



Food and Agriculture Organization
of the United Nations



Sweden
Sverige



Crop water requirement

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المركز العربي لدراسات المناطق الجافة و الأراضي القاحلة

(ACSAD)

Reference crop evapotranspiration (ET_o)

- The evapotranspiration rate from a reference surface, not short of water, is called the reference evapotranspiration and is denoted as ET_o. 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

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

ET₀: reference evapotranspiration [mm day⁻¹],

R_n: 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],

e_s: saturation vapour pressure [kPa],

e_a: actual vapour pressure [kPa],

e_s-e_a: 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

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

T_{min}: 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	... ≤ 1.0 m/s
light to moderate wind	1 – 3 m/s
moderate to strong wind	3 – 5 m/s
strong wind	... ≥ 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

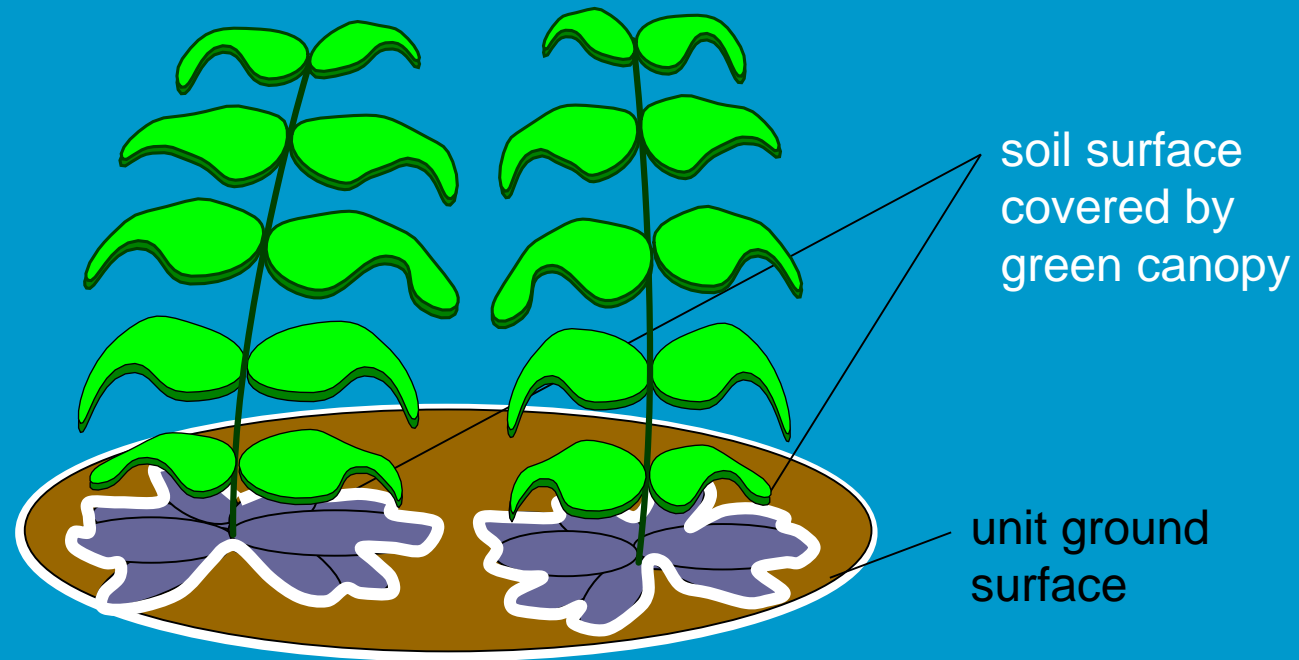
Instead of Leaf Area Index (LAI)
AquaCrop uses green canopy cover (CC)

Green Canopy Cover (CC)

$$CC = \frac{\text{soil surface covered by the green canopy}}{\text{unit ground surface area}} = \frac{\text{[leaf icons]}}{\text{[ground area icon]}}$$

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

0 % → 100 %

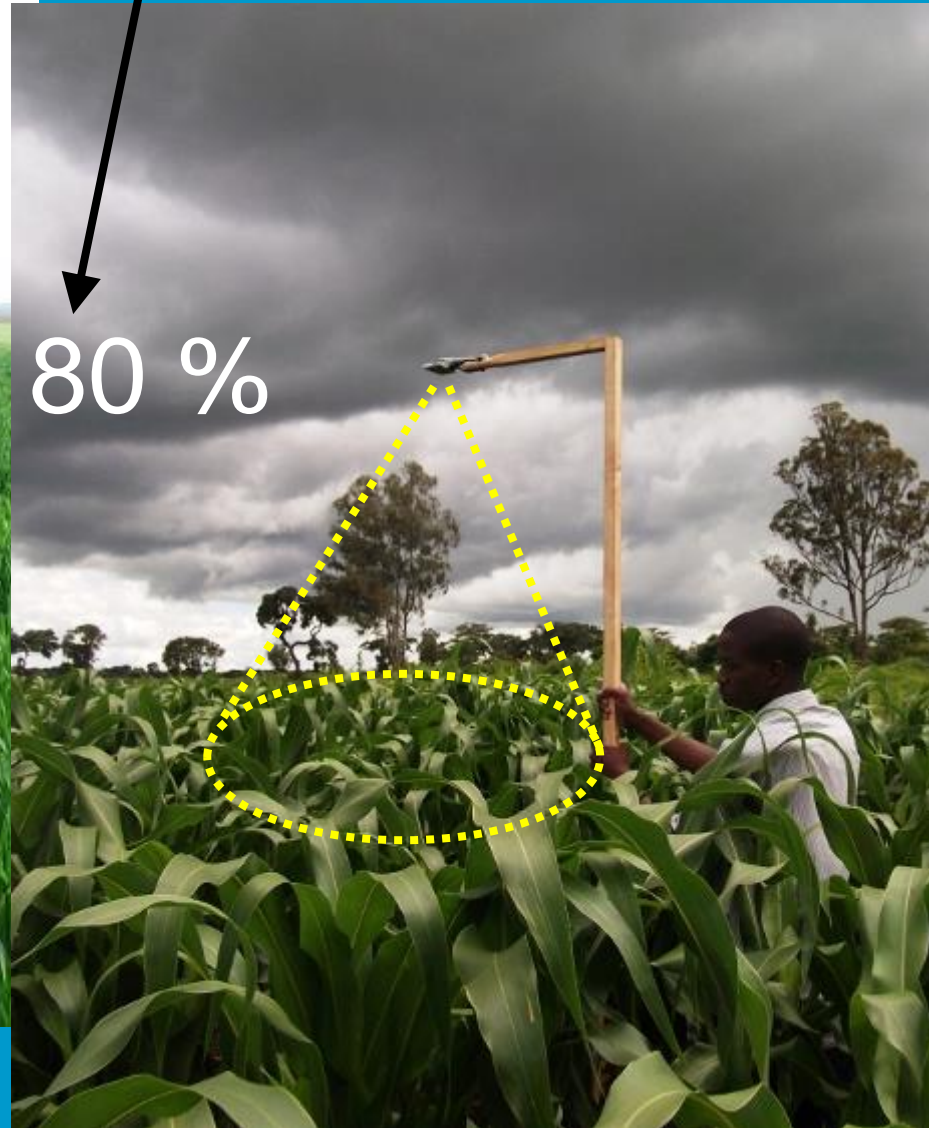


90 %



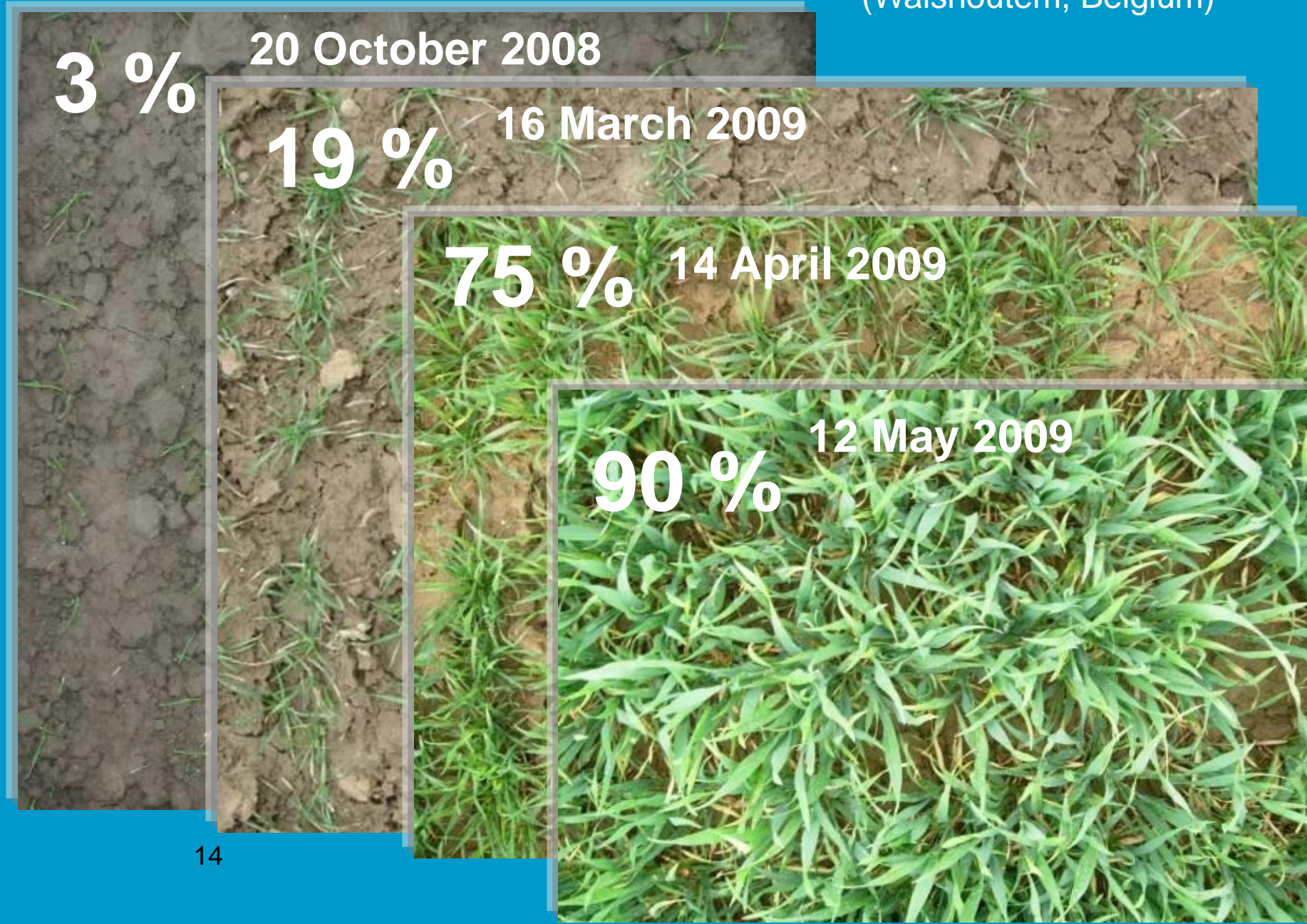
assess CC from picture
(software)

