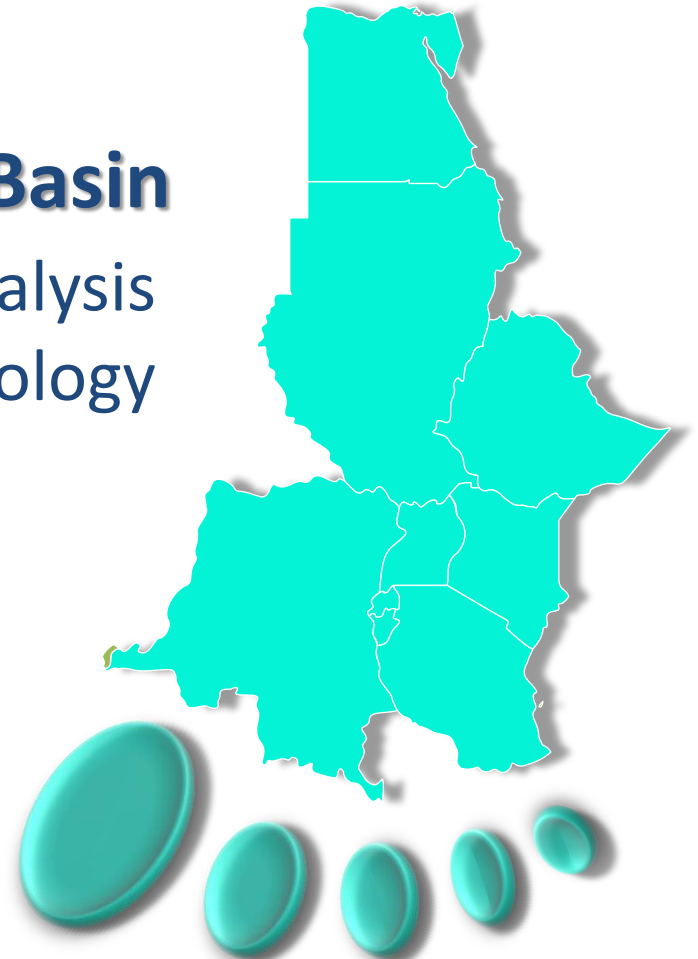


Water Footprint and the Nile Basin

Module 2: Water Footprint Analysis and Methodology



PEGASYS
Strategy and Development





Overview of this Module

Part 1: Water Footprint Analysis and Methodology

Part 2: Data Sources & Useful Tools

Part 3: Using CROPWAT



4: Water Footprint Analysis & Methodology

Understanding the Metric





Structure of this session

1. Water Footprint of a Product
2. Detailed Example: Water Footprint of a Crop
3. Detailed Example: Water Footprint of Livestock Products
4. Water Footprint of a Country



A Water Footprint

- The volume of fresh water used to produce the product, summed over the various steps of the production chain.
- When and where the water was used: a water footprint includes a temporal and spatial dimension. Such as:
 - Climate (evapotranspiration)
 - Rainfall
 - Productivity



Elements of Water Footprint

Green water footprint – volume of soil moisture (rainwater) evaporated in crop growth

Blue water footprint – volume of irrigated surface or ground water evaporated or incorporated into a product

Grey water footprint – volume of water required to dilute contamination by waste discharge and return flow





Water Footprint Example: Beer



Crop Cultivation

Crop Processing

Brewing

Distribution

Consumer

*Energy
Fertiliser/
pesticide
Crop Growth
(rainfed/
irrigated)*

*Transport
Energy
Crop Imports
Direct Water
Use*

*Energy
Transport
Packaging
Raw Materials
Waste
Direct Water
Use*

Transport

*Disposal
Recycling*

1

2

3

4



Detailed Example: Water Footprint of a Crop

$$WF = \frac{\text{Crop water use (m}^3\text{/ha)}}{\text{Crop yield (ton/ha)}}$$



Detailed Example: Water Footprint of a Crop

$$WF = \frac{\text{Crop Water Use}_{\text{green}} + \text{Crop Water Use}_{\text{blue}}}{\text{Crop yield (ton/ha)}}$$



Detailed Example: Water Footprint of a Crop

$$WF = \frac{\text{Crop Water Use}_{\text{green}} + \text{Crop Water Use}_{\text{blue}}}{\text{Crop yield (ton/ha)}}$$

What is Green
Crop Water Use?



Water Footprint of a Crop – Green Water

A photograph of a cornfield under a blue sky with white clouds. A large red arrow points upwards from the crops, and a smaller red arrow points downwards towards the crops. A blue semi-transparent box is overlaid on the bottom half of the image, containing the equation for green water footprint.

$WF_{\text{green}} = \text{Green Water Evapo-transpiration} + \text{Green Water incorporation to crop}$

1

2

3

4



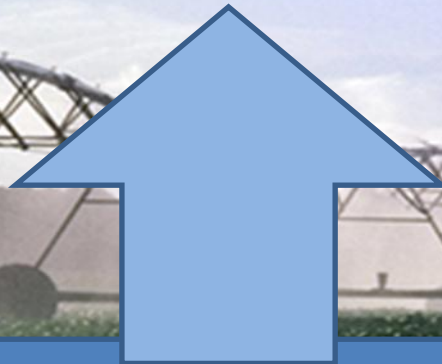
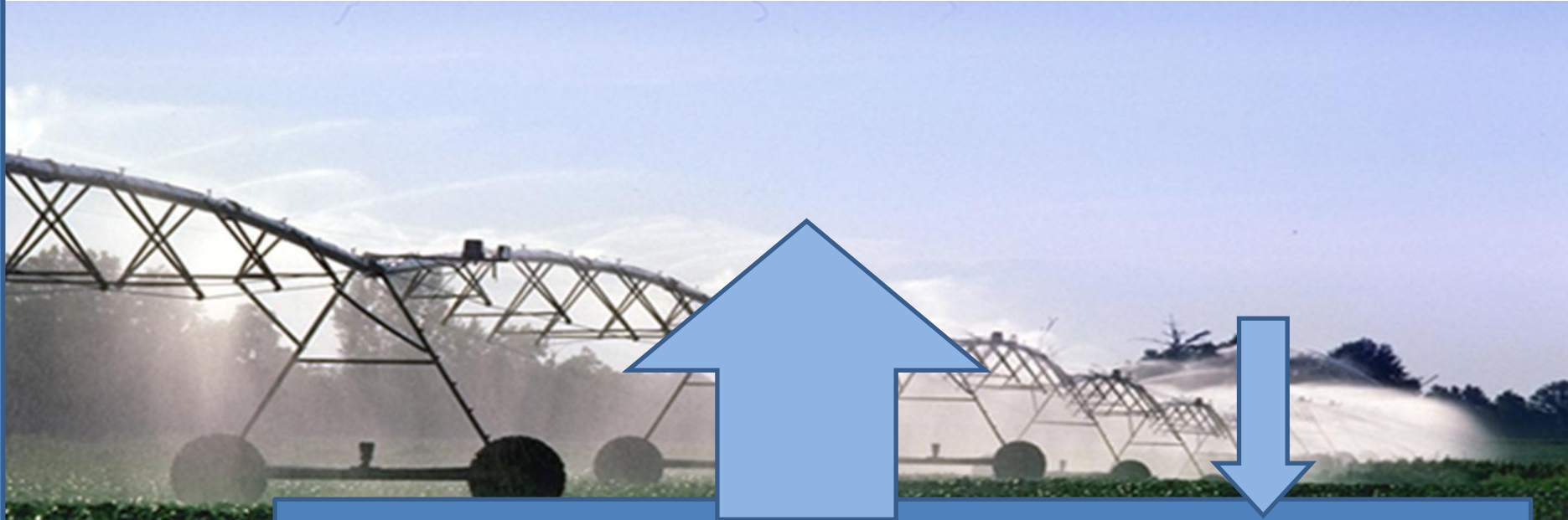
Detailed Example: Water Footprint of a Crop

$$WF = \frac{\text{Crop Water Use}_{\text{green}} + \text{Crop Water Use}_{\text{blue}}}{\text{Crop yield (ton/ha)}}$$

What is Blue Crop Water Use?



Water Footprint of a Crop – Blue Water



$$WF_{\text{blue}} = \text{Blue Water Evapo-} + \text{Blue Water}$$
$$\text{transpiration} + \text{Incorporation}$$
$$\text{to Crop}$$



CROPWAT Estimation Methods

1. CWR option – Optimal conditions
 - Without considering soil water balance
 - Ten-day time step effective rainfall

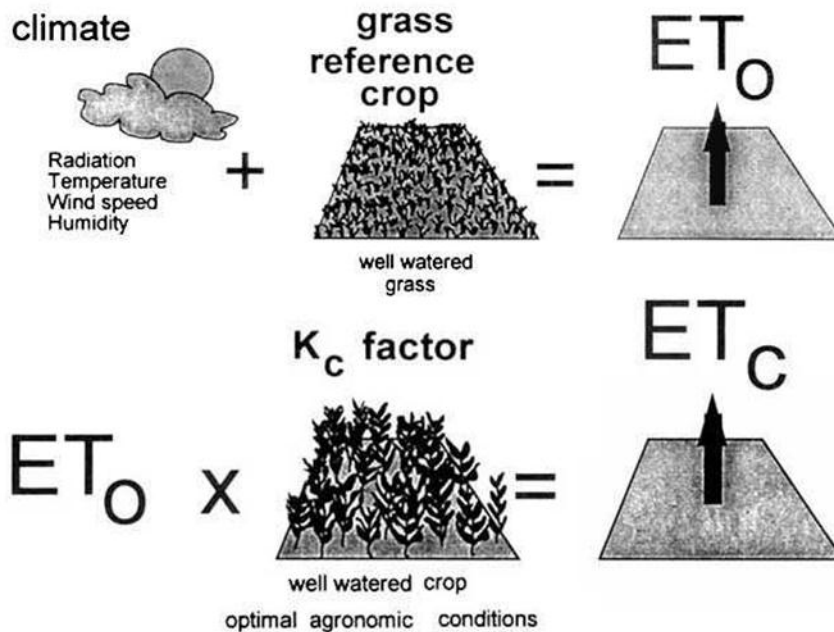
2. Irrigation schedule option – Non-optimal conditions
 - Considering soil water balance
 - Daily time step soil water balance

For the purposes of this training, we will only be examining CWR Option (further details of the Irrigation Schedule and using CROPWAT can be found in your training pack)



1. CWR Option - Crop Evapotranspiration

FIGURE 4. Reference (ET_0), crop evapotranspiration under standard (ET_C) and non-standard conditions ($ET_{C\ adj}$)



Reference crop evapotranspiration

Evapotranspiration rate from a hypothetical grass reference surface, not short of water

Crop evapotranspiration under standard conditions

Evapotranspiration from disease-free, well fertilized crops, grown in large fields, under optimum soil water conditions and achieving full production under the given climatic conditions

Allen et al. (1998)

Crop coefficient

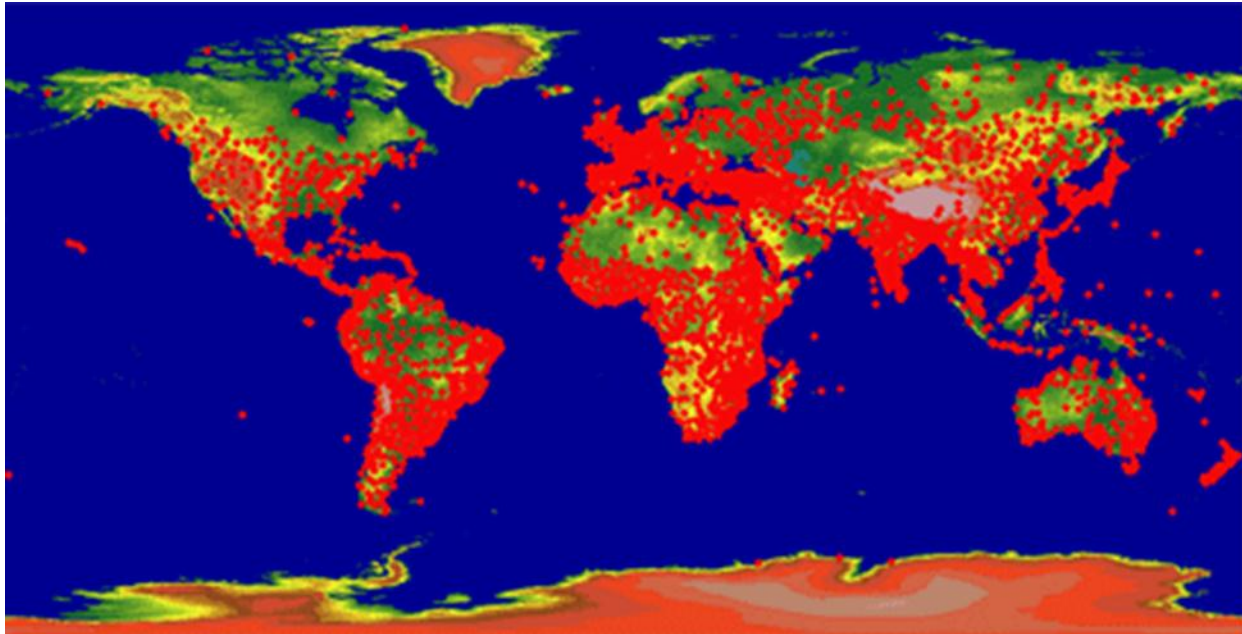
Characteristics: Crop height, albedo (reflectance), canopy resistance, evaporation from soil.



1. CWR Option - Climate Data

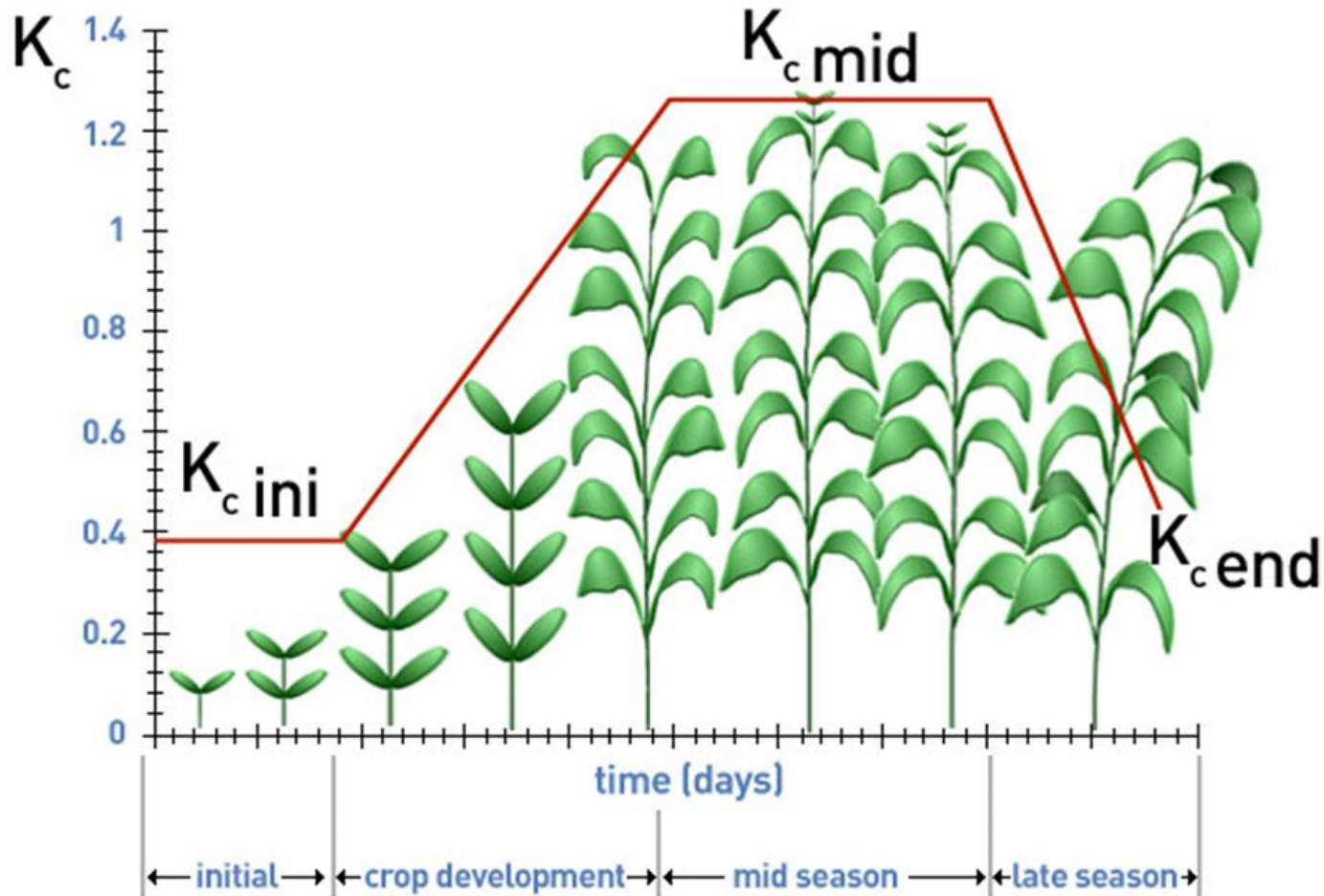
Climate data – **CLIMWAT 2.0** database (FAO, 2006)

Observed agroclimatic data of over 5000 stations worldwide (tries to cover 1971-2000)





