Crop water requirement

د. إيهاب جناد

مدير إدارة المياه-اكساد

ihjnad@yahoo.com

المركز العربي لدراسات المناطق الجافه و الأراضي القاحلة

(ACSAD)

Reference crop evapotranspiration (ETo)

- The evapotranspiration rate from a reference surface, not short of water, is called the reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m-1 and an albedo of 0.23.

FAO Penman-Monteith equation

$$ET_0 = \frac{0.408\Delta\,(R_n - G) + \gamma \dfrac{900}{T + 273}\, u_2(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34u_2)}$$

ETo: reference evapotranspiration [mm day-1],
Rn: net radiation at the crop surface [MJ m-2 day-1],
G: soil heat flux density [MJ m-2 day-1],
T: mean daily air temperature at 2 m height [°C],
U2: wind speed at 2 m height [m s-1],
es: saturation vapour pressure [kPa],
ea: actual vapour pressure [kPa],
es-ea: saturation vapour pressure deficit [kPa],
Δ: slope vapour pressure curve [kPa °C-1],
γ: psychrometric constant [kPa °C-1].

FAO Penman-Monteith equation
calculation of saturation vapour pressure

$$e_s = 0.6108 \; e^{\left[\frac{17.27T}{T+237.3}\right]}$$

e_s : saturation vapour pressure at T air temperature [kPa],
T: mean daily air temperature at 2 m height [°C],

FAO Penman-Monteith equation
calculation of actual vapour pressure

$$e_a = e_s \frac{RH}{100}$$

e_a : actual vapour pressure [kPa],

FAO Penman-Monteith equation

correction of wind speed which is not measured at height 2 m

$$u_2 = u_z \frac{4.87}{ln(67.8z - 5.42)}$$

FAO Penman – Monteith for missing climate data

FAO Penman – Monteith when some meteorological data is missed

In the absence of relative humidity data, the actual vapor pressure can be estimate from the following equation

$$e_a = 0.611\ e^{\left[\frac{17.27Tmin}{Tmin+237.3}\right]}$$

$Tmin$: minimum air temperature

FAO Penman – Monteith when some meteorological data is missed

In the absence of solar radiation data, incoming solar radiation can be estimate from the following equation

$$R_s = K_{Rs}\sqrt{(T_{max} + T_{min})}R_a$$

R_a : incoming solar radiation [MJ m-2 d-1],
T_{max} : maximum air temperature [°C],
T_{min} : minimum air temperature [°C],
K_{Rs} : adjustment coefficient (0.16 .. 0.19) [°C-0.5].

FAO Penman – Monteith
when some meteorological data is missed

In the absence of wind speed data, an average values could be used:

classes of monthly wind speed data

Description	mean monthly wind speed at 2 m
light wind light to moderate wind moderate to strong wind strong wind	... $\leq$ 1.0 m/s 1 – 3 m/s 3 – 5 m/s ... $\geq$ 5.0 m/s

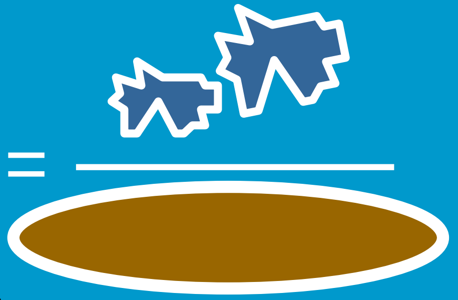
When no wind data is available within the region, a value of 2 m/sec could be used as a temporary estimate. This is an average over 2000 weather stations around the globe.

Estimation actual evapotranspiration in AquaCrop model

Instead of Leaf Area Index (LAI)
AquaCrop uses green canopy cover (CC)

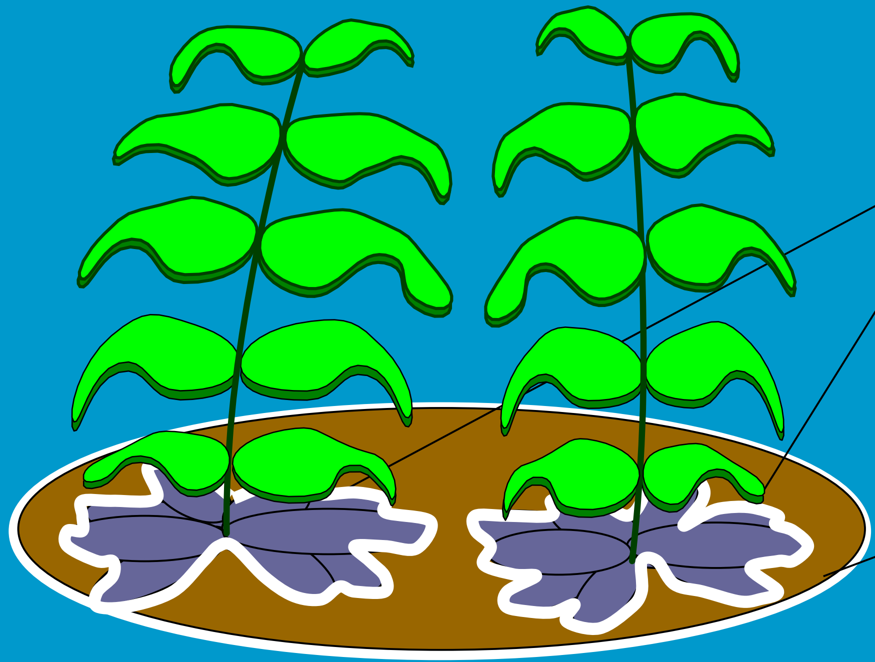
Green Canopy Cover (CC)

$$CC = \frac{\text{soil surface covered by the green canopy}}{\text{unit ground surface area}} =$$

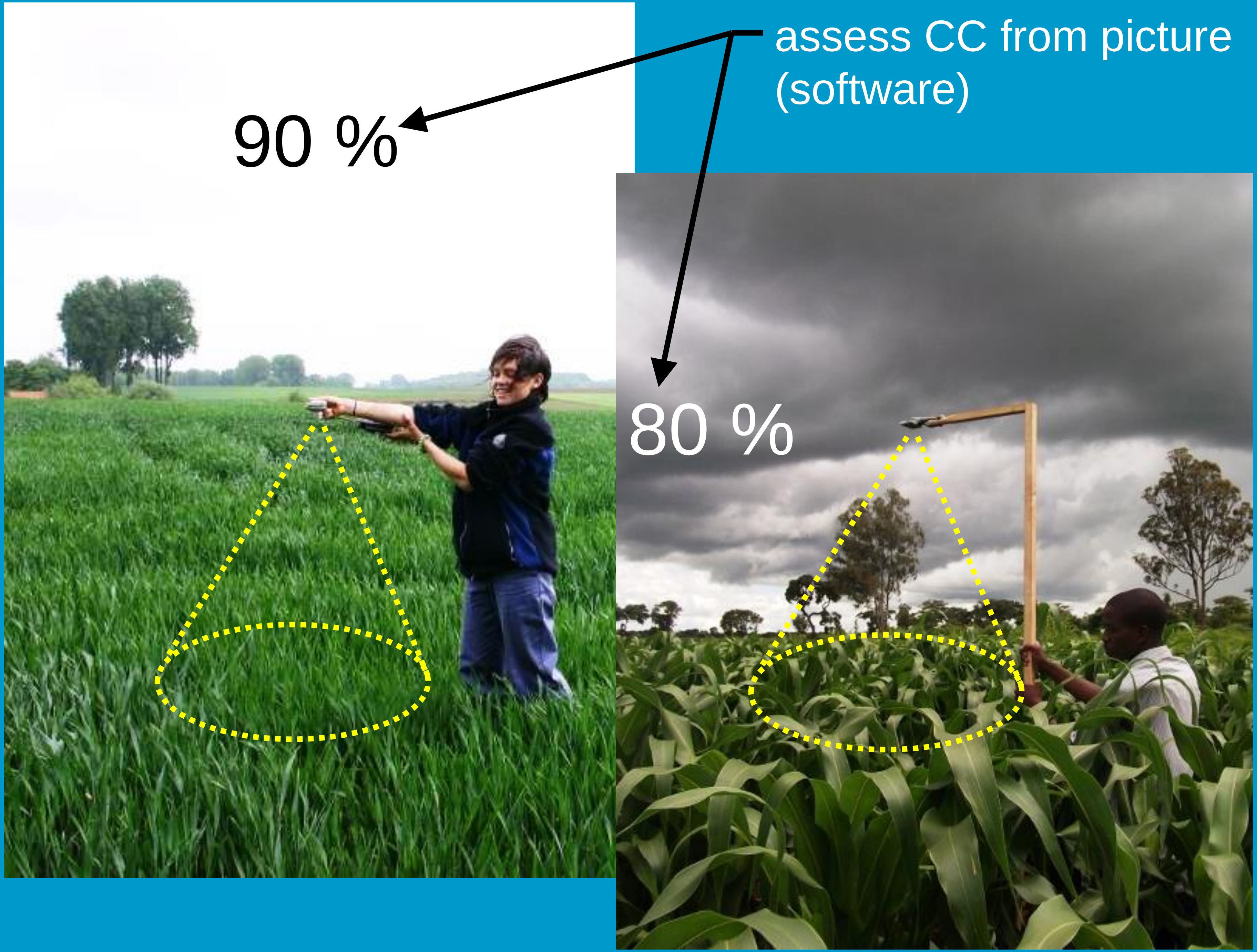


ranges from 0 (bare soil) to 1 (full canopy cover)

0 % $\longrightarrow$ 100 %

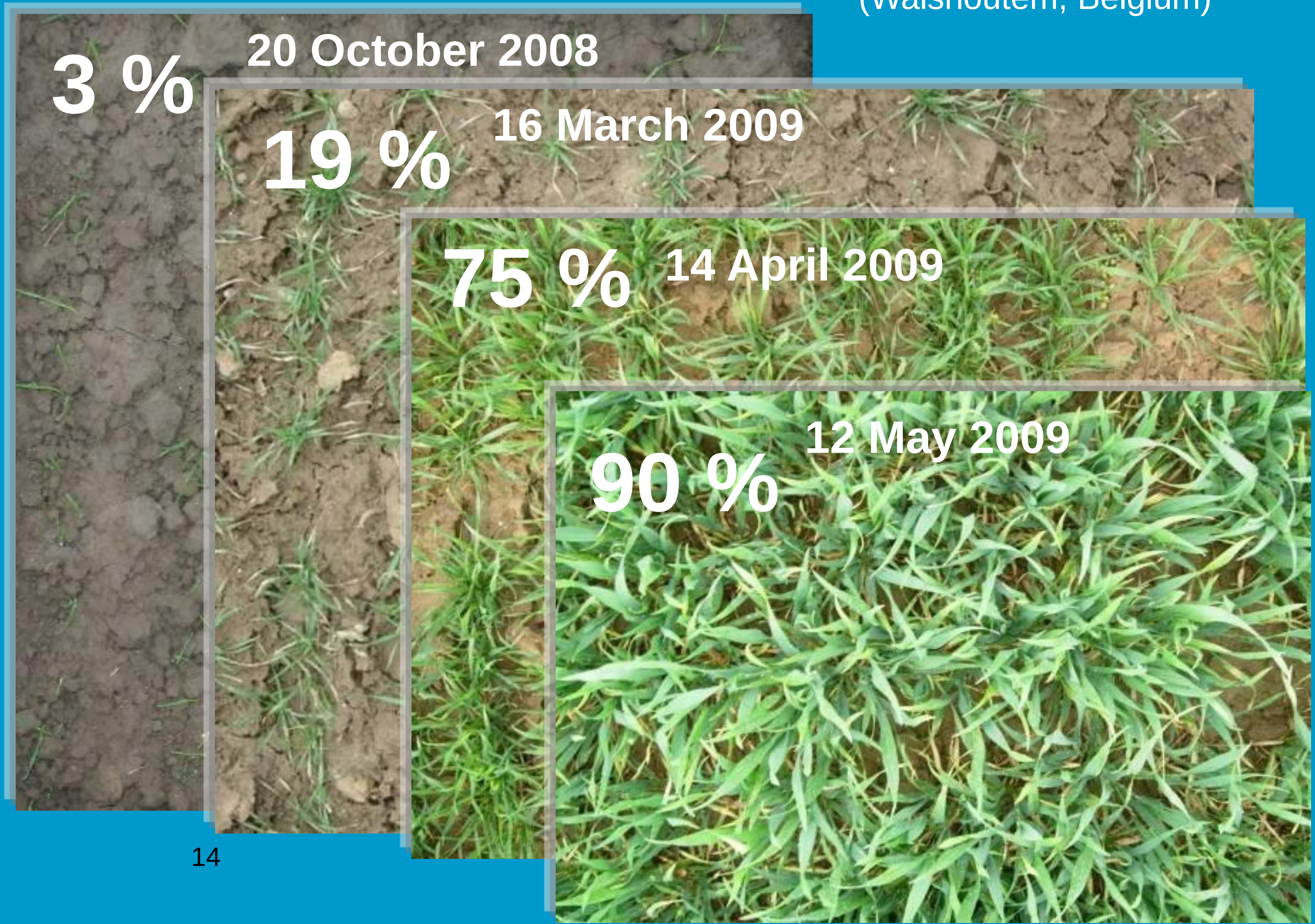


assess CC from picture (software)