80 %

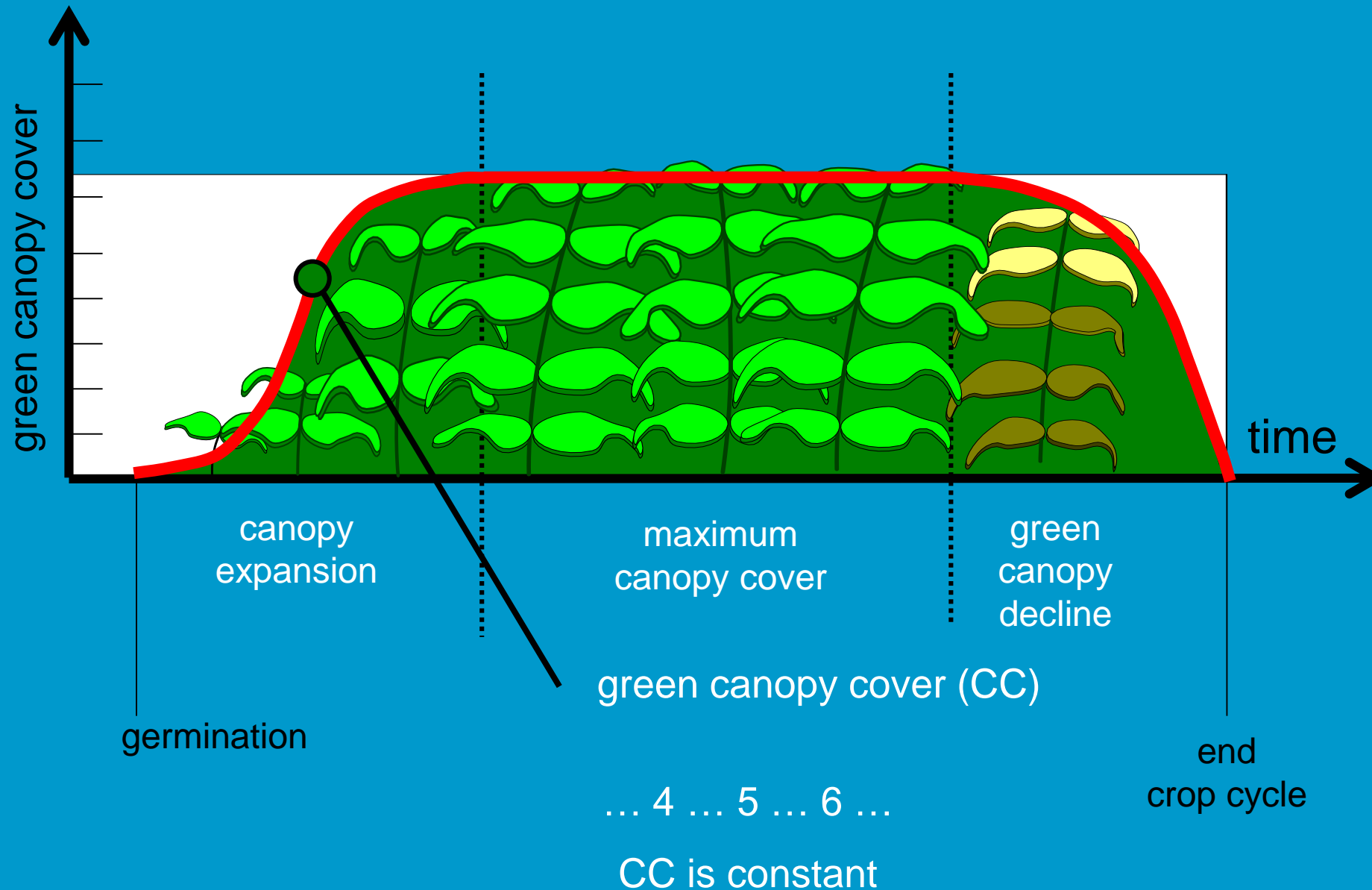


Green Canopy Cover (CC)

Winter wheat
(Walshoutem, Belgium)



Green canopy development (CC)



Crop transpiration

Objective and Structure of the presentation



Objective:

Understand how AquaCrop simulates crop transpiration

Structure:

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

simulation of crop transpiration for unlimited conditions

simulation of crop transpiration for limited conditions:

- soil water stress
- cold stress

$$\text{EvapoTranspiration} = Kc \times ETo$$

well watered soil

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

$$\text{Crop transpiration} = K_{c_{Tr}} \times ETo$$

$$+ \text{Soil evaporation} = K_e \times ETo$$

proportional to Canopy Cover

$$K_{c_{Tr}} \sim CC$$

crop transpiration coefficient

soil water evaporation coefficient

$$K_e \sim (1 - CC)$$

proportional to uncovered soil

$$E = K_r (1 - CC^*) K_{e_x} ET_o$$

evaporation
reduction

maximum soil
evaporation coefficient

← adjustment for withered canopy (f_{cc})
← adjustment for mulches (f_m)
← adjustment for partial wetting (f_w)

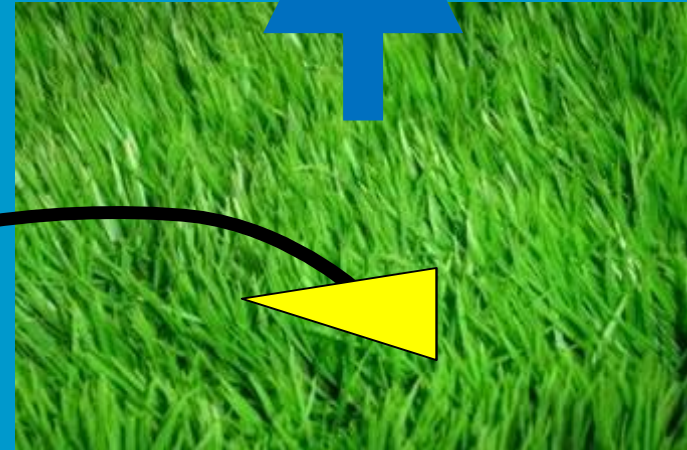
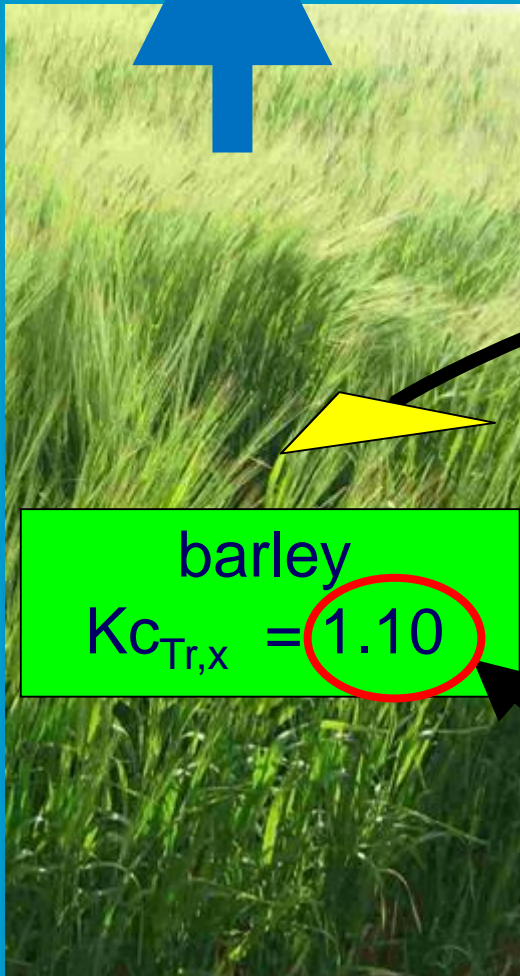
← soil water content in top soil

Maximum crop transpiration (Tr_x)

$$\begin{aligned} Tr_x &= Kc_{Tr} ETo \\ &= Kc_{Tr,x} \underbrace{CC^*}_{\vdots} ETo \end{aligned}$$

CC = 1 (full canopy cover)

$$Tr_x = K_{c_{Tr,x}} CC^* ETo$$



reference surface (grass)

$$K_{c_{Tr,x}} = 1.00$$

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

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

Kc_{Tr} : crop transpiration coefficient

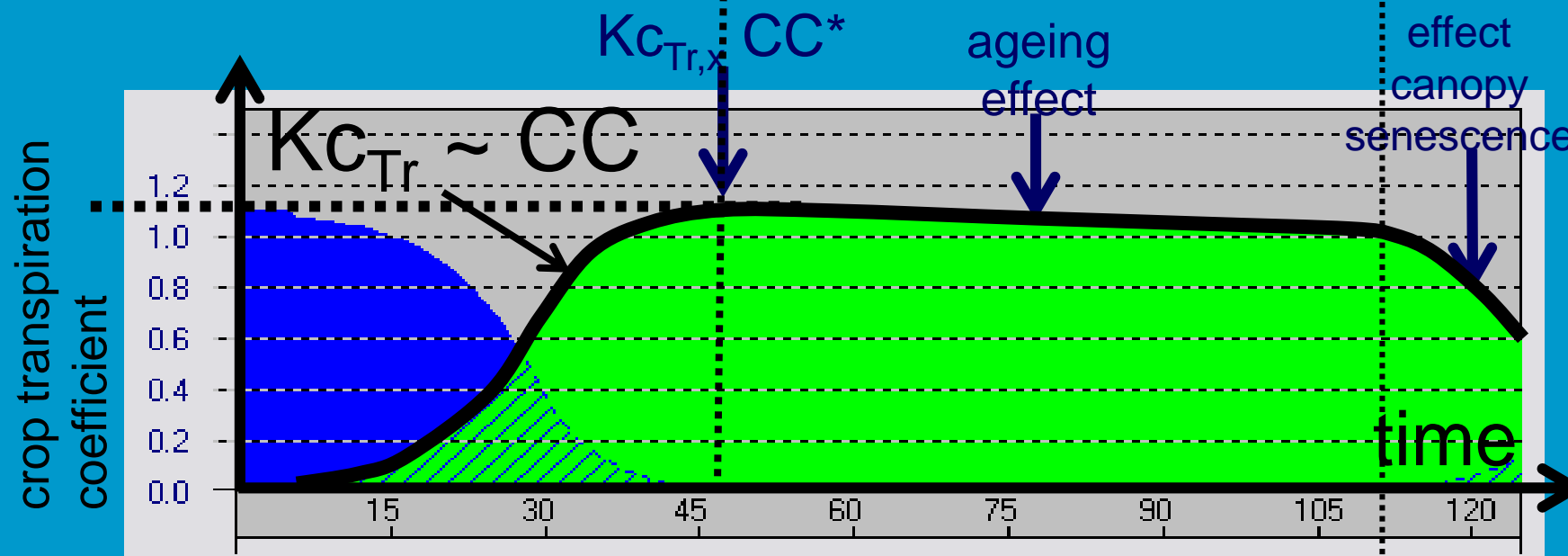
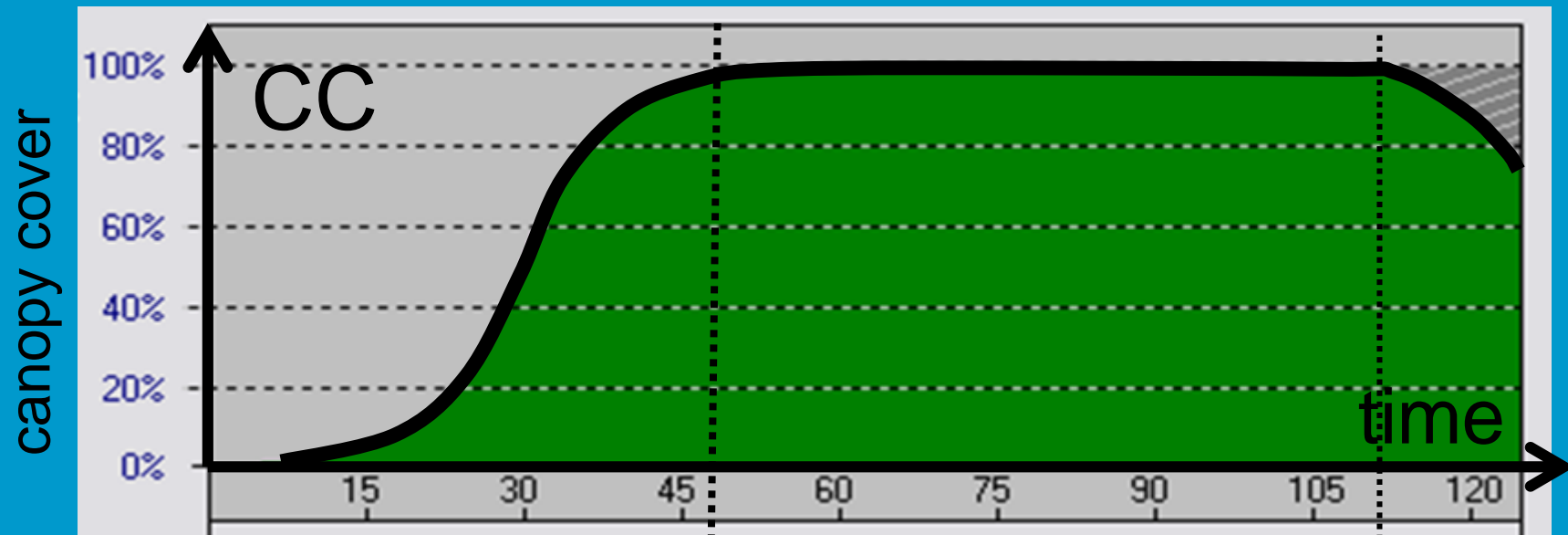
conservative crop parameter