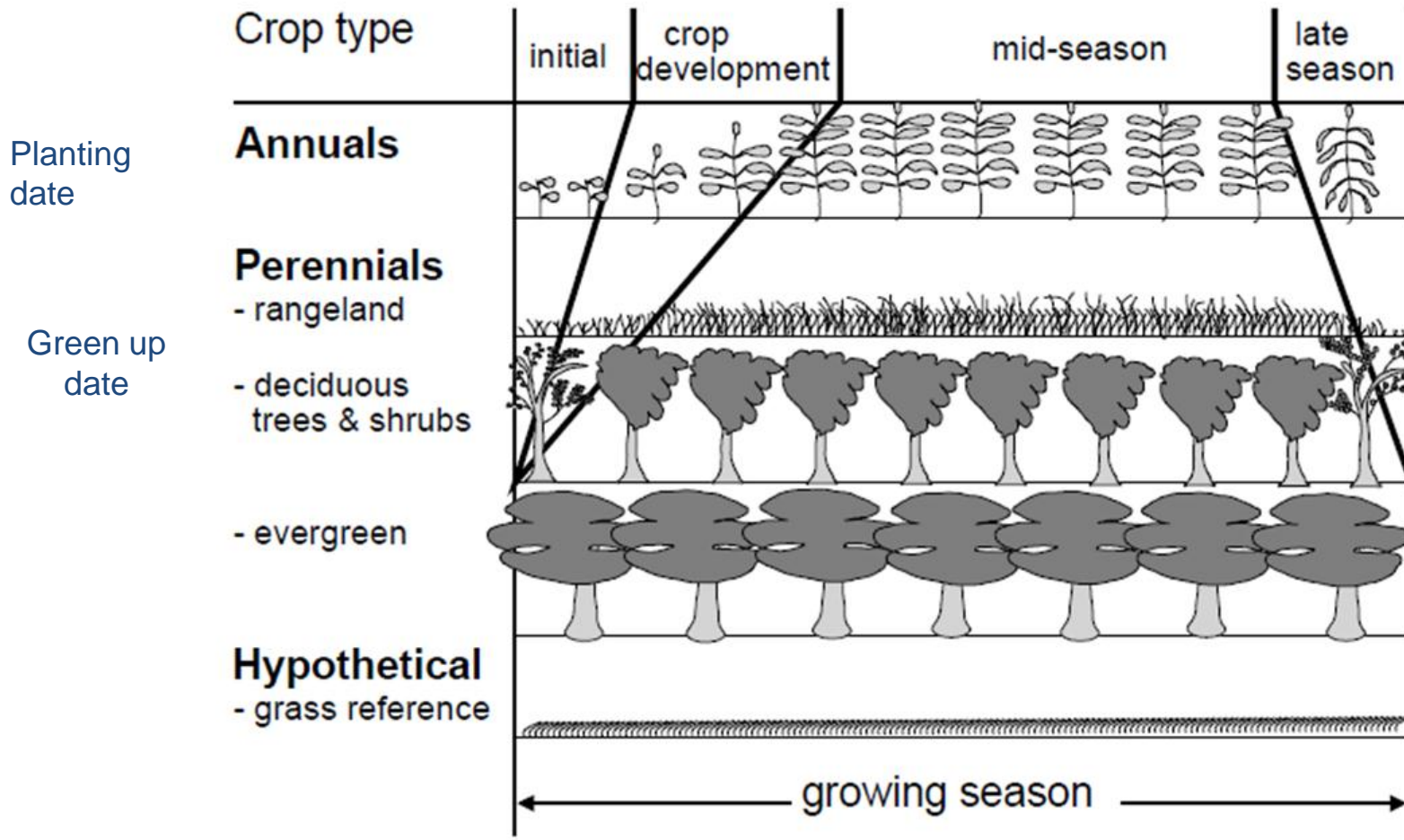
1. CWR Option - Crop Coefficient Curve





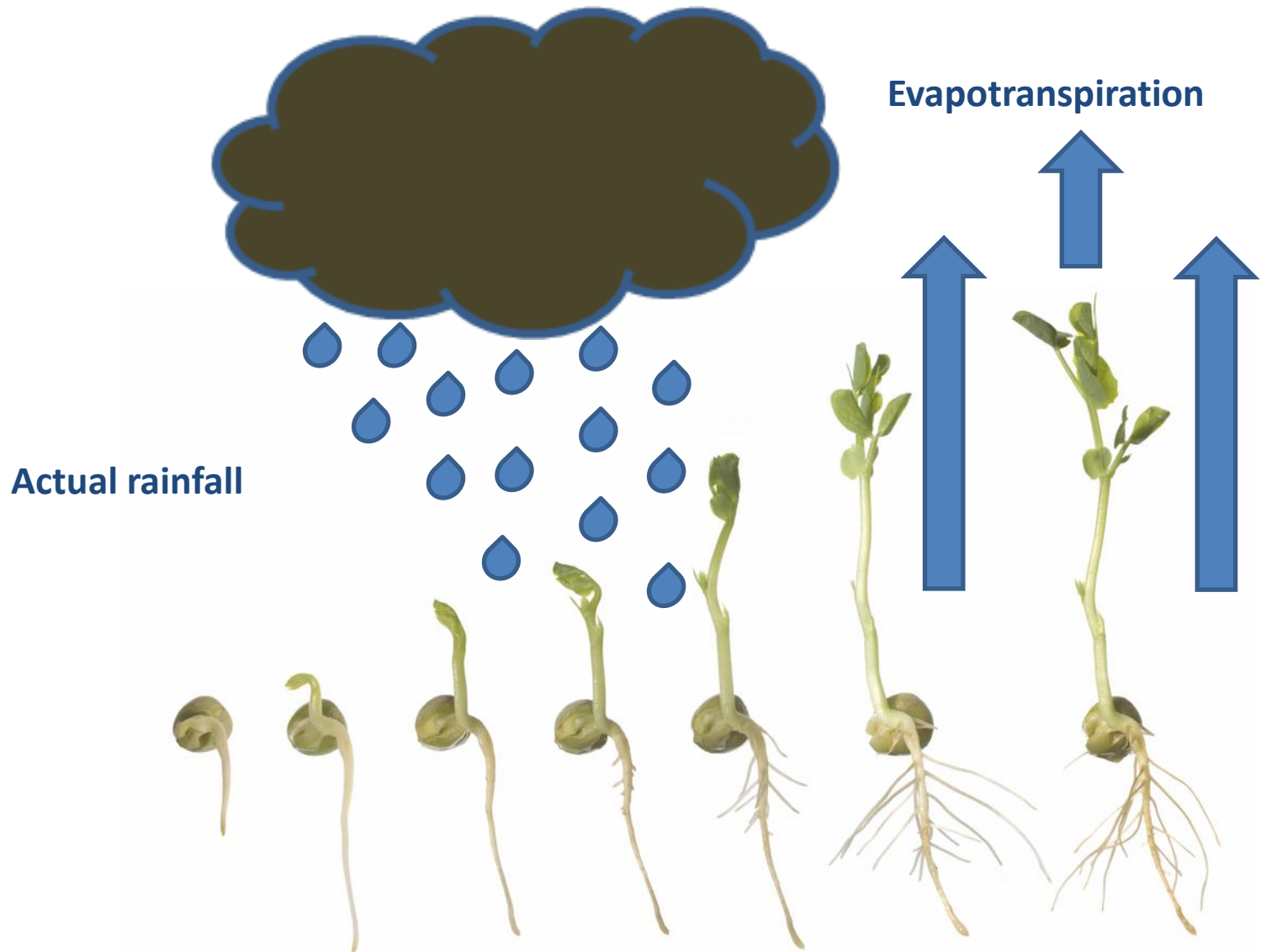
1. CWR Option

- Crop Growth Stages for Different Crops





Detailed example of **green** Crop Water Use



1

2

3

4

Summed over the entire growing period



Detailed Example: **Green** Water Footprint of a Crop

$$\text{Evapotranspiration}_{\text{green}} = \min(\text{crop evapotranspiration}, \text{effective rainfall})$$

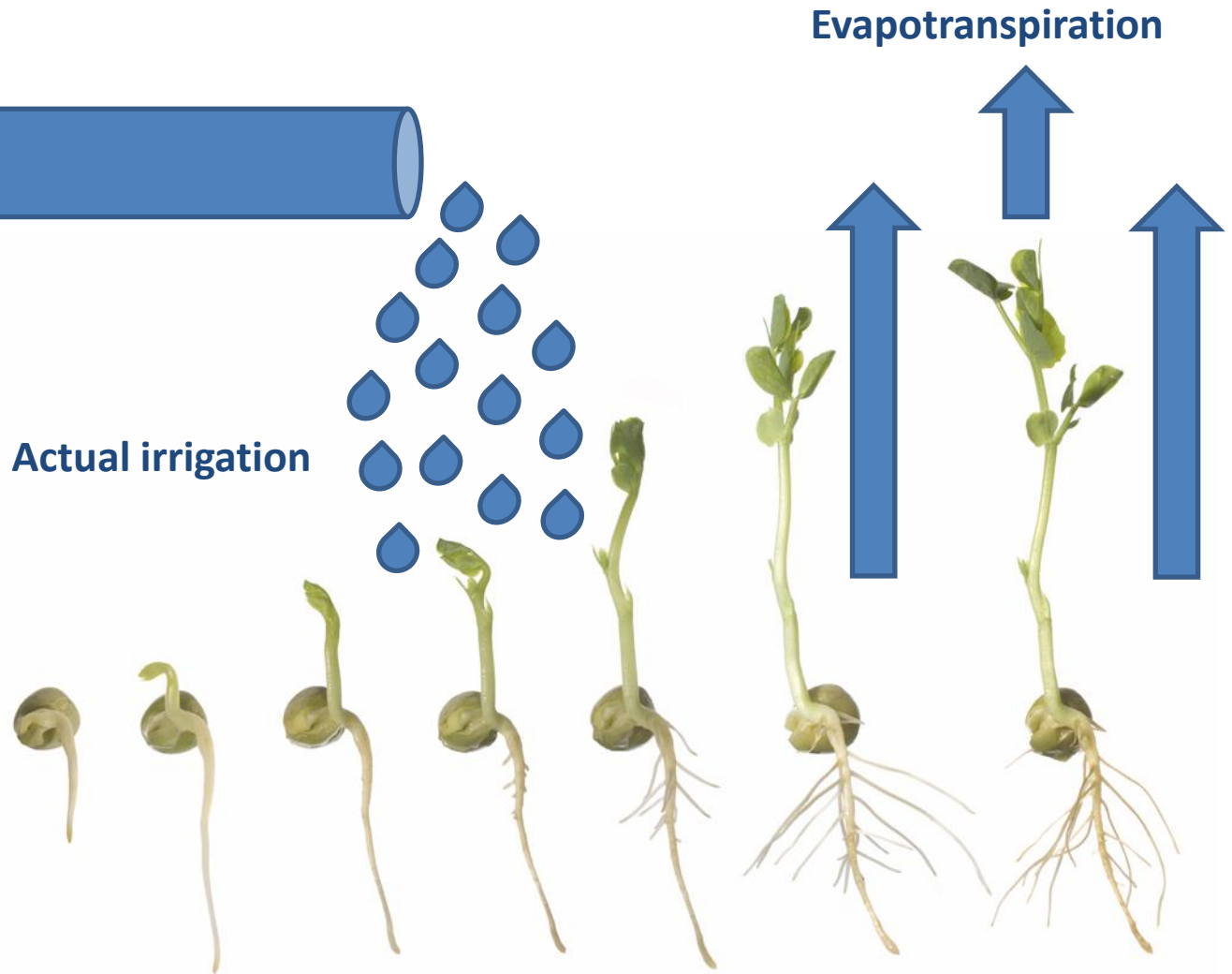
$$\text{CWU}_{\text{green}} = 10 \times \sum \text{Evapotranspiration}_{\text{green}}$$

$$\text{WF} = \frac{\text{Crop water use (m}^3\text{/ha)}}{\text{Crop yield (ton/ha)}}$$





Detailed example of blue Crop Water Use



1

2

3

4

Summed over the entire growing period



Detailed Example: **Blue** Water Footprint of a Crop

$$\text{Evapotranspiration}_{\text{blue}} = \min(\text{crop irrigation requirement, actual irrigation})$$

$$\text{CWU}_{\text{blue}} = 10 \times \sum \text{Evapotranspiration}_{\text{blue}}$$

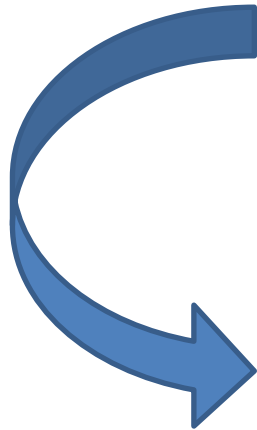
$$\text{WF} = \frac{\text{Crop water use (m}^3\text{/ha)}}{\text{Crop yield (ton/ha)}}$$





Detailed Example: Water Footprint of a Crop

$$WF = \frac{\text{Crop water use (m}^3\text{/ha)}}{\text{Crop yield (ton/ha)}}$$



Crop yield = crop production per unit area of land under cultivation

What influences Water Footprint?



$$WF = \frac{\text{Crop water use (m}^3\text{/ha)}}{\text{Crop yield (ton/ha)}}$$

Type of crop/product
Crop Evapotranspiration: climate

Fertilizer use
Irrigation practices
Not receiving optimal water
Soil



Water Footprint of a Crop – Grey Water

- Volume of polluted freshwater that associates with the production of a crop eg salinity return flow, fertilizers and other chemicals.
- Calculated as the volume of water that is required to assimilate pollutants based on ambient water quality standards.



Detailed Example: Water Footprint of a Livestock Product



1

2

3

4



Water Footprint Example: a Live Animal



Feed Cultivation *Animal Rearing*

Processing

Distribution

Consumer

Energy
Fertiliser/
pesticide
Crop Growth
(rainfed/
irrigated)

Crop Imports
Direct Water
Use

Energy
Transport
Packaging
Raw Materials
Waste
Direct Water
Use

Transport

Disposal
Recycling

Water Footprint of a Live Animal



$$WF_{\text{live animal}} = WF_{\text{drink}} + WF_{\text{service}} + WF_{\text{feed}}$$

- WF_{drink} = volume of water drunk by an animal
- WF_{service} = volume of water used to service an animal
- WF_{feed} = water embedded in the crops used to make up the feed



Water Footprint of a Live Animal - Water Footprint of Feed



- Water Footprint of Grass (m³/ton)
- Volume of grass eaten by an animal (ton)

$$WF_{\text{Feed}} = WF_{\text{Grass}} * \text{Volume}_{\text{Grass eaten}}$$



Water Footprint of a Country



1

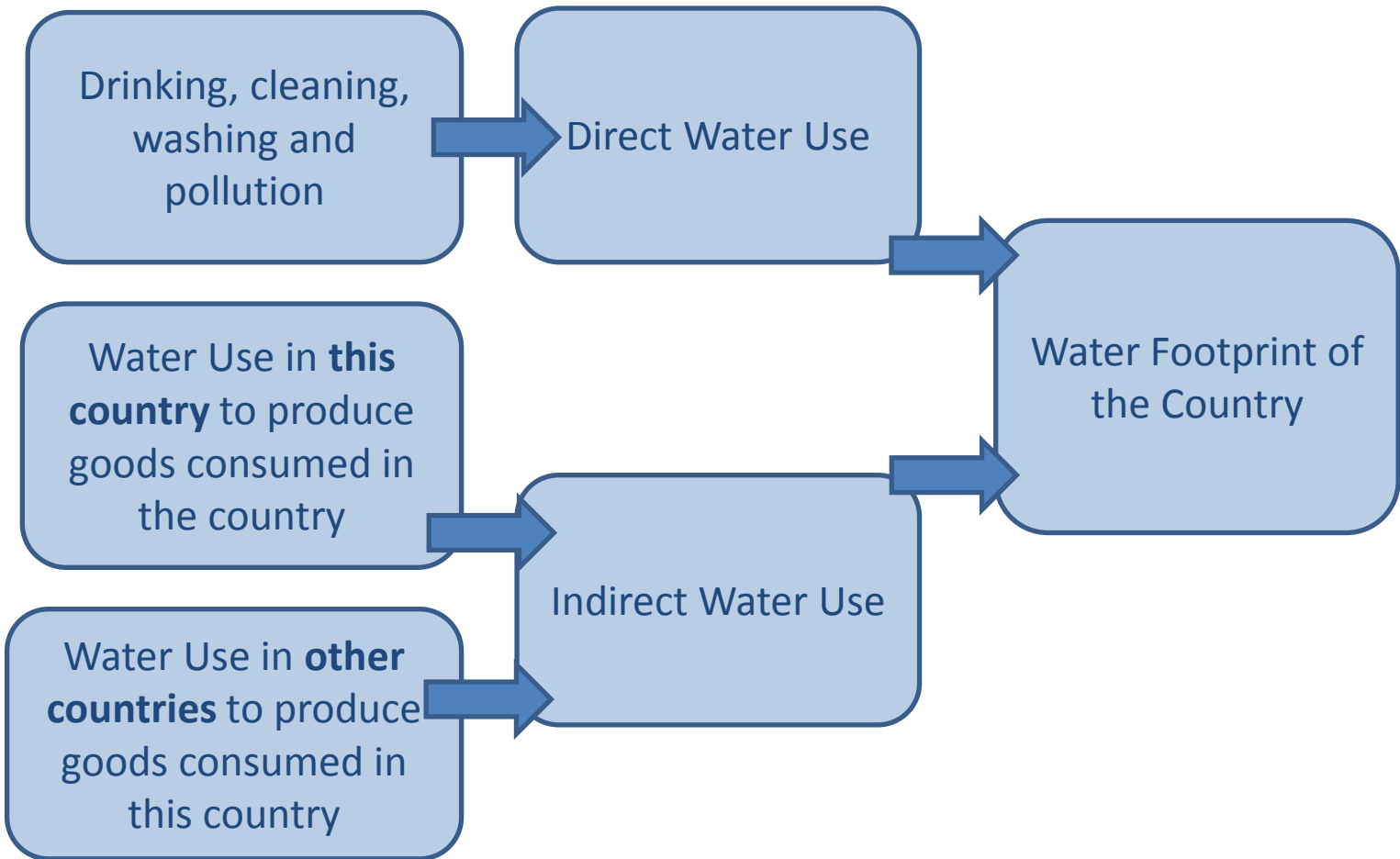
2

3

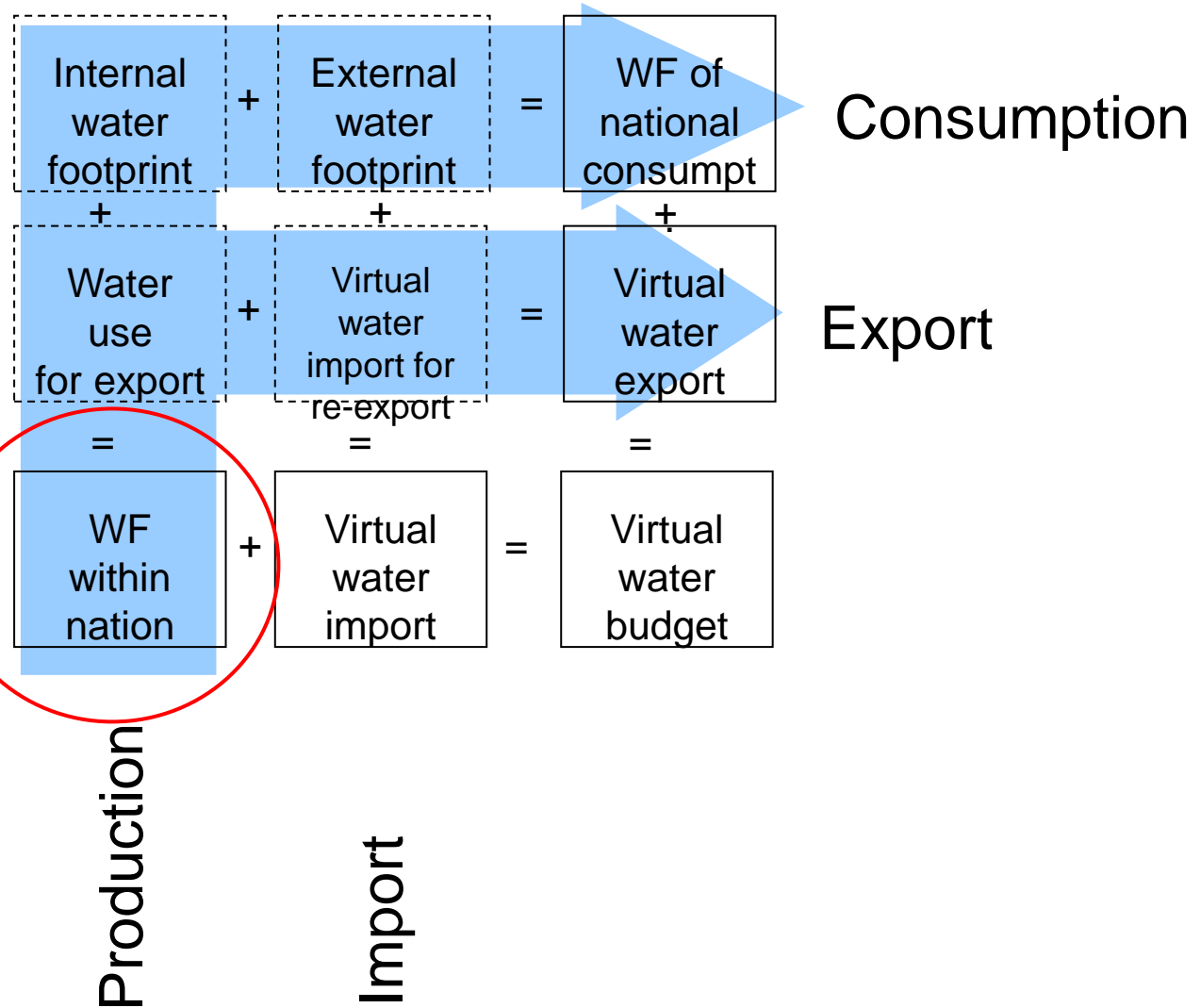
4



Water Footprint of a Country

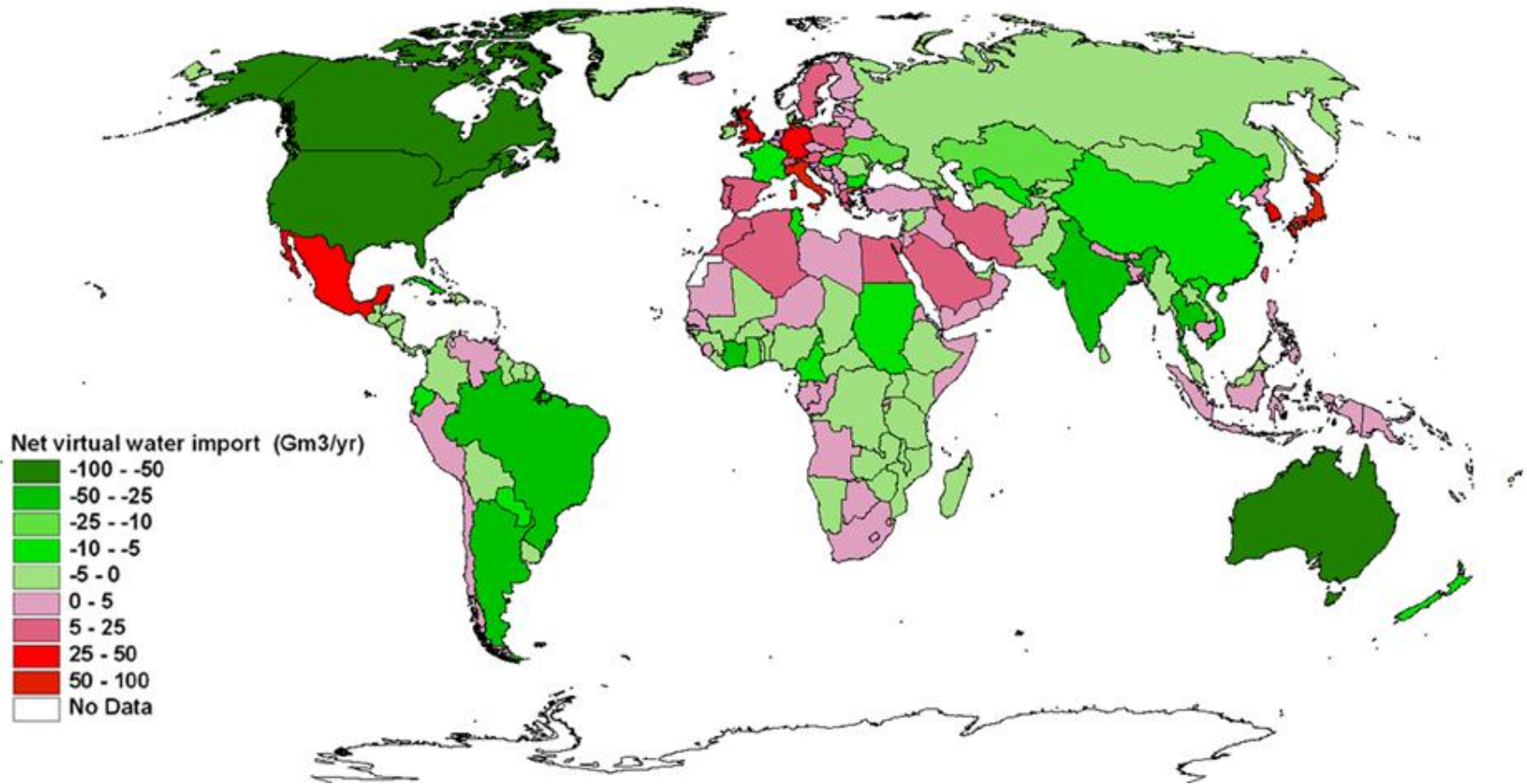


National Water Use Accounting Framework



The traditional statistics on water use, but then limited to withdrawals

Net Water Importers and Exporters



National virtual water balances related to the international trade of products. Period 1997-2001. Net exporters are shown in green and net importers in red



Data Sources and Useful Tools





Doing your own Water Footprint analysis

Basic Data required:

- Rainfall and evaporation data
- Crop growth and evapotranspiration data
- Irrigation practices
- Crop yield

Additional information:

- Production volumes
- Trade volumes
- Jobs associated with production
- Contribution to the GDP
- Other information of interest.