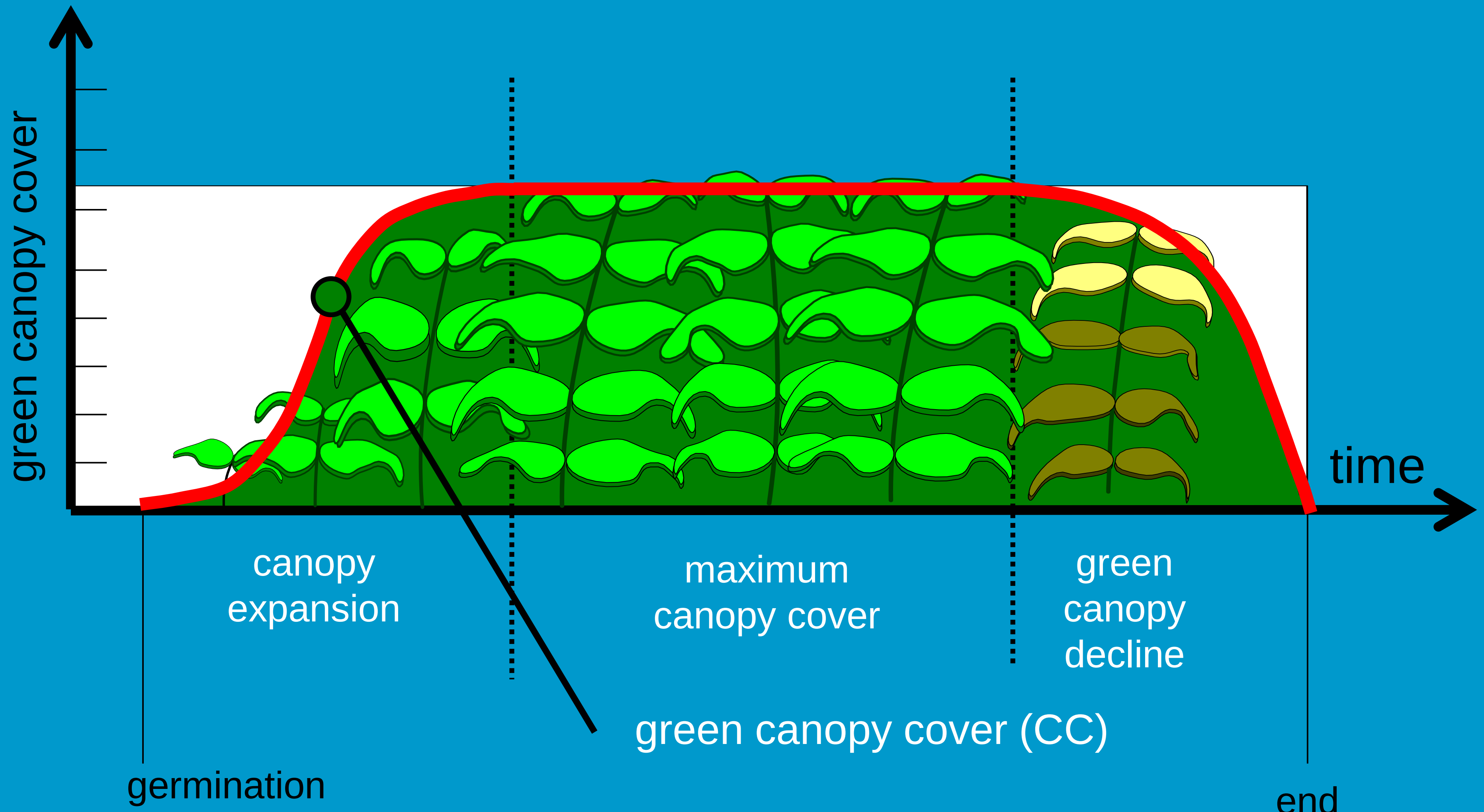


Green Canopy Cover (CC)

Winter wheat
(Walshoutem, Belgium)



Green canopy development (CC)



… 4 … 5 … 6 …

CC is constant

Crop transpiration

Objective and Structure of the presentation

Objective:

Understand how AquaCrop simulates crop transpiration

simulation of crop transpiration for unlimited conditions

Structure:

1. Maximum crop transpiration (Tr_x)
2. Actual crop transpiration (Tr)

simulation of crop transpiration for limited conditions:

- ❑ soil water stress
- ❑ cold stress

EvapoTranspiration = Kc x ETo

well watered soil

In AquaCrop ET is separated into crop transpiration (Tr) and soil evaporation (E)

Crop transpiration = Kc_{Tr} x ETo

\+ Soil evaporation = Ke x ETo

crop transpiration coefficient

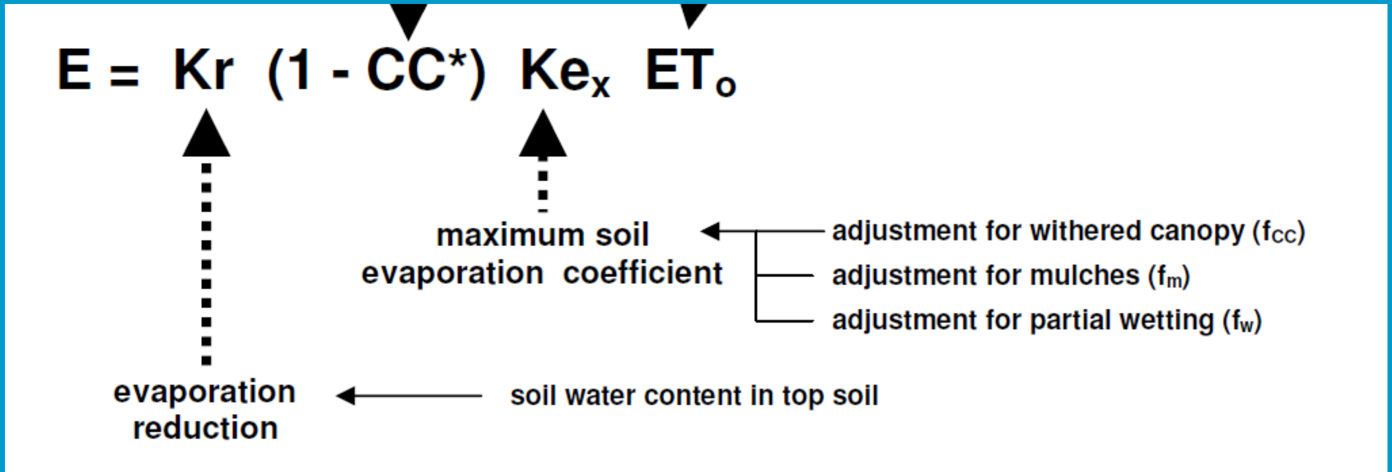
$Kc_{Tr} \sim CC$

proportional to Canopy Cover

soil water evaporation coefficient

$Ke \sim (1- CC)$

proportional to uncovered soil


$E = Kr\ (1 - CC^{*})\ Ke_x\ ET_o$
maximum soil evaporation coefficient
adjustment for withered canopy (f_{CC})
adjustment for mulches (f_m)
adjustment for partial wetting (f_w)
evaporation reduction
soil water content in top soil

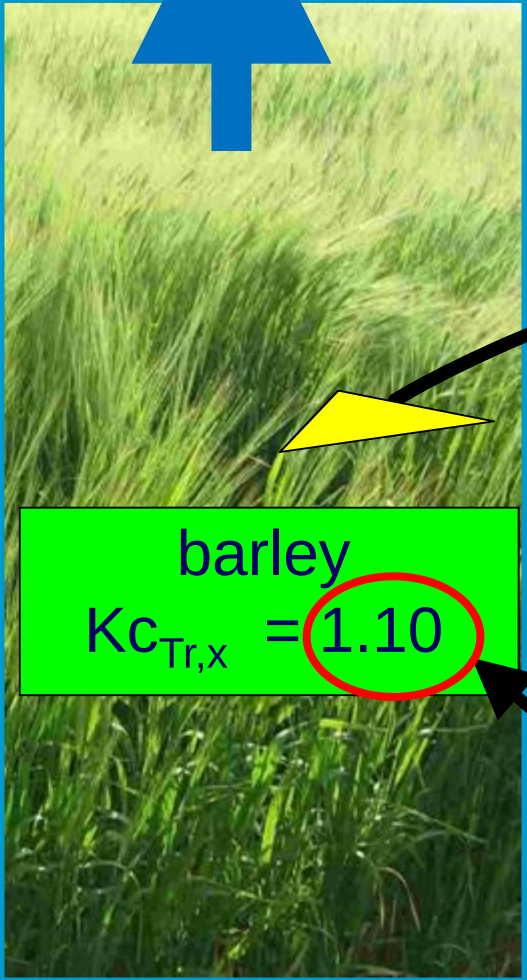
Maximum crop transpiration (Tr_x)

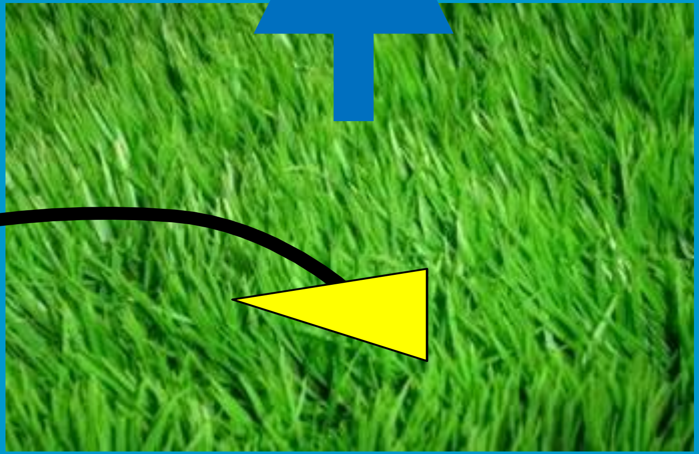
$$Tr_x = \boxed{Kc_{Tr}} \; ETo$$

$$= \boxed{Kc_{Tr,x} \;\; CC^*} \; ETo$$

CC = 1 (full canopy cover)

$$Tr_x = Kc_{Tr,x}\ CC^*\ ETo$$





reference surface (grass)
$Kc_{Tr,x} = 1.00$

integration of the effects of the characteristics that distinguish the crop with a complete canopy from reference grass

Kc_{Tr} : crop transpiration coefficient

$$Tr_x = \boxed{Kc_{Tr,x}\ CC^*}\ ETo$$

conservative crop parameter

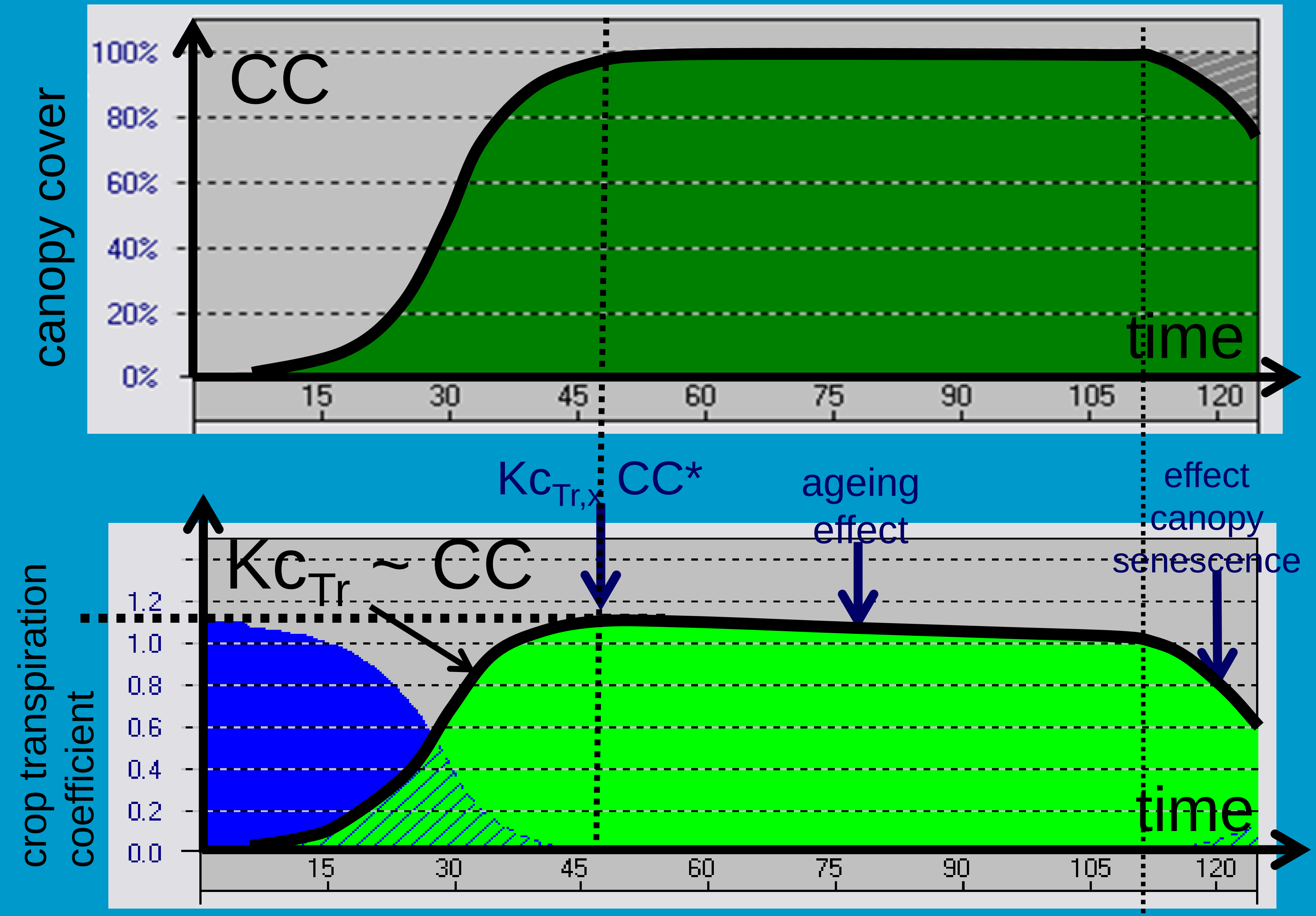
$Kc_{Tr,x}$: crop coefficient for maximum crop transpiration

= 1.10 for most crops (cotton, potato, rice, soybean, sugar beets, sunflower, tomato, wheat, barley, sugar cane, …

ageing effects

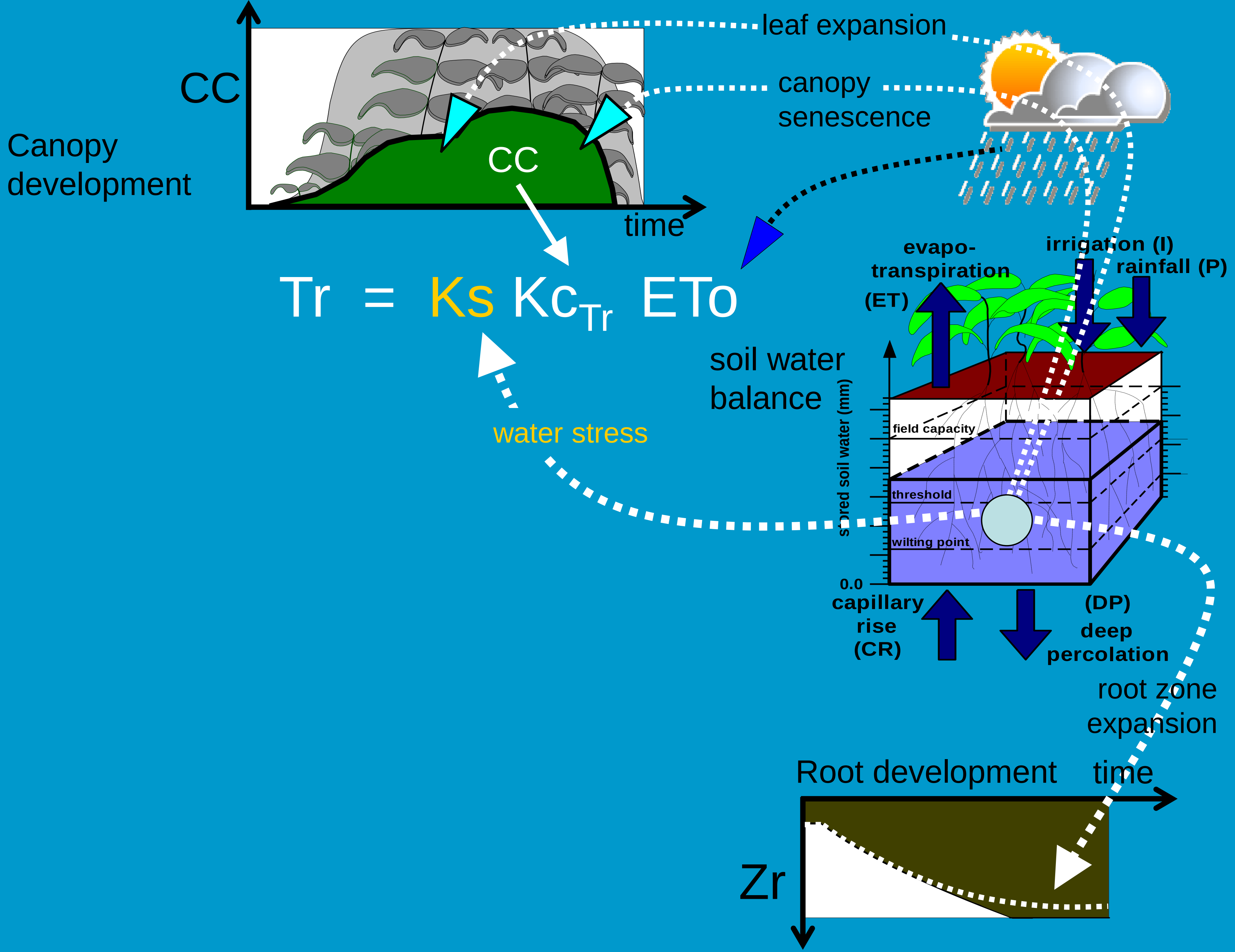
in mid-season the canopy ages slowly and undergoes a reduction in transpiration and photosynthetic capacity

once senescence is triggered the reduction in transpiration becomes stronger


CC
canopy cover
100%
80%
60%
40%
20%
0%
15
30
45
60
75
90
105
120
time
$Kc_{Tr,x}$ CC*
ageing effect
effect canopy senescence
Kc_{Tr} ~ CC
crop transpiration coefficient
1.2
1.0
0.8
0.6
0.4
0.2
0.0
15
30
45
60
75
90
105
120
time