$Kc_{Tr,x}$: 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

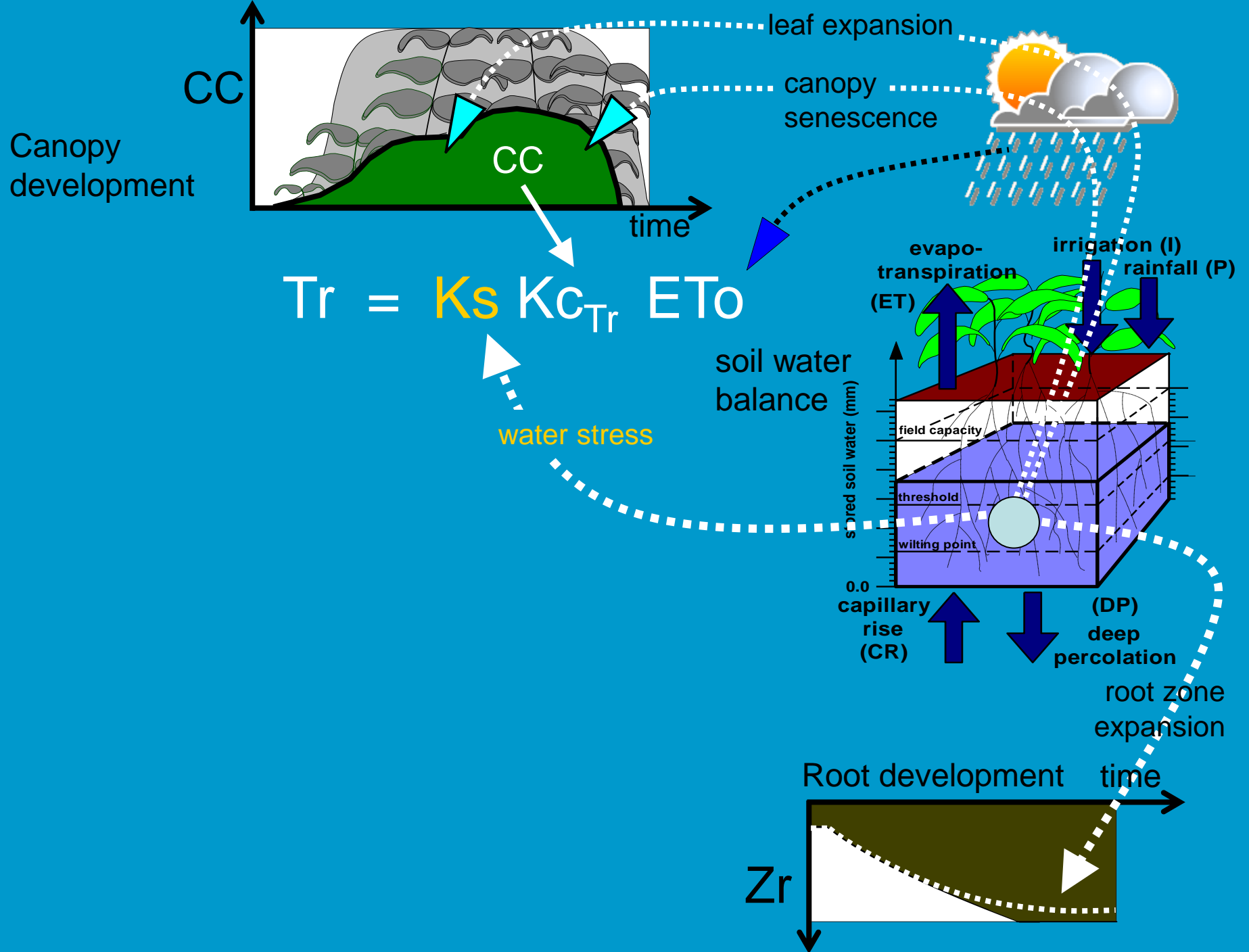
in mid-season the canopy ages slowly and undergoes a reduction in transpiration and photosynthetic capacity
once senescence is triggered the reduction in transpiration becomes stronger



Structure of the presentation



1. Maximum crop transpiration (T_{rx})
- ➔ 2. Actual crop transpiration (T_r)
 - soil water stress
 - cold stress



Actual crop transpiration (Tr)

$$Tr = K_s Tr_x$$

maximum
transpiration rate
 $= CC^* K_{c_{Tr,x}} E_{To}$

water stress coefficient

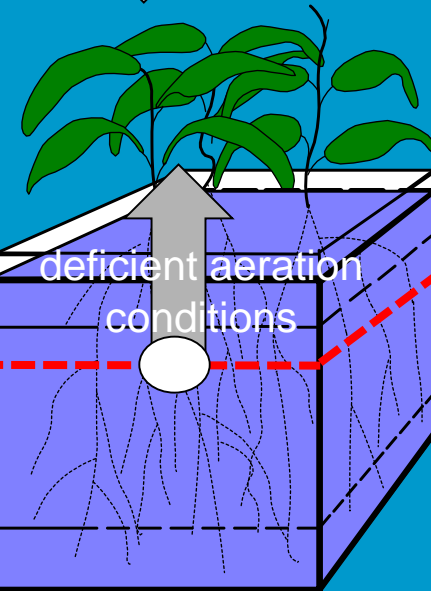
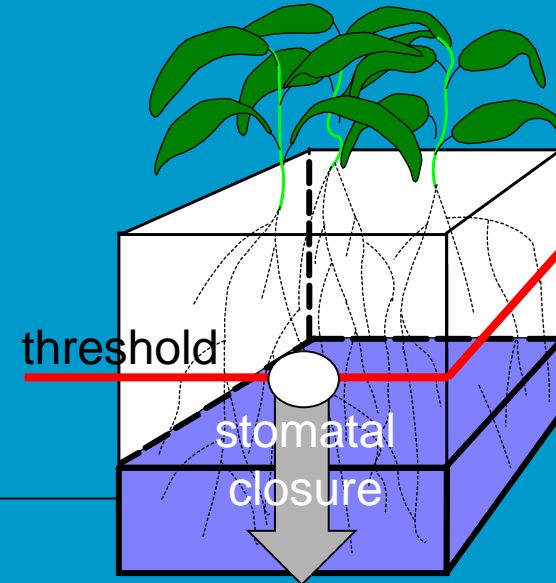
$K_{s_{sto}}$