Doing your own Water Footprint analysis

Useful information from non-governmental sources, include the following sources and tools:



Rainfall and Evaporation Data

http://www.fao.org/nr/water/infores_databases_climwat.html

▶ text only version ▶ print friendly

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NATURAL RESOURCES AND ENVIRONMENT DEPARTMENT



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CropWat

ClimWat

ETo Calculator

Wastewater

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Educational Material

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IPTRID



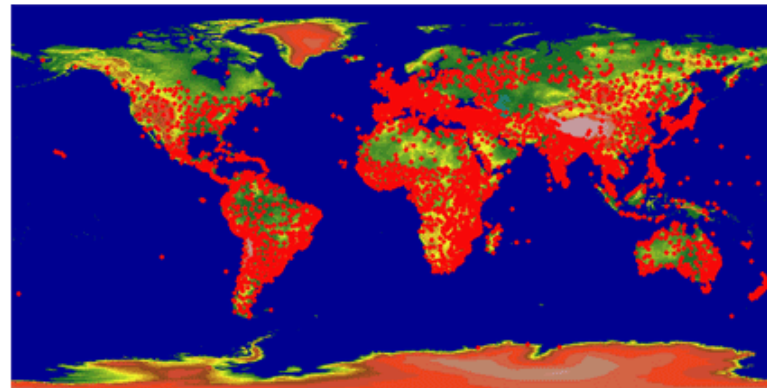
Databases

CLIMWAT 2.0 for CROPWAT

CLIMWAT is a climatic database to be used in combination with the computer program CROPWAT, and allows the calculation of crop water requirements, irrigation supply and irrigation scheduling for various crops for a range of climatological stations worldwide.

CLIMWAT 2.0 for CROPWAT is a joint publication of the **Water Development and Management Unit** and the **Climate Change and Bioenergy Unit** of FAO.

CLIMWAT 2.0 offers observed agroclimatic data of over 5000 stations worldwide distributed as shown below.



Location of stations included in CLIMWAT 2.0.

SEARCH

RELATED LINKS

Climate Change and Bioenergy Unit

Revised FAO Methodology for Crop Water Requirements

DOWNLOADS

ClimWat 2.0 for Cropwat

CONTACT US



Crop Growth and Evapotranspiration Data

http://www.fao.org/nr/water/infores_databases_cropwat.html

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NATURAL RESOURCES AND ENVIRONMENT DEPARTMENT



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Software

CropWat

CROPWAT is a decision support tool developed by the Land and Water Development Division of FAO.

CROPWAT 8.0 for Windows is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. CROPWAT 8.0 can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rainfed and irrigated conditions.



All calculation procedures used in CROPWAT 8.0 are based on the two FAO publications of the Irrigation and Drainage Series, namely, No. 56 "Crop Evapotranspiration - Guidelines for computing crop water requirements" and No. 33 titled "Yield response to water".

As a starting point, and only to be used when local data are not available, CROPWAT 8.0 includes standard crop and soil data. When local data are available, these data files can be easily modified or new ones can be created. Likewise, if local climatic data are not available, these can be obtained for over 5,000 stations worldwide from CLIMWAT, the associated climatic database. The development of irrigation schedules in CROPWAT 8.0 is based on the following assumptions:

SEARCH

RELATED LINKS

Revised methodology for crop water requirements

Topics: Irrigation

Topics: Water Productivity

Publications: Irrigation

Publications: Productivity

DOWNLOADS

CropWat 8.0

Example of CropWat 8.0 use

CONTACT US



Irrigation practices and Crop Yields

http://www.fao.org/ag/agl/fertistat/fst_fubc_en.asp





Production and Trade Volumes

<http://faostat.fao.org/default.aspx>

Google x FAO: Search result x FAO - Water Development : x FAO - Water Development : x FAOSTAT

← → ↻ faostat.fao.org/default.aspx



FOOD AND AGRICULTURE

Home Production Trade Food Supply Food Balance Sheets Food Security Prices Resources Forestry Fisheries Metadata Support/FAO
logon want to register? FAOSTAT videos CountrySTAT

FAOSTAT provides time-series and cross sectional data relating to food and agriculture for some 200 countries.

The national version of FAOSTAT, **CountrySTAT**, is being developed and implemented in a number of target countries, primarily in sub-saharan Africa. It will offer a two-way data exchange facility between countries and FAO as well as a facility to store data at the national and sub-national levels.

FAOSTAT User Dialogue 2010

One of the priorities of the Statistics Division is to involve the producers and custodians of statistics at FAO in a stronger communication with our users, and to gain a better understanding of their needs. Since July 2010 the free FAO data access policy has been implemented. The number of registered users has boomed since then from 400 to over 10 000 as of today.

We are seeking contact with registered users of FAOSTAT to open a qualitative feedback channel. We are looking for your views and experiences in using FAO's statistics as well as specific, technical suggestions. We would very much appreciate receiving your advice. To see the issues please click [here](#).

Latest news

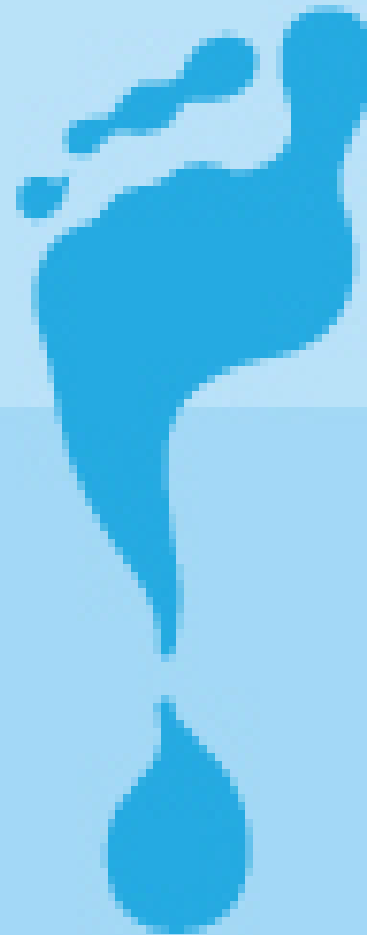
The following subject domains have been updated:

- **ForesSTAT (August 2011)**
- **PopSTAT (August 2011)**
- **ResourceSTAT-Land (July 2011)**
- **Forestry Trade Flows (July 2011)**
- **ResourceSTAT-Fertilizers (July 2011)**
- **ProdSTAT (May 2011)**
- **ResourceSTAT-Pesticides Consumption (March 2011)**
- **TradeSTAT-Detailed Trade Matrix (February 2011)**
- **ResourceSTAT-Machinery (December 2010)**
- **TradeSTAT-Detailed trade data (November 2010)**



Water Footprint Network

<http://www.waterfootprint.org>





Useful Additional References

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998) Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. Food and Agriculture Organization. Rome. Available from: <http://www.fao.org/docrep/X0490E/X0490E00.htm>

Chapagain, A.K. and Hoekstra, A.Y. (2004) Water footprints of nations. Value of Water Research Report Series No. 16, UNESCO-IHE, Delft, the Netherlands. Available from: <http://www.waterfootprint.org/?page=files/Research%20data>

Mekonnen, M.M. and Hoekstra, A.Y. (2011) The green, blue and grey water footprint of crops and derived crop products, Hydrology and Earth System Sciences, 15(5): 1577-1600. Available from: <http://www.waterfootprint.org/?page=files/Publications>

Chapagain, A.K. and Hoekstra, A.Y. (2003) 'Virtual water flows between nations in relation to trade in livestock and livestock products', Value of Water Research Report Series No.13, UNESCO-IHE. <http://www.waterfootprint.org/?page=files/Publications>

FAO (2003) Technical Conversion Factors for Agricultural Commodities. Food and Agriculture Organization of the United Nations, Rome. Online available: www.fao.org/WAICENT/FAOINFO/ECONOMIC/ESS/pdf/tcf.pdf

Hoekstra, A.Y. and Chapagain, A.K. (2008) Globalization of water: Sharing the planet's freshwater resources. Blackwell Publishing. Oxford, UK.

Monfreda, C., Ramankutty, N. and Foley, J.A. (2008) Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000, Global Biogeochemical Cycles, Vol. 22, GB1022, doi:10.1029/2007GB002947. Available from: <http://www.geog.mcgill.ca/~nramankutty/Datasets/Datasets.html>



4: Using CROPWAT





$$\text{WF} = \frac{\text{Crop water use (m}^3\text{/ha)}}{\text{Crop yield (ton/ha)}}$$

CROPWAT
(FAO, 2009a)

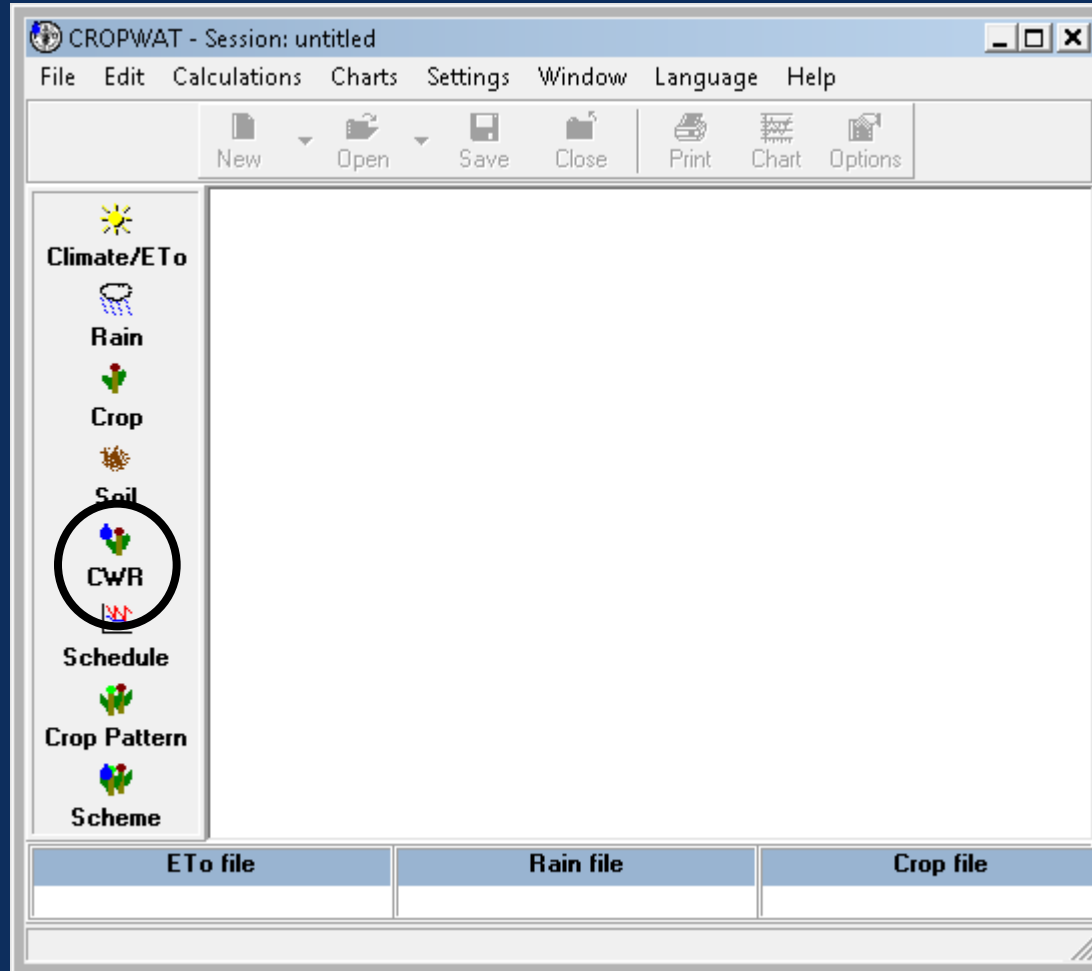
FAOSTAT
(FAO, 2009b)

CROPWAT estimation methods

1. CWR option – Optimal conditions
 - Without considering soil water balance
 - Ten-day time step effective rainfall
2. Irrigation schedule option – Non-optimal conditions
 - Considering soil water balance
 - Daily time step soil water balance



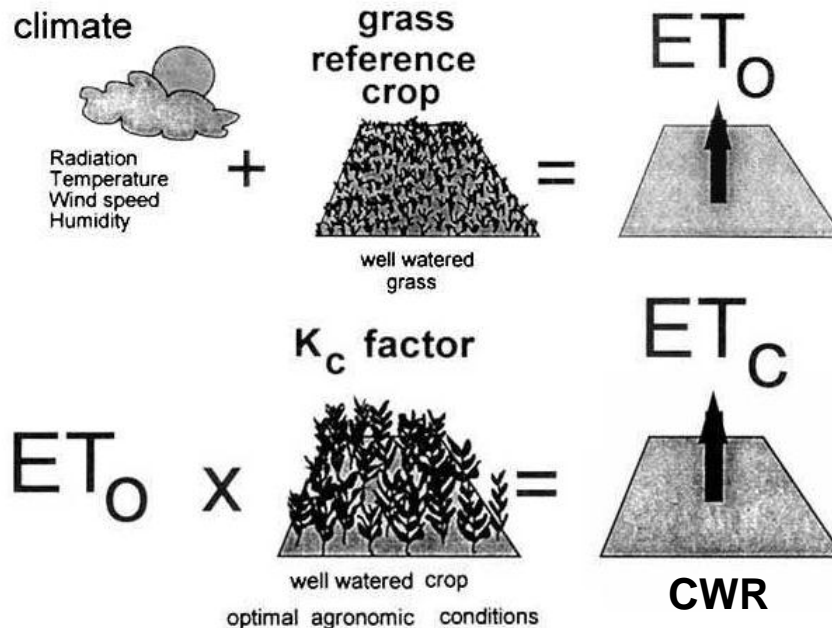
1. CWR option





1. CWR option

Reference (ET_0), crop evapotranspiration under standard (ET_C) and non-standard conditions ($ET_{C\ adj}$)



Reference crop evapotranspiration

Evapotranspiration rate from a hypothetical grass reference surface, not short of water

Crop evapotranspiration under standard conditions

Evapotranspiration from disease-free, well fertilized crops, grown in large fields, under optimum soil water conditions and achieving full production under the given climatic conditions

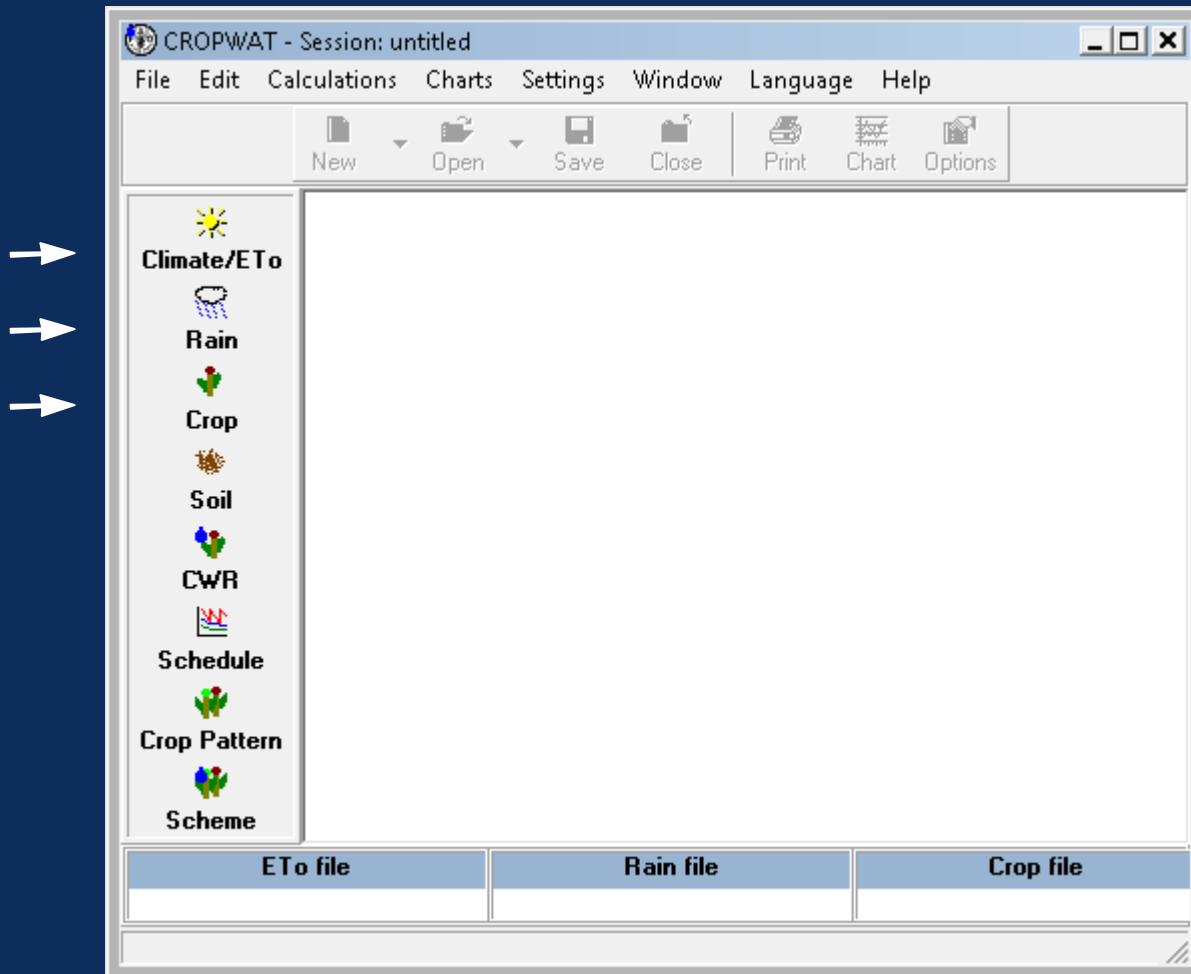
Allen et al. (1998)

Crop coefficient

Characteristics: Crop height, albedo (reflectance), canopy resistance, evaporation from soil.



