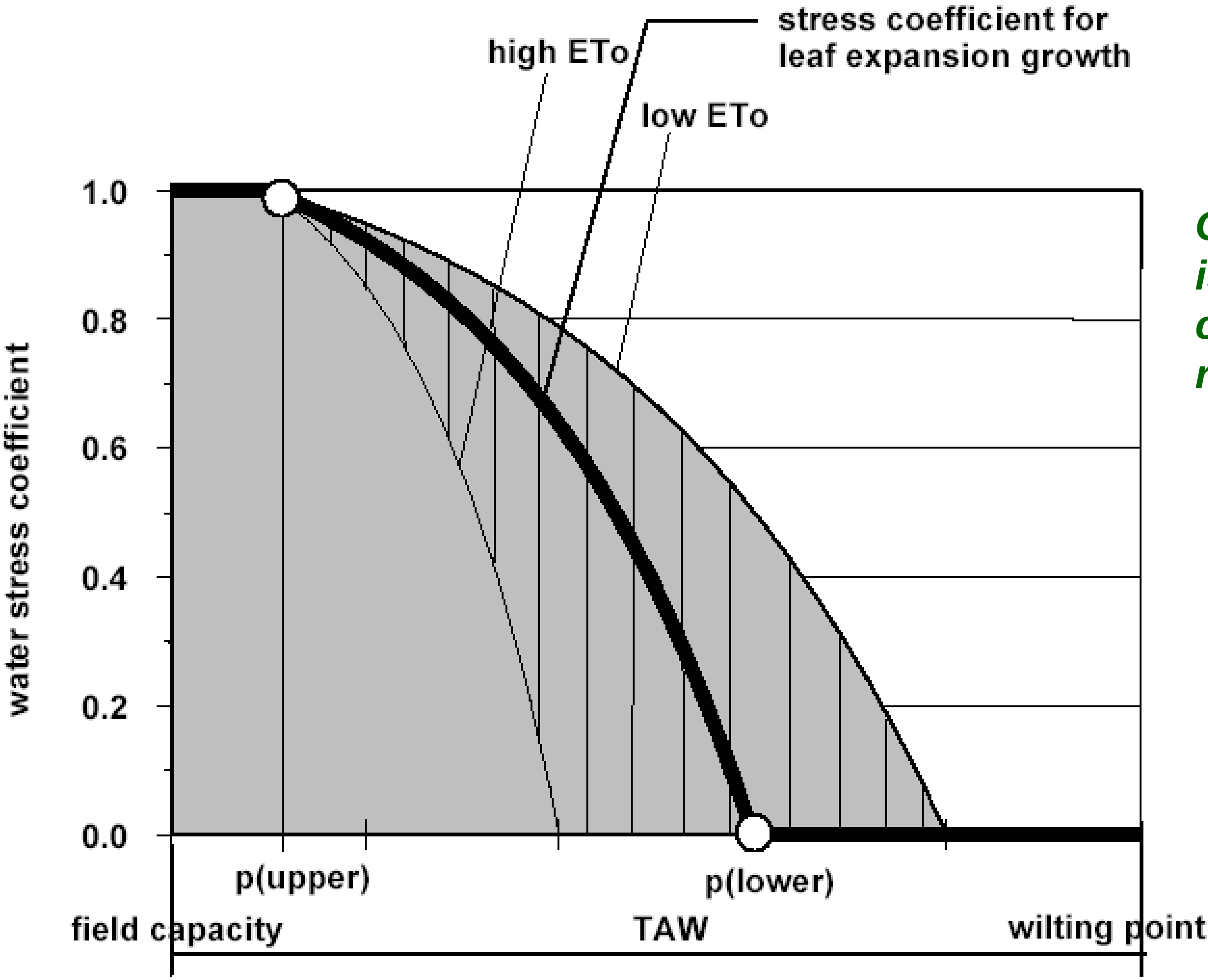
When $CC \leq CC_x/2$

Expected maximum canopy (CCx) is determined by the crop species, plant density, applied level of fertilizer, pest and disease control.

AQUACROP approach –
Green canopy cover decline



AQUACROP approach –
Water stress coefficient for leaf expansion growth

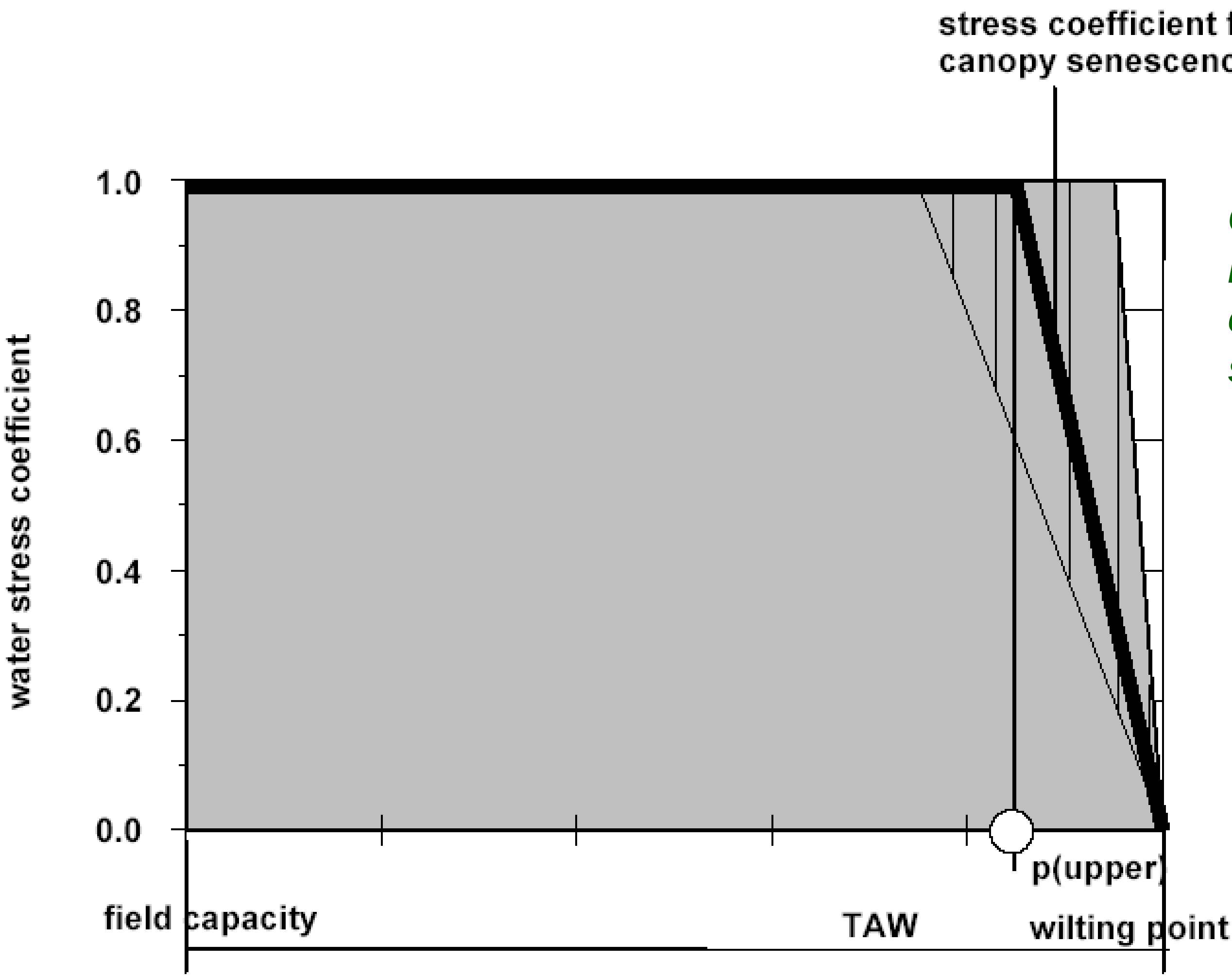


Canopy Growth Coefficient (CGC) is multiplied by water stress coefficient to account for reduction in leaf growth

$$p_{adj} = p_{lower} + C_a \left[0.04\left(5 - ET_{crop}\right)\right]$$

Ca – adjustment coefficient for ETcrop≠5mm/day

AQUACROP approach –
Water stress coefficient for canopy senescence



Canopy Growth Coefficient (CGC) is adjusted by water stress coefficient to account for canopy senescence

$$p_{adj} = p_{upper} + C_a \left[0.04\left(5 - ET_{crop}\right)\right]$$

Ca – adjustment coefficient for ETcrop≠5mm/day

AQUACROP approach –
Crop Evapo-transpiration estimate

- *Crop transpiration (T) and soil evaporation (E) are calculated separately each with its own Kc coefficient*

$$ETc=(Kc_{transpiration}+Kc_{evaporation})ETo$$

- *Both Kc coefficients are dependent on the canopy cover*
- *Crop transpiration is proportional to the fractional canopy cover (CC)*
- *Soil evaporation is proportional to the portion of the soil non shaded by the canopy (1-CC)*
- *When insufficient water is supplied, reduction coefficients are used:*

$$ETc=(Ks*Kc_{transpiration}+Kr*Kc_{evaporation})ETo$$

AQUACROP approach – Soil Evaporation estimate

- ***Soil evaporation takes place in two stages (Ritchie approach): an energy limiting stage (soil is wet) and a falling rate stage (there is no standing water on the soil surface)***