water stress coefficient for
stomatal closure

$K_{s_{aer}}$

water stress coefficient for
water logging

strong root zone
depletion

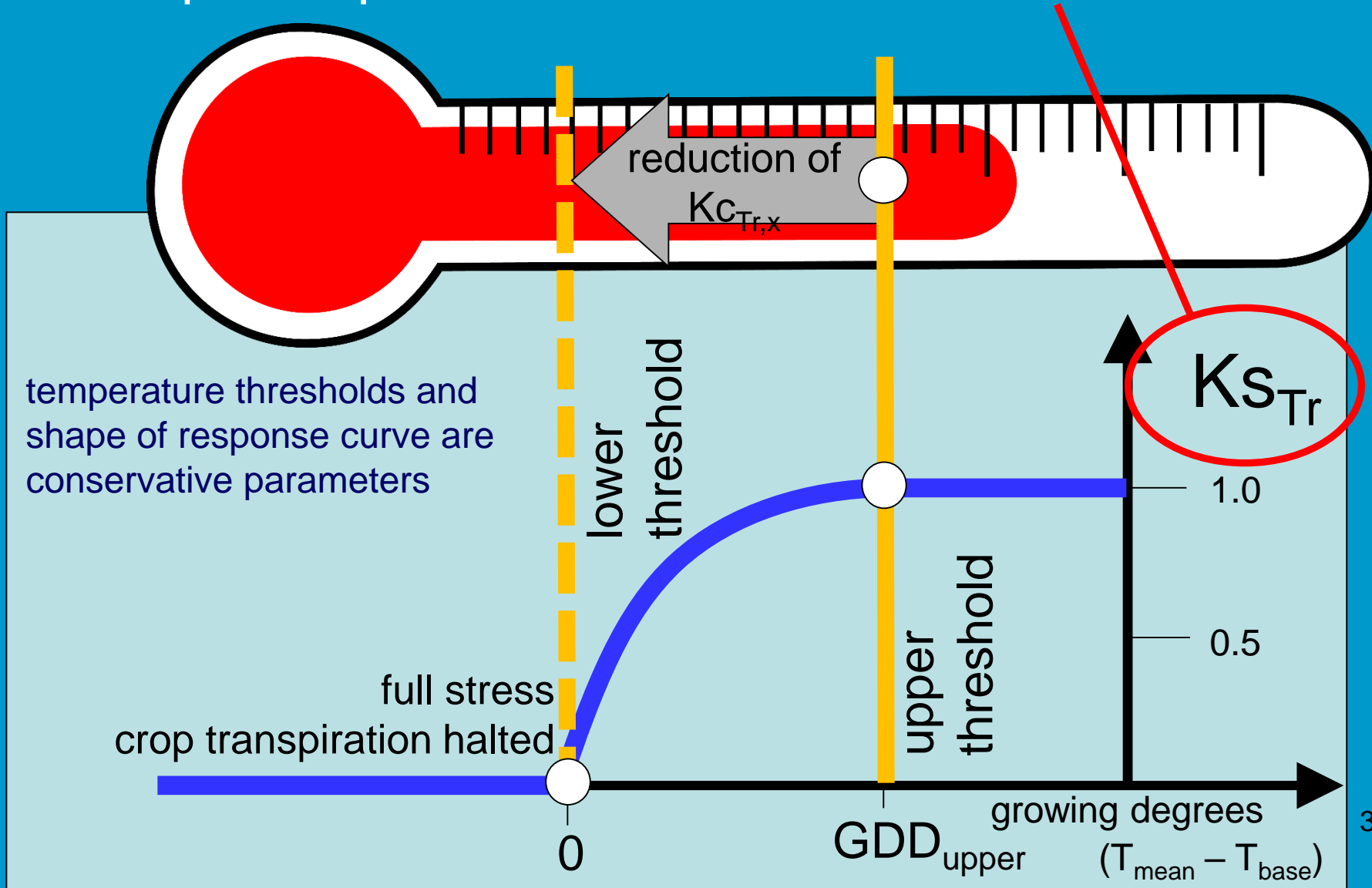


root zone close
to saturation

Stress coefficient for low temperature effect on crop transpiration

$K_{s_{Tr}}$ is modifier of the crop transpiration coefficient

$$Tr = (K_{s_{Tr}} K_{c_{Tr,x}}) CC^* ETo$$



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

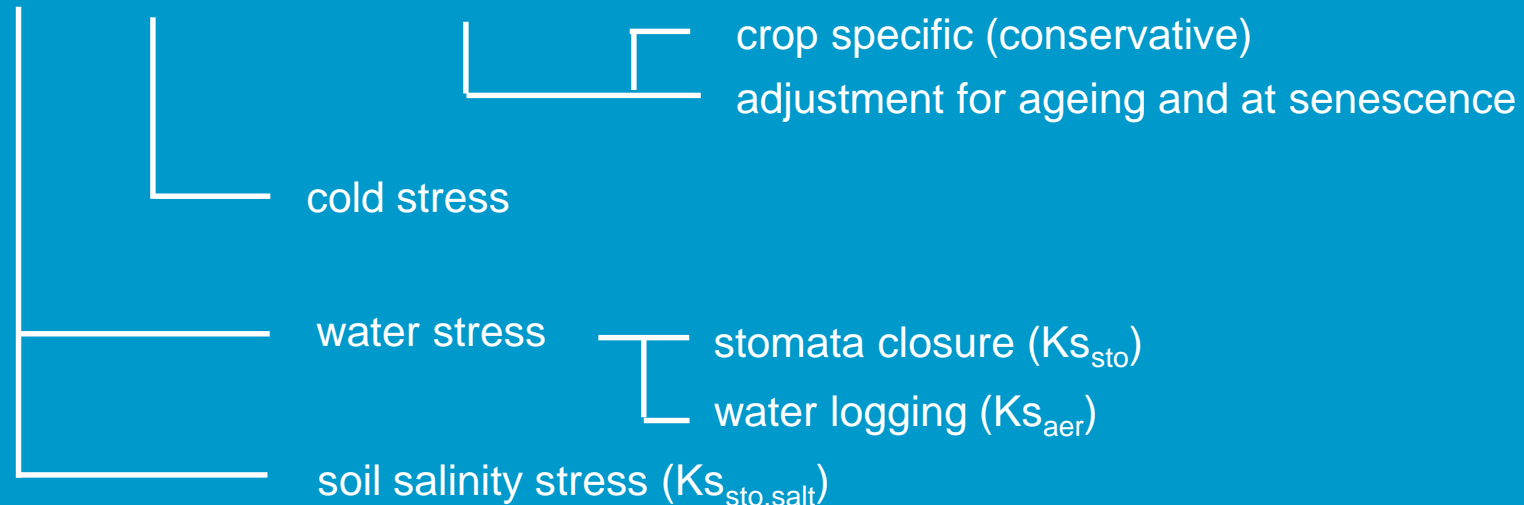
Crop Canopy (CC) development



evaporative demand of the atmosphere


adjustment for micro-advective effects (*)





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

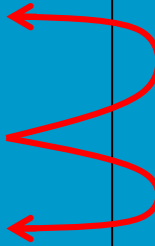


Irrigation management using AquaCrop model

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)



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

Irrigation method

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

furrow irrigation



sprinkler irrigation



drip irrigation



basin irrigation



irrigation method and percentage of soil surface wetted

The screenshot shows the 'Irrigation management' software window. The 'Irrigation method' tab is active, showing radio buttons for Sprinkler, Surface, and Drip irrigation. Under 'Surface irrigation', 'Furrow irrigation' is selected. A table titled 'indicative values percentage of soil surface wetted' lists various irrigation methods and their corresponding soil surface wetting percentages. A red circle highlights the 'adjustment for partial wetting' section, which includes a globe icon and a dropdown menu set to '80 %'. A blue arrow points to the 'Furrow irrigation' option, and a red arrow points from the 'Furrow irrigation' row in the table to the '80 %' dropdown.

Irrigation Method	Soil surface wetted %
Sprinkler :	
- Sprinkler irrigation	100
Surface :	
- Basin irrigation	100
- Border irrigation	100
- Furrow irrigation (every furrow), narrow bed...	60 - 100
- Furrow irrigation (every furrow), wide bed.....	40 - 60
- Furrow irrigation (alternated furrows)	30 - 50
Drip :	
- Trickle/Drip - Micro irrigation	15 - 40
- Subsurface	0

adjustment for partial wetting

Percentage of soil surface wetted. 80 %

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

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)

Irrigation management menu

Mode | Irrigation method | Irrigation events

Irrigation events

Add 1 events

Irrigation water quality: excellent
EC_w 0.0 dS/m

Day No. 1 - day 1 after sowing: 22 March

When? Depth? Quality

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				

assign

Clear All Events

Day No. 125 - maturity: 24 July

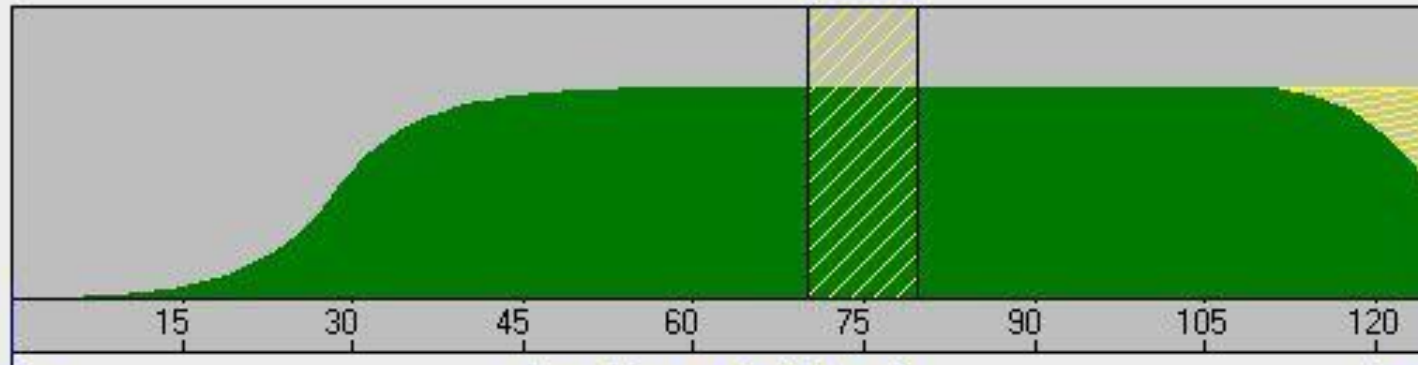
Growing cycle
Canopy Cover
Plot events

The screenshot shows a software interface for managing irrigation events. At the top, there are tabs for 'Mode', 'Irrigation method', and 'Irrigation events'. The main title is 'Irrigation events'. Below this, there is an 'Add' button followed by a dropdown menu set to '1' and the text 'events'. To the right, there is a section for 'Irrigation water quality' with a dropdown menu set to 'excellent' and a text input field for 'EC_w' set to '0.0' with the unit 'dS/m'. Below this is an 'assign' button with a downward arrow. The central part of the interface features a table with columns for 'Event', 'Date', 'Day No.', 'Net application (mm)', and 'dS/m'. The table contains 8 rows of data. To the left of the table is a calendar for the month of 'MARCH' with a red circle around the date '22'. Below the calendar is a 'Growing cycle' section with an image of green plants and three buttons: 'Canopy Cover' and 'Plot events'. At the bottom, there is a 'Clear All Events' button and a text box showing 'Day No. 125 - maturity: 24 July'. Annotations include blue arrows pointing from the 'Irrigation water quality' section to the 'When?', 'Depth?', and 'Quality' column headers, and a red arrow pointing from the 'Day No.' column header to the 'Day No.' column of the table.

Irrigation management menu

Mode | Irrigation method | Irrigation events

CC



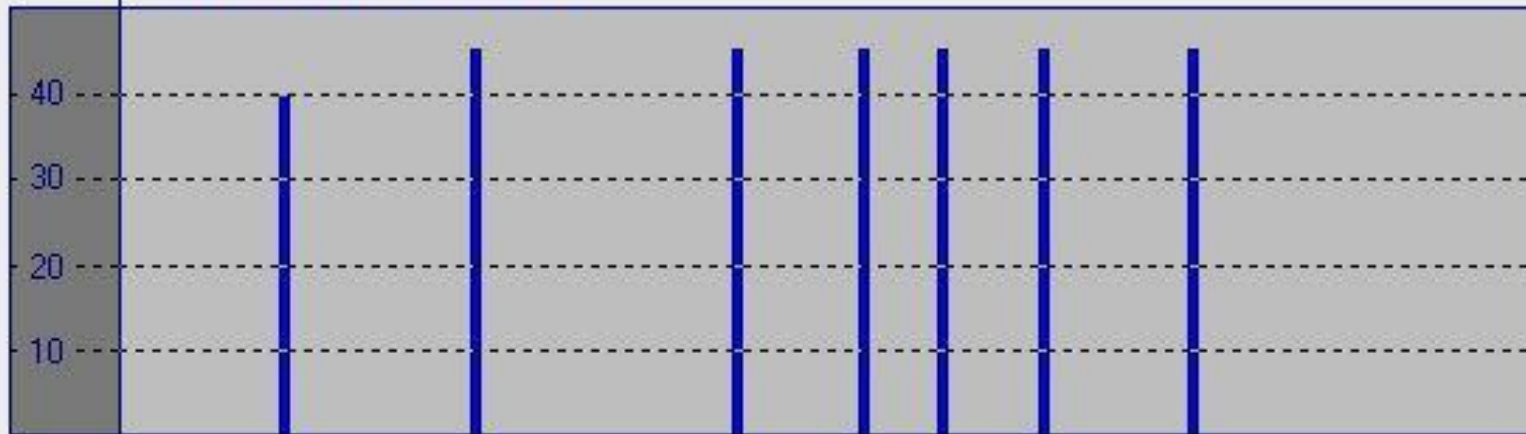
sowing
22 March

Growing cycle (days)