Structure of the presentation

1. Maximum crop transpiration (Trx)
2. Actual crop transpiration (Tr)
   - soil water stress
   - cold stress


leaf expansion
canopy
senescence
CC
Canopy
development
CC
time
Tr = Ks Kc_Tr ETo
water stress
soil water
balance
evapo-
transpiration
(ET)
irrigation (I)
rainfall (P)
stored soil water (mm)
field capacity
threshold
wilting point
0.0
capillary
rise
(CR)
(DP)
deep
percolation
root zone
expansion
Root development
time
Zr

Actual crop transpiration (Tr)

$$Tr = Ks\ Tr_x$$

maximum transpiration rate $= CC^*\ Kc_{Tr,x}\ ETo$

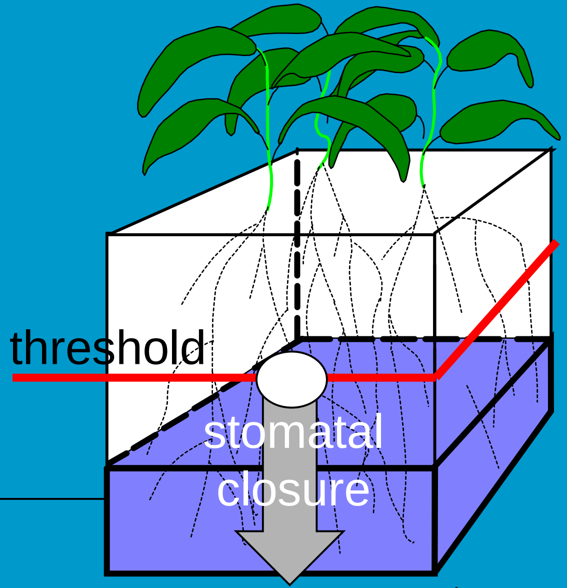
water stress coefficient

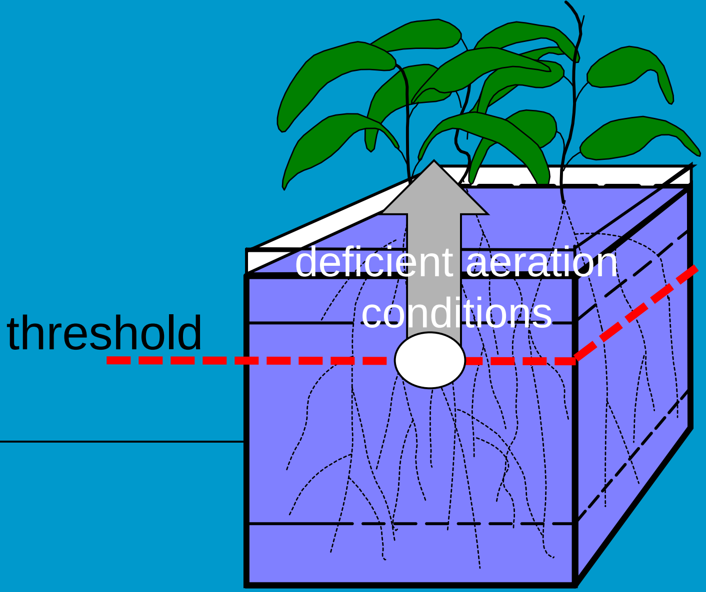
Ks_{sto}

water stress coefficient for stomatal closure

Ks_{aer}

water stress coefficient for water logging



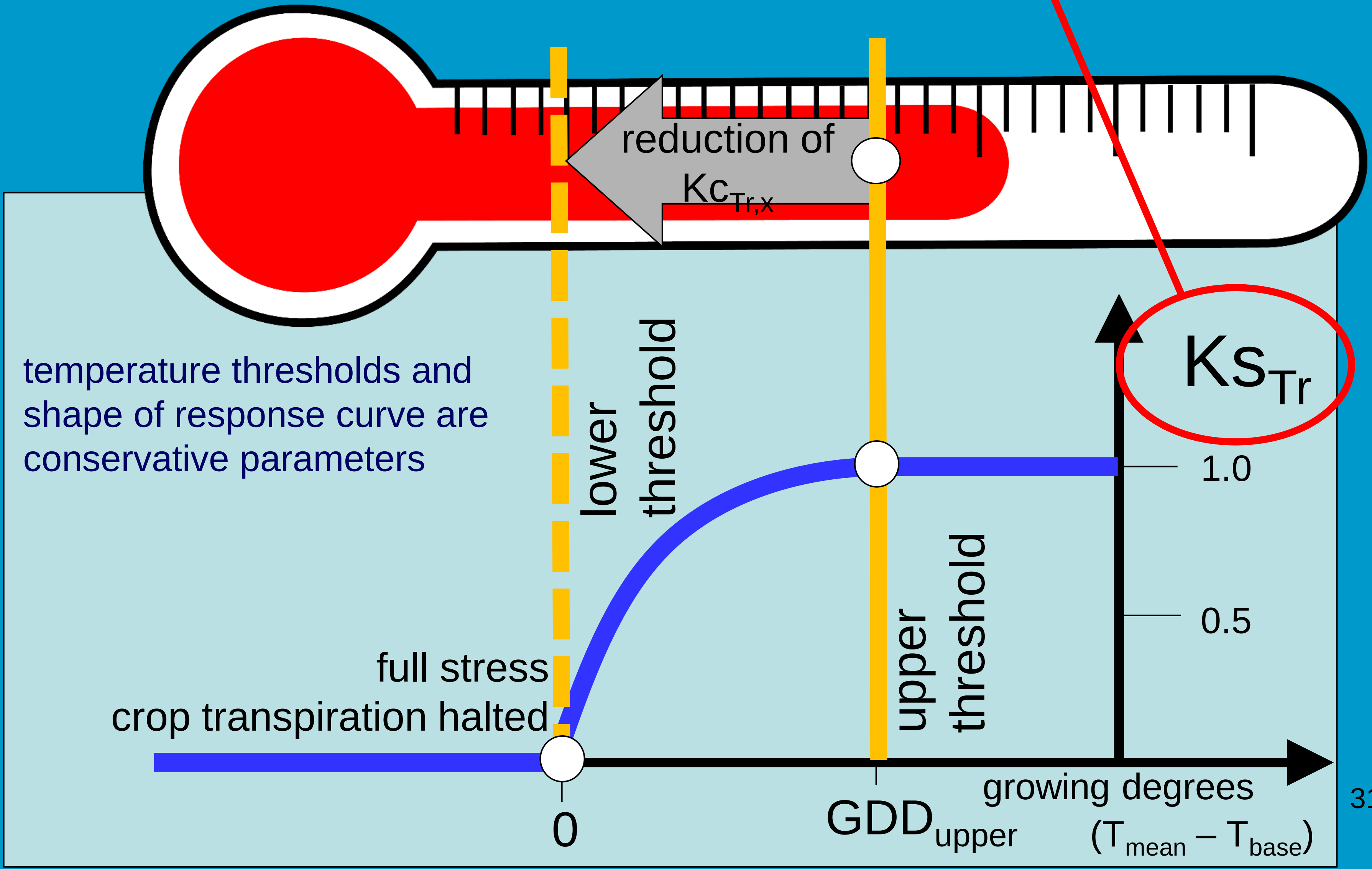


Stress coefficient for low temperature effect on crop transpiration

Ks_{Tr} is modifier of the crop transpiration coefficient

$$Tr = (Ks_{Tr}\ Kc_{Tr,x})\ CC^*\ ETo$$

temperature thresholds and shape of response curve are conservative parameters



Overview of factors affecting the simulation of crop transpiration (Tr)

Crop Canopy (CC) development

evaporative demand
of the atmosphere

adjustment for micro-
advective effects (*)

$$Tr \;=\; Ks\; Ks_{Tr}\; CC^{*}\; Kc_{Tr,x}\; ETo \text{ .... (crop transpiration)}$$

crop specific (conservative)

adjustment for ageing and at senescence

cold stress

water stress

stomata closure (Ks_{sto})

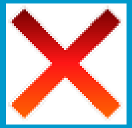
water logging (Ks_{aer})

soil salinity stress ($Ks_{sto,salt}$)

Irrigation management using AquaCrop model

Irrigation mode in AquaCrop

growing cycle

- Rainfed cropping (no irrigation in season) 

- Determination of Net irrigation water requirement ? 

- Irrigation schedule 
  - when
  - irrigation applications…….user defined
  - quantity
  - quality (salt content)

- Generation of Irrigation schedule 
  - when ← time criterion
  - irrigation applications…….generated
  - quantity ← depth criterion
  - quality (salt content)

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Structure of the presentation

1. Determination of net irrigation water requirement (I_{net})
2. Irrigation method
3. Irrigation schedule (specified events)
4. Generation of irrigation schedules
5. Off-season irrigation
6. Deficit irrigation

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Irrigation method

- Soil surface wetted (%)
- Timing and depth of irrigation applications

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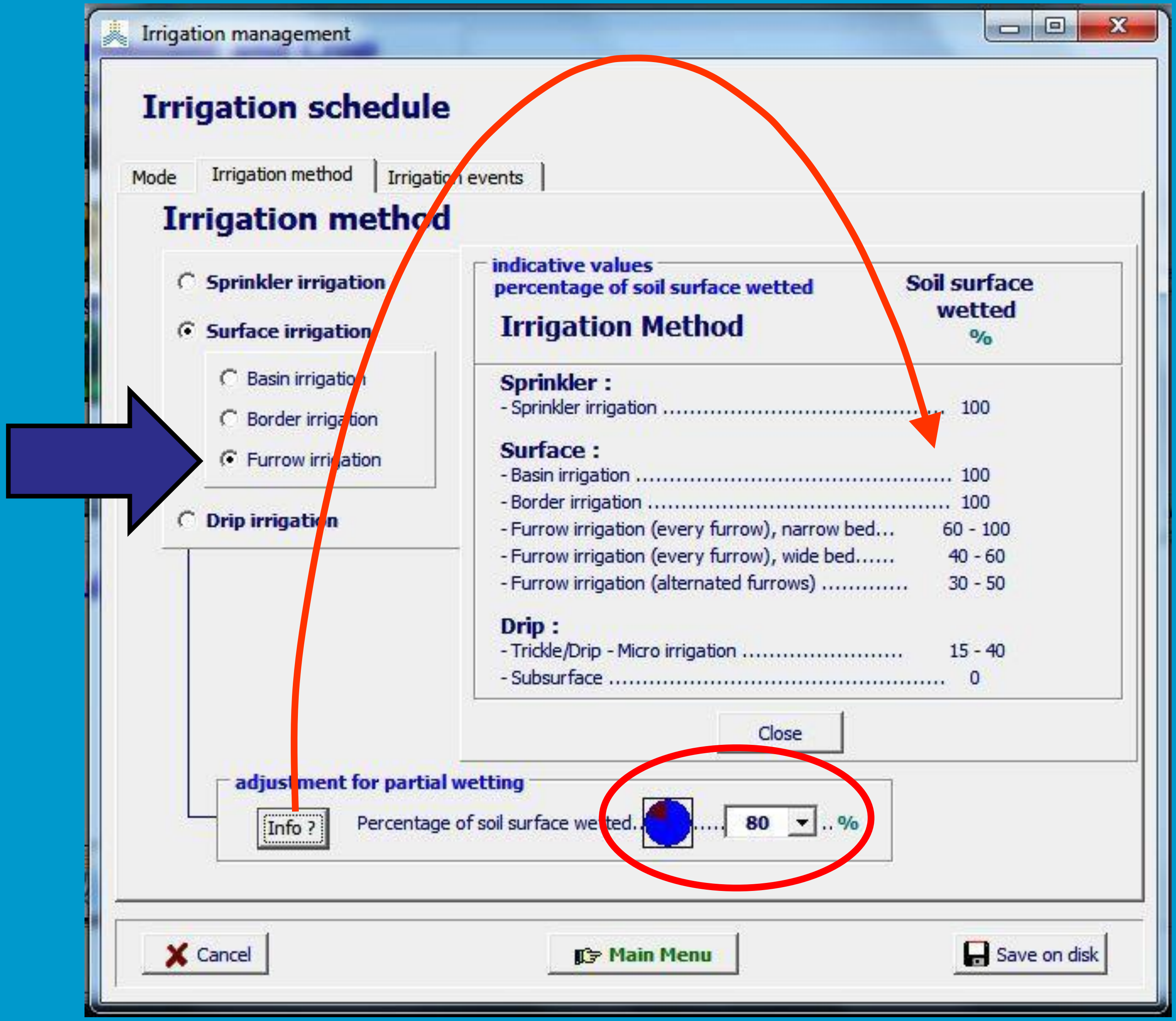
irrigation method and percentage of soil surface wetted



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Irrigation schedule (specified events)

Specify for each irrigation event:

- date
- water quality (salt content)
- net amount of water applied

amount of water that infiltrates in the soil (and is not lost by surface runoff or accounts for the uneven distribution of the water on the field)