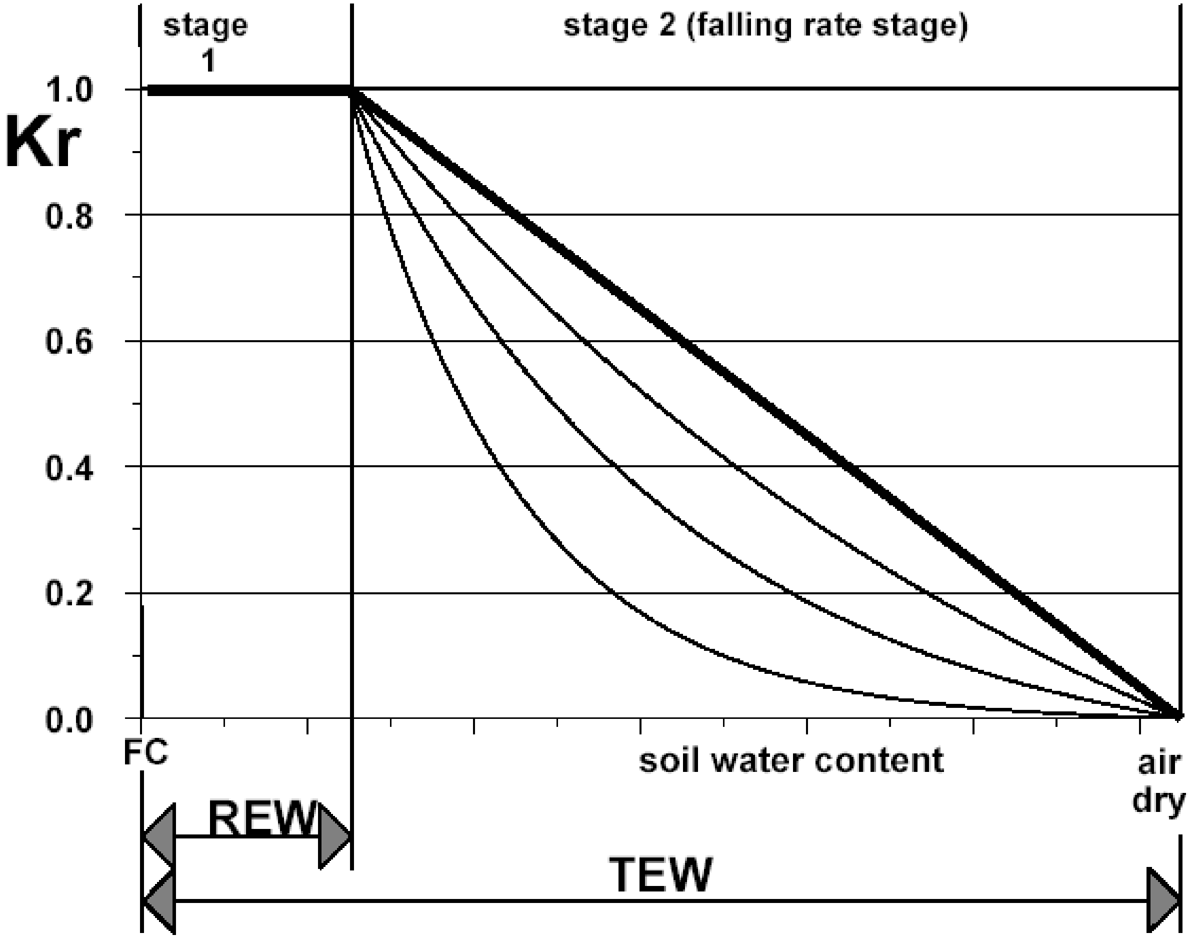
- ***Soil evaporation is determined by the energy available for evaporation (Energy limiting stage):***

$$E_I = Kc_{evaporation} * ETo$$

$$Kc_{evaporation} = (1-CC^*) * Kc_{wet\ bare\ soil}$$

- ***$Kc_{wet\ bare\ soil} \approx 1.1$ and CC^* is the corrected green canopy cover***
  - ***CC^* adjusted for the foliage shelter of the green canopy***
  - ***CC^* adjusted for withered canopy cover in the late season***
  - ***CC^* adjusted for mulches***
  - ***CC^* adjusted for partial wetting by irrigation***

AQUACROP approach –
Soil Evaporation estimate



Soil type	REW default
Sandy	4 mm
Loamy	10 mm
Clay	12 mm

Falling rate stage decrease functions – program parameters

Readily Evaporable Water (REW)

AQUACROP approach – Crop Transpiration estimate

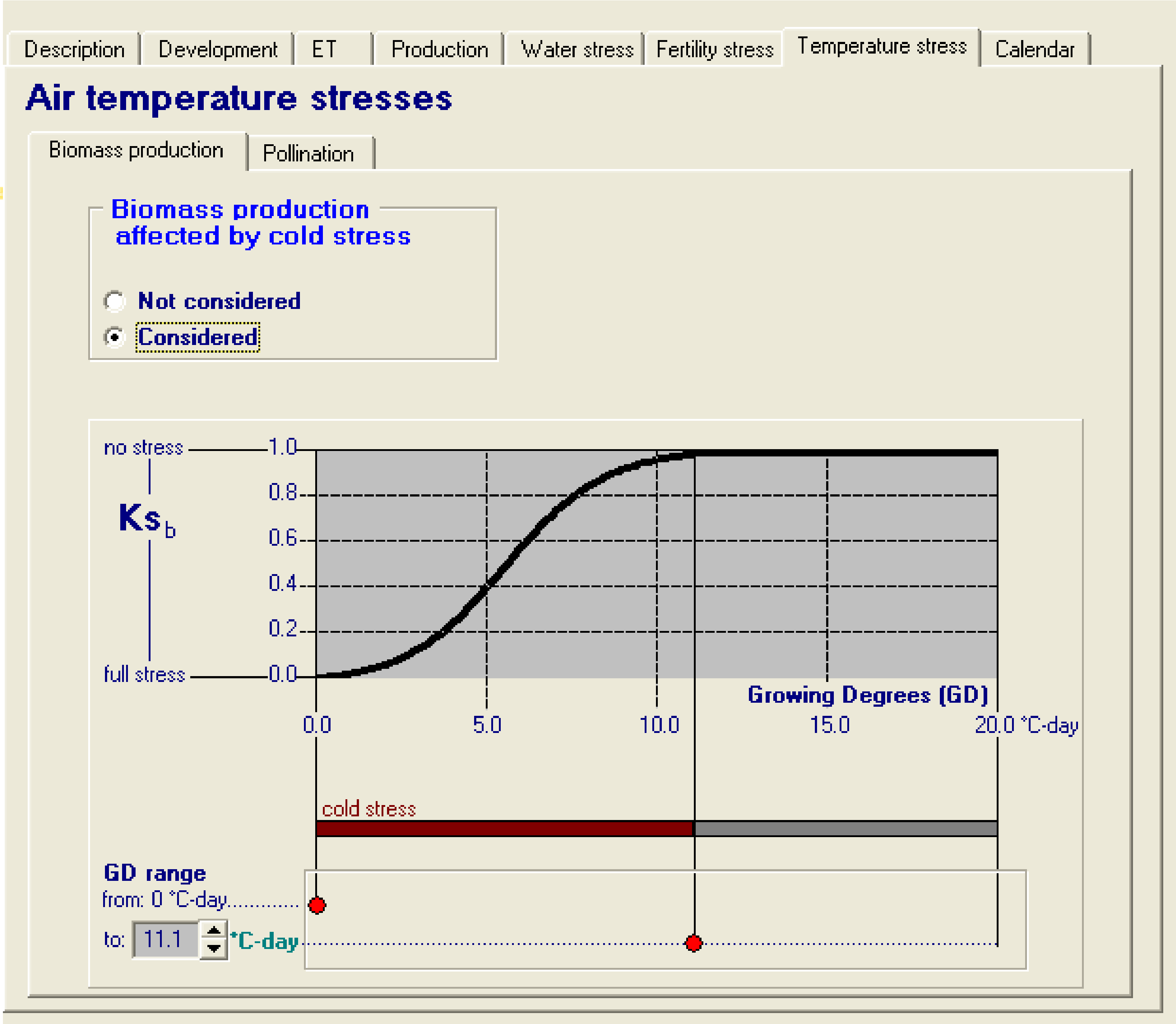
- ***Under well-watered conditions:*** $T_c = Kc_{transpiration} * ETo$