harvest
24 July

flowering period

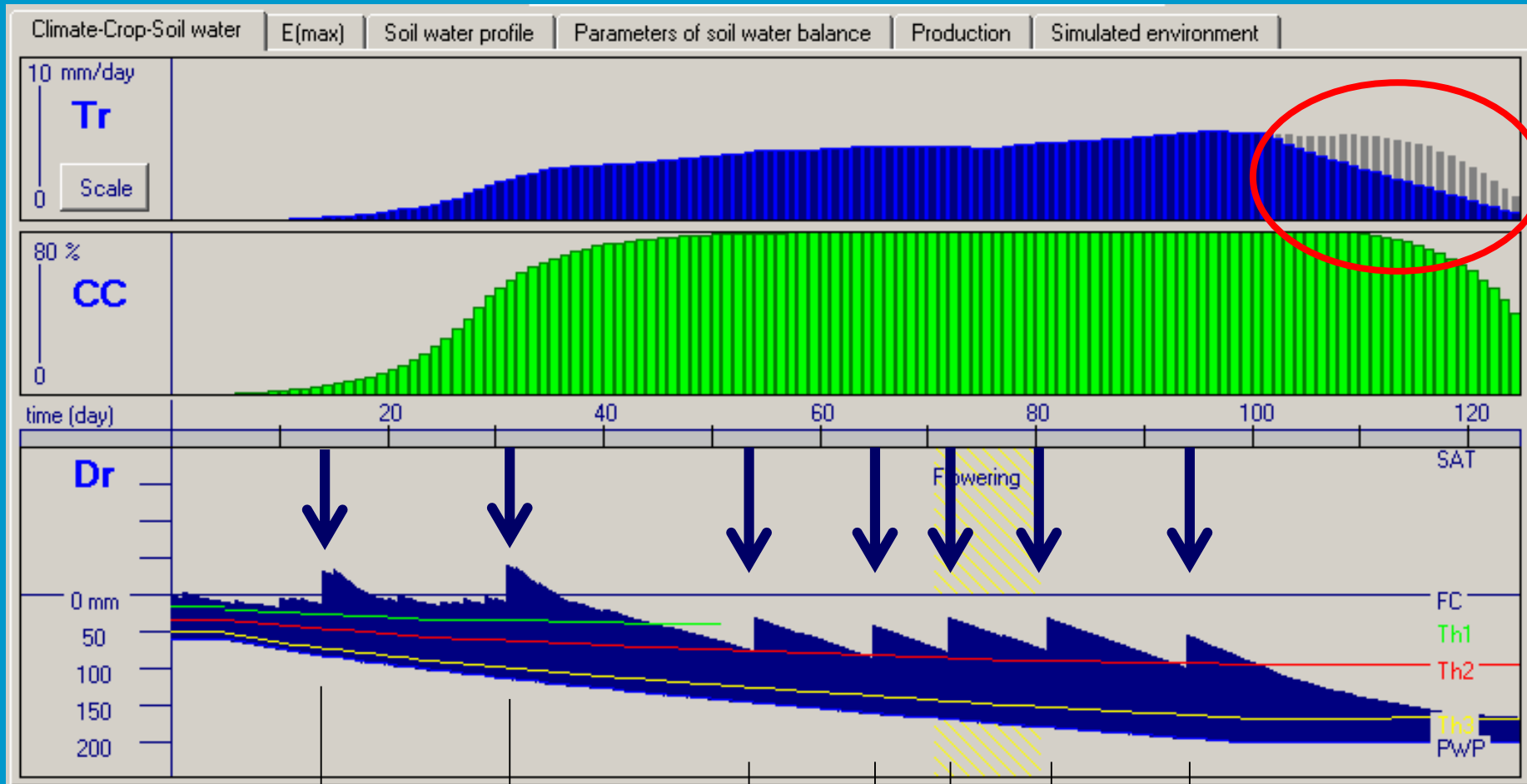
Irrigation applications (mm)



Close

simulation run → evaluate existing irrigation schedule

Simulation run menu



15 (40 mm) 32 (45 mm)

... 45 mm ...

42

42

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

Generation of irrigation schedules

for planning/checking particular irrigation strategies

AquaCrop generates irrigation schedule based on

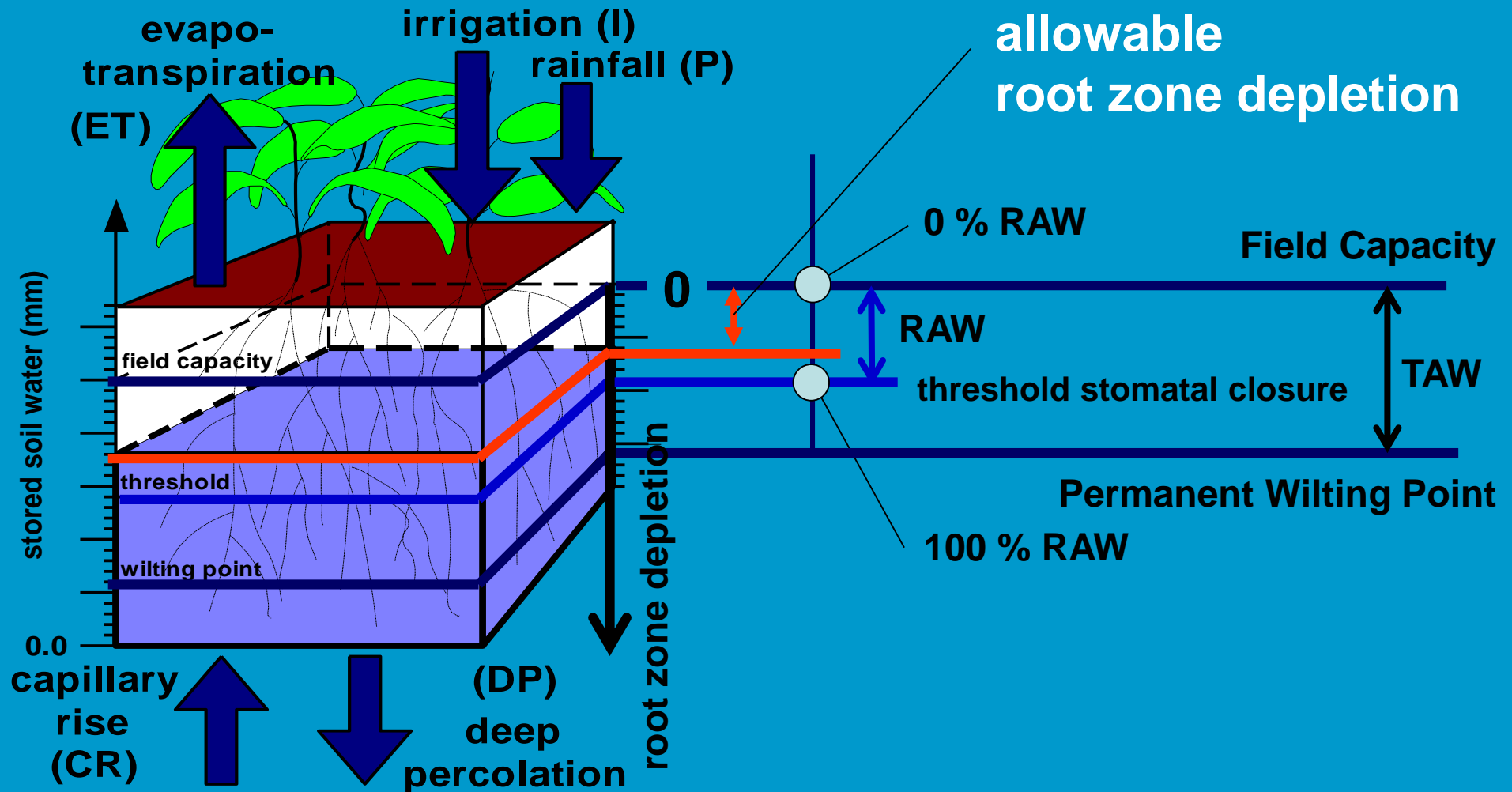
- time criterion (when to apply ?)
- depth criterion (how much to apply ?)

The criteria may vary during the crop cycle

The time criterion will often vary in the different growth stages

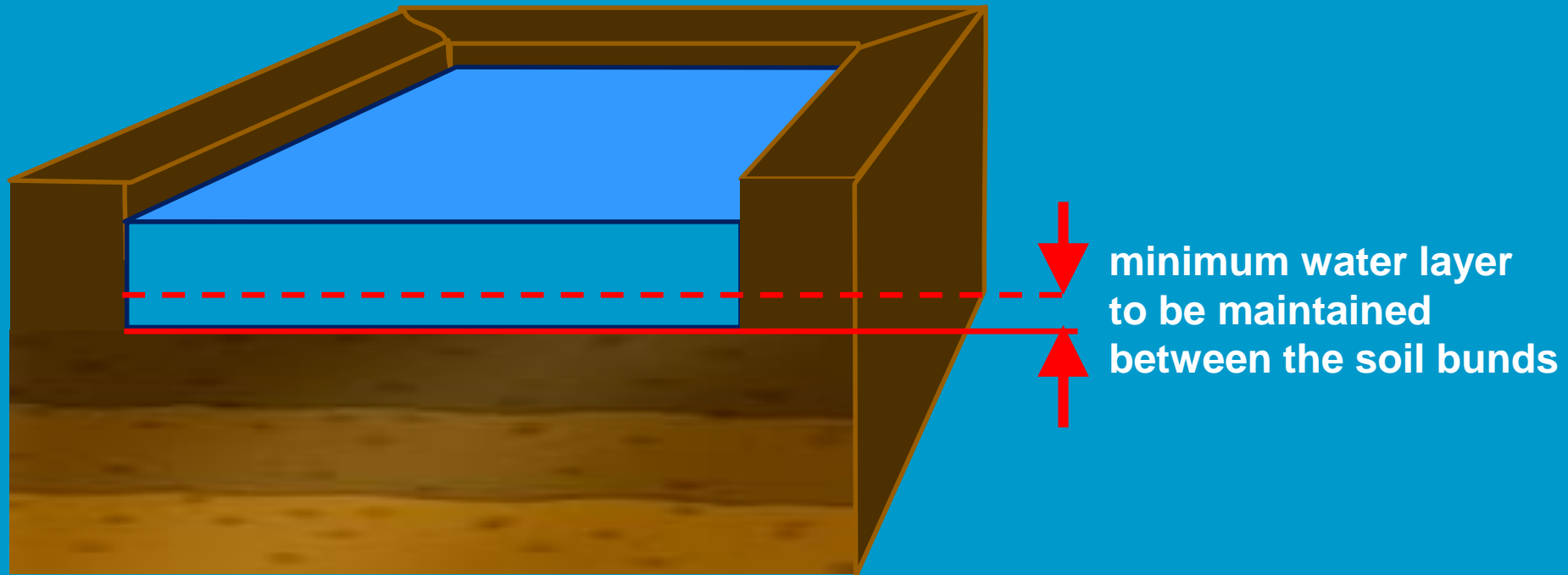
Time criterion (when to apply ?)