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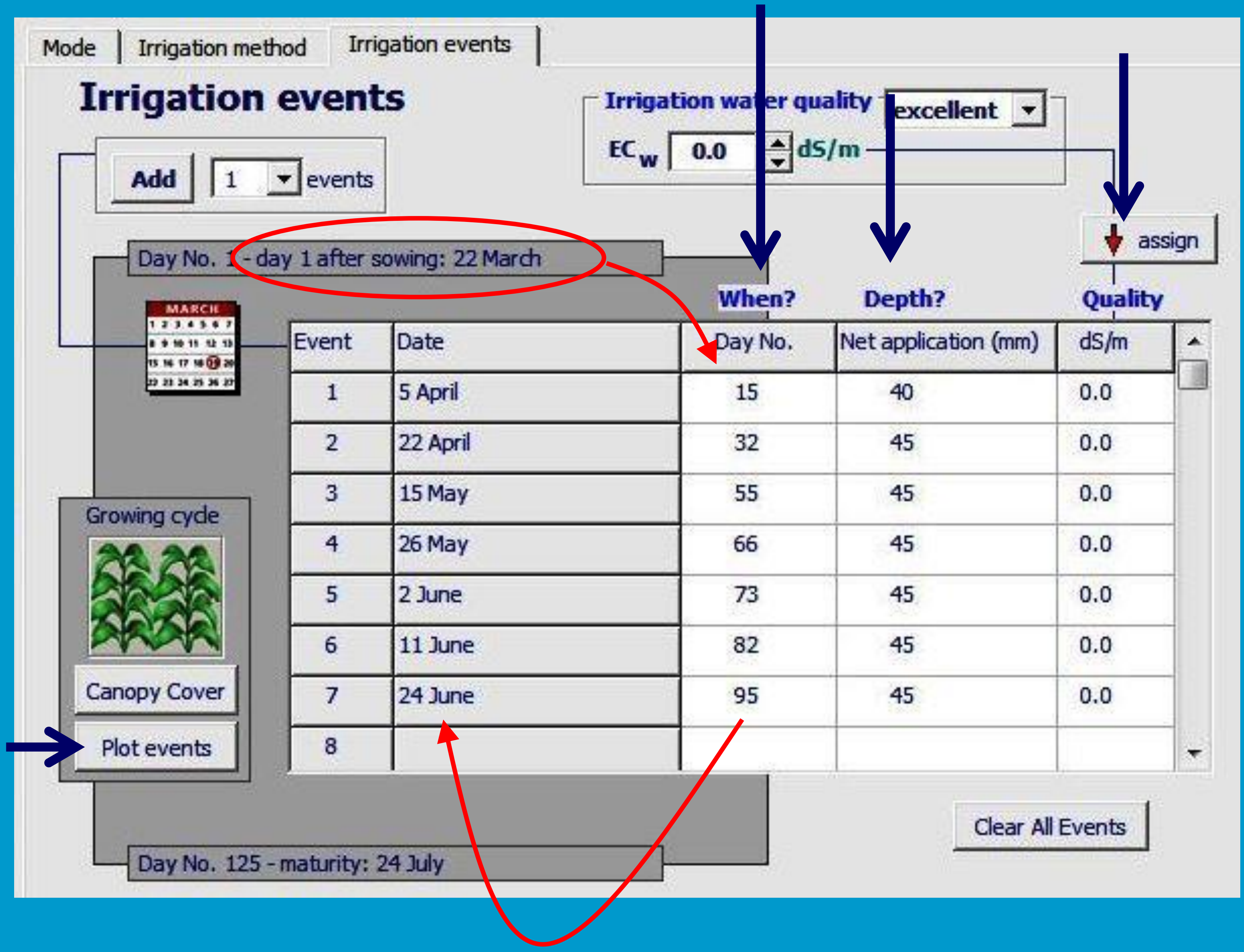
Irrigation management menu



Event	Date	Day No.	Net application (mm)	dS/m
1	5 April	15	40	0.0
2	22 April	32	45	0.0
3	15 May	55	45	0.0
4	26 May	66	45	0.0
5	2 June	73	45	0.0
6	11 June	82	45	0.0
7	24 June	95	45	0.0
8				

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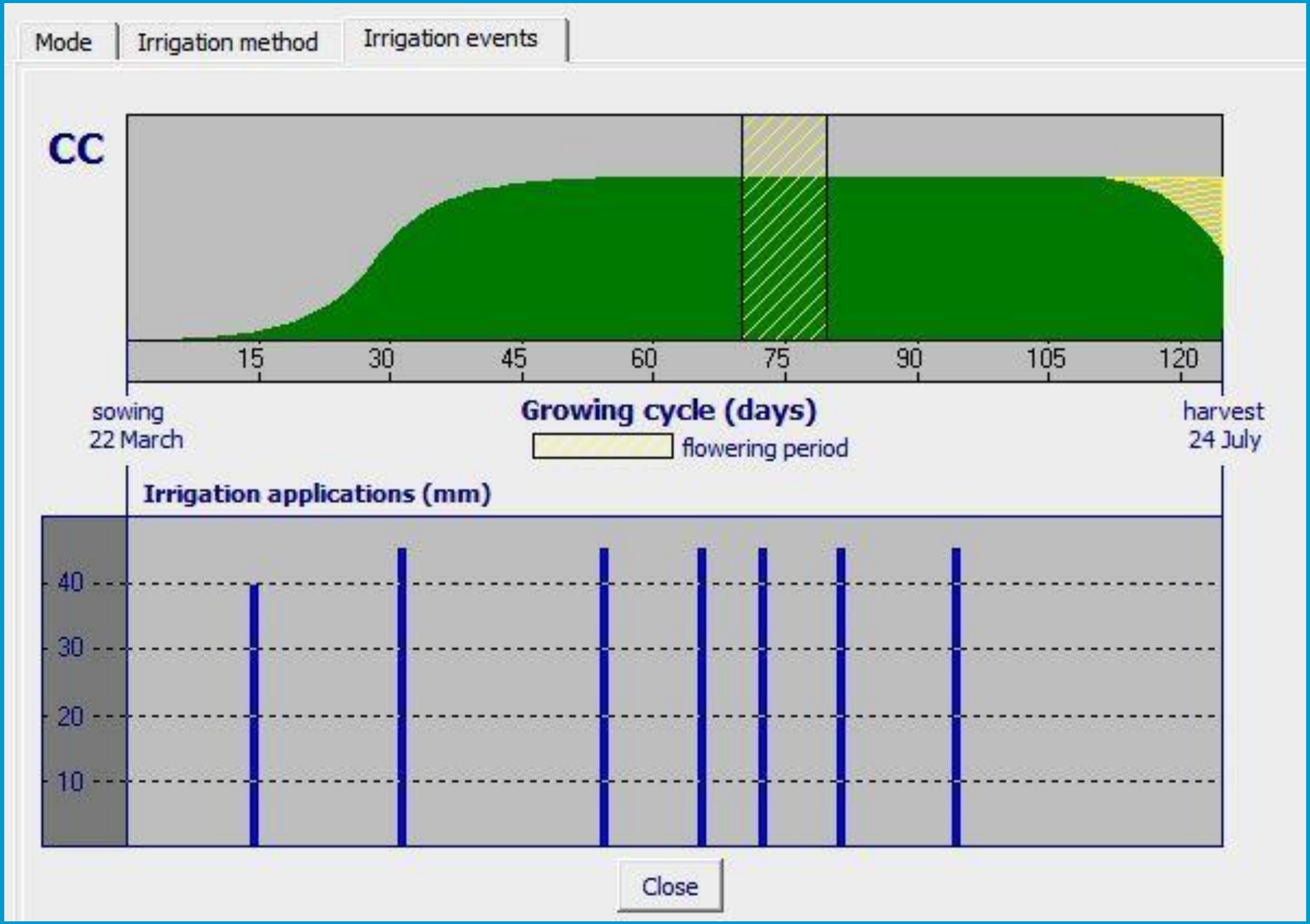
Irrigation management menu



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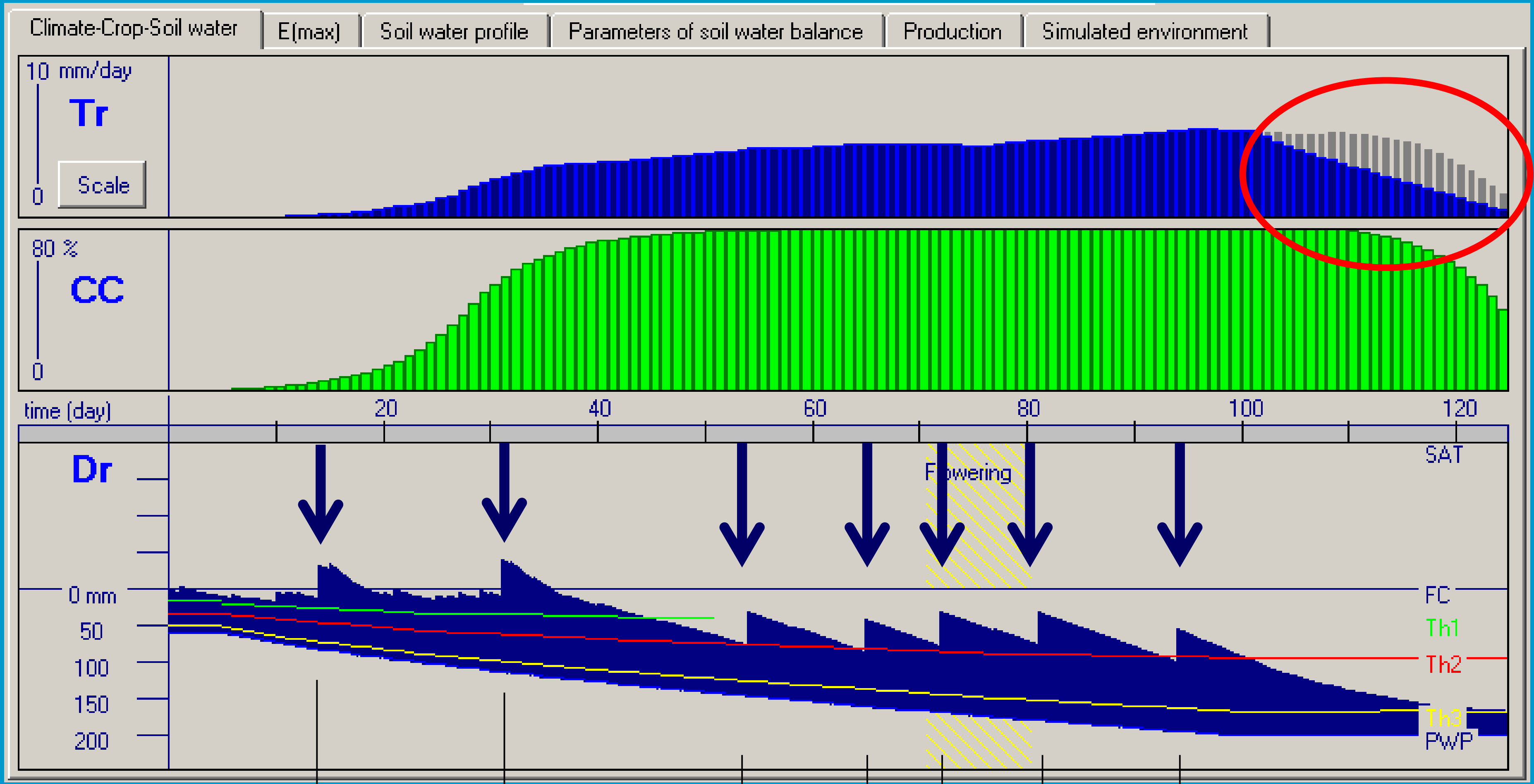
simulation run ⟶ evaluate existing irrigation schedule

Simulation run menu



15 (40 mm)

32 (45 mm)

… 45 mm …

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Generation of irrigation schedules

for planning/checking particular irrigation strategies

AquaCrop generates irrigation schedule based on

- **time criterion (when to apply ?)**
- **depth criterion (how much to apply ?)**

The criteria may vary during the crop cycle

The time criterion will often vary in the different growth stages

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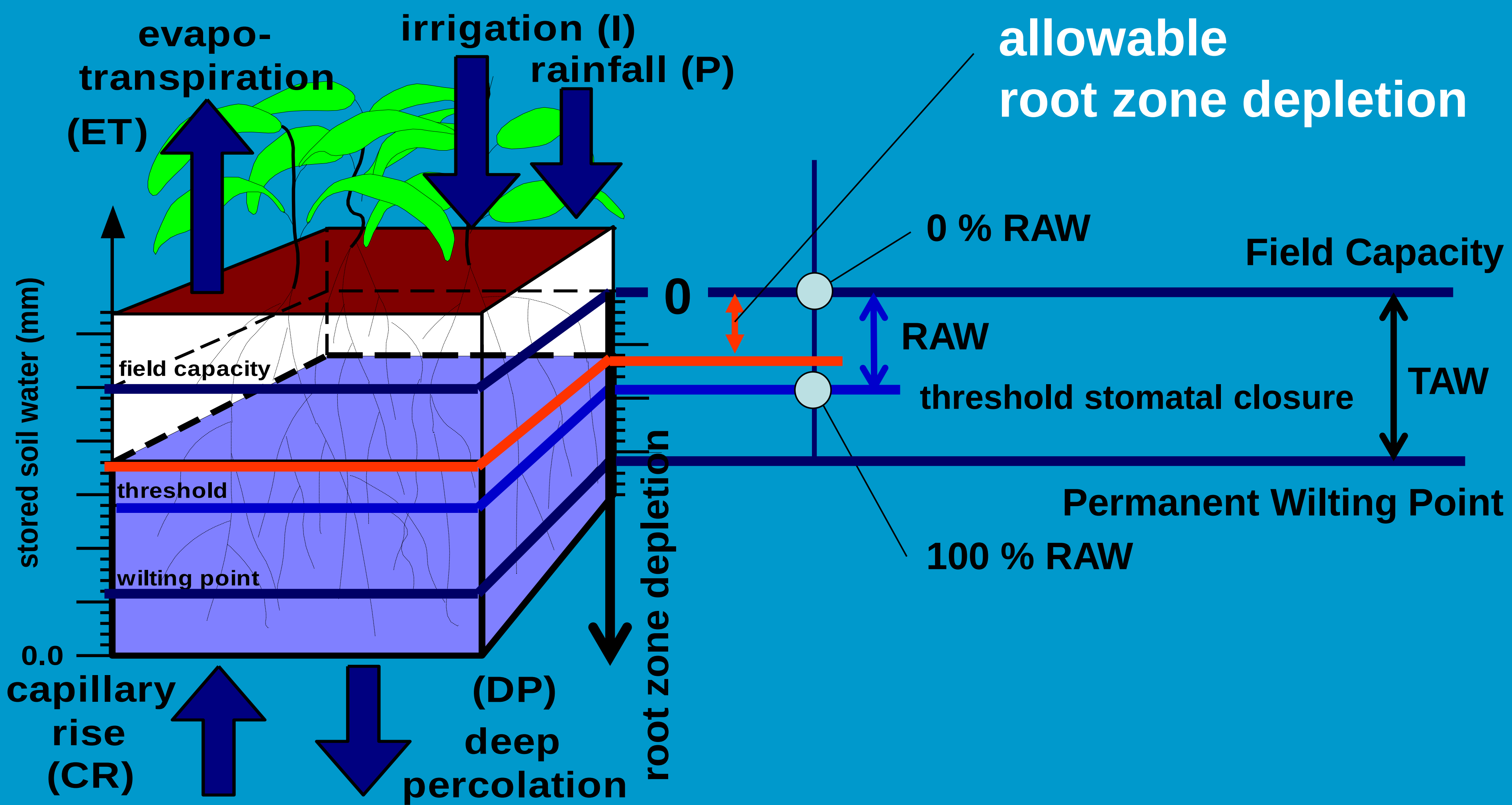
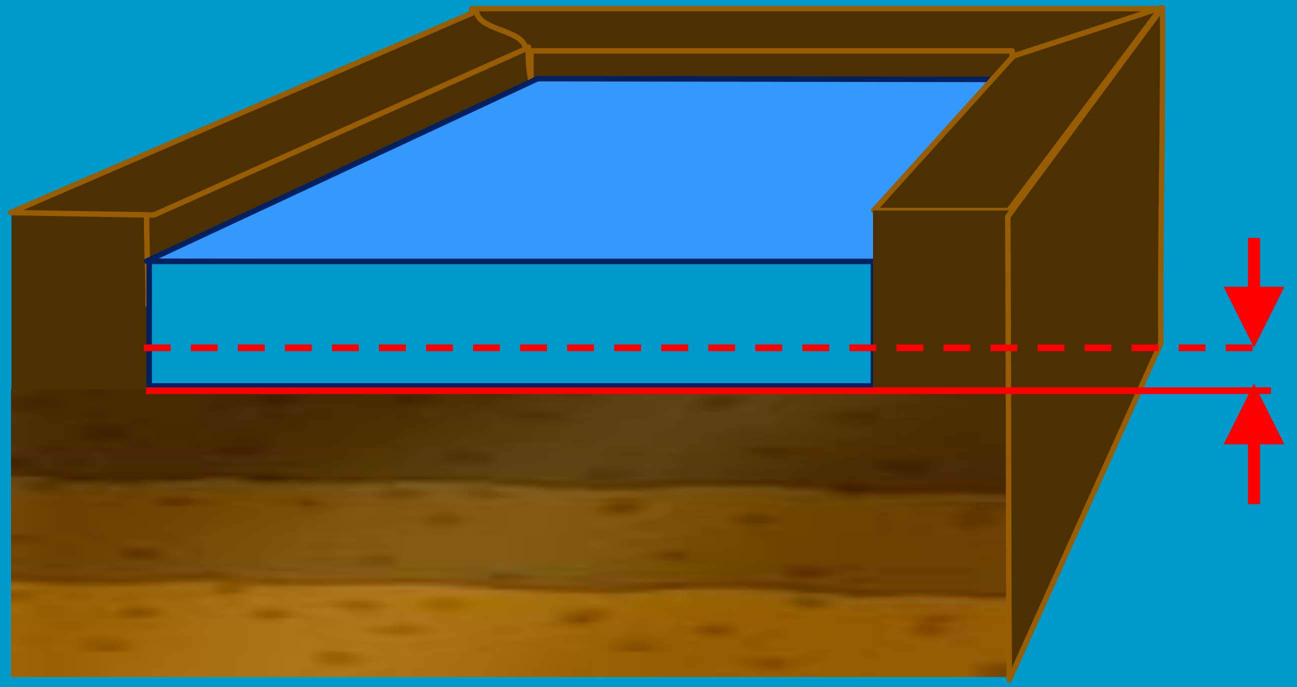
Time criterion (when to apply ?)