$$Kc_{transpiration} = CC^* \, Kc_{top}$$

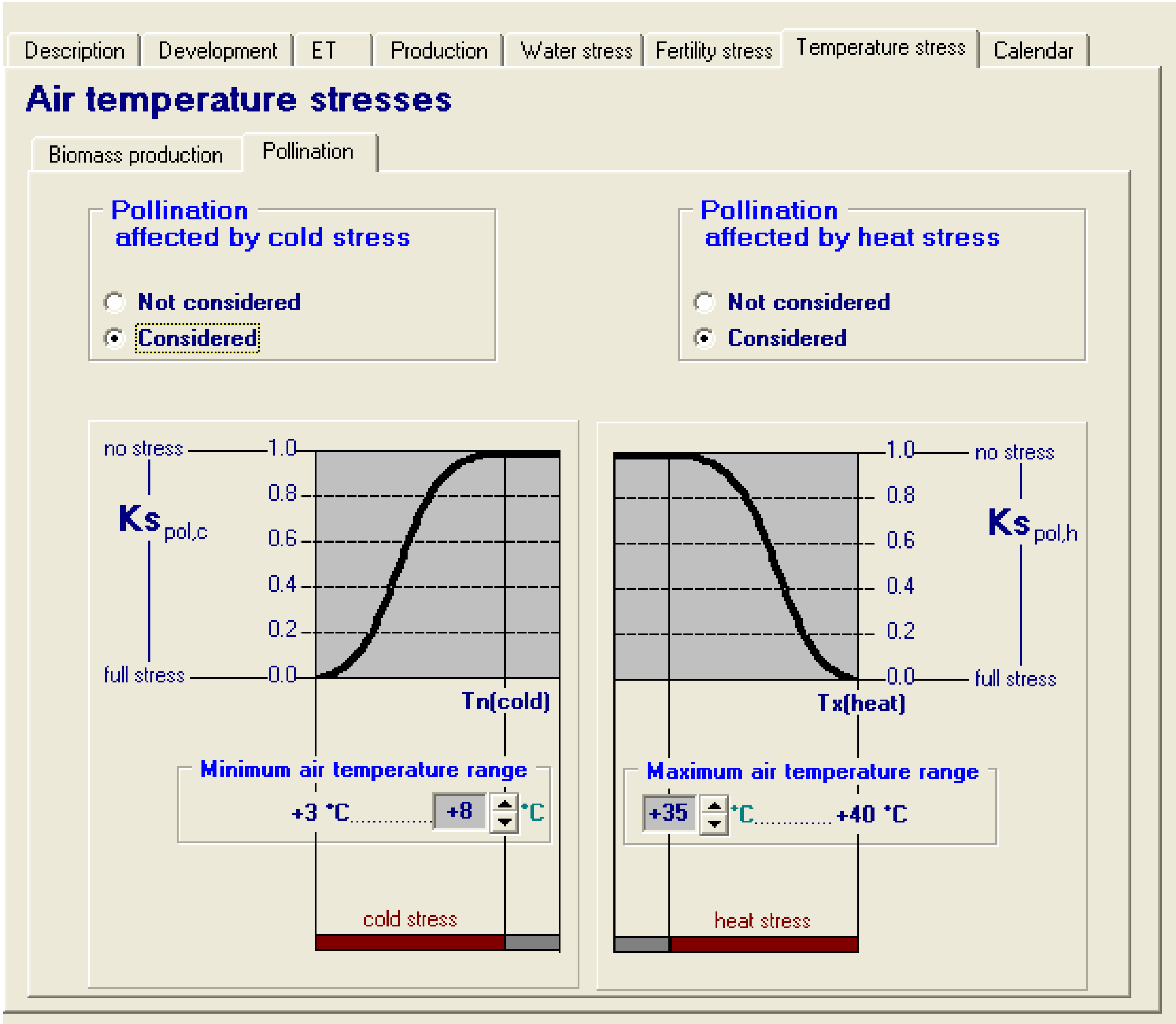
  - ***CC^* adjusted (increased) for the sheltering effect of the canopy***
  - ***Kc_{top} is the crop coefficient when the canopy cover is complete (CC=1)***

- ***Actual crop transpiration is:*** $T_a = K_s * T_c$

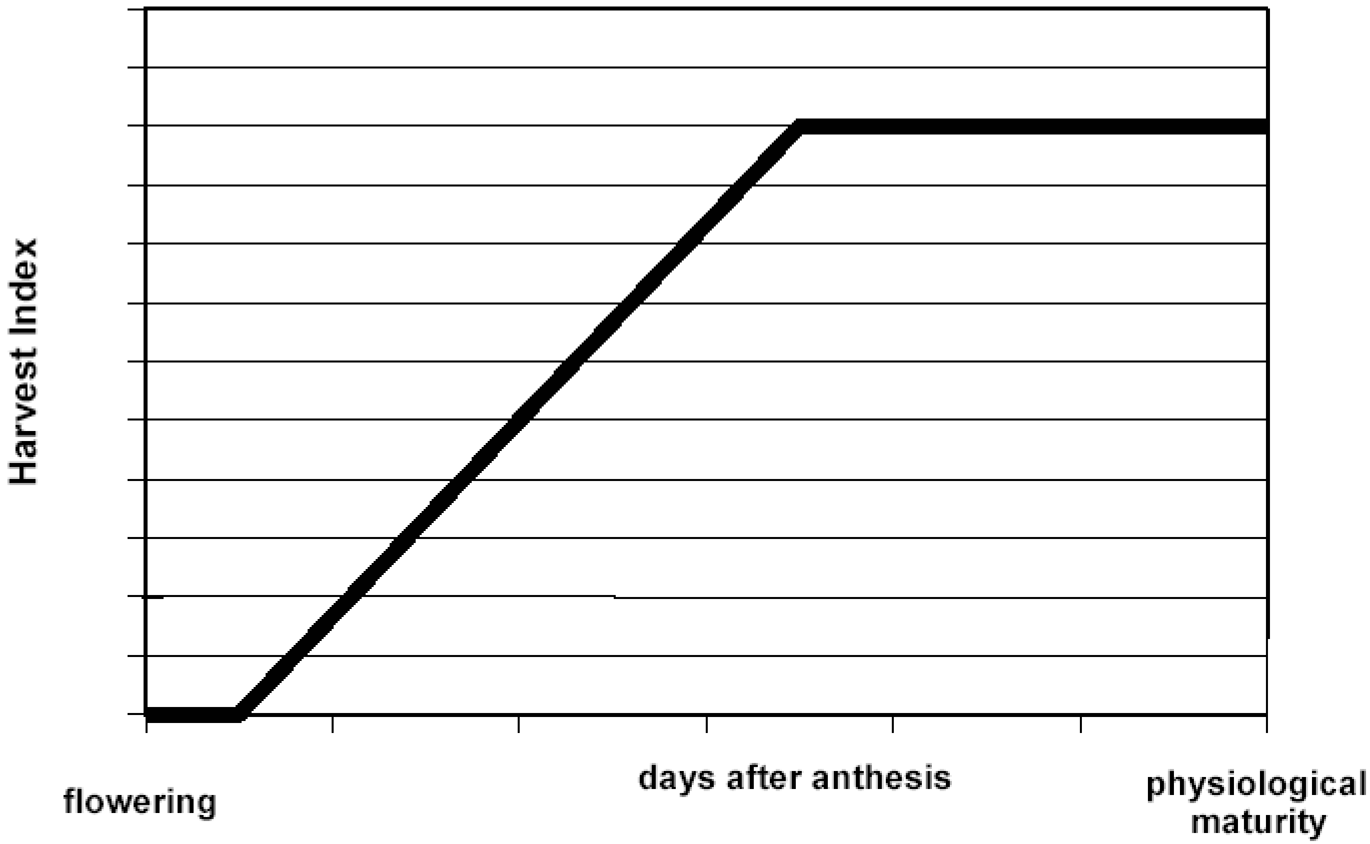
  - ***K_c is the water stress coefficient for water stress and water logging (aeration stress)***