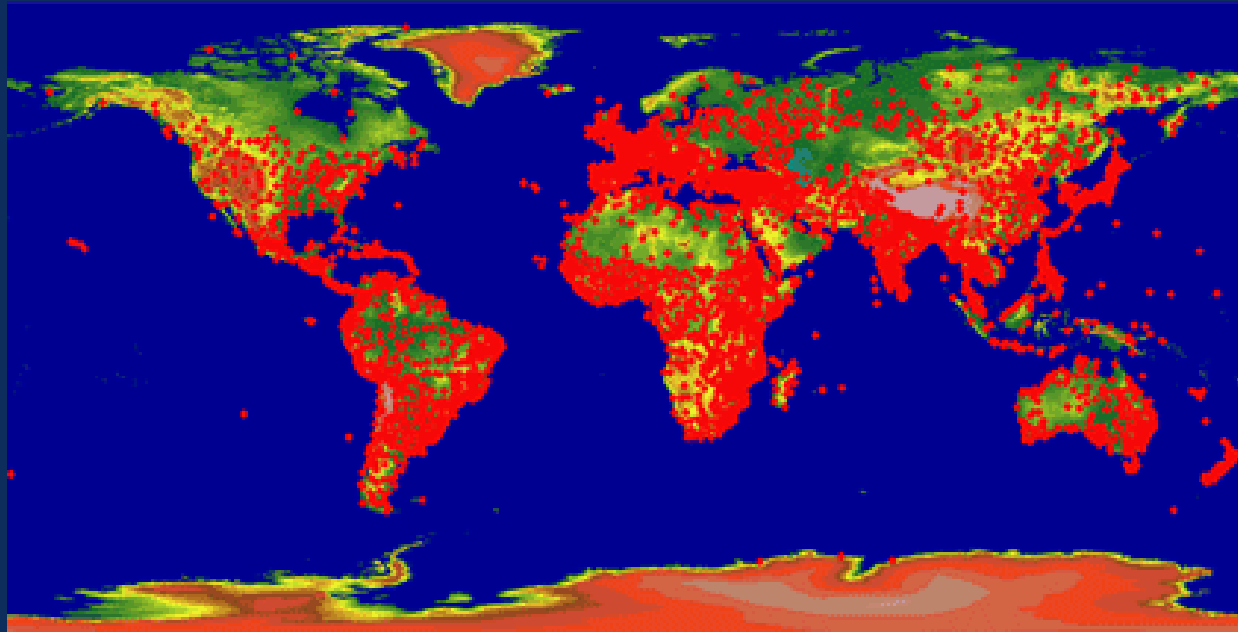
1. CWR option – Input





Climate data – **CLIMWAT 2.0** database (FAO, 2006)

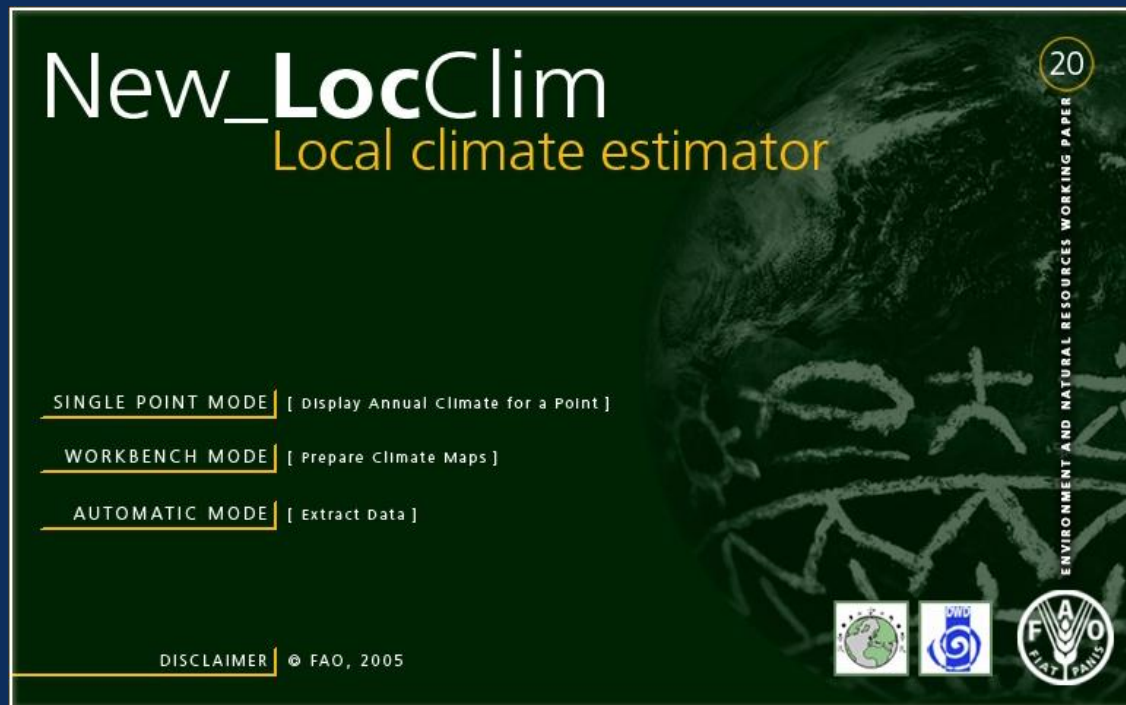
Observed agroclimatic data of over 5000 stations worldwide (tries to cover 1971-2000)





Climate data – **New LocClim** 1.10 database (FAO, 2005)

Interpolates where no observations are available





Climate data – Local Data can be added by hand to CROPWAT





CLIMWAT database

.CLI

GRONINGEN-AP-EELDE.cli - Notepad			
File	Edit	Format	View Help
"GRONINGEN-AP-EELDE", "", " 4", 0,0,0,0,0,0,0,0			
0.21	66.60		59.50
0.39	45.20		41.93
0.86	57.50		52.21
1.58	48.20		44.48
2.43	57.80		52.45
2.82	68.80		61.23
2.75	76.30		66.99
2.53	66.40		59.35
1.59	70.60		62.63
0.83	68.70		61.15
0.44	77.10		67.59
0.22	75.50		66.38

ET₀^{*}
(mm/day)

Monthly
rainfall
(mm/month)

Monthly
effective rainfall**
(mm/month)

*Penman-Monteith method
**USDA Soil Conservation
Service formula

.PEN

GRONINGEN-AP-EELDE.pen - Notepad						
File	Edit	Format	View	Help		
"Location 7", "GRONINGEN-AP-EELDE", 4, 53.13, "N.L.", 6.58, " 01"						
3.7	-1.5	95.4	457.9	0.45	2.06	0.21
4.5	-1.4	91.9	423.4	2.05	4.60	0.39
7.9	0.5	86.7	449.3	2.85	7.93	0.86
11.8	2.5	81.7	397.4	5.01	13.22	1.58
16.6	6.3	79.1	354.2	6.22	17.06	2.43
19.5	9.3	80.6	345.6	6.11	17.95	2.82
20.7	10.9	83.0	354.2	5.71	16.92	2.75
21.2	10.8	82.5	319.7	5.83	15.05	2.53
18.2	8.7	87.2	337.0	4.06	10.18	1.59
13.7	5.9	90.8	354.2	2.45	5.78	0.83
8.3	2.3	92.5	440.6	1.06	2.77	0.44
4.9	-0.2	95.7	449.3	0.13	1.53	0.22

Mean daily
maximum
temp. (°C)

Mean daily
minimum
temp. (°C)

Mean
relative
humidity (%)

Mean wind
speed
(km/day)

Mean
sunshine
hours per
day

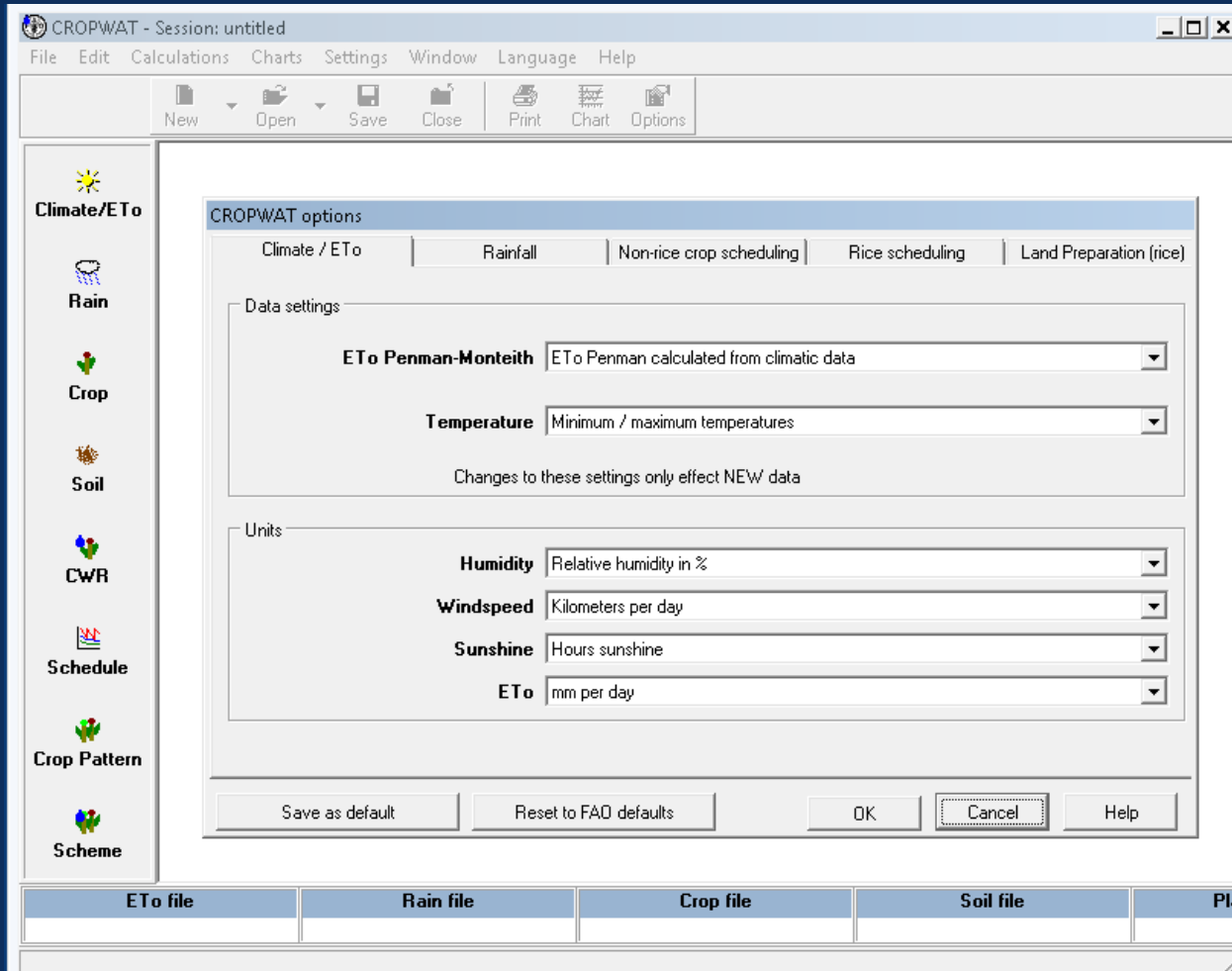
Mean solar
radiation
(MJ/m²/day)

ET₀^{*}
(mm/day)





ET₀ Penman-Monteith





Effective rainfall estimation method

CROPWAT - Session: untitled

File Edit Calculations Charts Settings Window Language Help

New Open Save Close Print Chart Options

Climate/ETo

Rain

Crop

Soil

CWR

Schedule

Crop Pattern

Scheme

CROPWAT options

Climate / ETo Rainfall Non-rice crop scheduling Rice scheduling Land Preparation (rice)

Effective rainfall method for CWR calculations

Fixed Percentage: 80 %

Dependable rain (FAO/AGLW formula)
 $P_{eff} = 0.6 * P - 10$ for $P_{month} \leq 70$ mm
 $P_{eff} = 0.8 * P - 24$ for $P_{month} > 70$ mm

Empirical formula
 $P_{eff} = 0.5 * P + 5$ for $P \leq 50$ mm
 $P_{eff} = 0.7 * P + 20$ for $P > 50$ mm

USDA soil conservation service
 $P_{eff} = (P * (125 - 0.2 * P)) / 125$ for $P \leq 250$ mm
 $P_{eff} = 125 + 0.1 * P$ for $P > 250$ mm

Rainfall not considered in irrigation calculations (effective rainfall = 0)

Note: in red are correction factors that CROPWAT applies to adjust formulas in the case of decade and daily rainfall data (for effective rainfall calculations daily data are aggregated per decade)

Save as default Reset to FAO defaults OK Cancel Help

ETo file Rain file Crop file Soil file Pla





Crop parameters

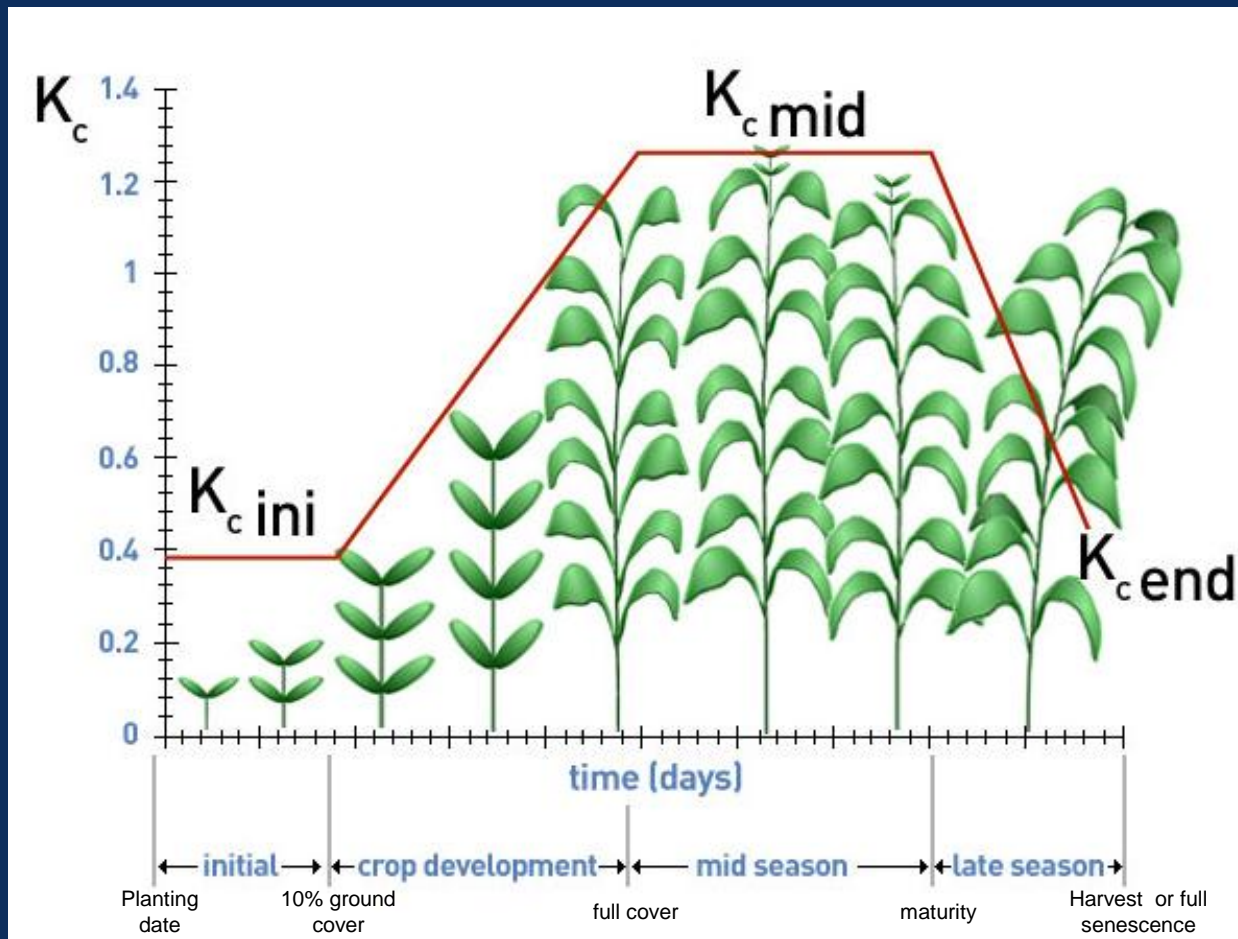
- Crop coefficients (Kc)
 - Global → CROPWAT (FAO, 2009a)
 - Regional → Table 12 in Allen et al. (1998)
 - Climate region → Chapagain and Hoekstra (2004) (App. VI)
 - Local → Agricultural research stations, farmers

- Crop growing period
(planting/green up date)
 - Global → CROPWAT (FAO, 2009a)
 - Regional → Table 11 in Allen et al. (1998)
 - Climate region → Chapagain and Hoekstra (2004) (App. VI)
 - Local → Agricultural research stations, farmers





Crop coefficient curve



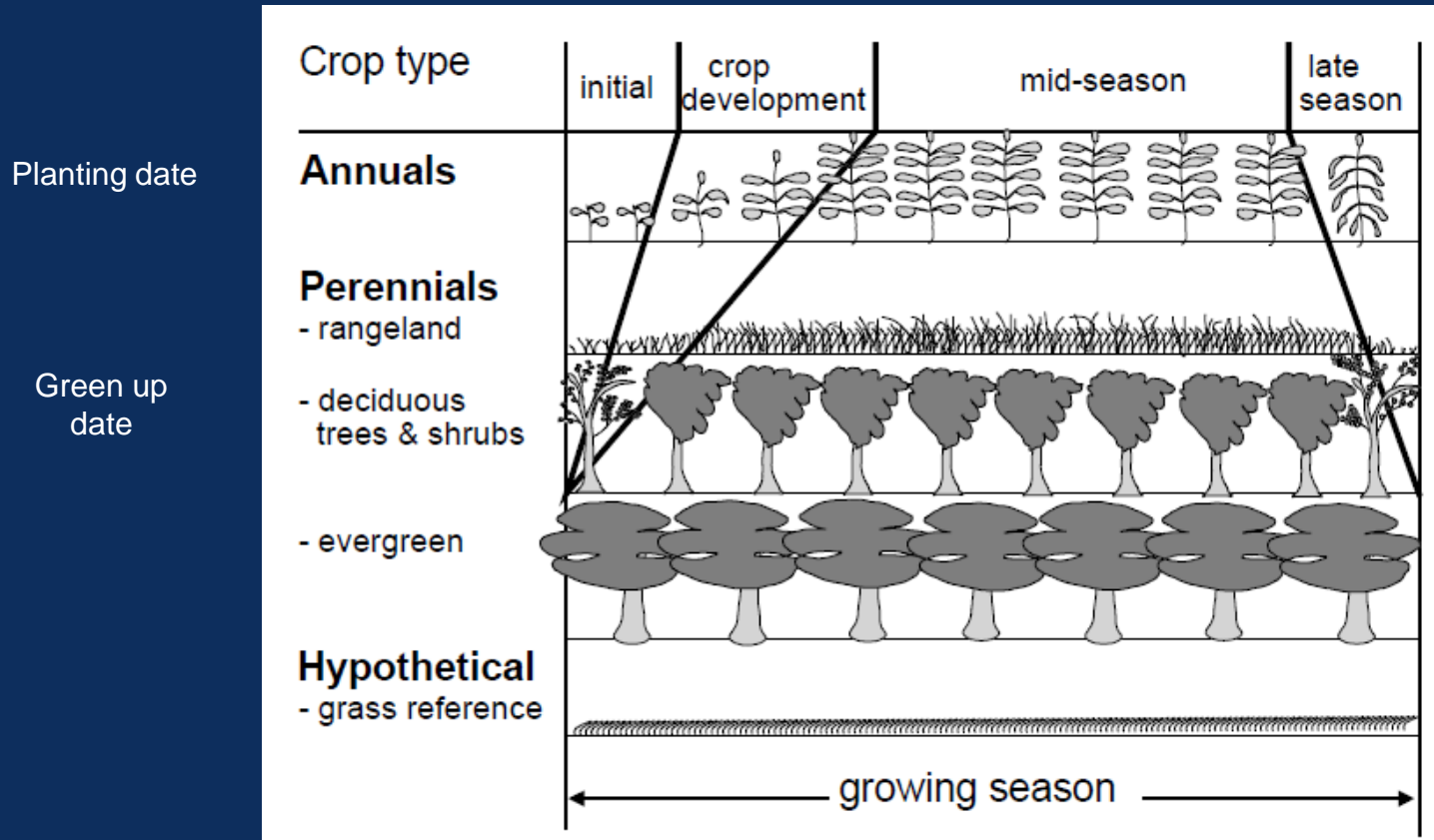
Length of growth stages

Allen et al. (1998)





Crop growth stages for different crops

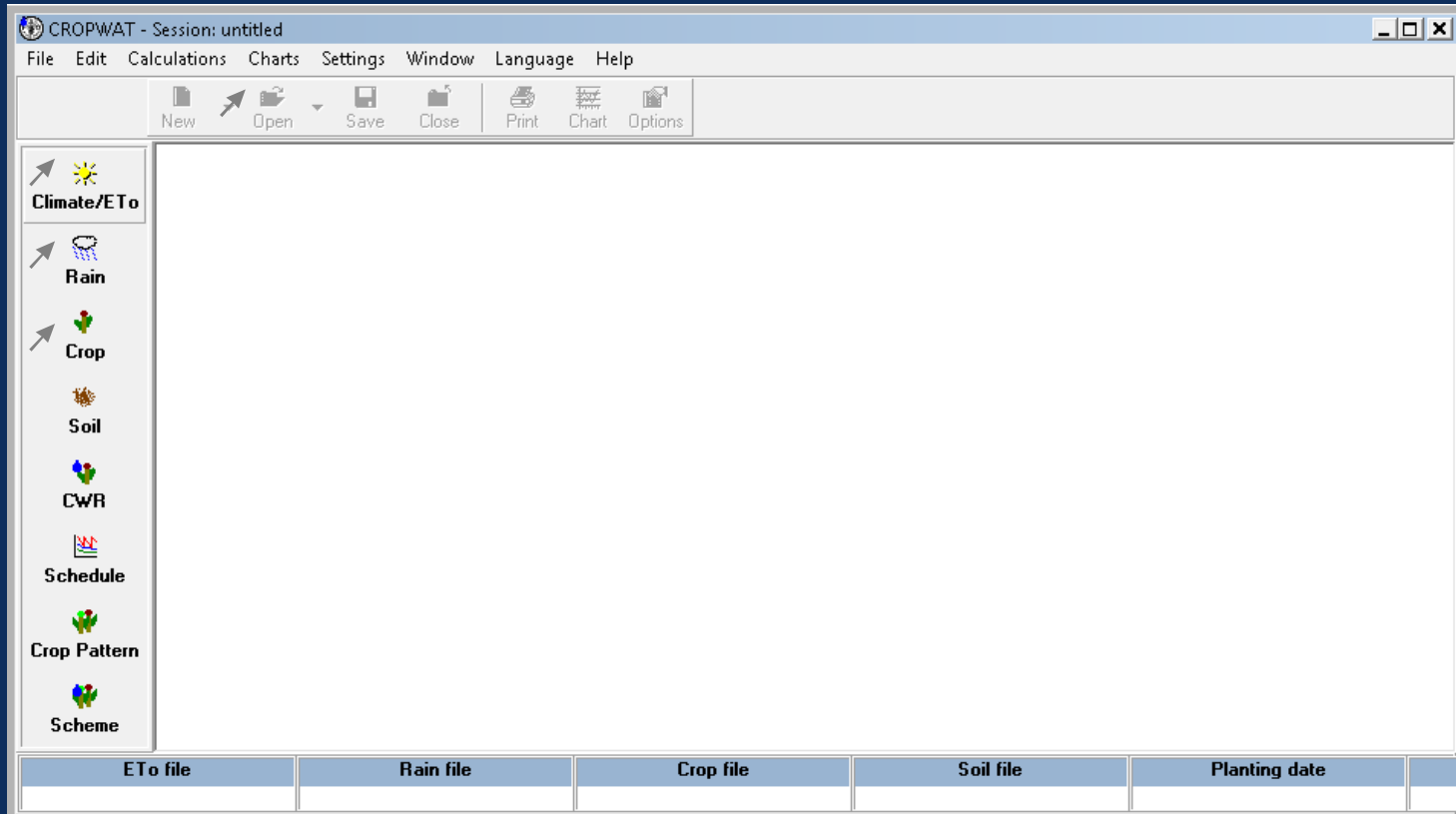


Allen et al. (1998)