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



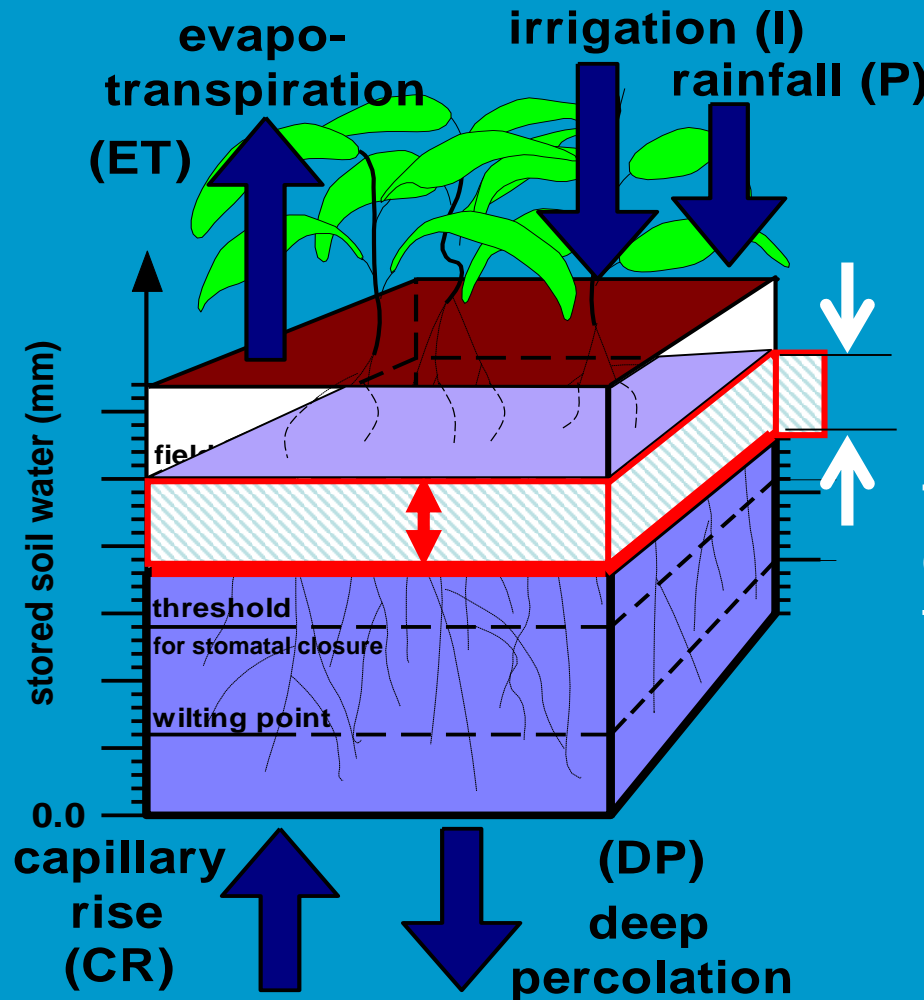
Time criterion (when to apply ?)

- 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



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



d_{net}

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	<input type="checkbox"/> Basin	50 – 150
	<input type="checkbox"/> Border	40 – 80
	<input type="checkbox"/> Furrow	30 – 60
Sprinkler	<input type="checkbox"/> Solid set	30 – 80
	<input type="checkbox"/> 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

The screenshot shows two overlapping dialog boxes. The 'Time Criteria' box is in the foreground and contains four radio button options: 'Fixed interval', 'Allowable depletion (mm water)', 'Allowable depletion (% of RAW)' (which is selected), and 'Water layer between bunds'. The 'Depth Criteria' box is partially visible behind it and contains two radio button options: 'Back to Field Capacity' (which is selected) and 'Fixed net application'. A blue arrow points from the 'Irrigation management menu' text to the 'Time Criteria' box. Another blue arrow points from the 'Irrigation management menu' text to the 'Depth Criteria' box. Dotted lines connect the selected options in both boxes to the corresponding columns in the table below.

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

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

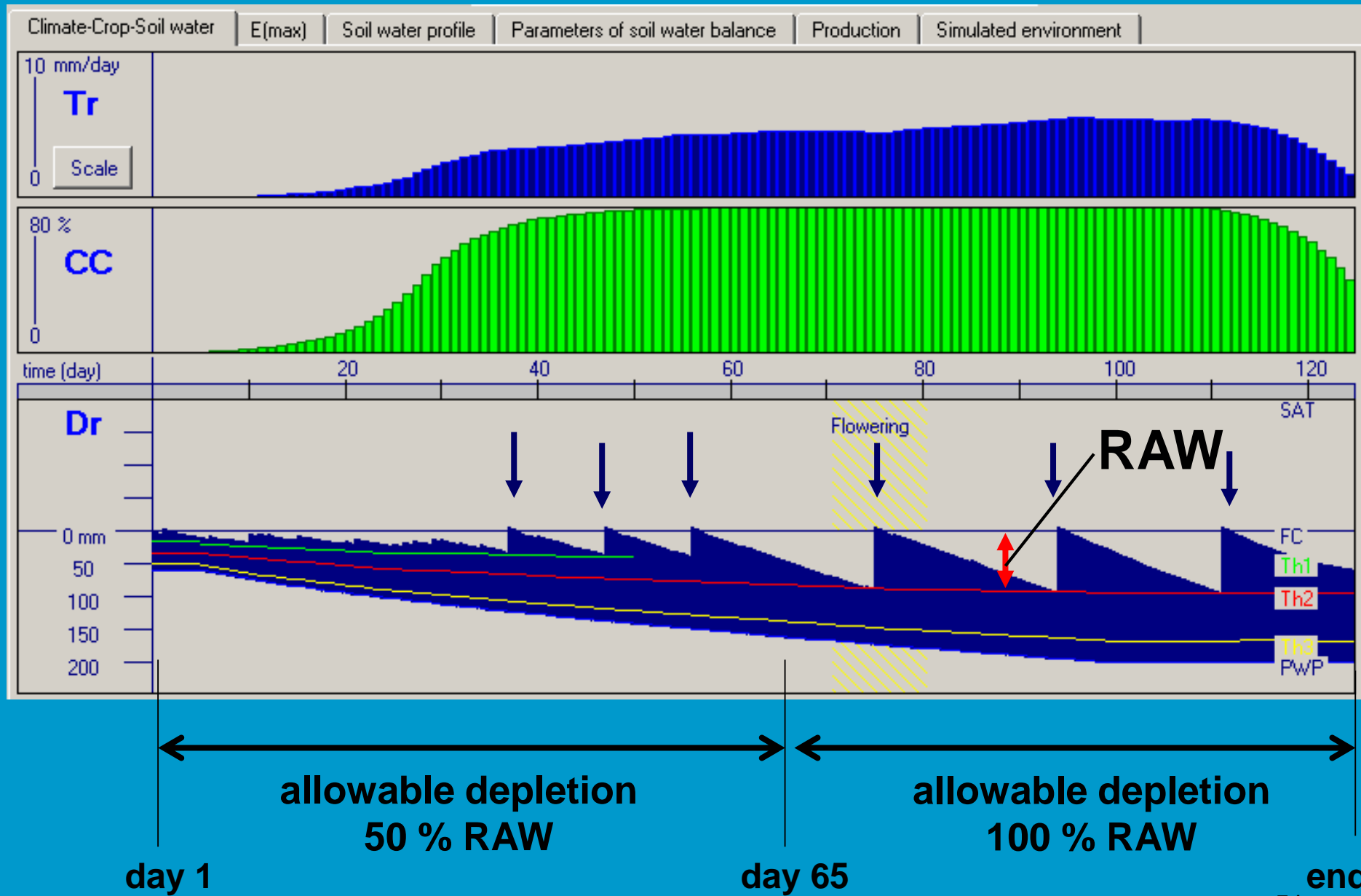
3. The values specified are valid

- 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)

Simulation run menu



display irrigation events (simulation run menu)

Simulation run menu

The screenshot shows the 'Soil water balance' menu in a simulation software. The menu bar includes 'Climate-Crop-Soil water', 'Ex', 'Soil water profile', 'Soil salinity', 'Soil water balance', 'Production', and 'Simulated environment'. The 'Soil water balance' menu is circled in blue. On the left, the 'INPUT' section shows '25 July 1979' and input fields for 'ETo', 'Rain', and 'Irrigation: net application'. The 'Irrigation Events' dialog box is open, displaying a table of events. A red arrow points from the 'Irrigation events' button in the main menu to the dialog box. A blue arrow points to the 'Irrigation events' button in the main 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

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

Time and depth criteria

soil bunds →

Time Criteria

- Fixed interval
- Allowable depletion (mm water)
- Allowable depletion (% of RAW)
- Water layer between bunds

Depth Criteria

- Back to Field Capacity
- Fixed net application

Irrigation water quality

EC_w excellent 0.0 dS/m

assign

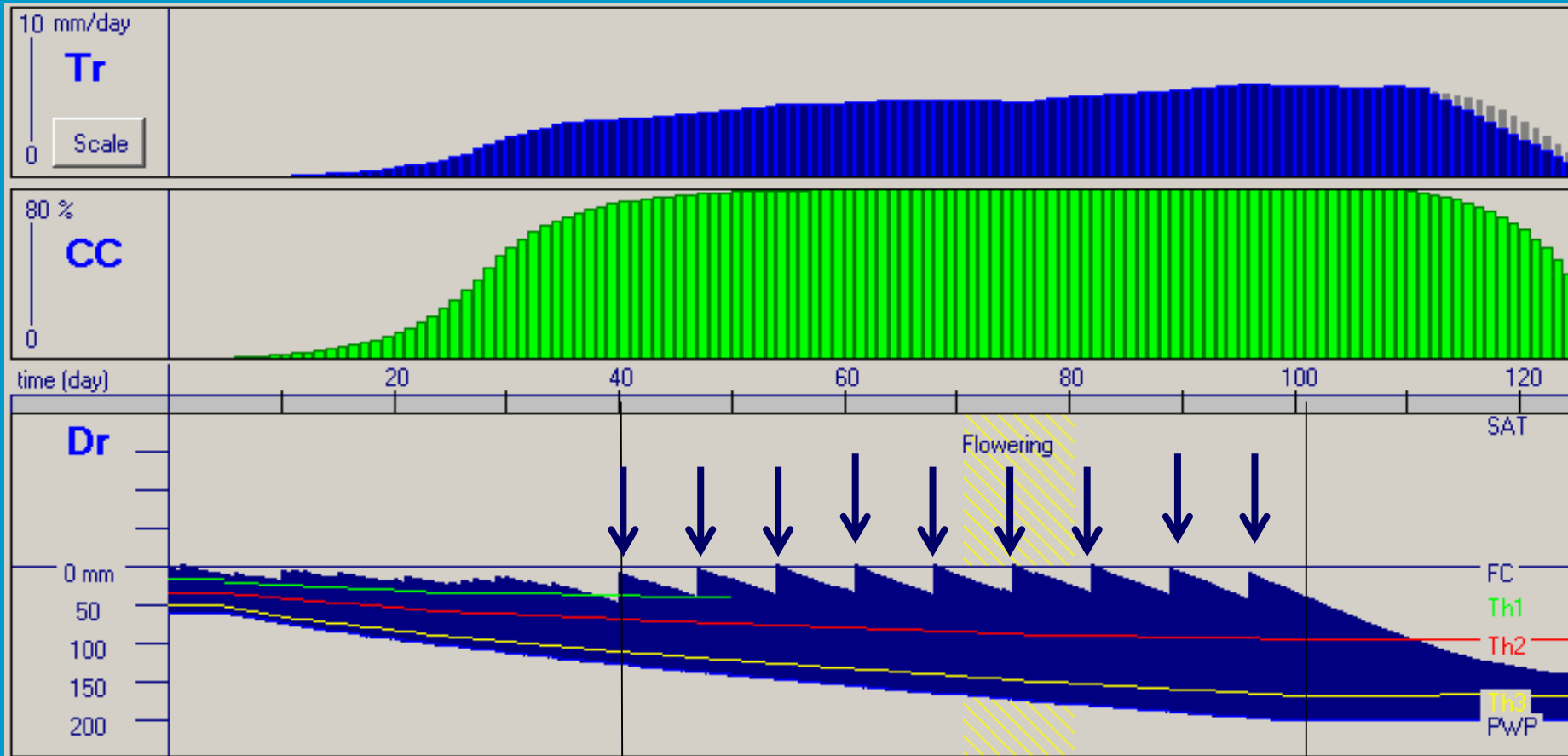
Day No. 1 - day 1 after sowing: 22 March 2000