Description
Development
ET
Production
Water stress
Fertility stress
Temperature stress
Calendar
Air temperature stresses
Biomass production
Pollination
Biomass production affected by cold stress
Not considered
Considered
no stress
full stress
Ks b
1.0
0.8
0.6
0.4
0.2
0.0
Growing Degrees (GD)
0.0
5.0
10.0
15.0
20.0 °C-day
cold stress
GD range
from: 0 °C-day
to: 11.1 °C-day


Description
Development
ET
Production
Water stress
Fertility stress
Temperature stress
Calendar
Air temperature stresses
Biomass production
Pollination
Pollination
affected by cold stress
Not considered
Considered
Pollination
affected by heat stress
Not considered
Considered
no stress
Ks pol,c
full stress
1.0
0.8
0.6
0.4
0.2
0.0
Tn(cold)
Minimum air temperature range
+3 °C
+8
°C
cold stress
1.0
0.8
0.6
0.4
0.2
0.0
no stress
Ks pol,h
full stress
Tx(heat)
Maximum air temperature range
+35
°C
+40 °C
heat stress

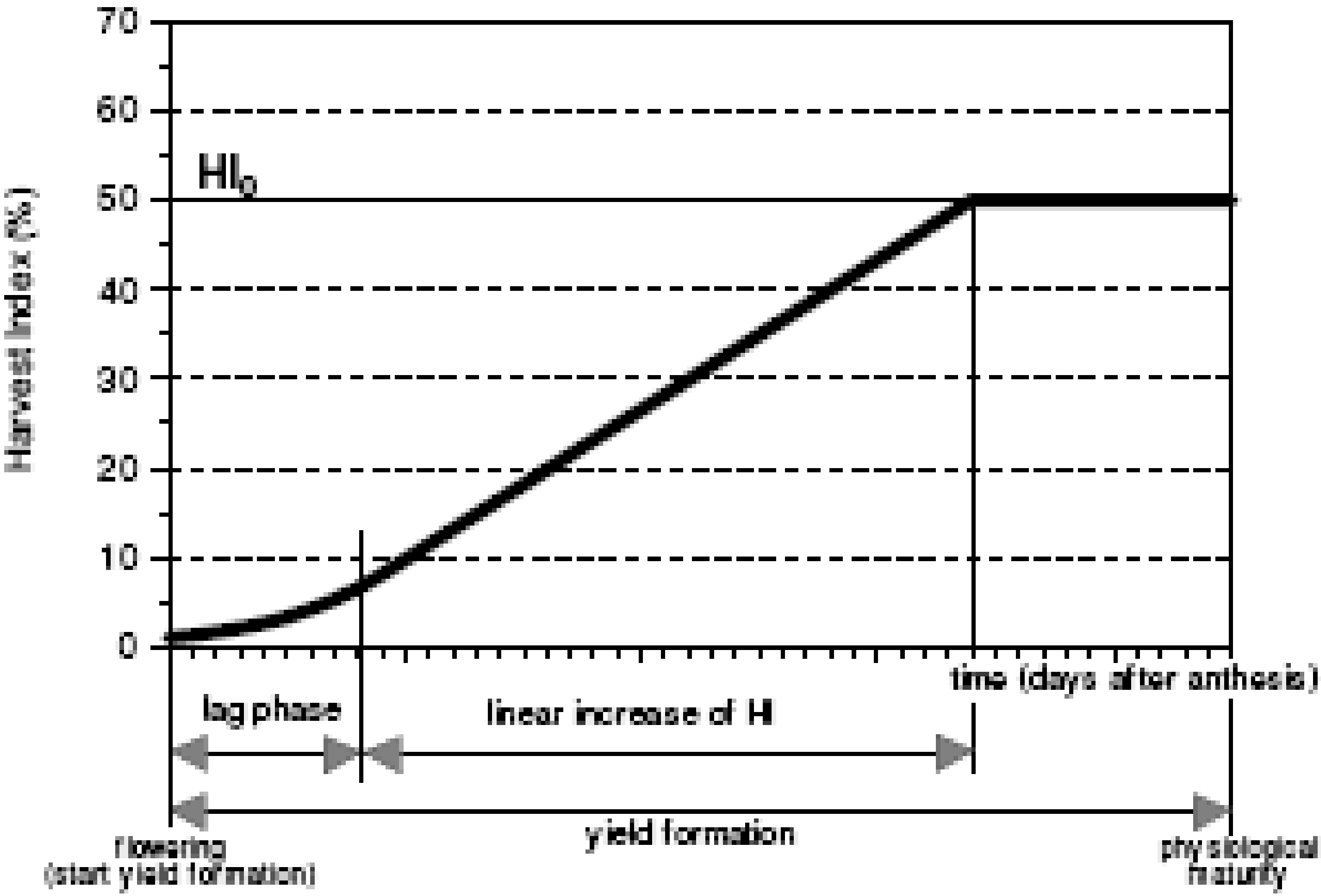
AQUACROP approach –
partitioning of biomass into yield part (Harvest Index)



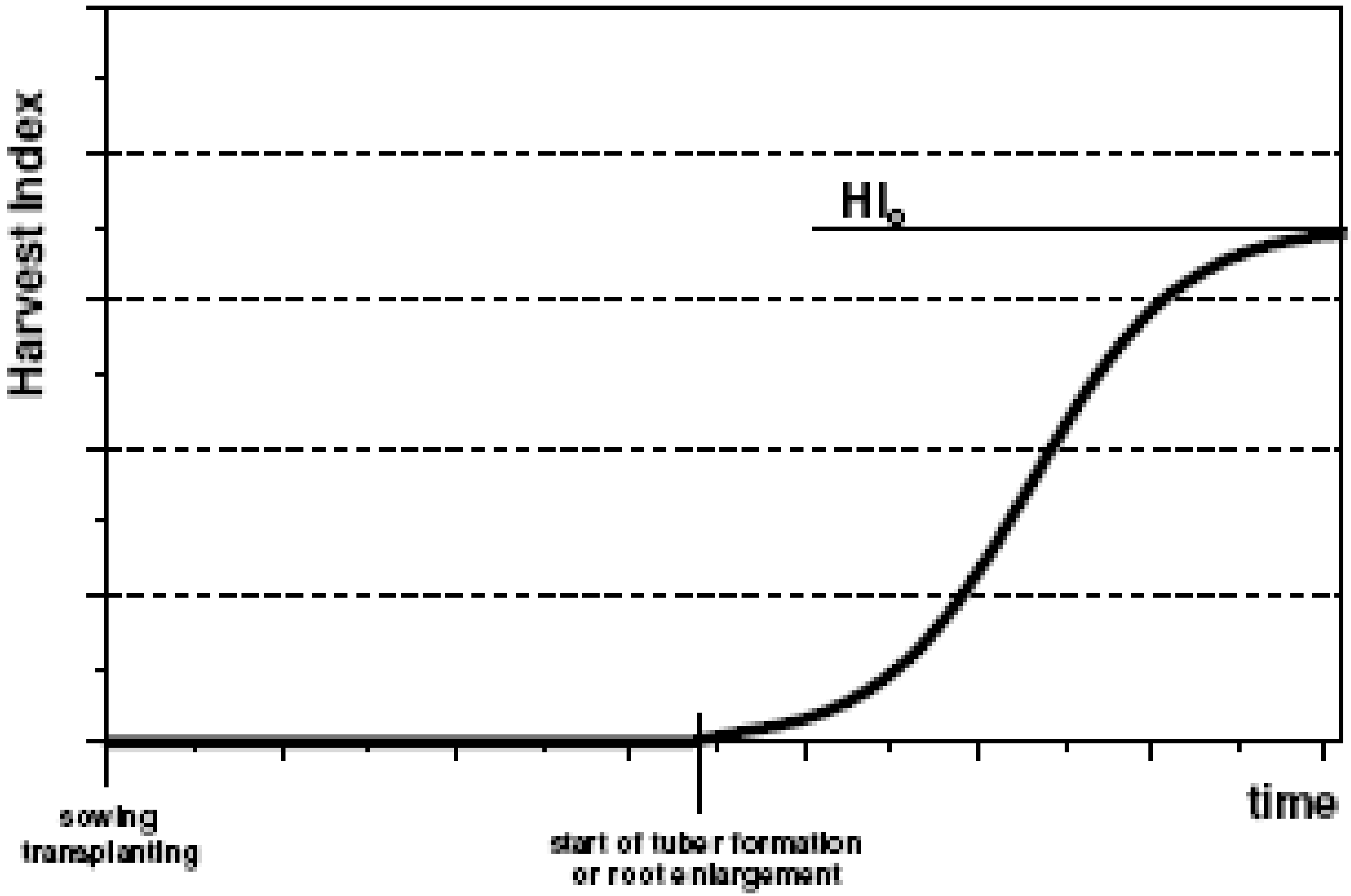
- *After an initial lag phase, the HI gradually increases shortly after flowering from zero to its maximum value*