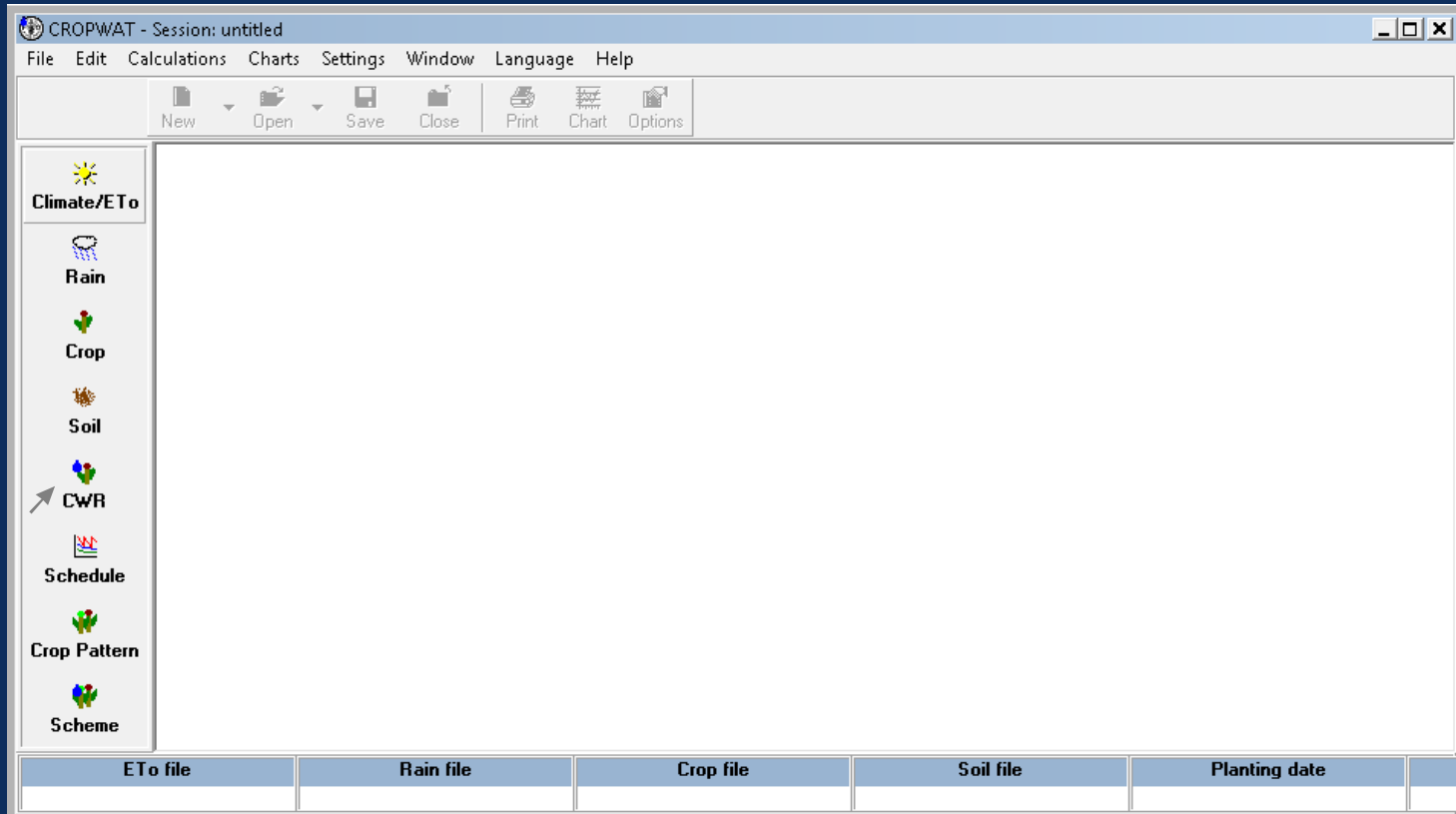


1. CWR option - input





1. CWR option - output





1. CWR option - output

Crop Water Requirements

ETo station: GRONINGEN-AP-EELD Crop: Sugarbeet

Rain station: GRONINGEN-AP-EELD Planting date: 10/04

CWR

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.35	0.52	0.5	1.5	0.5
Apr	2	Init	0.35	0.62	6.2	14.1	0.0
Apr	3	Init	0.35	0.72	7.2	15.2	0.0
May	1	Init	0.35	0.83	8.3	16.6	0.0
May	2	Init	0.35	0.93	9.3	17.5	0.0
May	3	Deve	0.36	1.00	11.0	18.5	0.0
Jun	1	Deve	0.51	1.51	15.1	19.5	0.0
Jun	2	Deve	0.73	2.25	22.5	20.5	2.0
Jun	3	Deve	0.95	2.90	29.0	21.1	7.9
Jul	1	Mid	1.17	3.52	35.2	22.1	13.1
Jul	2	Mid	1.23	3.67	36.7	22.9	13.8
Jul	3	Mid	1.23	3.59	39.5	21.9	17.6
Aug	1	Mid	1.23	3.50	35.0	20.3	14.7
Aug	2	Mid	1.23	3.41	34.1	19.3	14.8
Aug	3	Late	1.22	2.97	32.7	19.8	12.9
Sep	1	Late	1.11	2.33	23.3	20.6	2.7
Sep	2	Late	0.98	1.73	17.3	21.1	0.0
Sep	3	Late	0.86	1.27	12.7	20.8	0.0
Oct	1	Late	0.76	0.91	5.5	12.2	0.0
					381.2	345.6	100.1





1. CWR option - output

Crop Water Requirements

ETo station: GRONINGEN-AP-EELD Crop: Sugarbeet

Rain station: GRONINGEN-AP-EELD CWR Planting date: 10/04

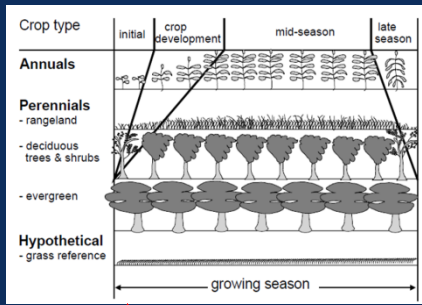
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.35	0.52	0.5	1.5	0.5
Apr	2	Init	0.35	0.62	6.2	14.1	0.0
Apr	3	Init	0.35	0.72	7.2	15.2	0.0
May	1	Init	0.35	0.83	8.3	16.6	0.0
May	2	Init	0.35	0.93	9.3	17.5	0.0
May	3	Deve	0.36	1.00	11.0	18.5	0.0
Jun	1	Deve	0.51	2.25	22.5	21.1	0.0
Jun	2	Deve	0.73	2.90	29.0	21.1	2.0
Jun	3	Deve	0.95	2.90	29.0	21.1	7.9
Jul	1	Mid	1.17	3.52	35.2	22.1	13.1
Jul	2	Mid	1.23	3.67	36.7	22.9	13.8
Jul	3	Mid	1.23	3.59	39.5	21.9	17.6
Aug	1	Mid	1.23	3.50	35.0	20.3	14.7
Aug	2	Mid	1.23	3.41	34.1	19.3	14.8
Aug	3	Late	1.22	2.97	32.7	19.8	12.9
Sep	1	Late	1.11	2.33	23.3	20.6	2.7
Sep	2	Late	0.98	1.73	17.3	21.1	0.0
Sep	3	Late	0.86	1.27	12.7	20.8	0.0
Oct	1	Late	0.76	0.91	5.5	12.2	0.0
					381.2	345.6	100.1

Copy table ▸ Data only
Data and Headers

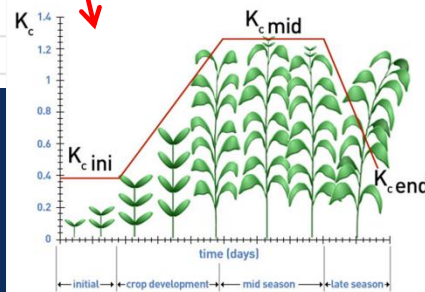
→ CWR



Data from CROPWAT



Month	Decade	Crop Development Stage	Crop Coefficient Kc coeff	Crop Evapo Transpiration ETc mm/day	Crop Evapo transpiration ETc mm/dec	Effective Rainfall Eff rain mm/dec	Irrigation Requirement Irr. Req. mm/dec	Actual Irrigation Act. Irrig. mm/dec
Aug	1	Init	0.3	0.98	8.8	5.2	5.3	0
Aug	2	Init	0.3	1.02	10.2	4.2	7	0
Aug	3	Deve	0.43	1.55	17	5.3	12.8	0
Sep	1	Deve	0.7	2.67	26.7	6.1	21.6	0
Sep	2	Deve	0.96	3.86	38.6	7.9	32.7	0
Sep	3	Mid	1.18	5.02	50.2	10.4	41.8	0
Oct	1	Mid	1.2	5.41	54.1	12.4	43.7	0
Oct	2	Mid	1.2	5.69	56.9	14.3	44.6	0
Oct	3	Mid	1.2	5.69	62.6	19.7	45.2	0
Nov	1	Late	1.14	5.41	54.1	25.3	30.3	0
Nov	2	Late	0.88	4.14	41.4	31.9	12.5	0
Nov	3	Late	0.59	2.78	33.7	30	0	0
Dec	1	Late	0.39	1.83	9.3	12.5	0	0
						165.2	297.5	0





1. CWR option - output

$$ET = ET_c$$

$$ET_g = \min(ET_c, P_{eff})$$

$$ET_b = \max(0, ET_c - P_{eff}) * Irr. \text{ Fraction (ie the volume of irrigation in reality)}$$

CWR

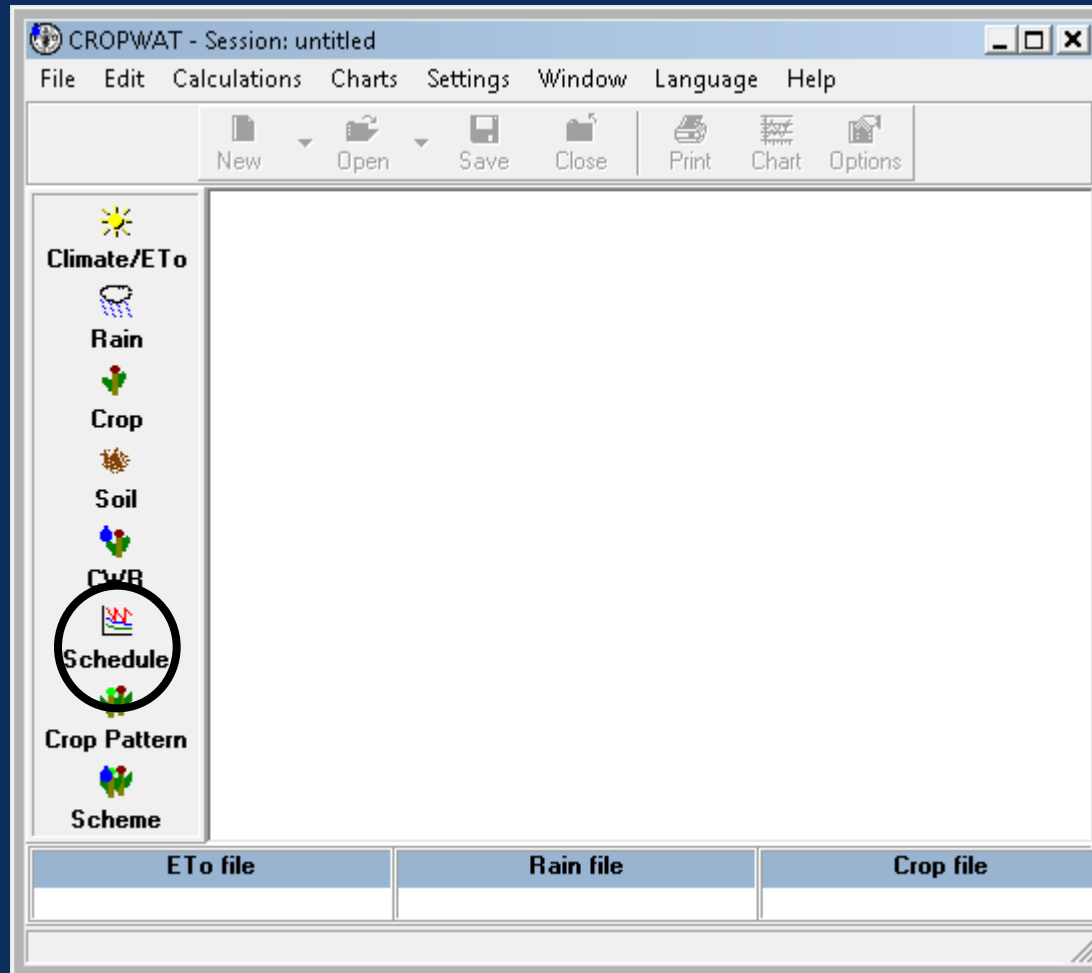
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.	ET	ET _g	ET _b
			coeff	mm/day	mm/dec	mm/dec	mm/dec	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.35	0.52	0.5	1.5	0.5	0.5	0.5	0
Apr	2	Init	0.35	0.62	6.2	14.1	0	6.2	6.2	0
Apr	3	Init	0.35	0.72	7.2	15.2	0	7.2	7.2	0
May	1	Init	0.35	0.83	8.3	16.6	0	8.3	8.3	0
May	2	Init	0.35	0.93	9.3	17.5	0	9.3	9.3	0
May	3	Deve	0.36	1	11	18.5	0	11	11	0
Jun	1	Deve	0.51	1.51	15.1	19.5	0	15.1	15.1	0
Jun	2	Deve	0.73	2.25	22.5	20.5	2	22.5	20.5	2
Jun	3	Deve	0.95	2.9	29	21.1	7.9	29	21.1	7.9
Jul	1	Mid	1.17	3.52	35.2	22.1	13.1	35.2	22.1	13.1
Jul	2	Mid	1.23	3.67	36.7	22.9	13.8	36.7	22.9	13.8
Jul	3	Mid	1.23	3.59	39.5	21.9	17.6	39.5	21.9	17.6
Aug	1	Mid	1.23	3.5	35	20.3	14.7	35	20.3	14.7
Aug	2	Mid	1.23	3.41	34.1	19.3	14.8	34.1	19.3	14.8
Aug	3	Late	1.22	2.97	32.7	19.8	12.9	32.7	19.8	12.9
Sep	1	Late	1.11	2.33	23.3	20.6	2.7	23.3	20.6	2.7
Sep	2	Late	0.98	1.73	17.3	21.1	0	17.3	17.3	0
Sep	3	Late	0.86	1.27	12.7	20.8	0	12.7	12.7	0
Oct	1	Late	0.76	0.91	5.5	12.2	0	5.5	5.5	0
Total					381	346	100	381	282	100

Growing period



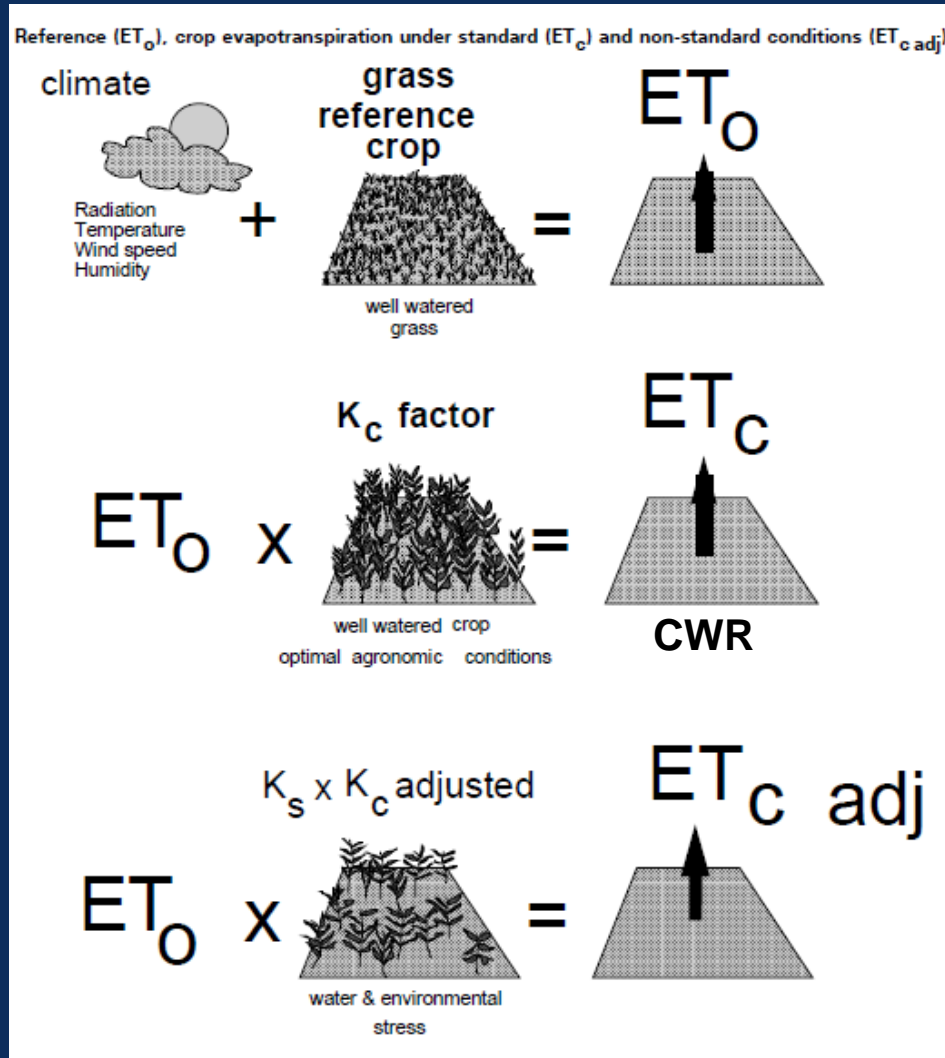


2. Irrigation schedule option



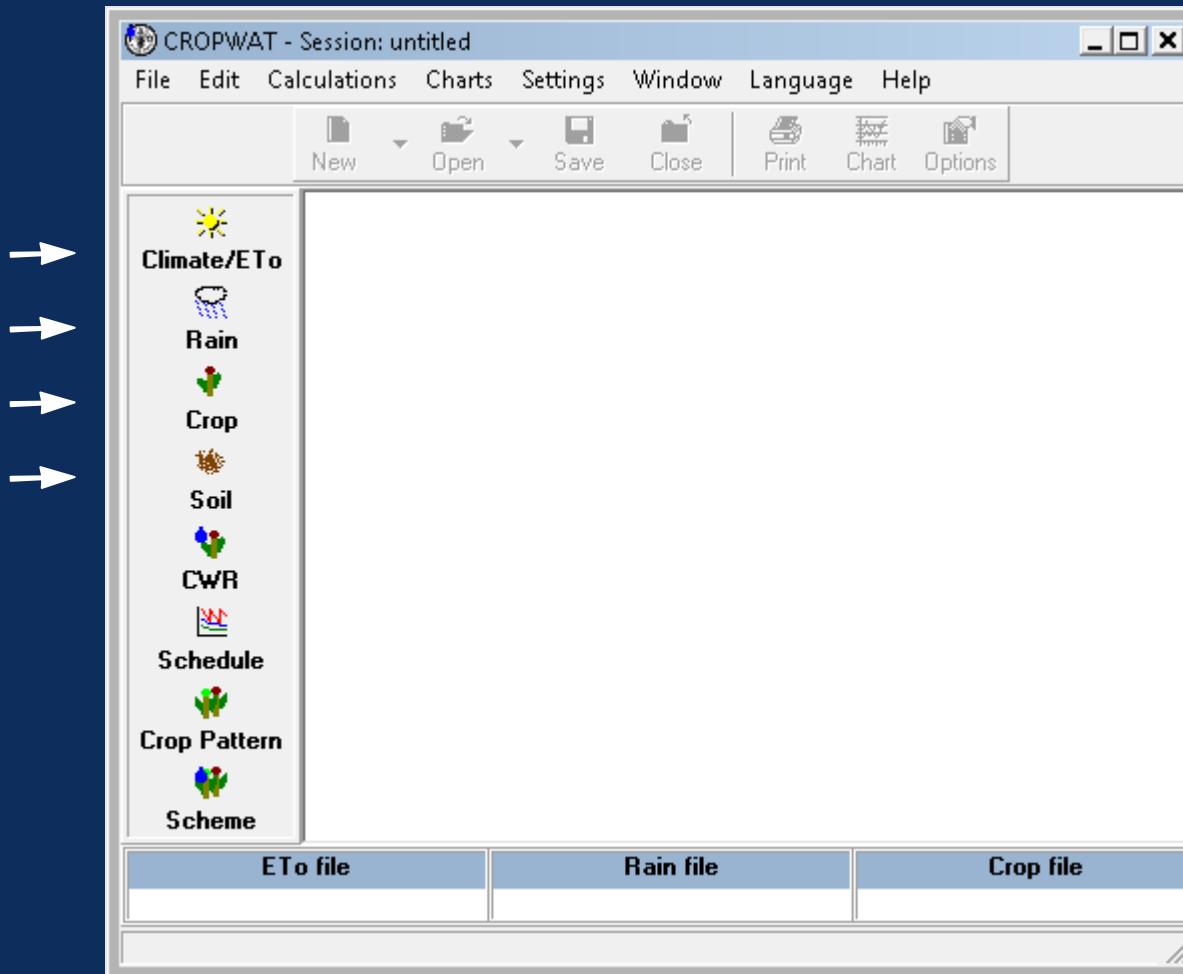


2. Irrigation schedule option





2. Irrigation schedule option input





Soil data (FAO, 2009a)

Soil - C:\ProgramData\CROPWAT\data\soils\FAO\MEDIUM.SOI

Soil name:

General soil data

Total available soil moisture (FC - WP)	<input type="text" value="290.0"/>	mm/meter
Maximum rain infiltration rate	<input type="text" value="40"/>	mm/day
Maximum rooting depth	<input type="text" value="900"/>	centimeters
Initial soil moisture depletion (as % TAM)	<input type="text" value="0"/>	%
Initial available soil moisture	<input type="text" value="290.0"/>	mm/meter





Soil data (FAO, 2009a)

Field Capacity (FC)

- The amount of moisture that remains in the soil after the excess water has drained away.
- FC varies with soil type

Wilting Point (WP)

- The minimum amount of soil moisture required for a plant to remain upright.
- If soil contains less moisture than the wilting point for that plant, it will wilt, but can recover.