MARCH

Date	Day No.	Interval (days)	Depth (mm)	Quality
22 March 2000	1	41	35	0.0
1 May 2000	41	7	35	0.0
1 July 2000	102	200	35	0.0

Growing cycle

Simulation run menu



May

June

weekly irrigation of 35 mm

1 May

1 July

54

54

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

Off – season irrigation

pre-irrigation

to obtain optimal soil water conditions at planting

post season irrigation

to leach salts

out of the root zone

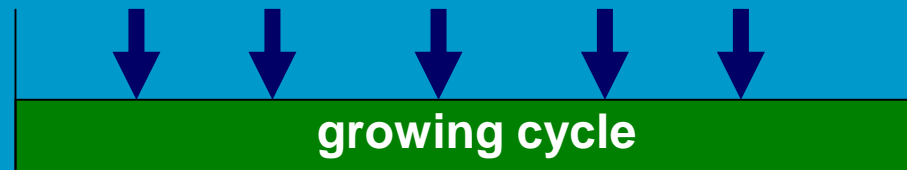
1. Simulation starts before growing cycle



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



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



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

The screenshot displays the 'Environment and Crop' configuration window. It is organized into several sections:

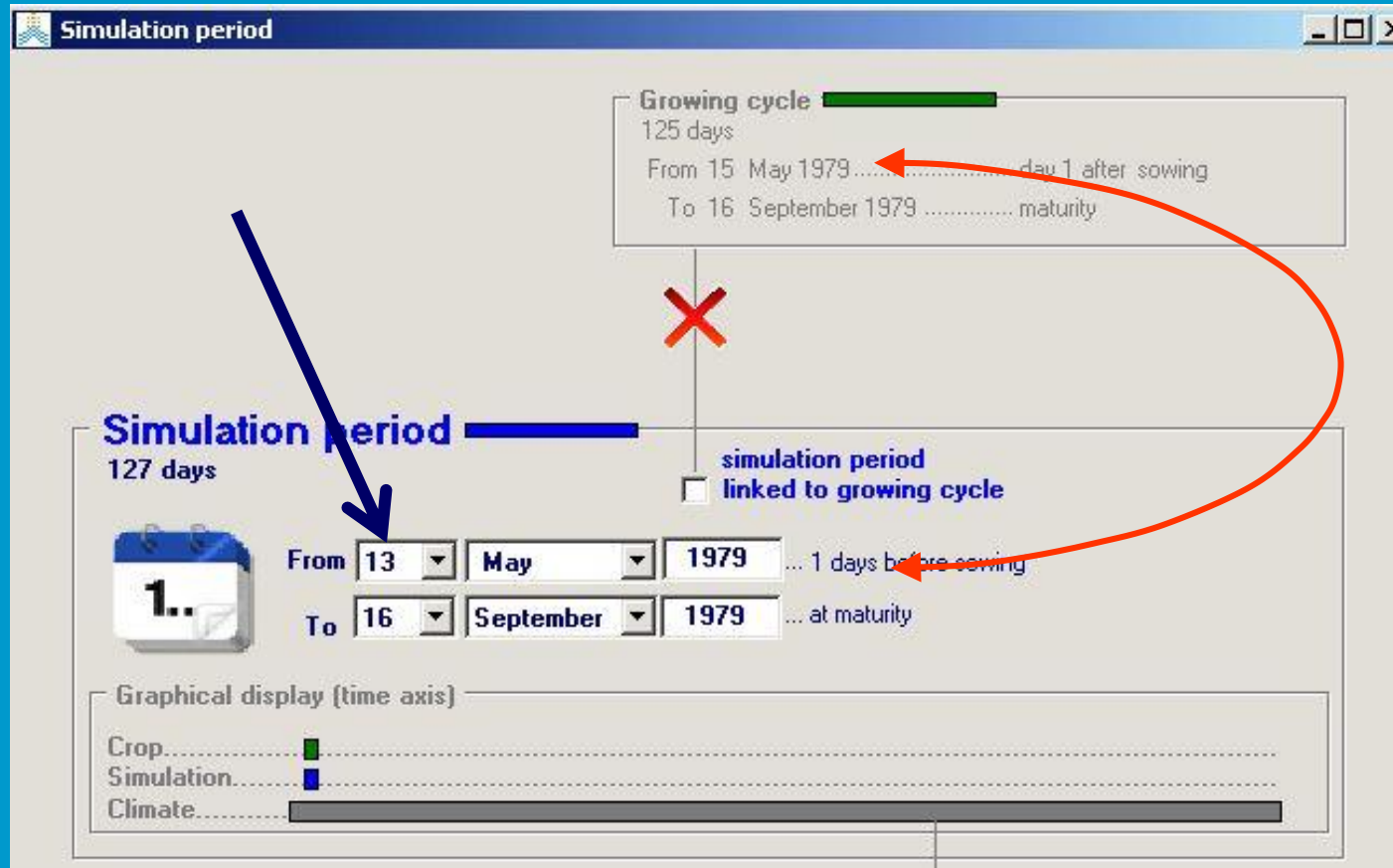
- Climate:** A dropdown menu is set to 'Tunis.CLI' with the description 'Tunis (Tunisia) climatic data'.
- Crop:** A dropdown menu is set to 'DEFAULT.CRO' with the description 'a generic crop'. Below it, the 'Growing cycle' is specified as 'Day 1 after sowing: 15 May 1979 - Maturity: 16 September 1979' and 'Calendar mode' is selected.
- Management:** This section contains three sub-items:
 - Irrigation:** A dropdown menu is set to '(None)' with the description 'Rainfed cropping'. A blue arrow points to this menu from the text 'Specify irrigation in growing cycle'.
 - Field:** A dropdown menu is set to '(None)' with the description 'No specific field management'.
 - Soil:** This section contains two sub-items:
 - Soil profile:** A dropdown menu is set to 'DEFAULT.SOL' with the description 'deep loamy soil profile'.
 - Groundwater:** A dropdown menu is set to '(None)' with the description 'no shallow groundwater table'.
- Simulation:** This section contains five sub-items:
 - Simulation period:** A text field contains 'Simulation period: From: 13 May 1979 - To: 16 September 1979'. A blue arrow points to this field from the text 'Specify simulation period'.
 - Initial conditions:** A dropdown menu is set to '(None)' with the description 'Soil water profile at Field Capacity'.
 - Off-season:** A dropdown menu is set to '(None)' with the description 'No specific off-season conditions'. A blue arrow points to this menu from the text 'Specify irrigation in off-season'.
 - Project:** A dropdown menu is set to '(None)' with the description 'No specific project'.
 - Field data:** A dropdown menu is set to '(None)' with the description 'No field observations'.

At the bottom of the window, there is a 'Run' button with a double-left arrow icon next to it.

1. Simulation starts before growing cycle

Specify simulation period

Simulation period menu



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

Description | Mulches off-season | Irrigation events off-season

adjustment for partial wetting
Info ? Percentage of soil surface wetted... 100 %

Before cropping period

Day No. 1 = 13 May 1979

Irrigation water quality
Electrical conductivity
0.0 dS/m
Class excellent

Event	Date	Day No.	Application depth (mm)
1	13 May 1979	1	50
2			
3			
4			
5			

Day No. 2 = 14 May 1979

From 15 May 1979

growing cycle

To 16 September 1979

Clear All Events

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



- Select irrigation method (drip)

Irrigation management menu

Generation of irrigation schedule

Mode **Irrigation method** Time and Depth criteria

Irrigation method

Sprinkler irrigation

Surface irrigation

Basin irrigation

Border irrigation

Furrow irrigation

Drip irrigation

adjustment for partial wetting

Info ?

Percentage of soil surface wetted.



30

..%

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



- Specify time and depth criteria and water quality

Irrigation management menu

Mode | Irrigation method | **Time and Depth criteria**

Time and depth criteria

Fixed interval
 Allowable depletion (mm water)
 Allowable depletion (% of RAW)
 Water layer between bunds

Depth Criteria
 Back to Field Capacity
 Fixed net application

Irrigation water quality
EC_w 0.0 dS/m
excellent
assign

soil bunds →

Day No. 1 - day 1 after sowing: 15 May 1979

MARCH
1 2 3 4 5 6 7
8 9 10 11 12 13
14 15 16 17 18 19 20
21 22 23 24 25 26 27

Date	Day No.	Depletion (mm)	Depth (mm)	Quality
15 May 1979	1	10	10	0.0
1 September 1979	110	500	0	0.0