$$Yield_i = BM_i \frac{dHI}{dt}$$

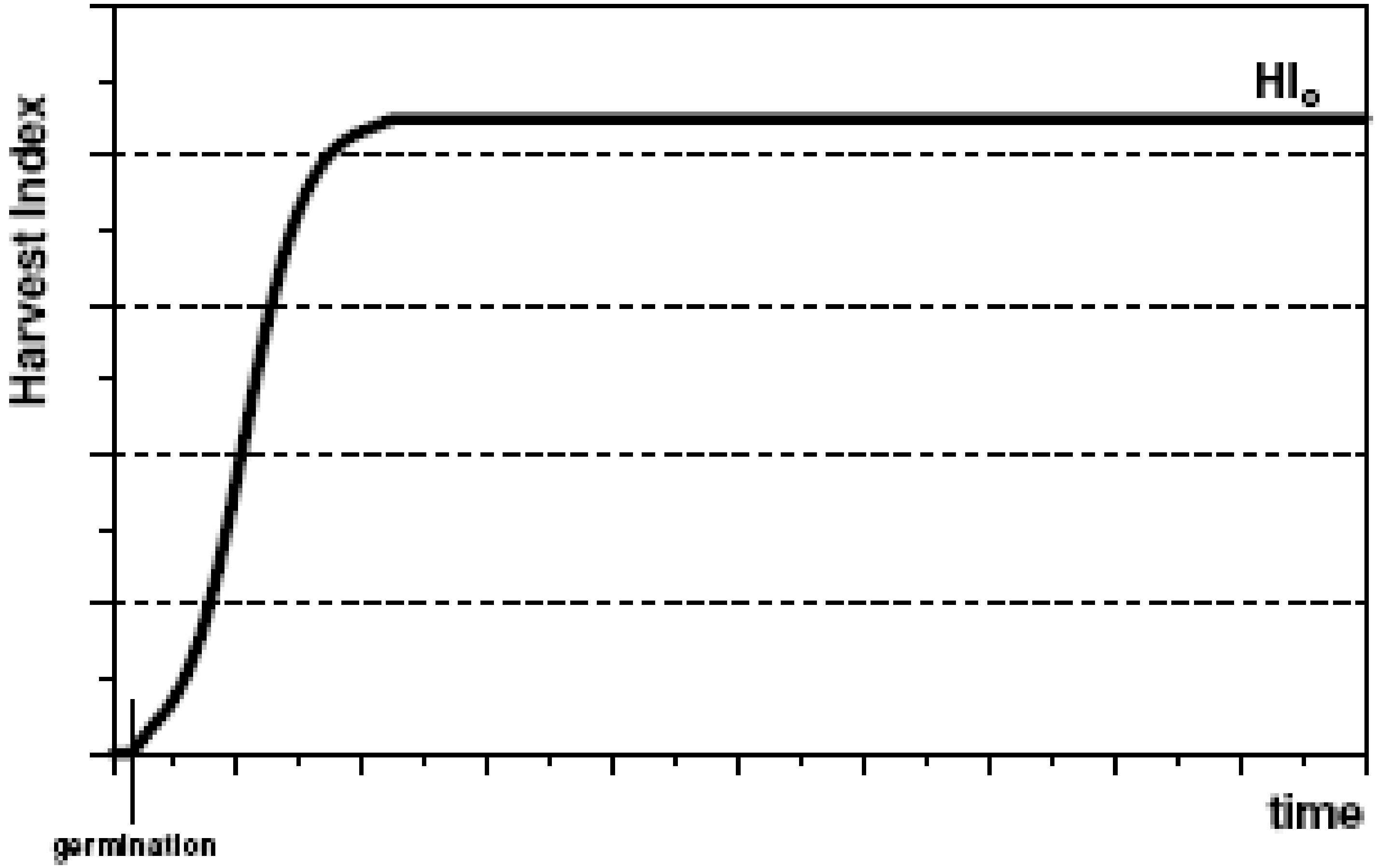
Building up of Harvest Index
from flowering till physiological maturity
for fruit/grain producing crops



Building up of Harvest Index along the growth cycle for root/tuber crops

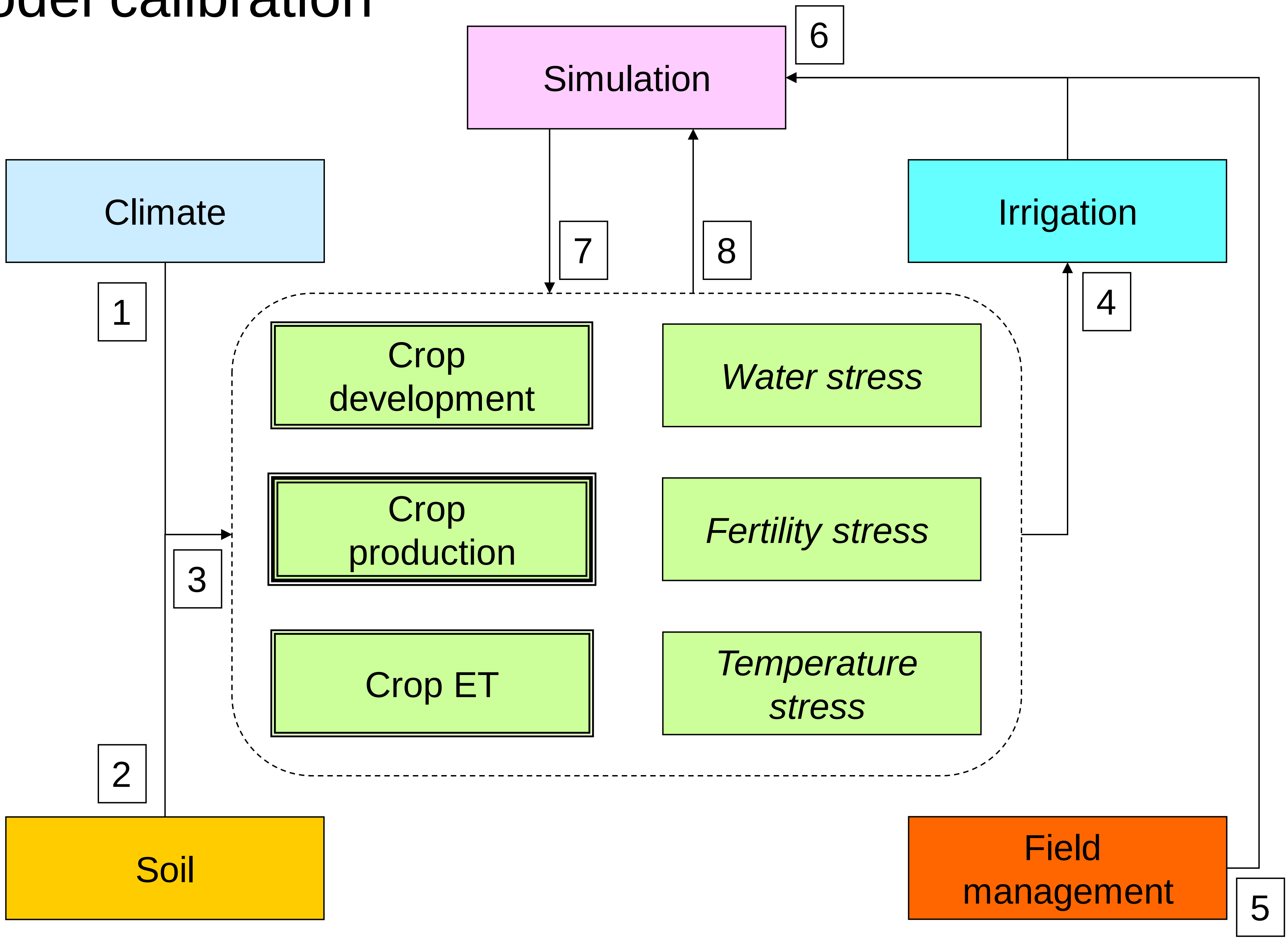


Building up of Harvest Index along the growth cycle for leafy vegetable crops



e.g. latuga, chicory, crab beet (chard), …the crops where leaf part represents the yield

Model calibration



Model calibration steps

1. Insert climate data (*field measurements*)
2. Insert soil data (*field measurements*)
3. Insert Crop data (check consistency between the growing season and climate data)
4. Insert irrigation data (full irrigation – no water stress)
5. Insert field management data (if any)
6. Run simulation (for no water and fertility stress) and

   check if simulated Biomass, Yield and ETc are close enough to measured Biomass, Yield and ETc