– when the root zone depletion reaches a specific threshold expressed in mm or as % of RAW



Time criterion (when to apply ?)

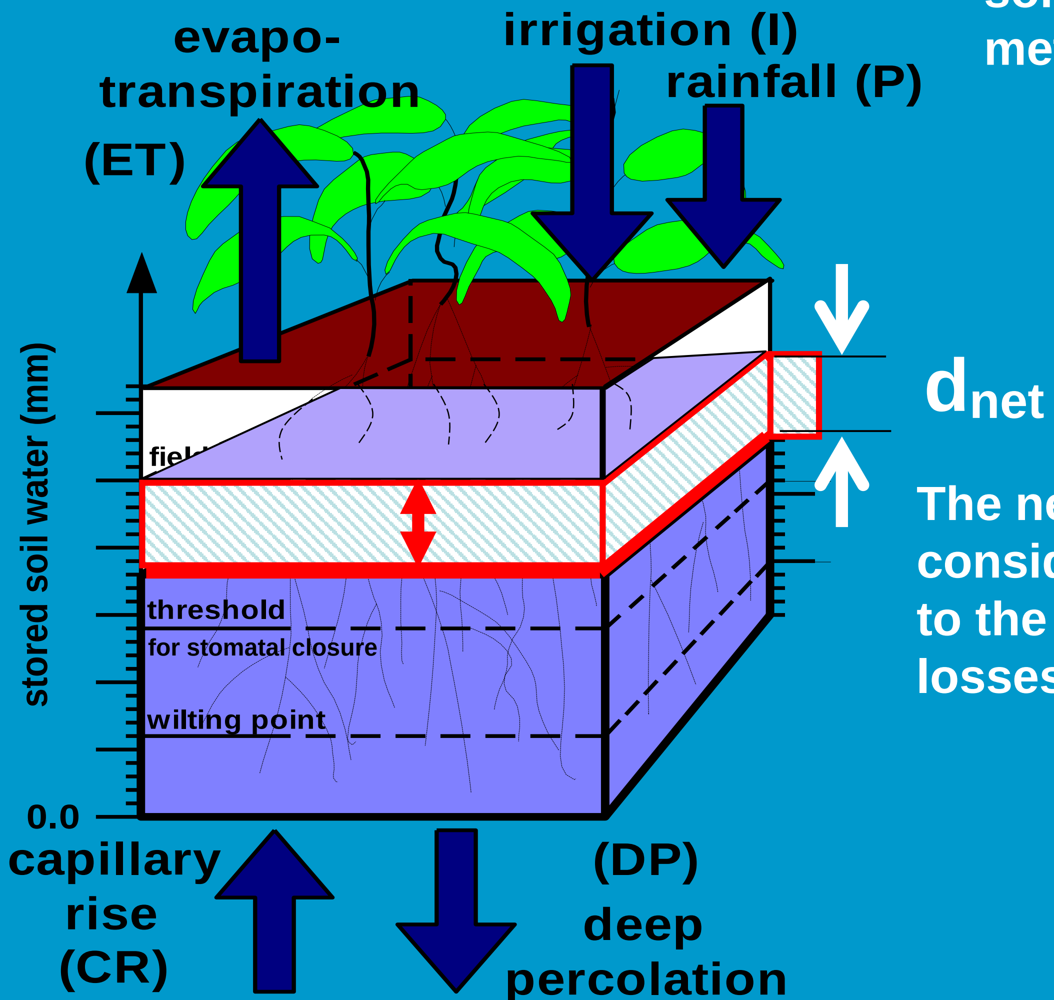
- at a fixed interval
  useful in case of a rotational method of irrigation among irrigation groups
- when the water layer between bunds, drops below a minimum level
  in case of paddy rice irrigation



minimum water layer
to be maintained
between the soil bunds

Depth criterion (how much to apply ?)

- back to Field Capacity —— +/- extra amount of water (mm)
- fixed application dose —— selected in function of local practices, soil and crop parameters and irrigation method



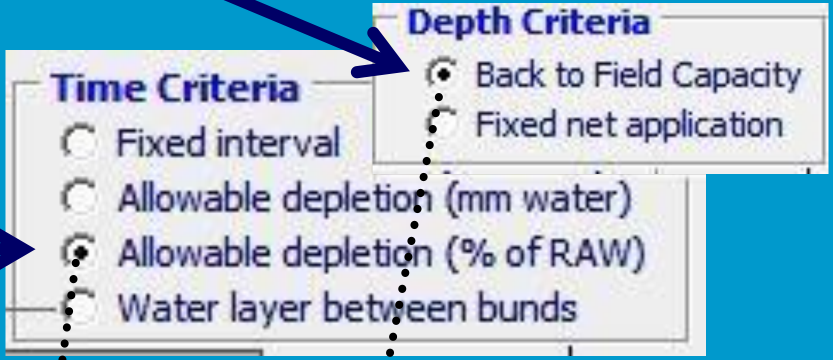
The net application dose (d_{net}) does not consider extra water that has to be applied to the field to account for conveyance losses or runoff from the field.

Indicative irrigation application depths (doses) for various irrigation methods

Irrigation method		Application depth [mm]
Surface	❑ Basin	50 – 150
	❑ Border	40 – 80
	❑ Furrow	30 – 60
Sprinkler	❑ Solid set	30 – 80
	❑ Center pivot, linear move, travelling gun (if infiltration allows)	15 – 35 (up to 80)
Localized	Drip, micro-sprinkler, …	5 – 25

1. Select time and depth criteria

Irrigation management menu



2. Specify the values linked with the time and depth criteria and water quality valid at day 1 of the crop cycle

	valid From	When ?	Depth ?	Quality
Date	Day No.	Depleted % RAW	To FC +/-(mm)	dS/m
22 March	1	50	0	0.0

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	valid From	When ?	Depth ?	Quality
Date	Day No.	Depleted % RAW	To FC +/-(mm)	dS/m
22 March	1	50	0	0.0

3. The values specified are valid
   - till the date where another value is specified

	valid From	When ?	Depth ?	Quality
Date	Day No.	Depleted % RAW	To FC +/-(mm)	dS/m
22 March	1	50	0	0.0
25 May	65	100	0	0.5

   - to the end of cropping period (when no values at later days are specified)

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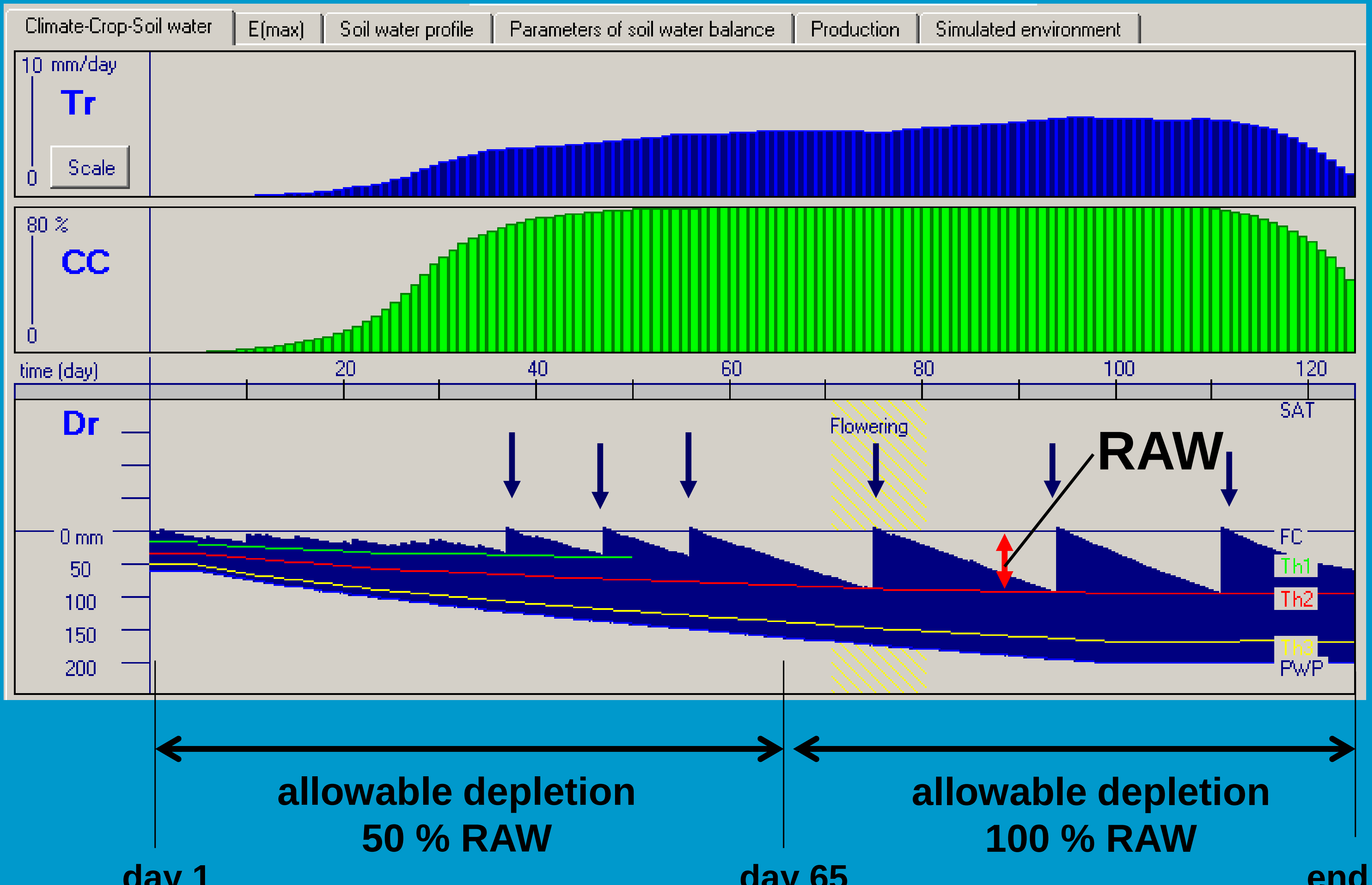
Simulation run menu



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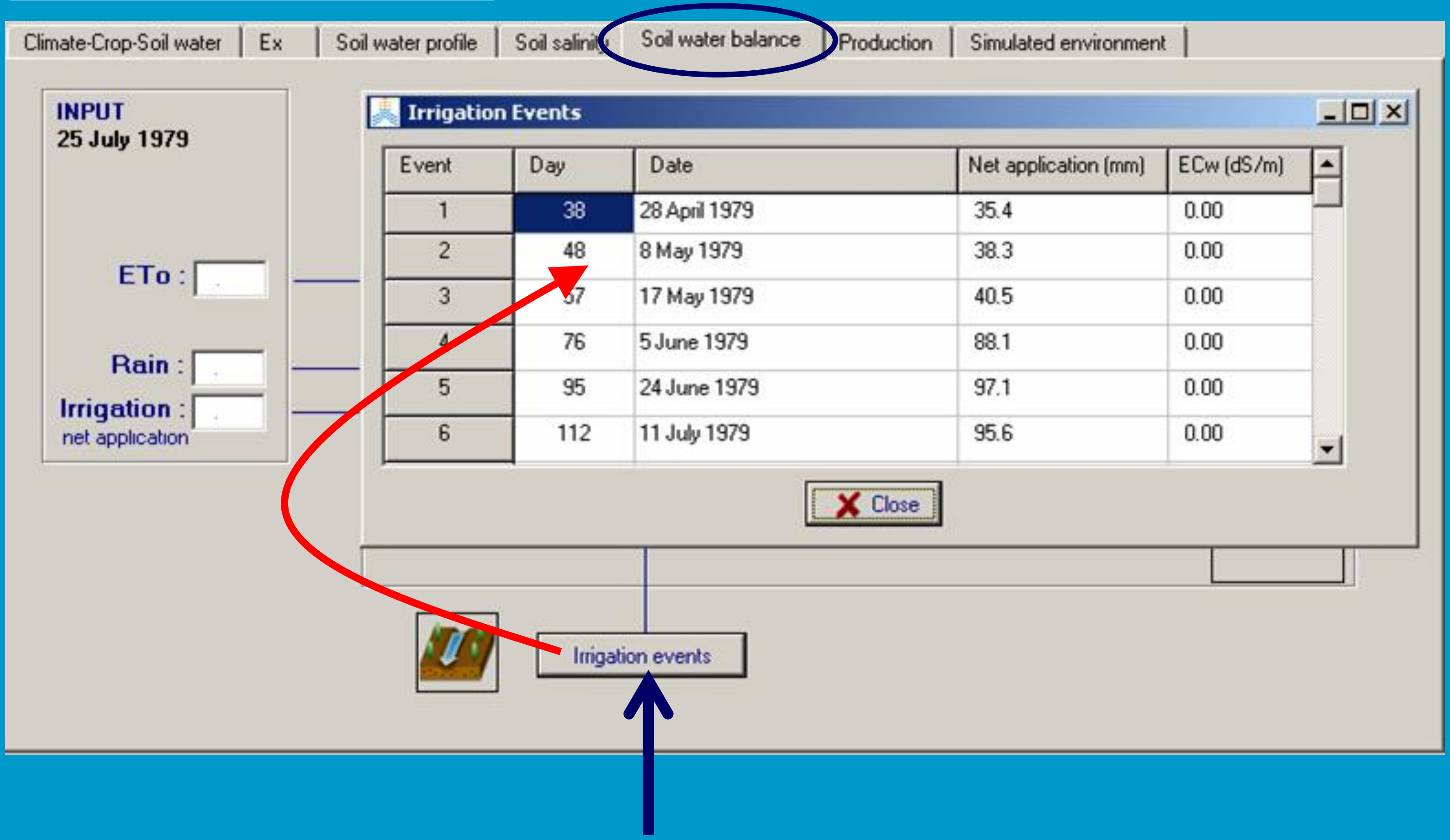
display irrigation events (simulation run menu)