Total Available Water

- Water held in the soil available to plants
- Difference between the water content at field capacity and wilting point

Readily Available Water

- Fraction of TAW that a crop can extract from the root zone without suffering water stress



Actual evapotranspiration

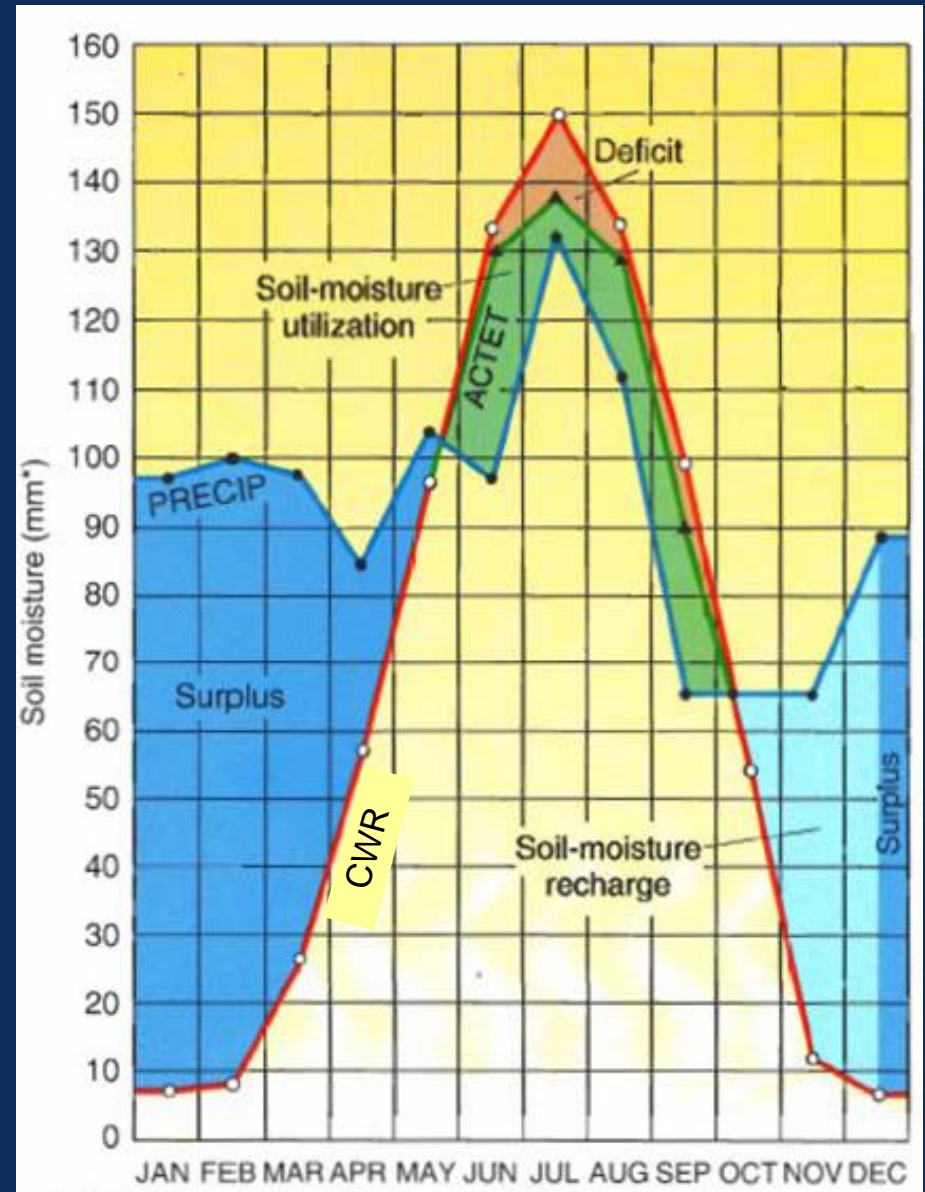
Reference
evapotranspiration
 ET_o



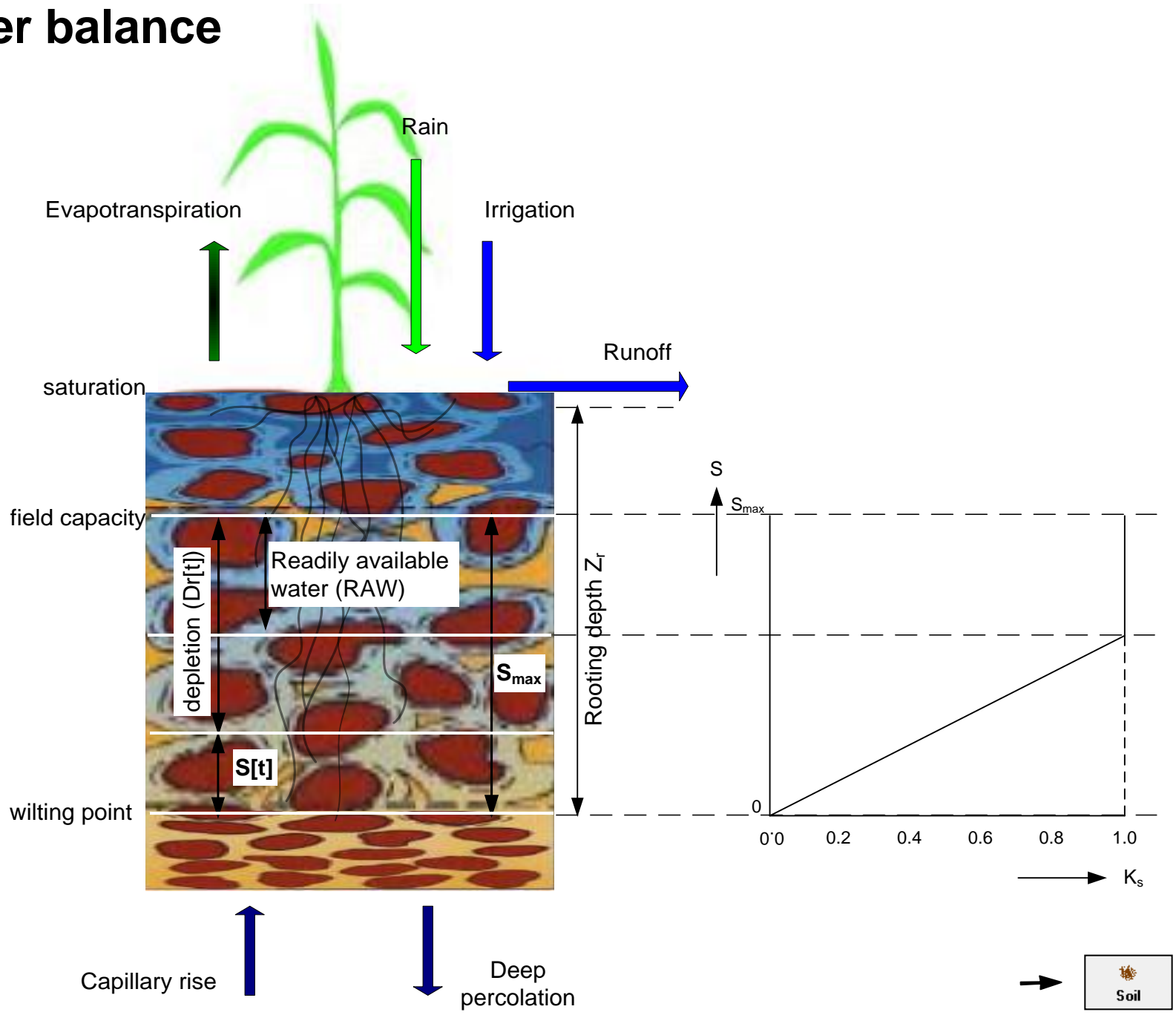
Crop water requirement
CWR
 $CWR = ET_o \times K_c$



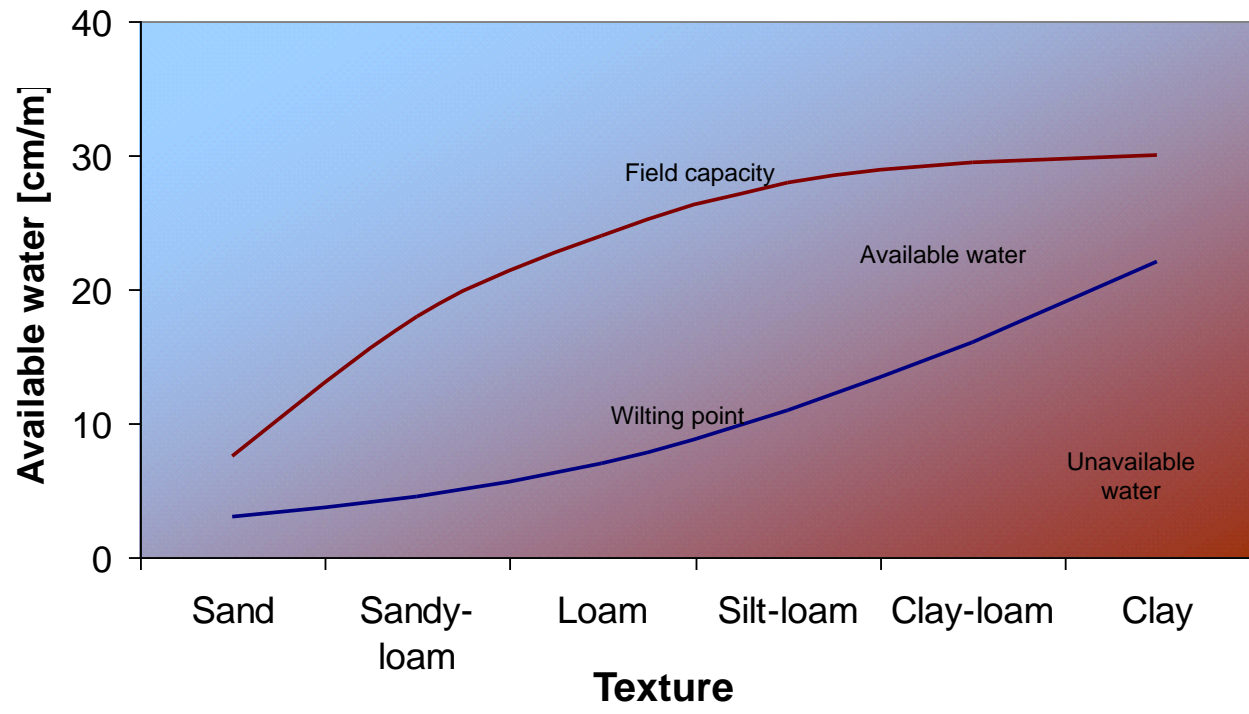
Actual
evapotranspiration ET_a
 $ET_a = CWR \times K_s$



Soil water balance

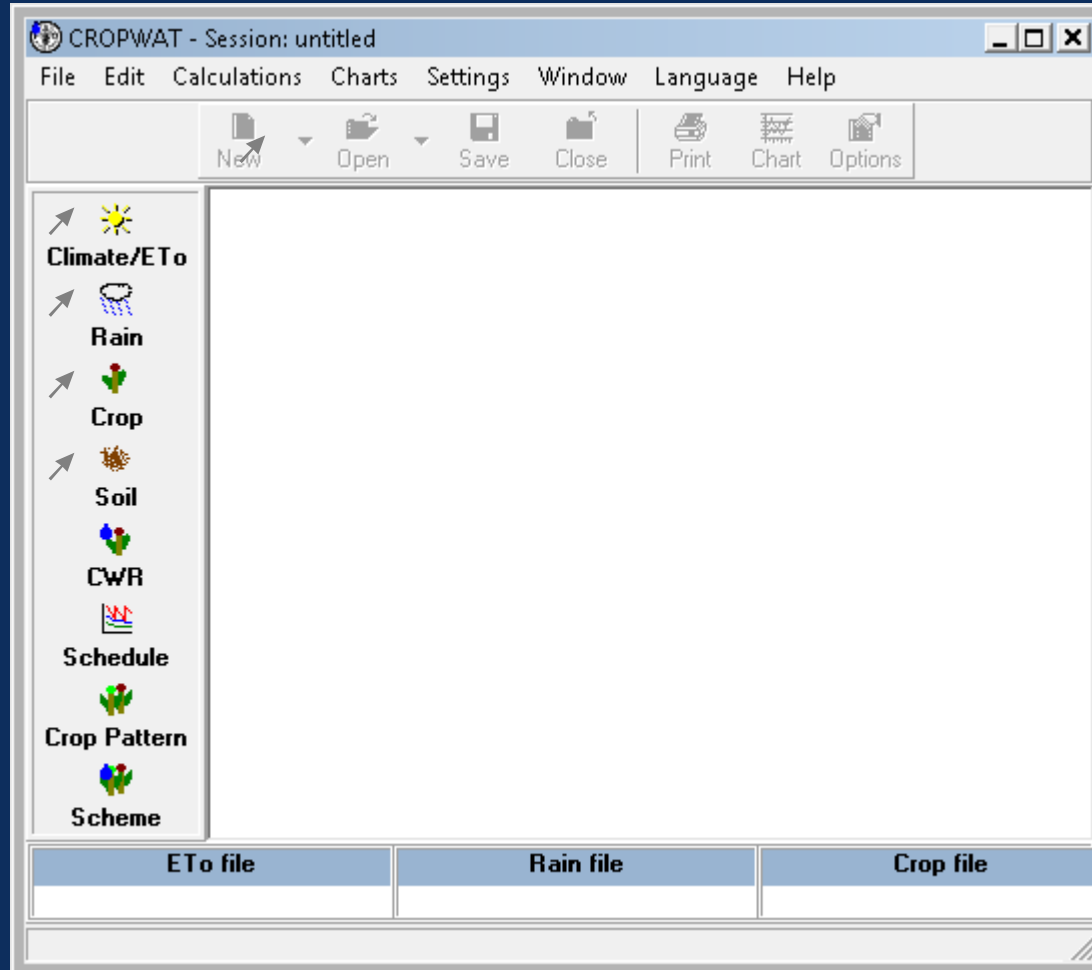


Soil water balance



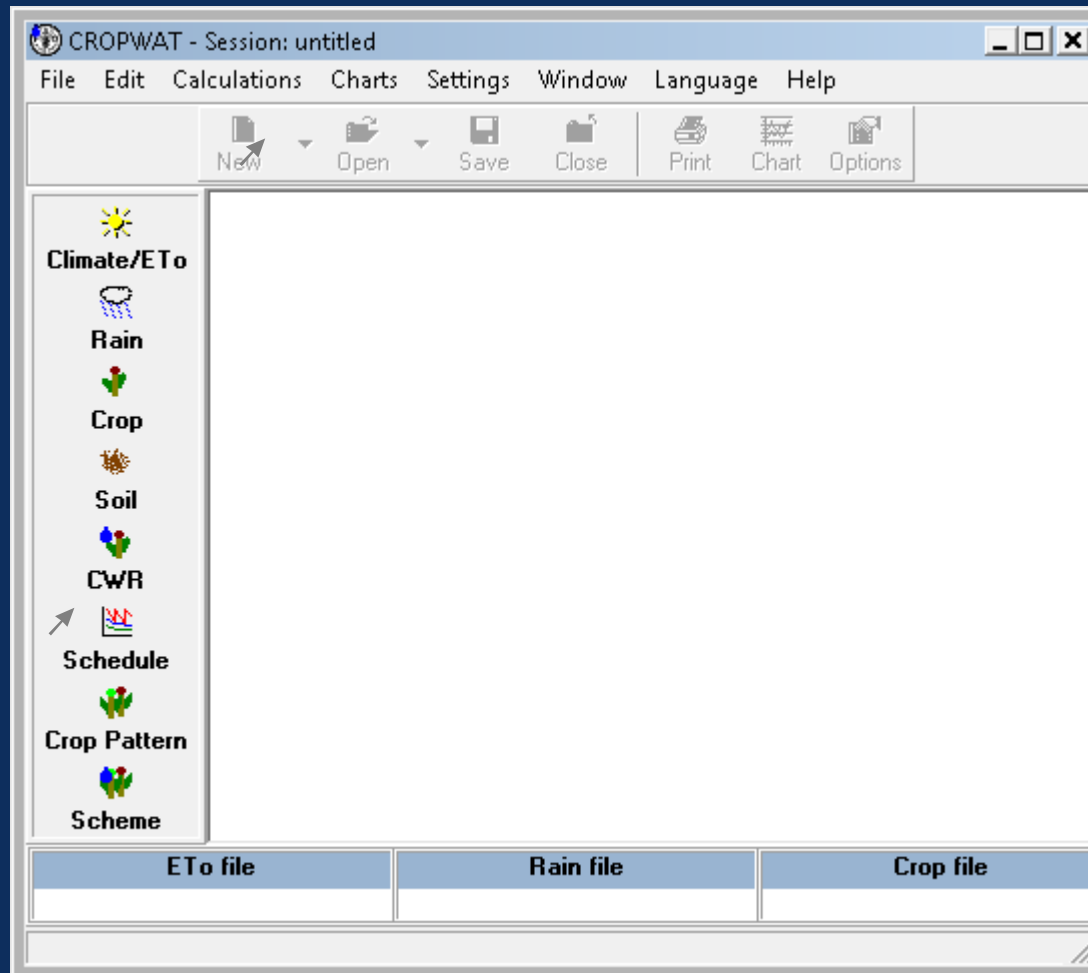


2. Irrigation schedule option – input





2. Irrigation schedule option – output





2. Irrigation schedule option - output

Crop irrigation schedule

ETo station GRONINGEN-AP-EELD **Crop** Sugarbeet **Planting date** 10/04 **Yield red.**
Rain station GRONINGEN-AP-EELD **Soil** Medium (loam) **Harvest date** 06/10 **0.0 %**

Table format:
 Irrigation schedule
 Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr
			mm	fract.	mm/day	%	mm	mm	mm	mm
10 Apr	1	Init	0.0	1.00	0.5	1	0.0	0.5	0.0	0.0
11 Apr	2	Init	0.0	1.00	0.6	1	0.0	1.1	0.0	0.0
12 Apr	3	Init	0.0	1.00	0.6	2	0.0	1.8	0.0	0.0
13 Apr	4	Init	7.6	1.00	0.6	1	0.0	0.6	0.0	0.0
14 Apr	5	Init	0.0	1.00	0.6	1	0.0	1.2	0.0	0.0
15 Apr	6	Init	0.0	1.00	0.6	2	0.0	1.8	0.0	0.0
16 Apr	7	Init	0.0	1.00	0.6	2	0.0	2.5	0.0	0.0
17 Apr	8	Init	7.6	1.00	0.6	1	0.0	0.6	0.0	0.0
18 Apr	9	Init	0.0	1.00	0.6	1	0.0	1.2	0.0	0.0

Totals

Total gross irrigation	0.0 mm	Total rainfall	383.0 mm
Total net irrigation	0.0 mm	Effective rainfall	319.5 mm
Total irrigation losses	0.0 mm	Total rain loss	63.4 mm
Actual water use by crop	380.3 mm	Moist deficit at harvest	60.8 mm
Potential water use by crop	380.3 mm	Actual irrigation requirement	60.8 mm
Efficiency irrigation schedule	- %	Efficiency rain	83.4 %
Deficiency irrigation schedule	0.0 %		