7. Adjust Crop parameters (mainly through WP)
8. Run simulation again with adjusted crop parameters

Calibrate model for non-optimal water and fertility conditions after the calibration for optimal conditions has been completed

Objective of model calibration

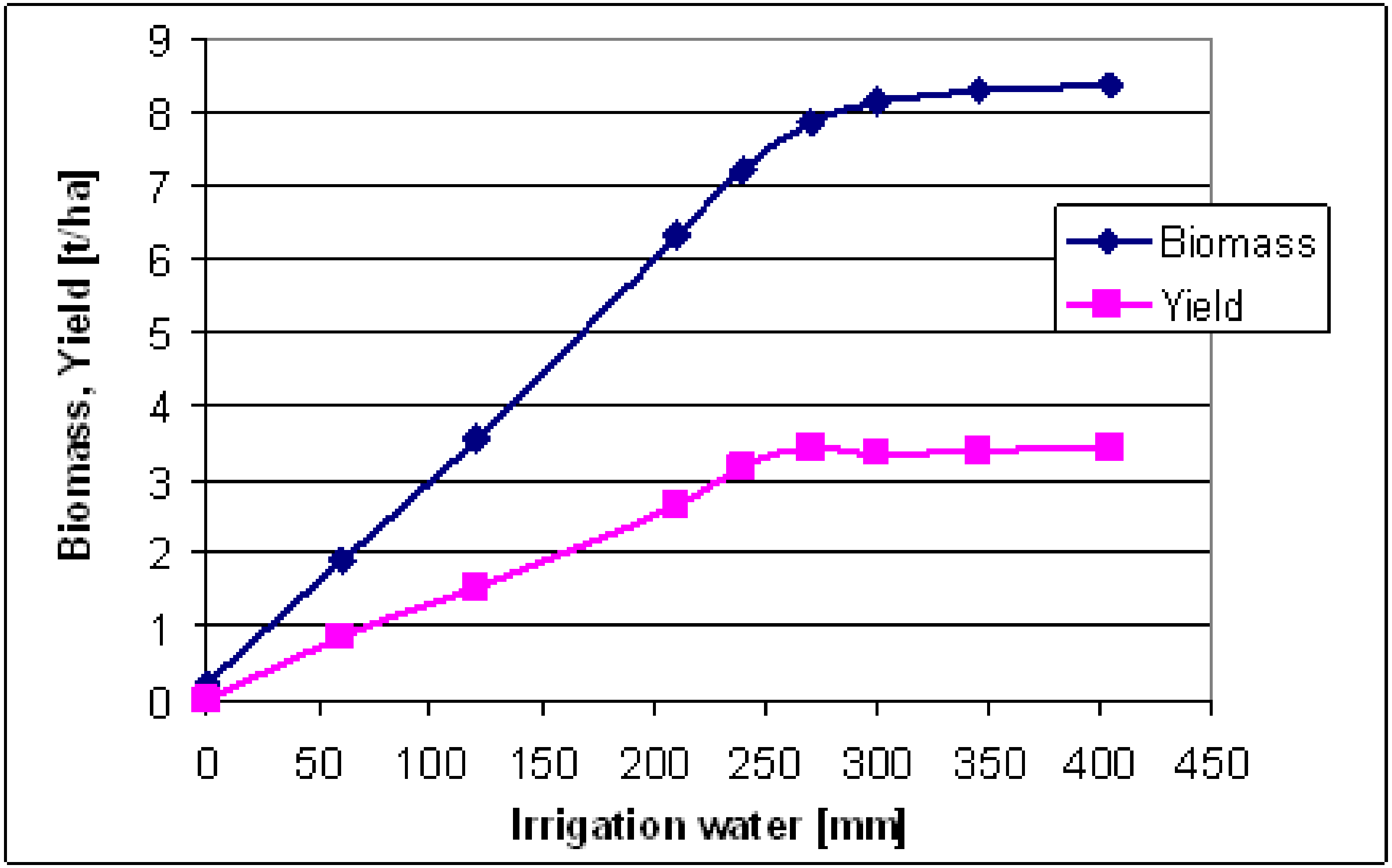
- To adjust the model parameters (within a pre-defined range) to fit the model outputs to fir measured (experimental) data

$$\mathbf{Biomass_{simulated} \approx Biomass_{measured}}$$

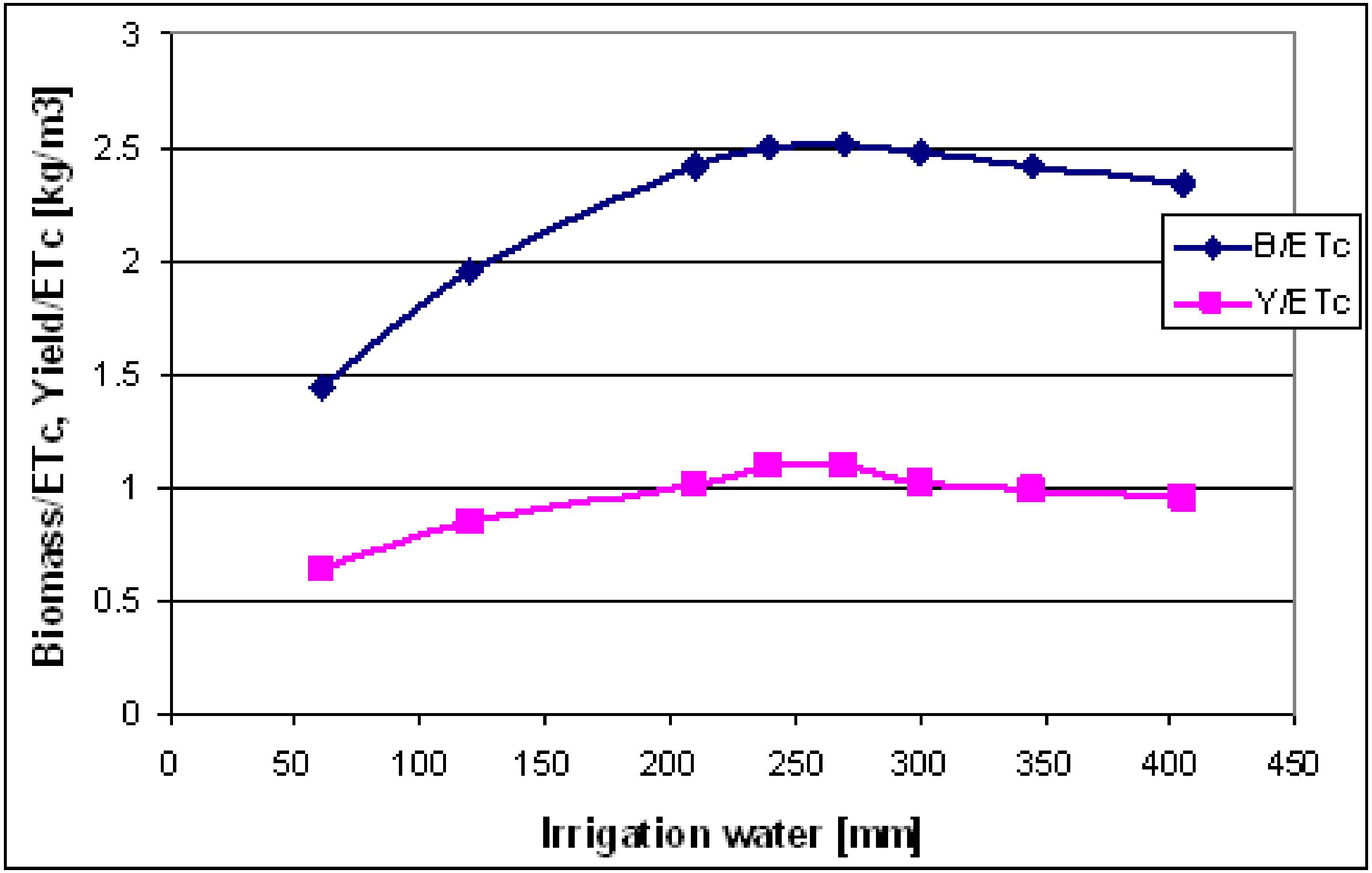
$$\mathbf{Yield_{simulated} \approx Yield_{measured}}$$