Simulation run menu



Event	Day	Date	Net application (mm)	ECw (dS/m)
1	38	28 April 1979	35.4	0.00
2	48	8 May 1979	38.3	0.00
3	57	17 May 1979	40.5	0.00
4	76	5 June 1979	88.1	0.00
5	95	24 June 1979	97.1	0.00
6	112	11 July 1979	95.6	0.00

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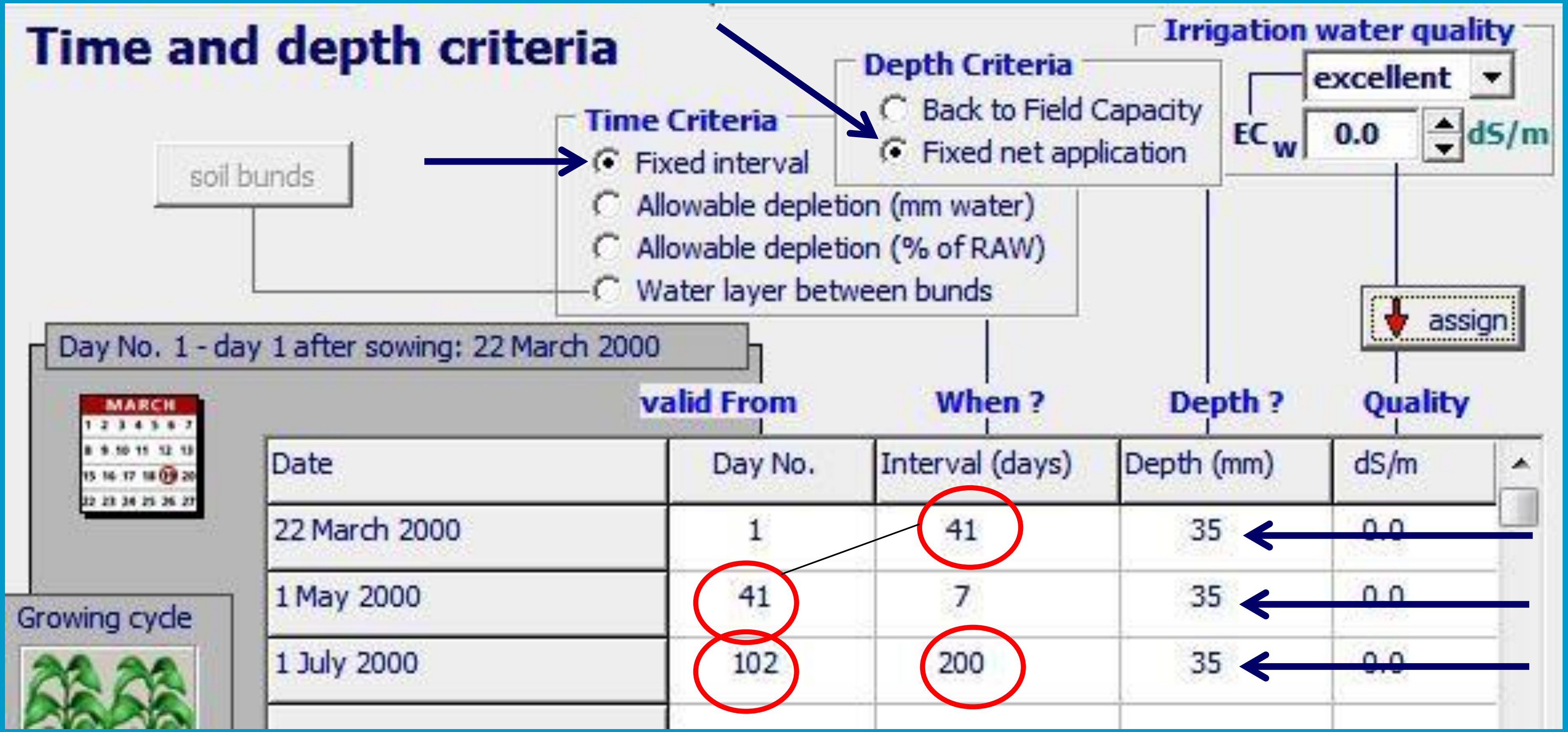
Example

Sprinkler irrigation (35 mm) starts at 1 May (41 DAS) with a fixed interval of a week (7 days) and ends at the beginning of July (102 DAS)

Irrigation management menu



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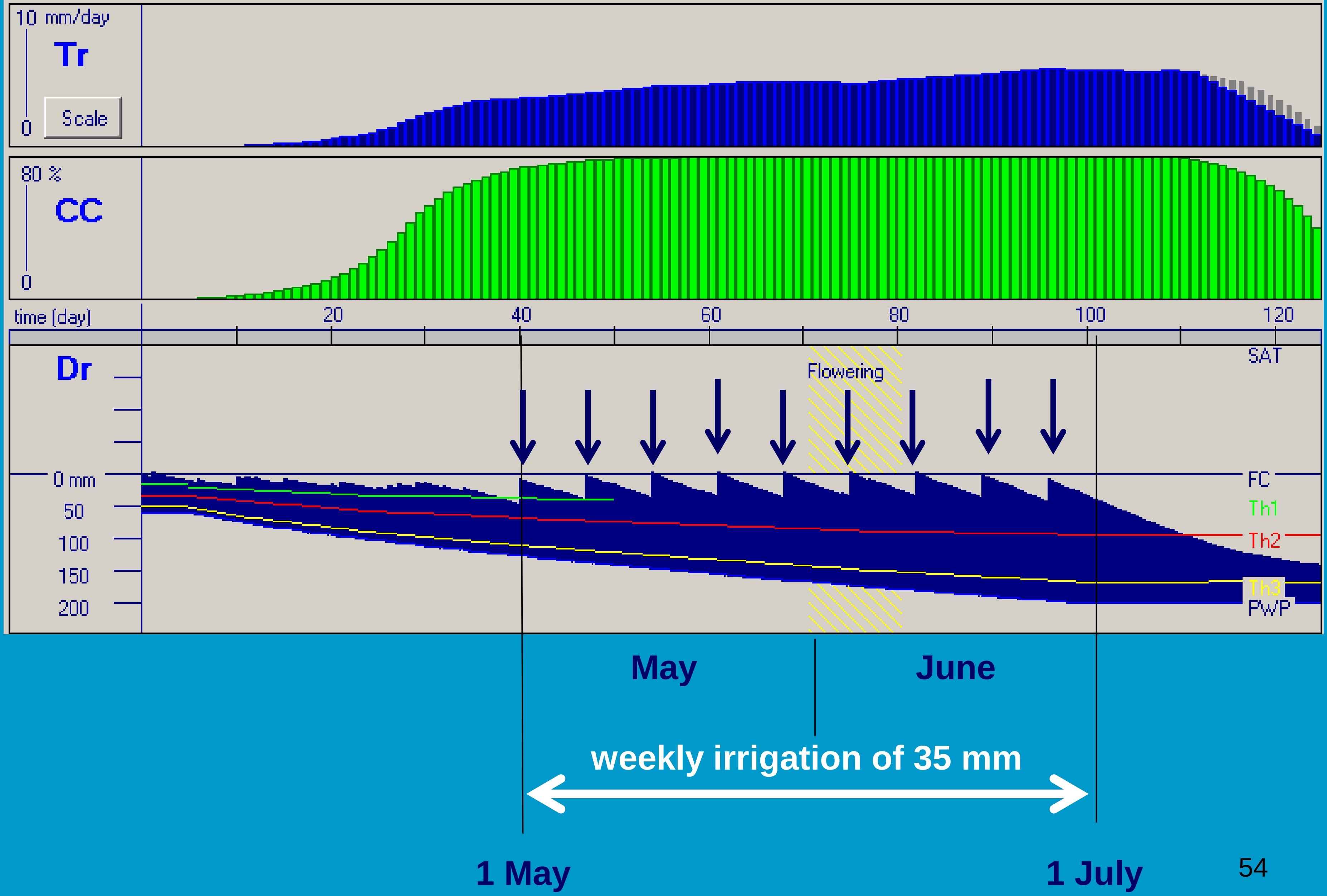
Simulation run menu



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Structure of the presentation

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Off – season irrigation

pre-irrigation

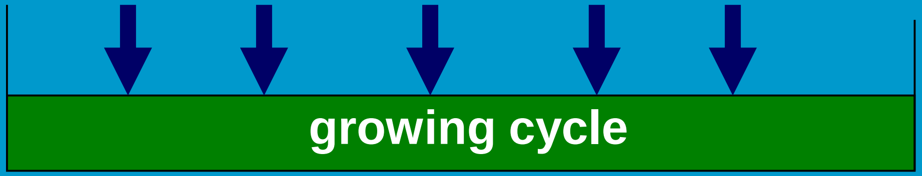
to obtain optimal soil water conditions at planting

post season irrigation
to leach salts
out of the root zone

1. Simulation starts before growing cycle

2. Specify pre-irrigation event(s) in the off-season

3. Specify irrigation event(s) or time and depth criteria
in growing cycle



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Example

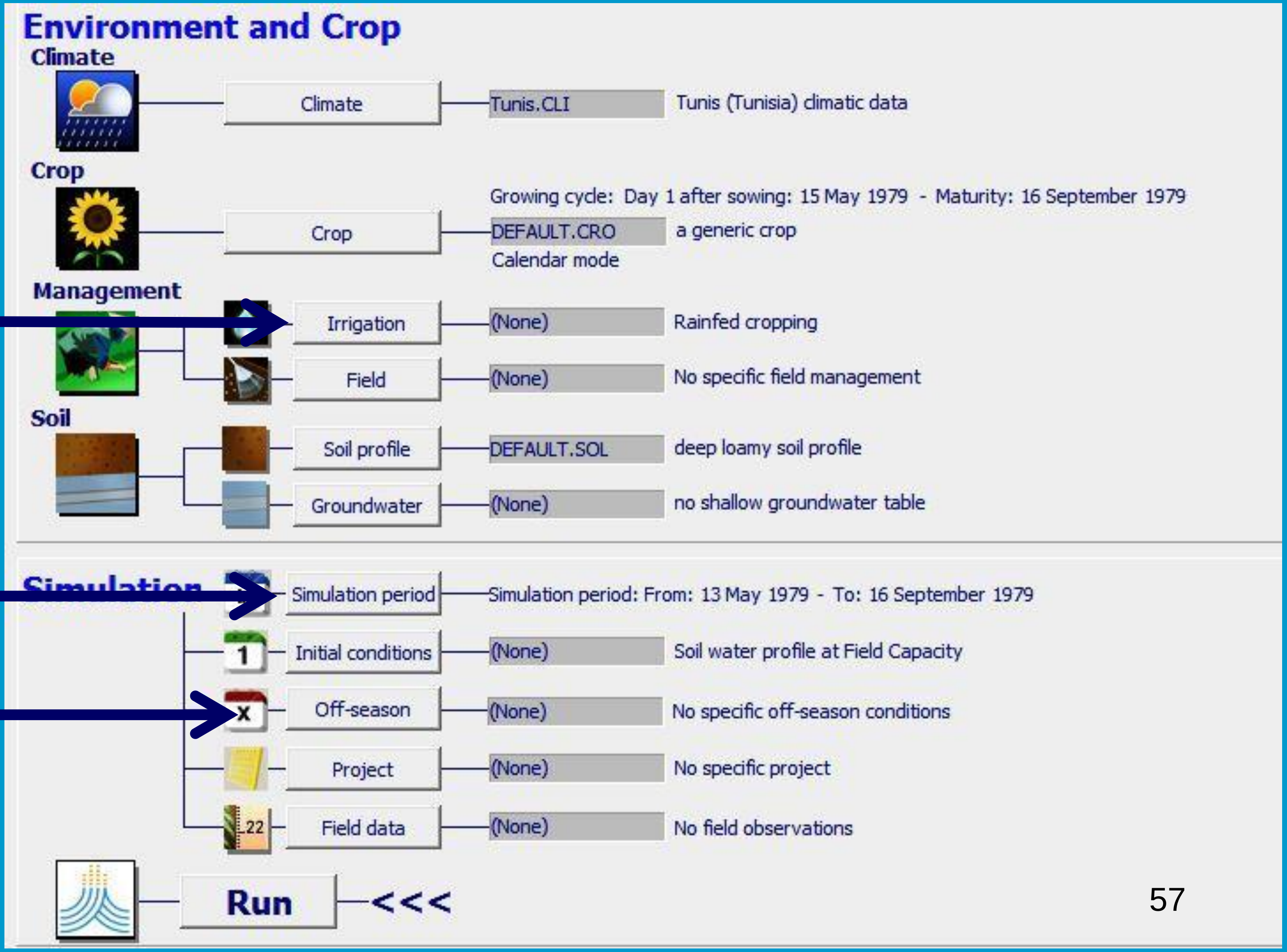
- Growing cycle: 15 May – 16 September
- Drip irrigation (10 mm) till 1 September
- Pre-irrigation (sprinkler) of 50 mm at 13 May