Yield reductions

Stagelabel	A	B	C	D	Season
------------	---	---	---	---	--------





2. Irrigation schedule option - output

CROPWAT - Session: untitled

File Edit Calculations Charts Settings Window Language Help

New Open Save Close Print Chart Options

Crop irrigation schedule

ETo station: GRONINGEN-AP-EELD Crop: Sugarbeet Planting date: 10/04 Yield red.: 0.0 %
 Rain station: GRONINGEN-AP-EELD Soil: Medium (loam) Harvest date: 06/10

Table format:
 Irrigation schedule
 Daily soil moisture balance

Timing: Irrigate at critical depletion
 Application: Refill soil to field capacity
 Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr
			mm	fract.	mm/day	%	mm	mm	mm	mm
10 Apr	1	Init	0.0	1.00	0.5	1	0.0	0.5	0.0	0.0
11 Apr	2	Init	0.0	1.00	0.6	1	0.0	1.1	0.0	0.0
12 Apr	3	Init	0.0	1.00	0.6	2	0.0	1.8	0.0	0.0
13 Apr	4	Init	7.6	1.00	0.6	1	0.0	0.6	0.0	0.0
14 Apr	5	Init	0.0	1.00	0.6	1	0.0	1.2	0.0	0.0
15 Apr	6	Init	0.0	1.00	0.6	2	0.0	1.8	0.0	0.0
16 Apr	7	Init	0.0	1.00	0.6	2	0.0	2.5	0.0	0.0
17 Apr	8	Init	7.6	1.00	0.6	1	0.0	0.6	0.0	0.0
18 Apr	9	Init	0.0	1.00	0.6	1	0.0	1.2	0.0	0.0

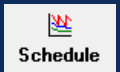
Totals

Total gross irrigation	0.0	mm	Total rainfall	383.0	mm
Total net irrigation	0.0	mm	Effective rainfall	319.5	mm
Total irrigation losses	0.0	mm	Total rain loss	63.4	mm
Actual water use by crop	380.3	mm	Moist deficit at harvest	60.8	mm
Potential water use by crop	380.3	mm	Actual irrigation requirement	60.8	mm
Efficiency irrigation schedule	-	%	Efficiency rain	83.4	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Stagelabel	A	B	C	D	Season

Schedule





2. Irrigation schedule option - output

Rainfed conditions

$$ET_{green} (irr = 0) = ET_{tot} (irr = 0)$$

$$ET_{blue} (irr = 0) = 0$$

Irrigated conditions

$$ET_{green} (irr = 1) = ET_{green} (irr = 0)$$

$$ET_{blue} (irr = 1) = ET_{tot} (irr = 1) - ET_{green} (irr = 0)$$

Rainfed scenario ($irr = 0$)

CROPWAT options
Non-rice crop scheduling

Scheduling criteria for non-rice crops

Irrigation timing
No irrigation (rainfed) [v]
No irrigation (only rainfall)

Irrigation application
Refill soil to field capacity [v]
Refill soil moisture content to 100% field capacity

Irrigation efficiency
Irrigation efficiency: 70 %

Save as default Reset to FAO defaults OK Cancel Help

Irrigated scenario ($irr = 1$)

CROPWAT options
Non-rice crop scheduling

Scheduling criteria for non-rice crops

Irrigation timing
Irrigate at critical depletion [v]
Irrigation at 100% critical depletion

Irrigation application
Refill soil to field capacity [v]
Refill soil moisture content to 100% field capacity

Irrigation efficiency
Irrigation efficiency: 70 %

Save as default Reset to FAO defaults OK Cancel Help



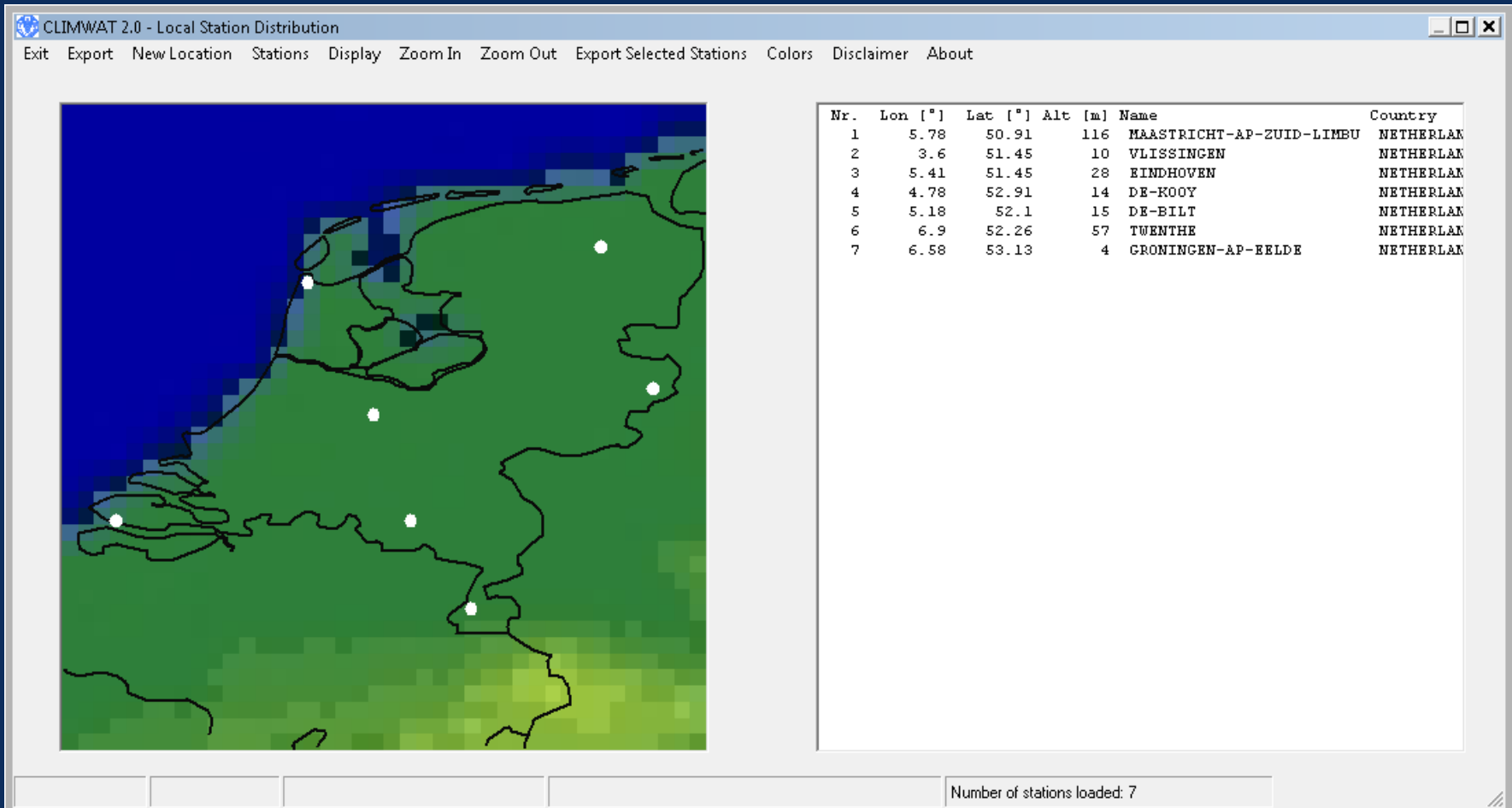
Calculating the process water footprint of growing a crop: An example for sugar beet in Northern Netherlands





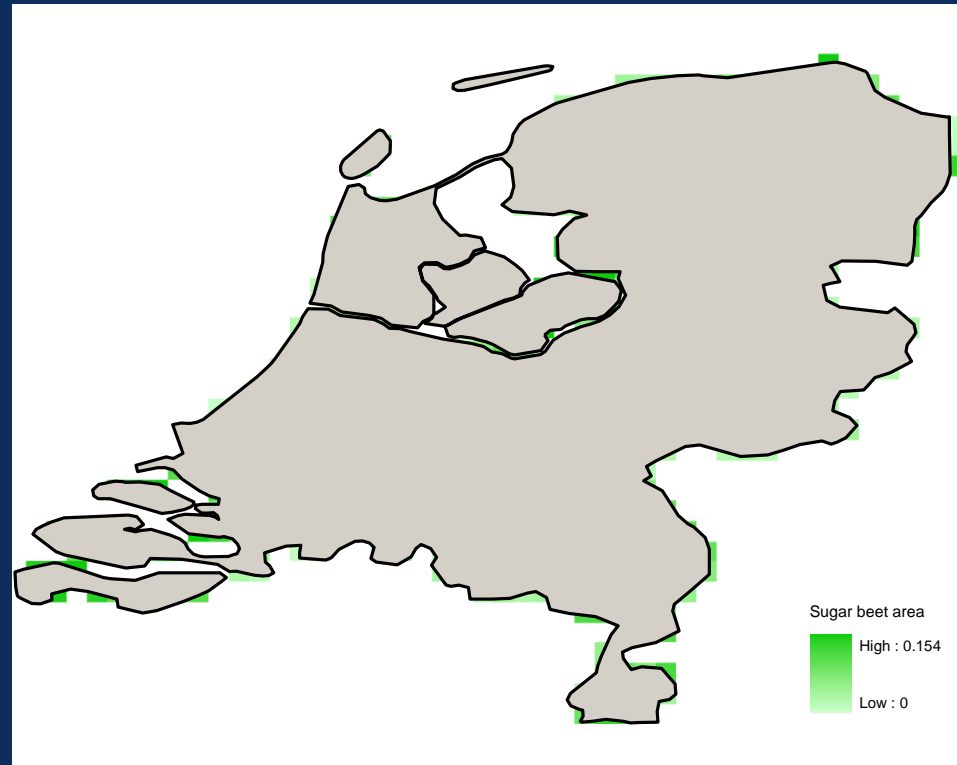
Climate data - CLIMWAT database (FAO, 2006)

Observed agroclimatic data of over 5000 stations worldwide (tries to cover 1971-2000)





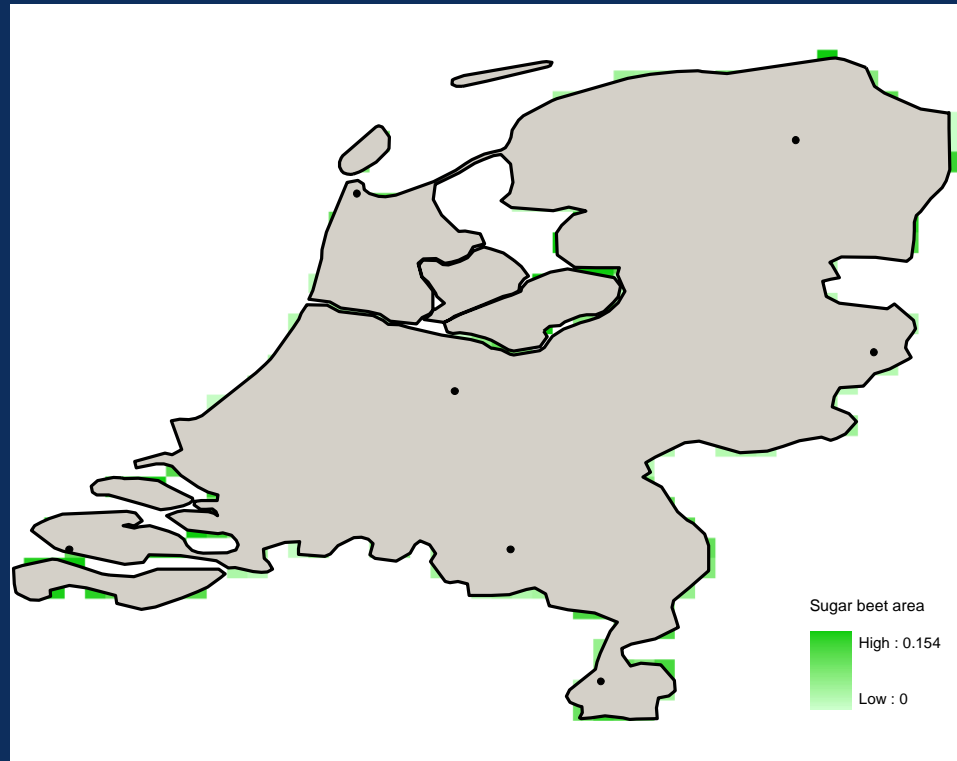
Crop distribution maps



Sugar beet harvested area in the Netherlands
(unit: proportion of grid cell area) Source: Monfreda et al. (2008)



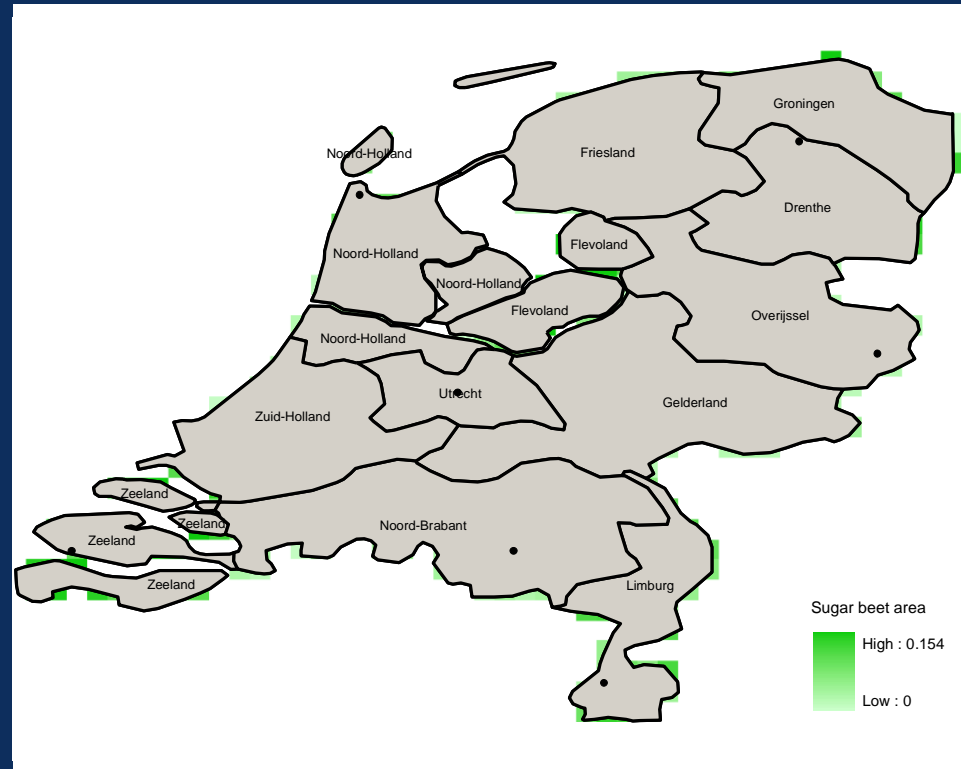
Crop distribution maps – Climate data



Climate stations (dots) and sugar beet harvested area in the Netherlands
(unit: proportion of grid cell area) Source: FAO (2006) Monfreda et al. (2008)



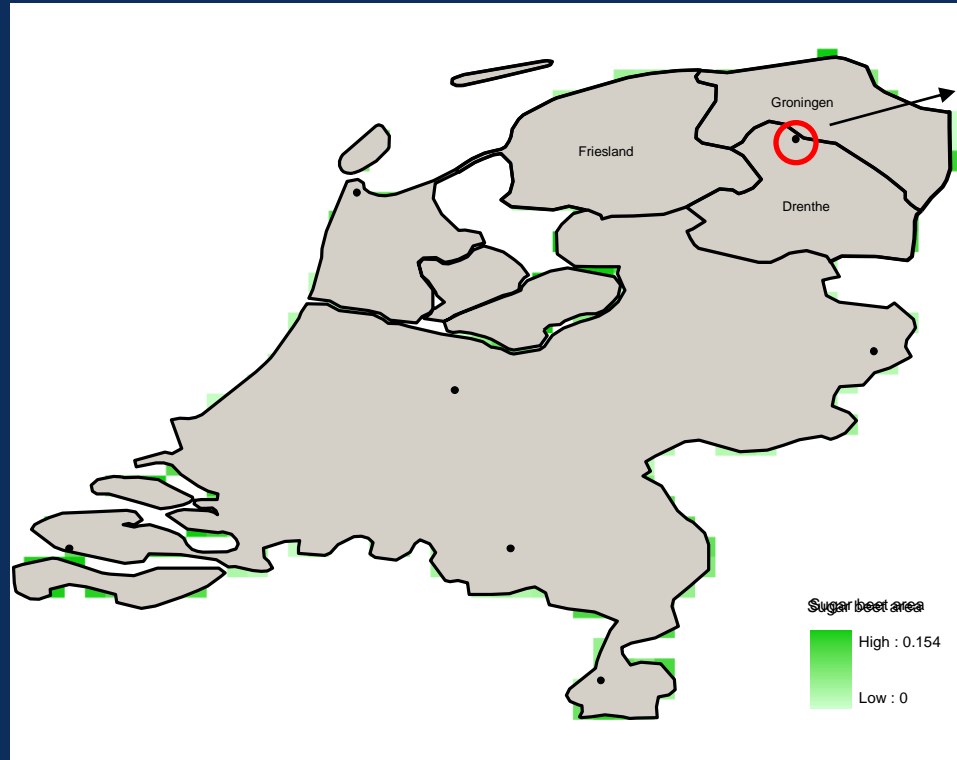
Crop distribution maps – Climate data



Climate stations (dots) and sugar beet harvested area in the Netherlands
(unit: proportion of grid cell area) Source: FAO (2006) Monfreda et al. (2008)



Crop distribution maps – Climate data



Groningen Ap Eelde

Climate stations (dots) and sugar beet harvested area in the Netherlands
(unit: proportion of grid cell area) Source: FAO (2006) Monfreda et al. (2008)



Climate data - CLIMWAT

.CLI

GRONINGEN-AP-EELDE.cli - Notepad			
File	Edit	Format	View Help
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0.21	66.60	59.50	
0.39	45.20	41.93	
0.86	57.50	52.21	
1.58	48.20	44.48	
2.43	57.80	52.45	
2.82	68.80	61.23	
2.75	76.30	66.99	
2.53	66.40	59.35	
1.59	70.60	62.63	
0.83	68.70	61.15	
0.44	77.10	67.59	
0.22	75.50	66.38	

ET₀
(mm/day)

Monthly
rainfall
(mm/month)

Monthly
effective rainfall**
(mm/month)

*Penman-Monteith method

**USDA Soil Conservation Service formula

.PEN

GRONINGEN-AP-EELDE.pen - Notepad							
File	Edit	Format	View	Help			
"Location 7", "GRONINGEN-AP-EELDE", 4, 53.13, "N.L.", 6.58, " 01"							
3.7	-1.5	95.4	457.9	0.45	2.06	0.21	
4.5	-1.4	91.9	423.4	2.05	4.60	0.39	
7.9	0.5	86.7	449.3	2.85	7.93	0.86	
11.8	2.5	81.7	397.4	5.01	13.22	1.58	
16.6	6.3	79.1	354.2	6.22	17.06	2.43	
19.5	9.3	80.6	345.6	6.11	17.95	2.82	
20.7	10.9	83.0	354.2	5.71	16.92	2.75	
21.2	10.8	82.5	319.7	5.83	15.05	2.53	
18.2	8.7	87.2	337.0	4.06	10.18	1.59	
13.7	5.9	90.8	354.2	2.45	5.78	0.83	
8.3	2.3	92.5	440.6	1.06	2.77	0.44	
4.9	-0.2	95.7	449.3	0.13	1.53	0.22	

Mean daily
maximum
temp. (°C)

Mean daily
minimum
temp. (°C)

Mean
relative
humidity (%)

Mean wind
speed
(km/day)

Mean
sunshine
hours per
day

Mean solar
radiation
(MJ/m²/day)

ET
(mm)