Growing cycle
Canopy Cover
Thresholds

Day No. 125 - maturity: 16 September 1979

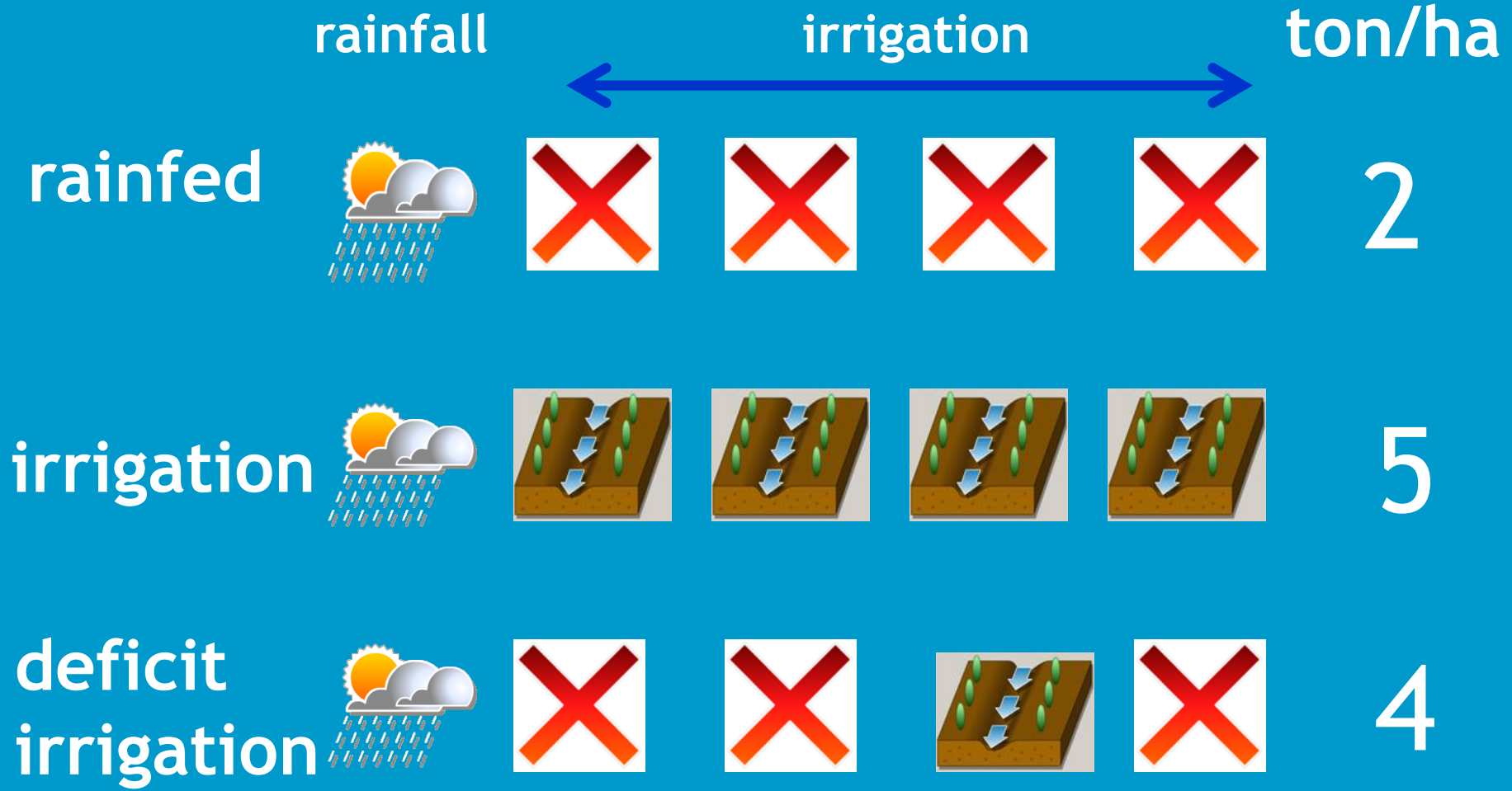
Clear All Events

61

Structure of the presentation



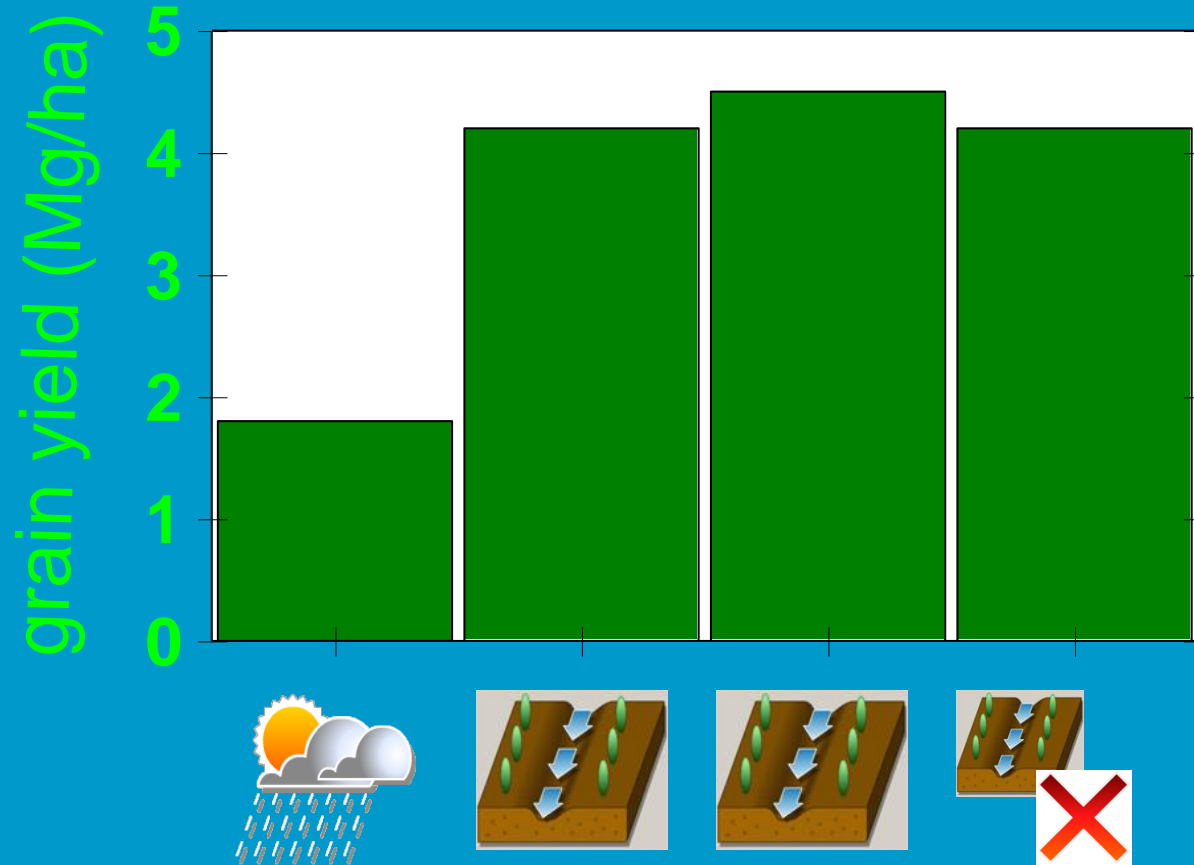
1. Determination of net irrigation water requirement (I_{net})
2. Irrigation method
3. Irrigation schedule (specified events)
4. Generation of irrigation schedules
5. Off-season irrigation
- ➔ 6. Deficit irrigation



Wheat production in Syria



Grain yield



Irrigation strategy

none

local

guidelines

deficit

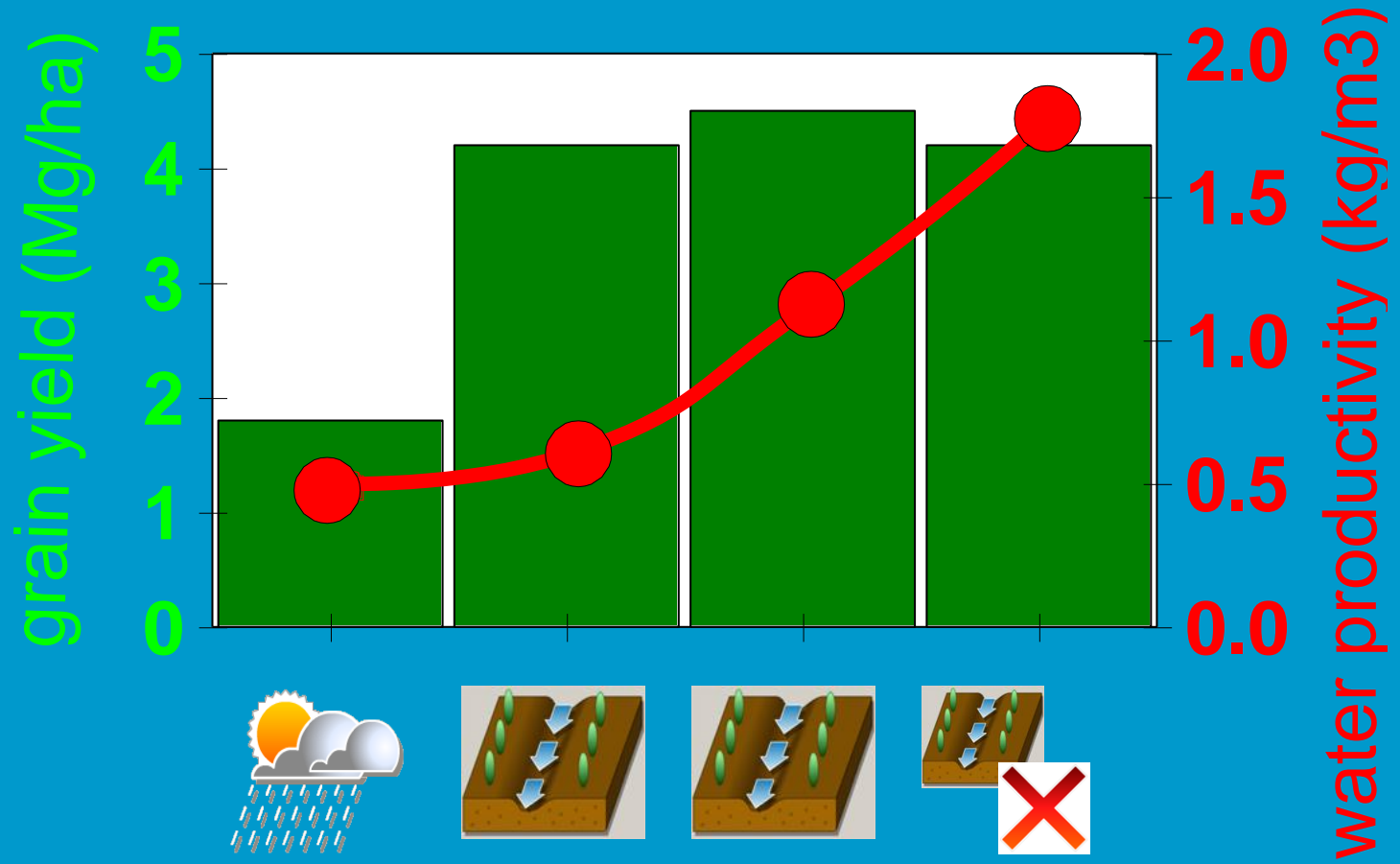
-

2,980

2,220

1,110 m³/hectare

ET water productivity (WP_{ET})



Irrigation strategy	none	local	guidelines	deficit
	-	2,980	2,220	1,110
	m³/hectare			

Source IWMI, annual report 2002-2003

References

FAO Irrigation and Drainage paper Nr. 66

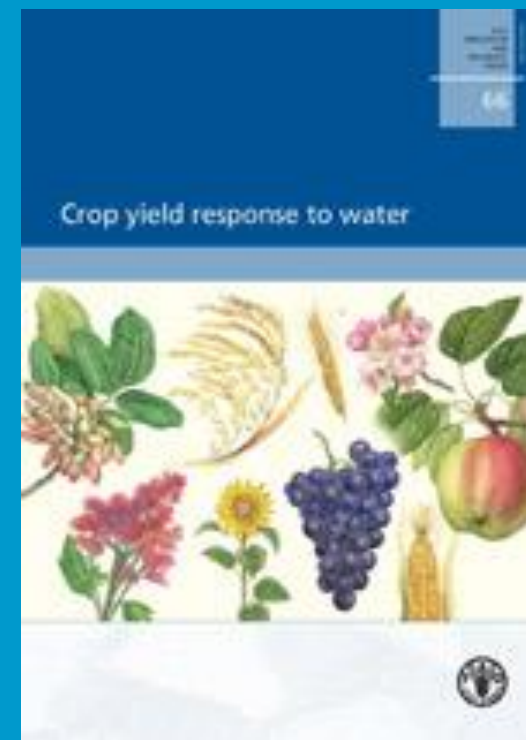
Steduto, P., Hsiao, T.C., Fereres, E., and Raes, D. 2012.
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Reference manual

Raes, D., Steduto, P., Hsiao, T.C., and Fereres, E. 2017.
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AquaCrop-The FAO crop model to simulate yield response to water

- ❑ Steduto, P., Hsiao, T.C., Raes, D. and Fereres, E. 2009.
I. Concepts and underlying principles. *Agronomy Journal*, 101(3): 426-437
- ❑ Raes, D., Steduto, P., Hsiao, T.C., and Fereres, E. 2009.
II. Main algorithms and software description. *Agronomy Journal*, 101(3): 438-447
- ❑ Hsiao, T.C., Heng, L., Steduto, P., Rojas-Lara, B., Raes, D., and Fereres, E. 2009.
III. Parameterization and testing for maize. *Agronomy Journal*, 101(3): 448-459

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Food and Agriculture Organization
of the United Nations

AquaCrop – Training module: Irrigation management

Nr. 5.1 (Unit 5. Management). May 2017

prepared by Dirk Raes

The logo of KU Leuven, consisting of the text 'KU LEUVEN' in white capital letters on a dark blue rectangular background.

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