Main menu

Specify irrigation in growing cycle

Specify simulation period

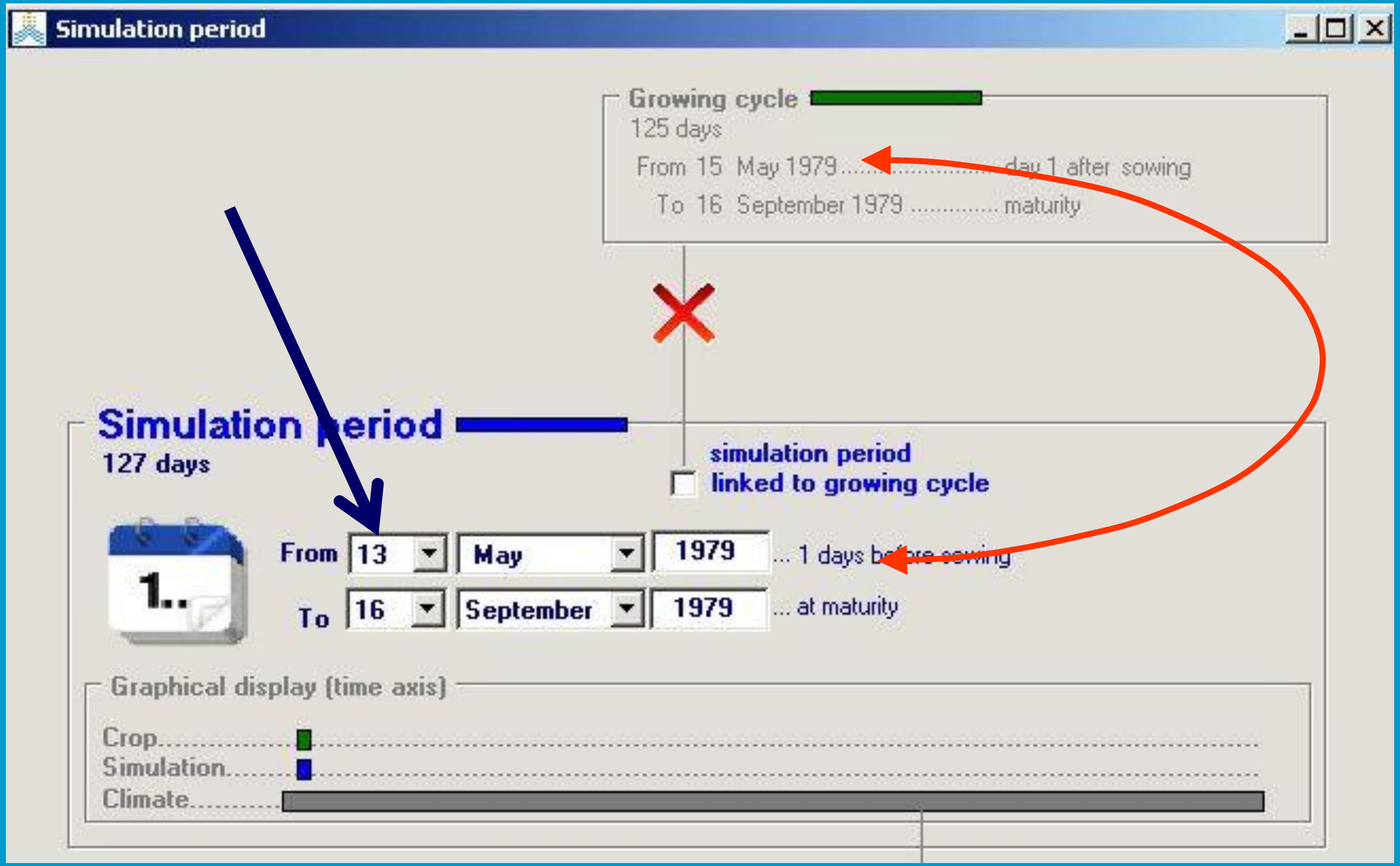
Specify irrigation in off-season



1. Simulation starts before growing cycle

Specify simulation period

Simulation period menu



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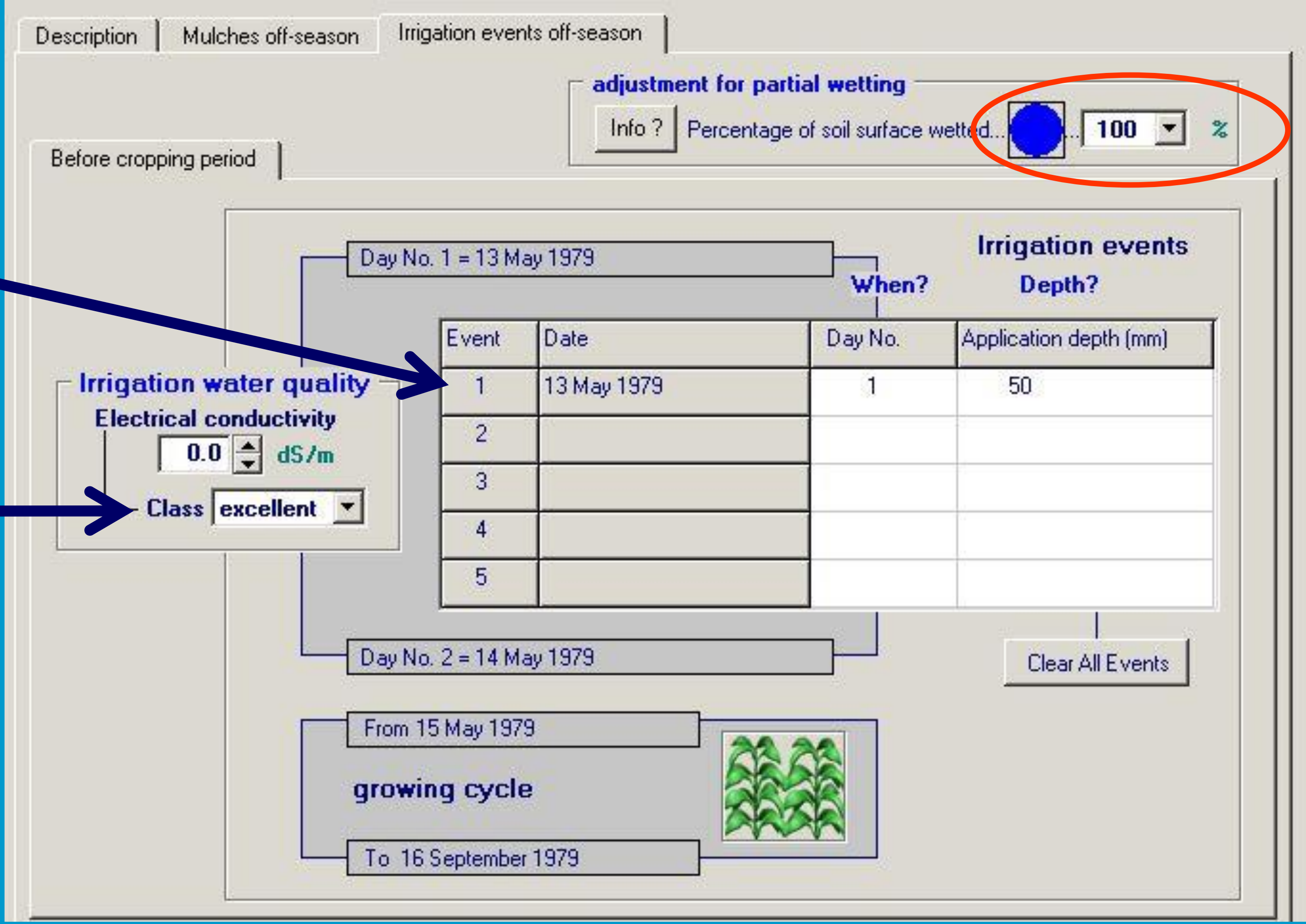
2. Specify pre-irrigation event(s) in the off-season

Pre-irrigation (sprinkler) of 50 mm at 13 May
excellent water quality

Off-season conditions menu



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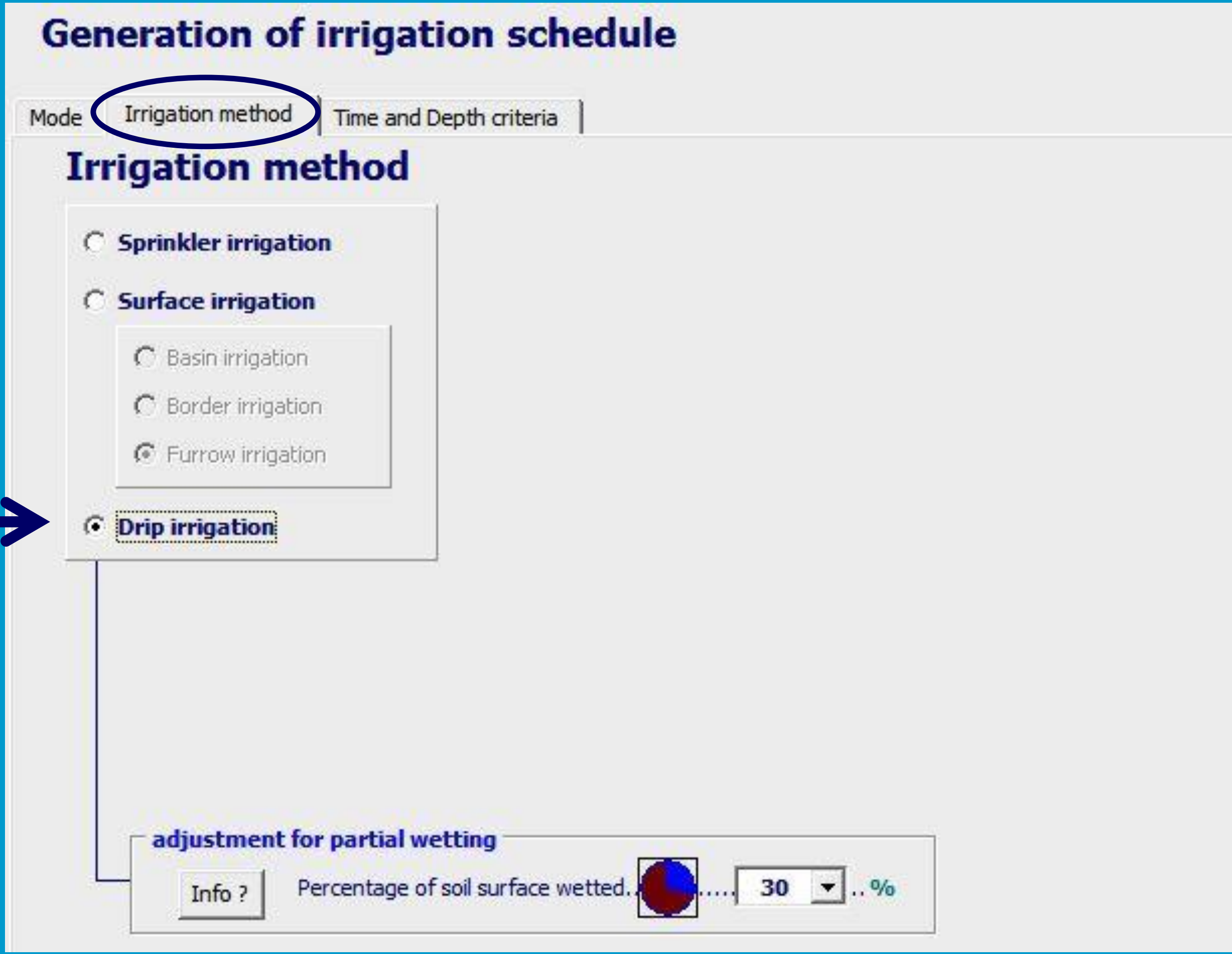
3. Specify irrigation event(s) or time and depth criteria in growing cycle

- Select irrigation method (drip)

Irrigation management menu



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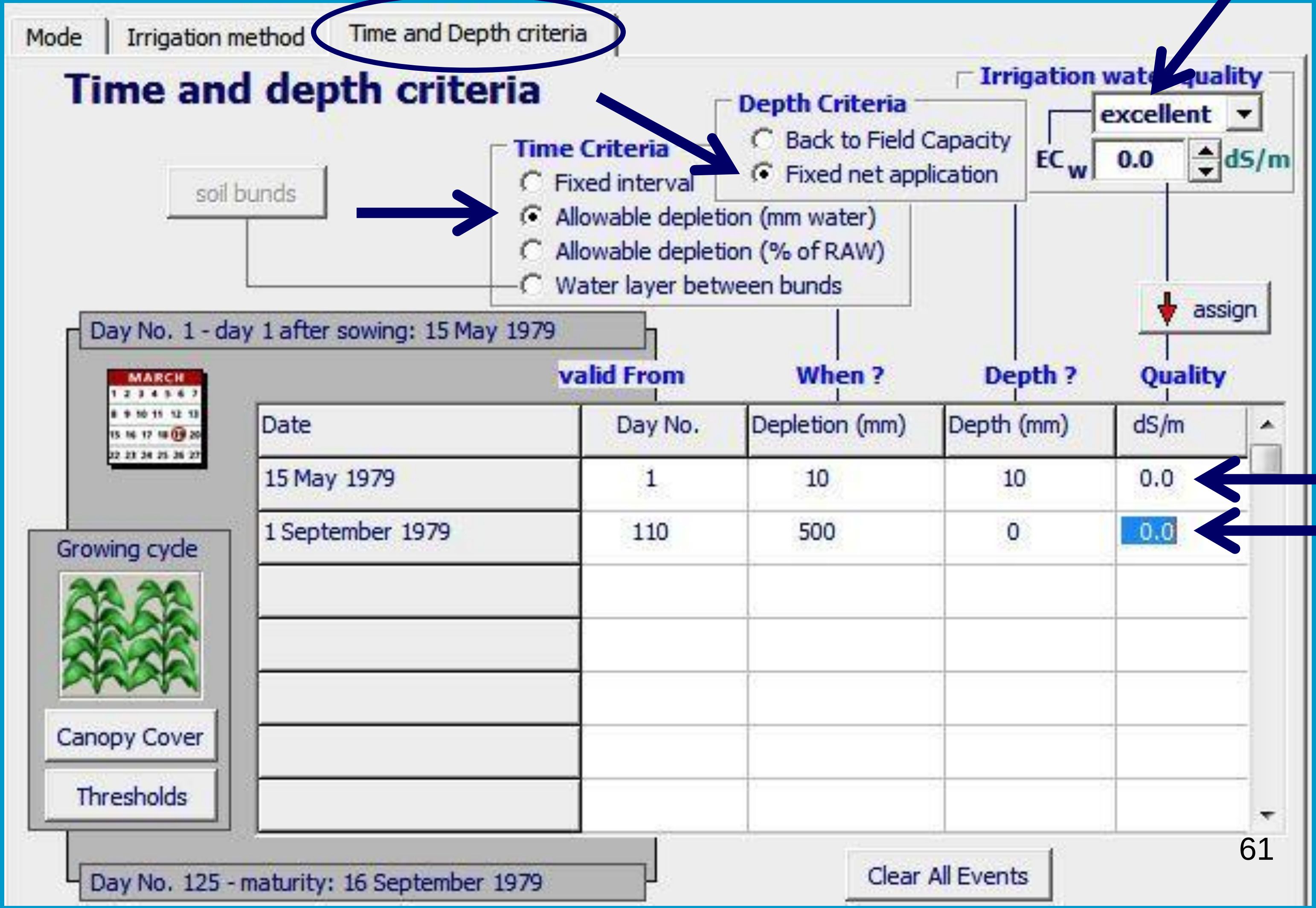
3. Specify irrigation event(s) or time and depth criteria in growing cycle