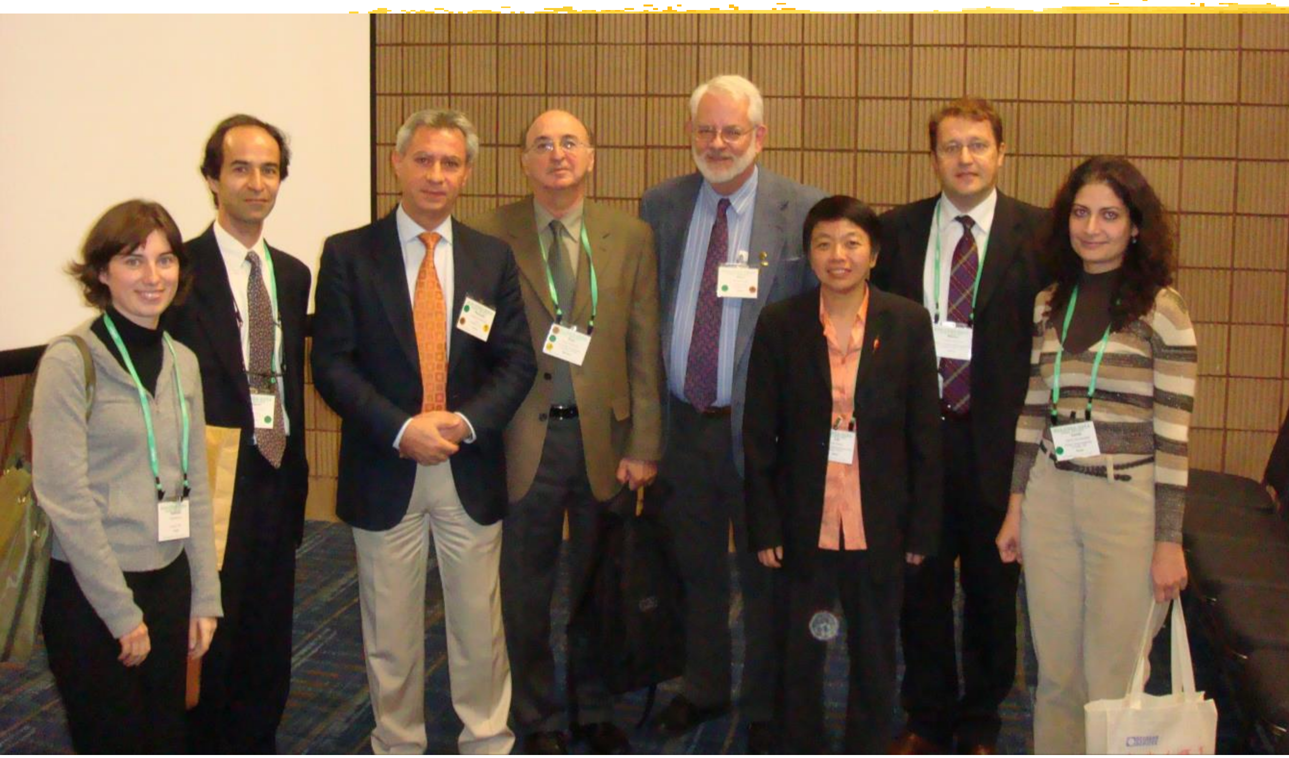
$$\mathbf{ETc_{simulated} \approx ETc_{measured}}$$

Biomass and yield as a function of irrigation water supply



Biomass and yield water productivity as a function of irrigation water supply





Parameters	Pepper-Policoro	Pepper-Lebanon	Pepper-Ercolano 1997	Pepper-Ercolano 1998
Sowing date	11/05/1993	31/05/2005	09/06/1997	05/06/1998
Harvest date	28/09/1993	17/09/2005	22/09/1997	12/10/1998
Cultivars	Capsicum annuum L., cv Marengo	cv Mercury	Capsicum annum-Marconi	Capsicum annum-Marconi

Parameters	Eggplant-Policoro	Eggplant-Matera	Eggplant-Ercolano 2000	Eggplant-Ercolano 2001
Sowing date	09/05/2003	05/05/2005	13/06/2000	22/05/2001
Harvest date	18/08/2003	13/09/2005		
Cultivars	gena L. var. esculentun	Melongena L., cv bla	num Melongena L., cv cima di	num Melongena L., cv cima di v
planting density (pl/m2)	2	2	4.3	4.3

Parameters	Melon-Policoro	Melon-Policoro	Melon-Policoro	Melon-Policoro
	without mulching	with mulching	without mulching	with mulching
Sowing date	24/04/2001	24/04/2001	11/05/1999	11/05/1999
Harvest date	20/07/2001	07/07/2001	02/08/1999	18/07/1999
Cultivars	Cucumis melo, cv Campero	Cucumis melo, cv Campero	Cucumis melo, cv Campero	Cucumis melo, cv Campero
planting density (pl/m2)	1	1	1	1

Melon-Matera	Melon-Matera
without mulching	with mulching
06/06/2001	06/06/2001
27/08/2001	27/08/2001
Cucumis melo, cv Nabucco	Cucumis melo, cv Nabucco
0.5	0.5

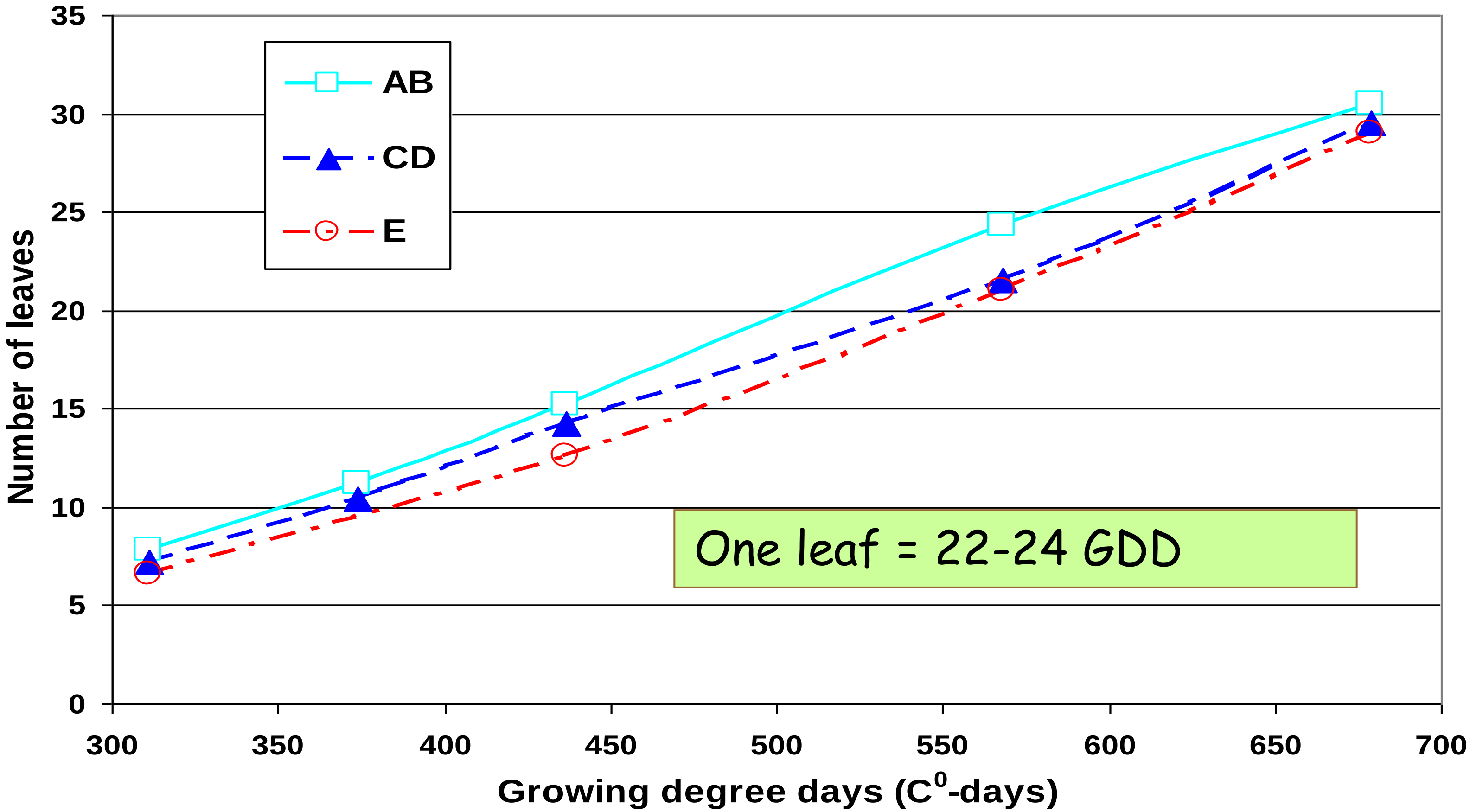
Some examples from the fields ...