- Specify time and depth criteria and water quality

Irrigation management menu



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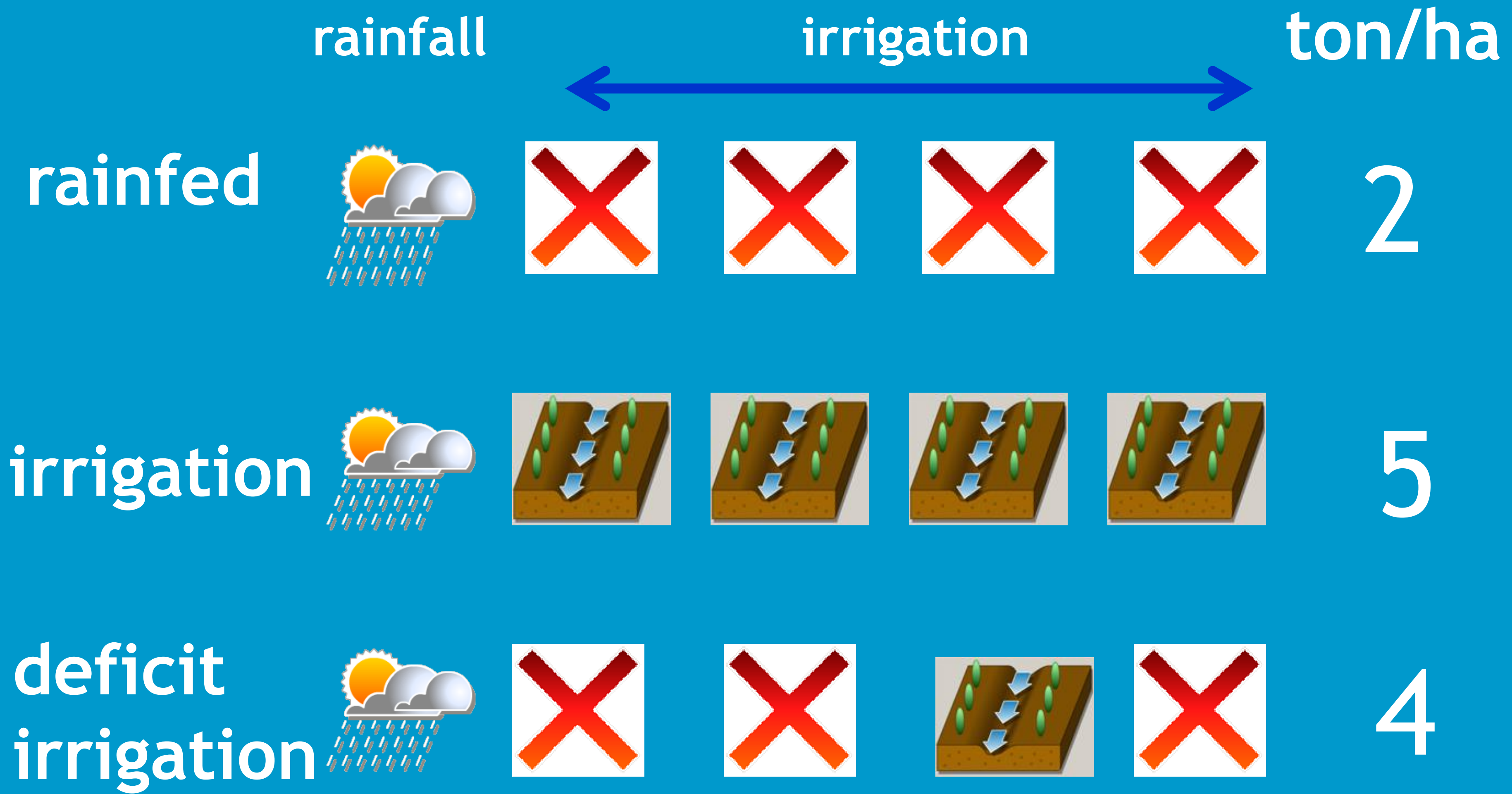
rainfall
irrigation
ton/ha
rainfed
2
irrigation
5
deficit irrigation
4

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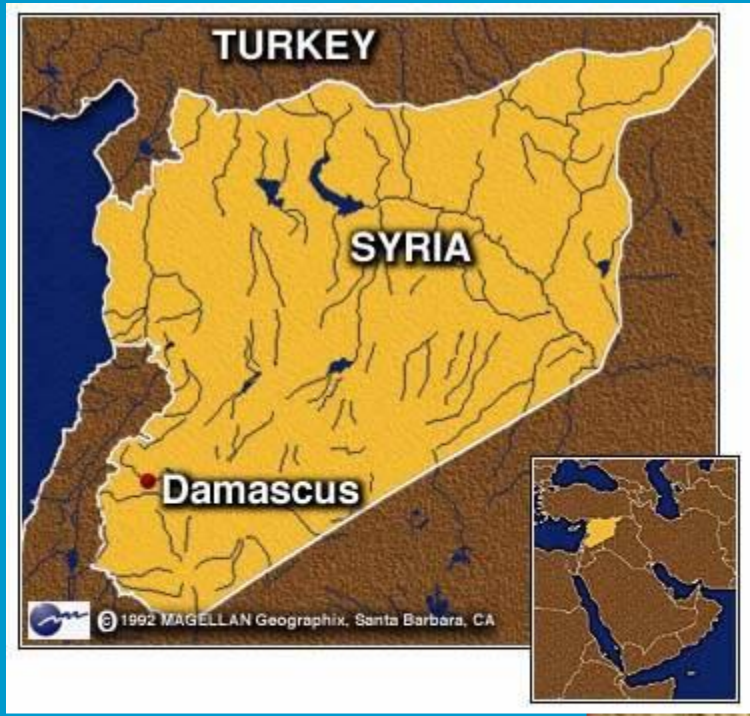
Wheat production in Syria



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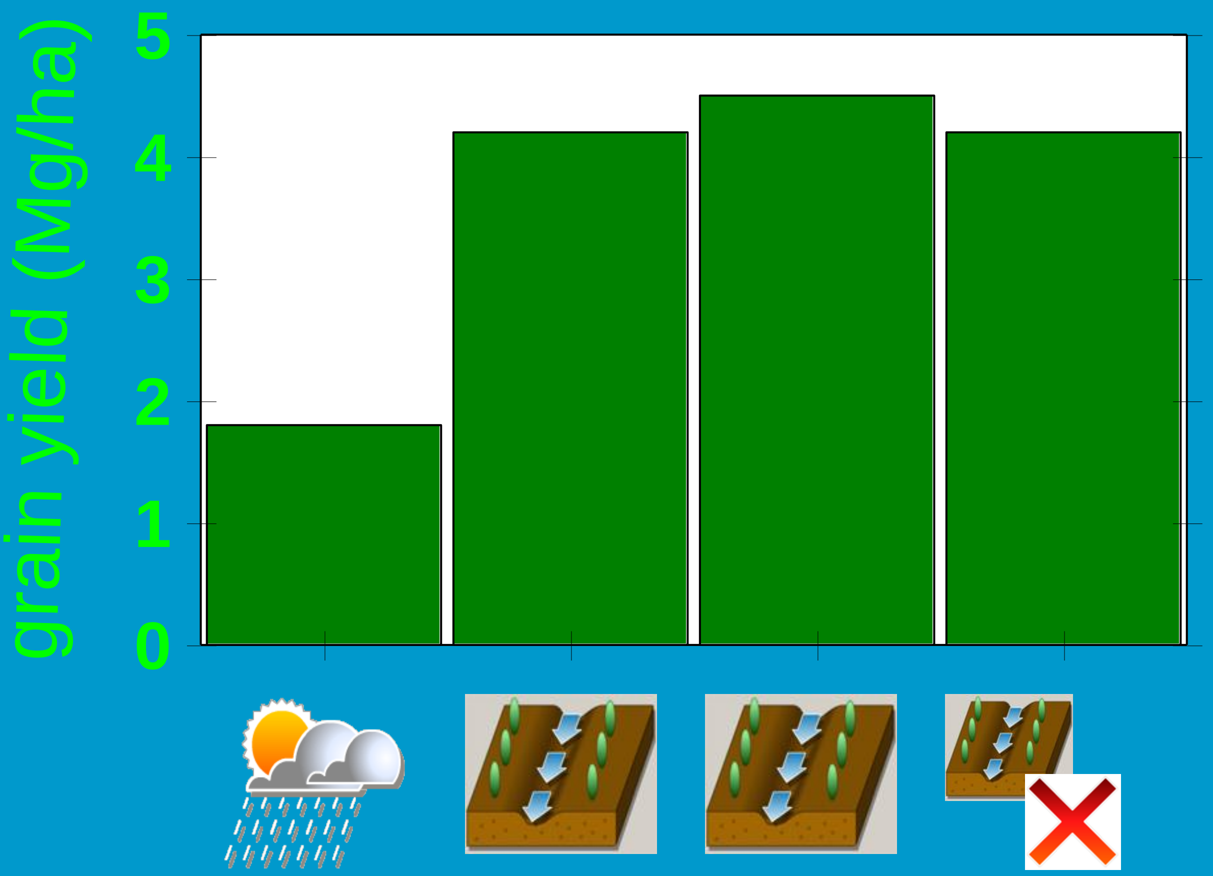
Source IWMI, annual report 2002-2003

Grain yield



Irrigation strategy	none	local	guidelines	deficit	
	-	2,980	2,220	1,110	m^3/hectare

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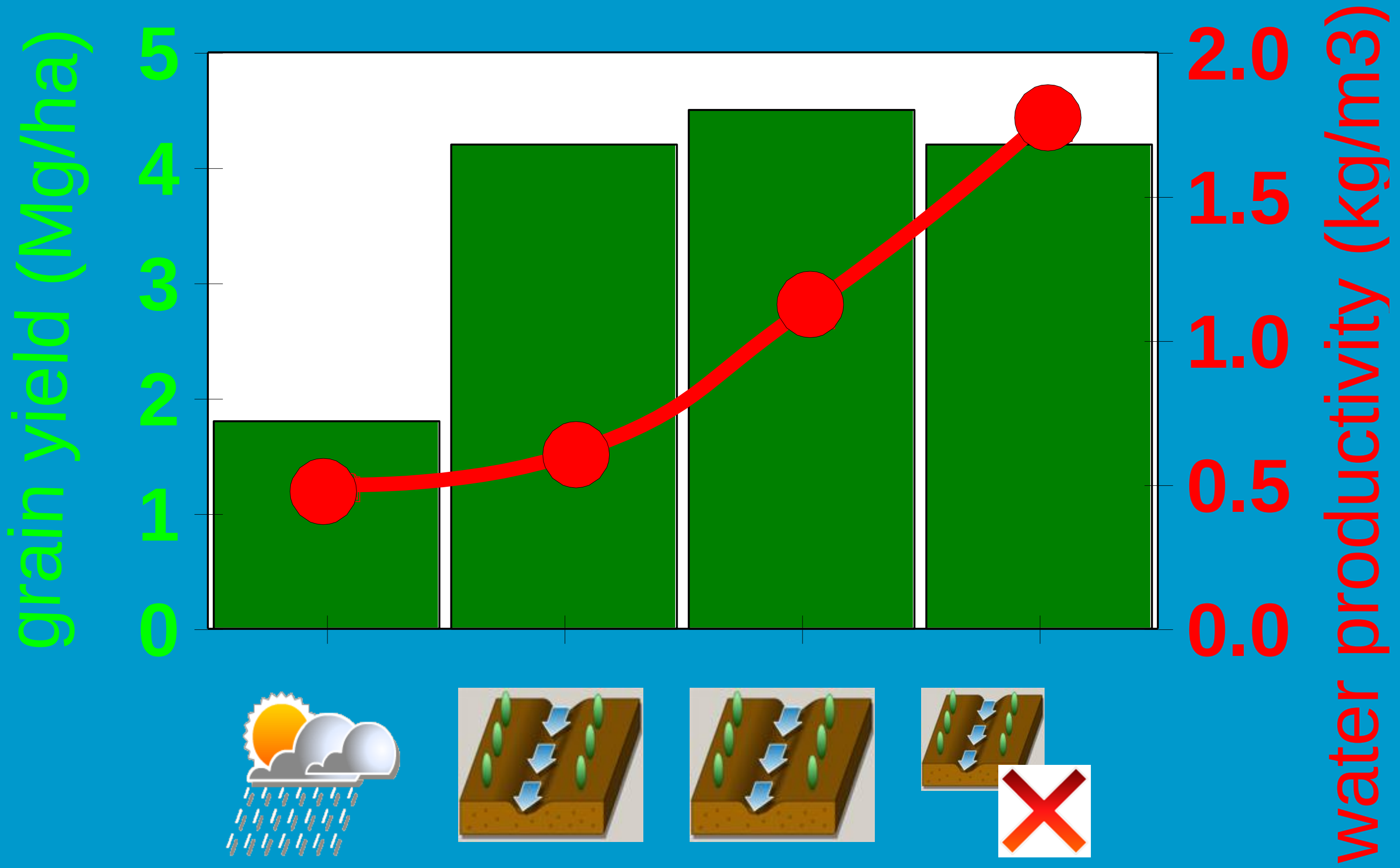
Source IWMI, annual report 2002-2003

ET water productivity (WP_{ET})



Irrigation strategy	none	local	guidelines	deficit	
	-	2,980	2,220	1,110	m^3/hectare

Source IWMI, annual report 2002-2003

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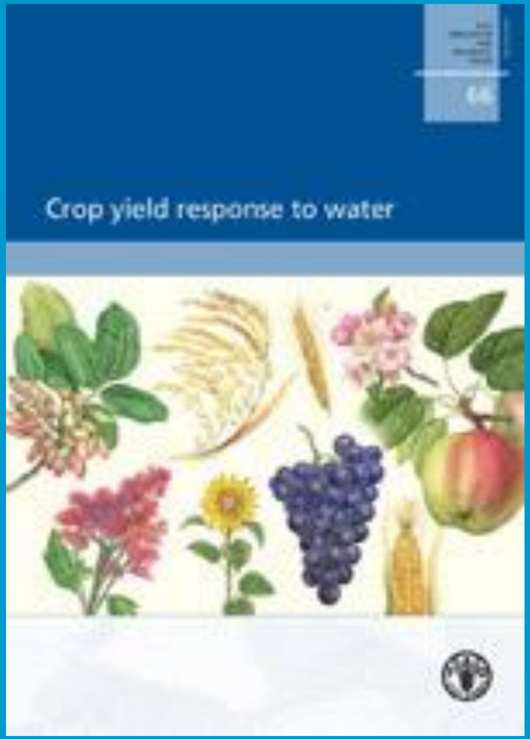
References



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Credit

Food and Agriculture Organization
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AquaCrop – Training module: Irrigation management

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prepared by Dirk Raes

KU LEUVEN

Faculty of Bioscience Engineering
Department of Earth and Environmental Sciences
Celestijnenlaan 200E - PostBox 02411
B-3001 Leuven, Belgium