Calibration steps *of CropSyst model*

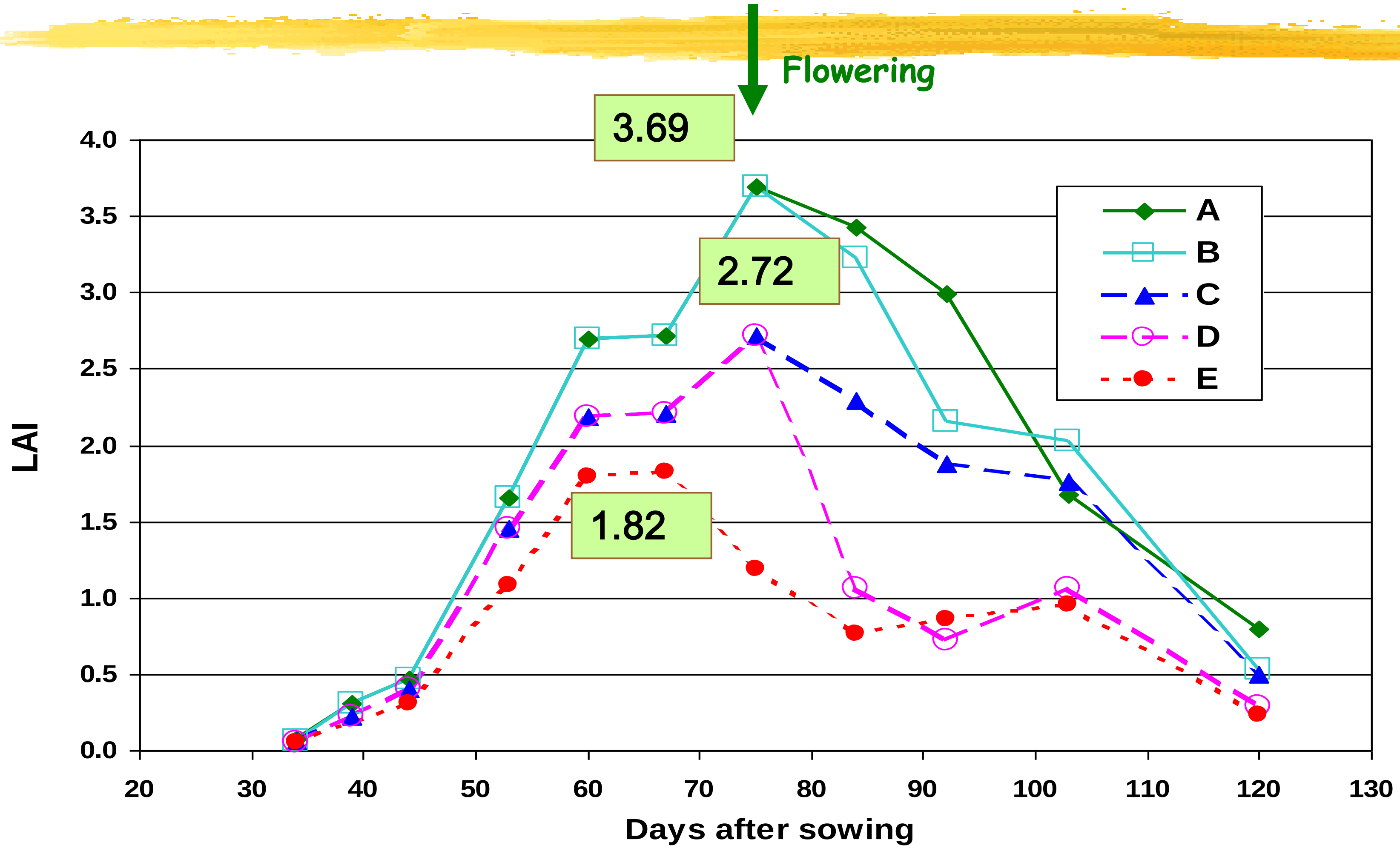
1. Crop phenology – the description of the crop growing cycle where the main phenological stages (emergence, vegetative growth, flowering, maturity) are defined correctly by means of days or growing degree-days (GDD) since sowing/planting.
2. Crop morphology – initial/maximum root depth, initial/maximum crop ground cover, maximum LAI (maximum values of all of them as a function of time), the light extinction coefficient, etc.
3. Crop physiology – specific leaf area (SLA), the stem/leaf partitioning coefficient, optimum temperature for growth, leaf area duration, etc.
4. Crop water use – Crop ET coefficient, the maximum daily water uptake
5. Efficiency coefficients – the biomass-transpiration coefficient; the light to biomass (conversion) coefficient
6. Nitrogen related parameters

Number of leaves vs. GDD – sunflower (SANBRO) – IAMB 2005

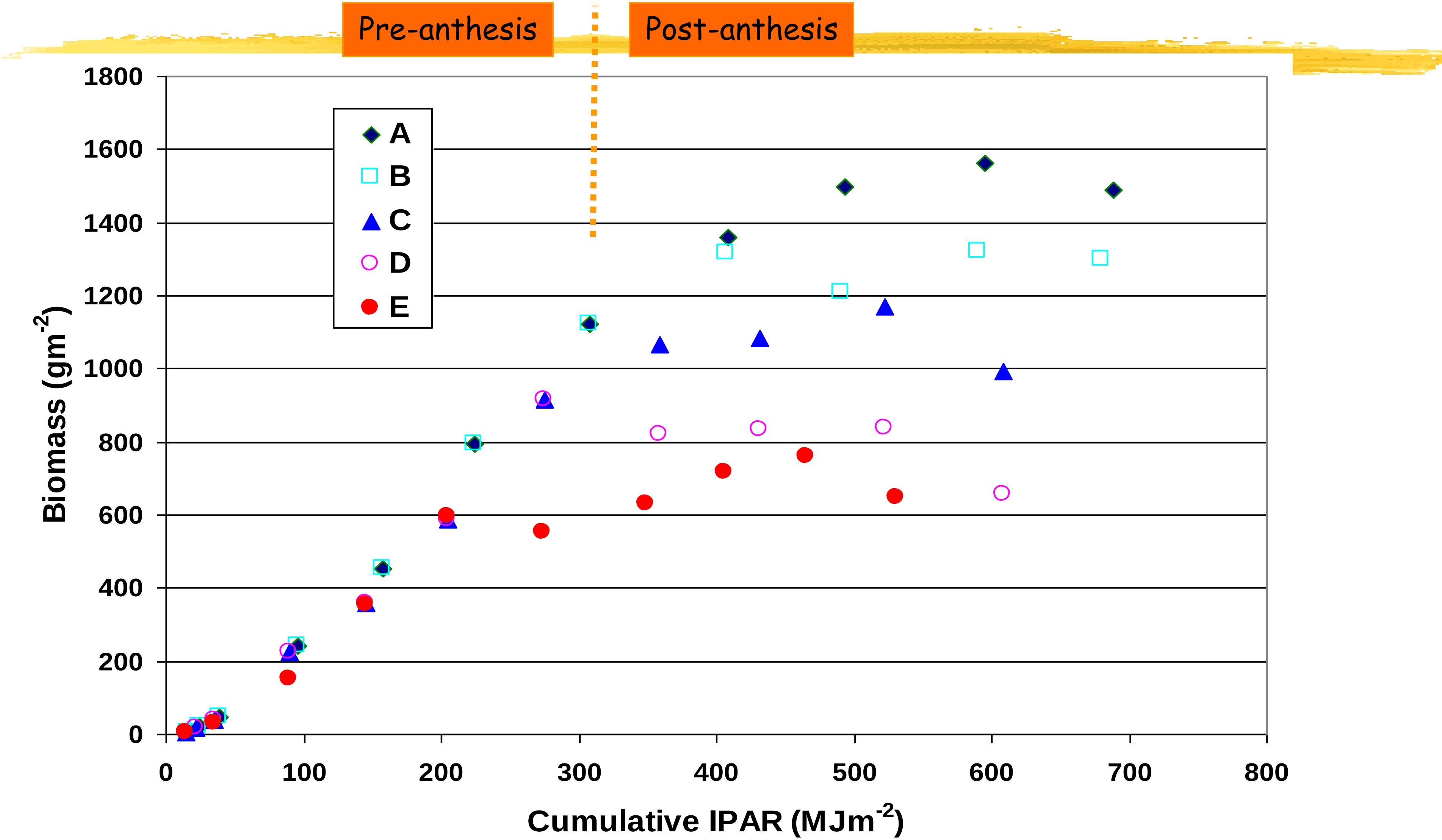
One week before flowering



Seasonal variation of LAI
- sunflower (SANBRO) - IAMB 2005



Biomass vs. Cumulative IPAR



Biomass vs. Cumulative IPAR (two stages)

1 - pre-anthesis
2 - post-anthesis