Crop parameters for sugar beet

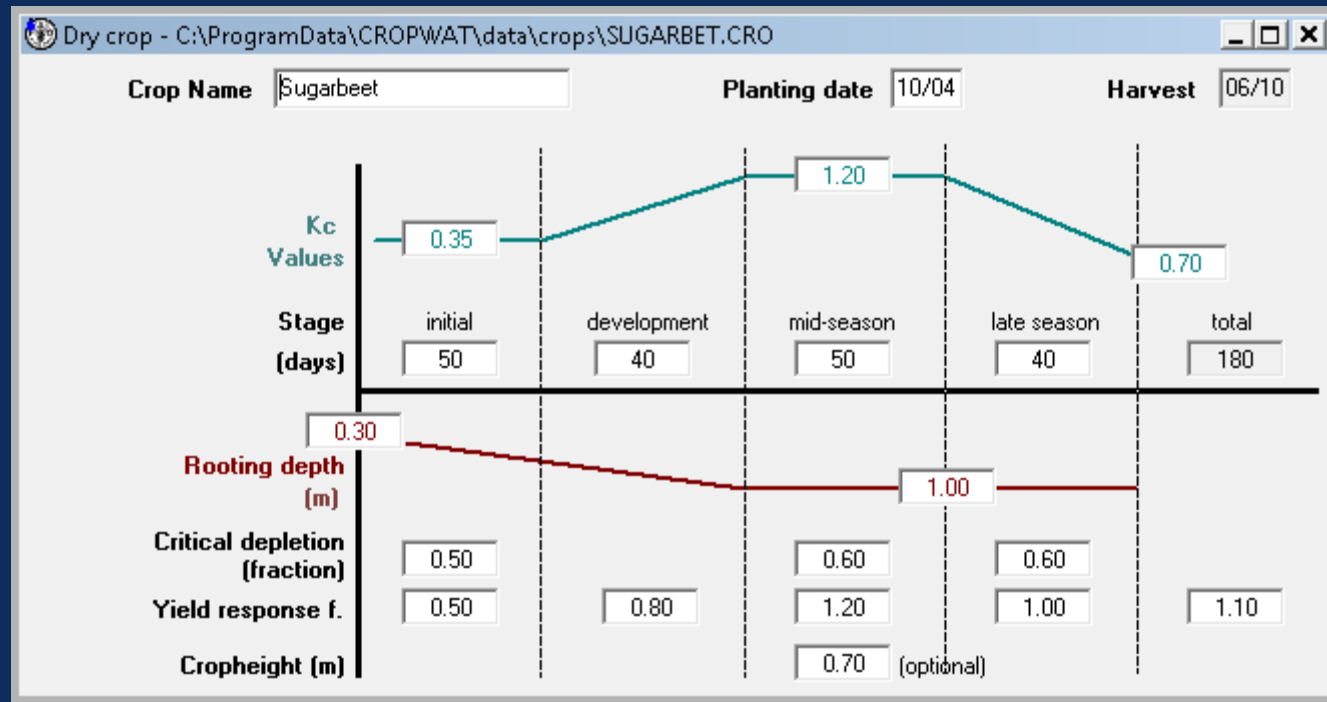
Source	Level	Kc ini	Kc mid	Kc end	Initial stage	Dev stage	Mid stage	Late stage	Planting/ Green up date	Rooting depth (m)	Critical depletion level (p)	Yield response factor (Ky)
Chapagain and Hoekstra (2004)	Per Climate Region	0.35	1.20	0.70	50	40	50	40	1 April			
Allen et al. (1998)	Per region	0.35	1.20	0.70	50	40	50	40	April			
CROPWAT (FAO, 2009a)	Global	0.35	1.20	0.70	25	35	50	50		0.3-1	0.5-0.6-0.6	0.5-0.8-1.2-1-1.1
IRS (2009)*	Local								10 April			

*Institute of Sugar Beet Research in the Netherlands



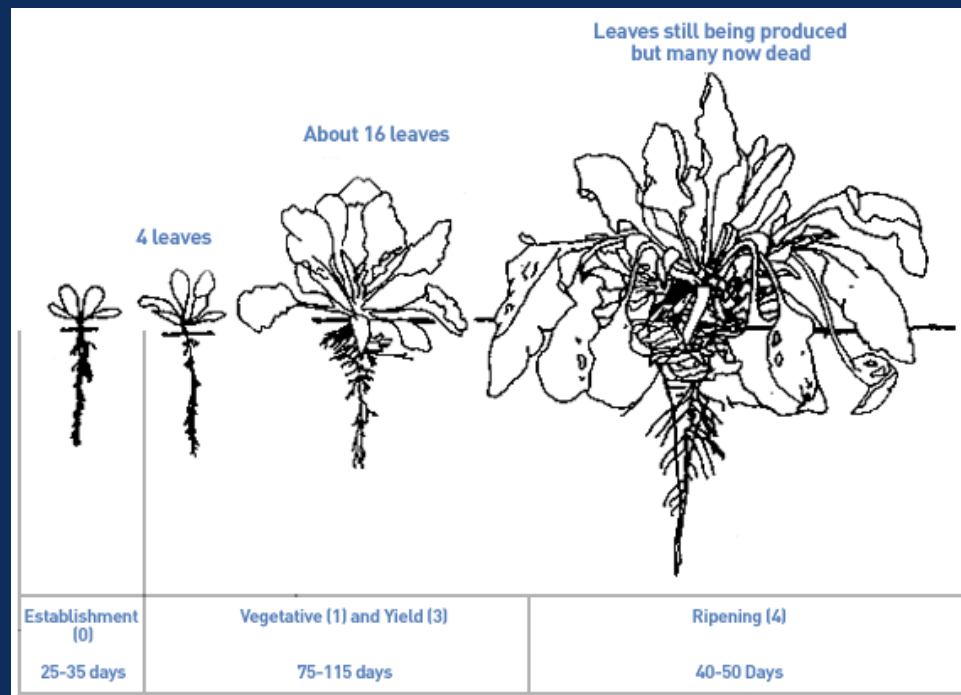


Crop parameters for sugar beet





Crop parameters for sugar beet





Crop parameters for sugarbeet

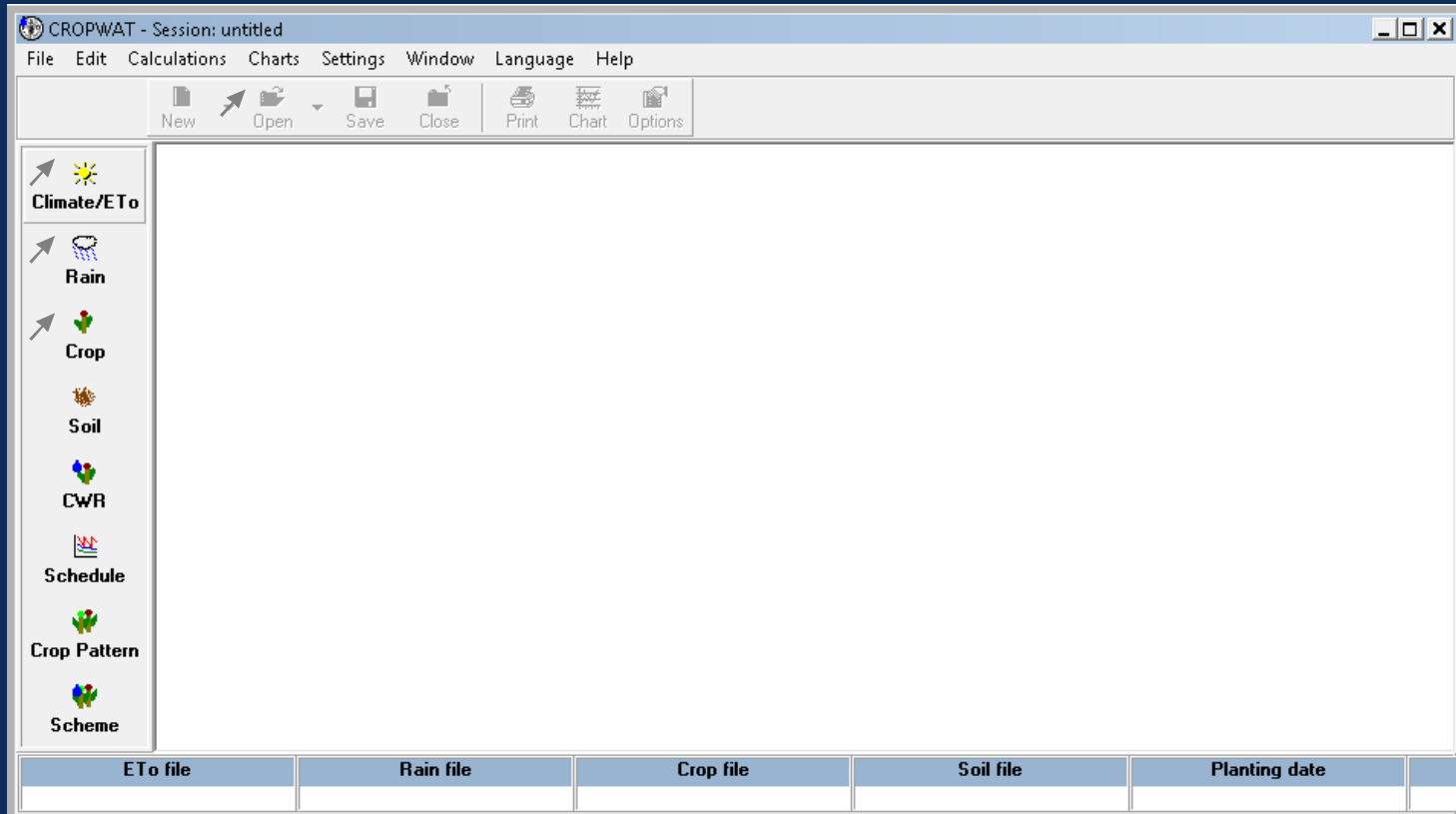
```
SUGARBET.CRO - Notepad
File Edit Format View Help
CROPWAT 8.0 Crop data
Sugarbeet
50 40 50 40
 0.35 1.20 0.70
 0.30 1.00
 0.50 0.60 0.60
 0.50 0.80 1.20 1.00 1.10
 0.70
```

- Crop length of the growing season
- Crop coefficients (Kc init, Kc mid, Kc end)
- Rooting depth (m)
- Critical depletion level (P)
- Yield response factor (Ky)
- Height (provide if available)



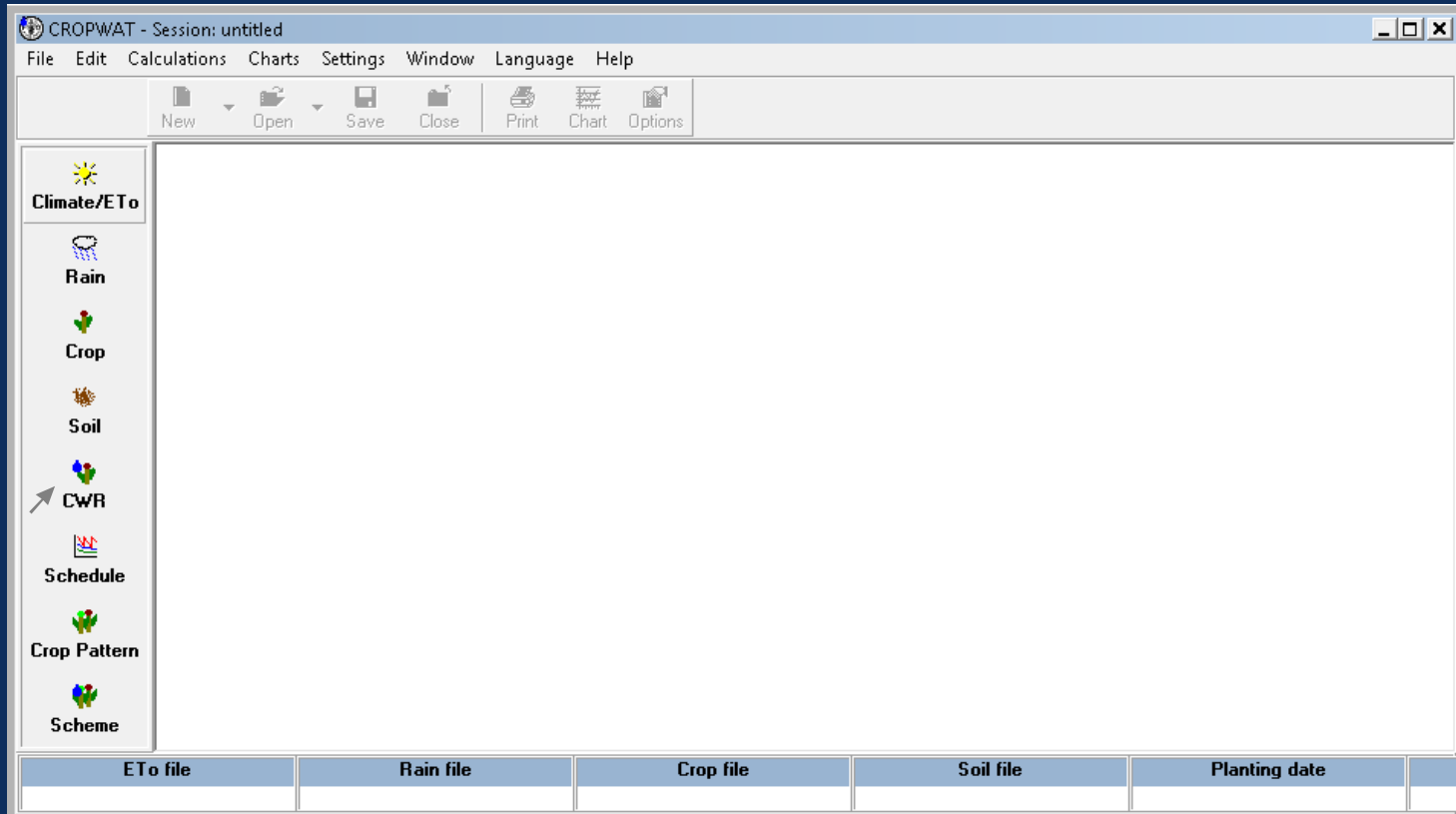


1. CWR option - input





1. CWR option - output





1. CWR option - output

Crop Water Requirements

ETo station: GRONINGEN-AP-EELD Crop: Sugarbeet

Rain station: GRONINGEN-AP-EELD Planting date: 10/04

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.35	0.52	0.5	1.5	0.5
Apr	2	Init	0.35	0.62	6.2	14.1	0.0
Apr	3	Init	0.35	0.72	7.2	15.2	0.0
May	1	Init	0.35	0.83	8.3	16.6	0.0
May	2	Init	0.35	0.93	9.3	17.5	0.0
May	3	Deve	0.36	1.00	11.0	18.5	0.0
Jun	1	Deve	0.51	1.51	15.1	19.5	0.0
Jun	2	Deve	0.73	2.25	22.5	20.5	2.0
Jun	3	Deve	0.95	2.90	29.0	21.1	7.9
Jul	1	Mid	1.17	3.52	35.2	22.1	13.1
Jul	2	Mid	1.23	3.67	36.7	22.9	13.8
Jul	3	Mid	1.23	3.59	39.5	21.9	17.6
Aug	1	Mid	1.23	3.50	35.0	20.3	14.7
Aug	2	Mid	1.23	3.41	34.1	19.3	14.8
Aug	3	Late	1.22	2.97	32.7	19.8	12.9
Sep	1	Late	1.11	2.33	23.3	20.6	2.7
Sep	2	Late	0.98	1.73	17.3	21.1	0.0
Sep	3	Late	0.86	1.27	12.7	20.8	0.0
Oct	1	Late	0.76	0.91	5.5	12.2	0.0
					381.2	345.6	100.1

$$IR = ETc - P_{eff}$$





1. CWR option - output

Crop Water Requirements

ETo station: GRONINGEN-AP-EELD Crop: Sugarbeet

Rain station: GRONINGEN-AP-EELD Planting date: 10/04

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.35	0.52	0.5	1.5	0.5
Apr	2	Init	0.35	0.62	6.2	14.1	0.0
Apr	3	Init	0.35	0.72	7.2	15.2	0.0
May	1	Init	0.35	0.83	8.3	16.6	0.0
May	2	Init	0.35	0.93	9.3	17.5	0.0
May	3	Deve	0.36	1.00	11.0	18.5	0.0
Jun	1	Deve	0.51	2.25	22.5	21.1	0.0
Jun	2	Deve	0.73	2.90	29.0	21.1	2.0
Jun	3	Deve	0.95	2.90	29.0	21.1	7.9
Jul	1	Mid	1.17	3.52	35.2	22.1	13.1
Jul	2	Mid	1.23	3.67	36.7	22.9	13.8
Jul	3	Mid	1.23	3.59	39.5	21.9	17.6
Aug	1	Mid	1.23	3.50	35.0	20.3	14.7
Aug	2	Mid	1.23	3.41	34.1	19.3	14.8
Aug	3	Late	1.22	2.97	32.7	19.8	12.9
Sep	1	Late	1.11	2.33	23.3	20.6	2.7
Sep	2	Late	0.98	1.73	17.3	21.1	0.0
Sep	3	Late	0.86	1.27	12.7	20.8	0.0
Oct	1	Late	0.76	0.91	5.5	12.2	0.0
					381.2	345.6	100.1



1. CWR option - output

$$ET = ET_c$$

$$ET_g = \min(ET_c, P_{eff})$$

$$ET_b = \max(0, ET_c - P_{eff}) * \text{Irr. fraction}$$

Growing period

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec	ET mm/dec	ET _g mm/dec	ET _b mm/dec
Apr	1	Init	0.35	0.52	0.5	1.5	0.5	0.5	0.5	0
Apr	2	Init	0.35	0.62	6.2	14.1	0	6.2	6.2	0
Apr	3	Init	0.35	0.72	7.2	15.2	0	7.2	7.2	0
May	1	Init	0.35	0.83	8.3	16.6	0	8.3	8.3	0
May	2	Init	0.35	0.93	9.3	17.5	0	9.3	9.3	0
May	3	Deve	0.36	1	11	18.5	0	11	11	0
Jun	1	Deve	0.51	1.51	15.1	19.5	0	15.1	15.1	0
Jun	2	Deve	0.73	2.25	22.5	20.5	2	22.5	20.5	2
Jun	3	Deve	0.95	2.9	29	21.1	7.9	29	21.1	7.9
Jul	1	Mid	1.17	3.52	35.2	22.1	13.1	35.2	22.1	13.1
Jul	2	Mid	1.23	3.67	36.7	22.9	13.8	36.7	22.9	13.8
Jul	3	Mid	1.23	3.59	39.5	21.9	17.6	39.5	21.9	17.6
Aug	1	Mid	1.23	3.5	35	20.3	14.7	35	20.3	14.7
Aug	2	Mid	1.23	3.41	34.1	19.3	14.8	34.1	19.3	14.8
Aug	3	Late	1.22	2.97	32.7	19.8	12.9	32.7	19.8	12.9
Sep	1	Late	1.11	2.33	23.3	20.6	2.7	23.3	20.6	2.7
Sep	2	Late	0.98	1.73	17.3	21.1	0	17.3	17.3	0
Sep	3	Late	0.86	1.27	12.7	20.8	0	12.7	12.7	0
Oct	1	Late	0.76	0.91	5.5	12.2	0	5.5	5.5	0
Total					381	346	100	381	282	100





1. CWR option

Water footprint estimation

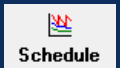
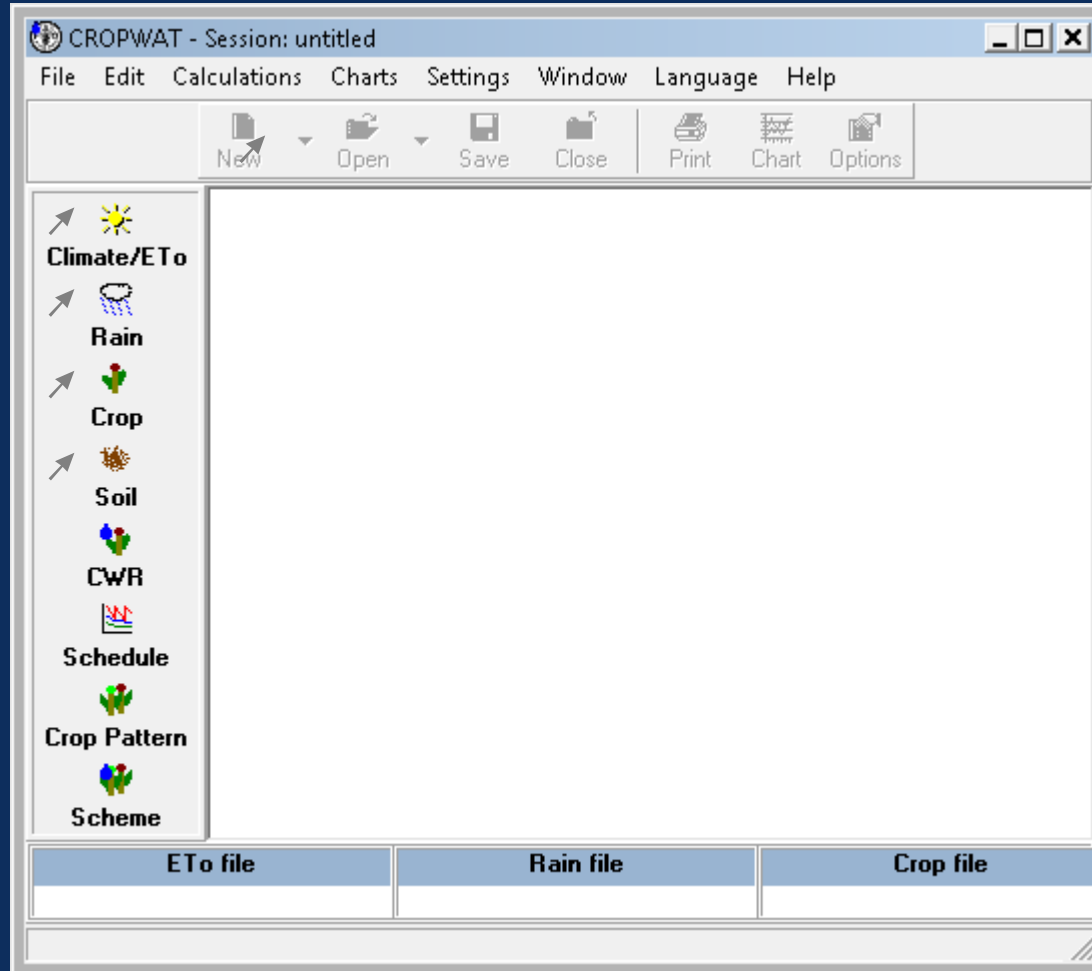
ET_g	ET_b	ET	CWU_g	CWU_b	CWU	Y^*	$WF_{proc,green}$	$WF_{proc,blue}$	WF_{proc}
mm/period			m^3/ha			ton/ha	m^3/ton		
282	100	381	2816	995	3811	59	48	17	65

*IRS (1999-2006) for Northern Netherlands





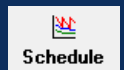
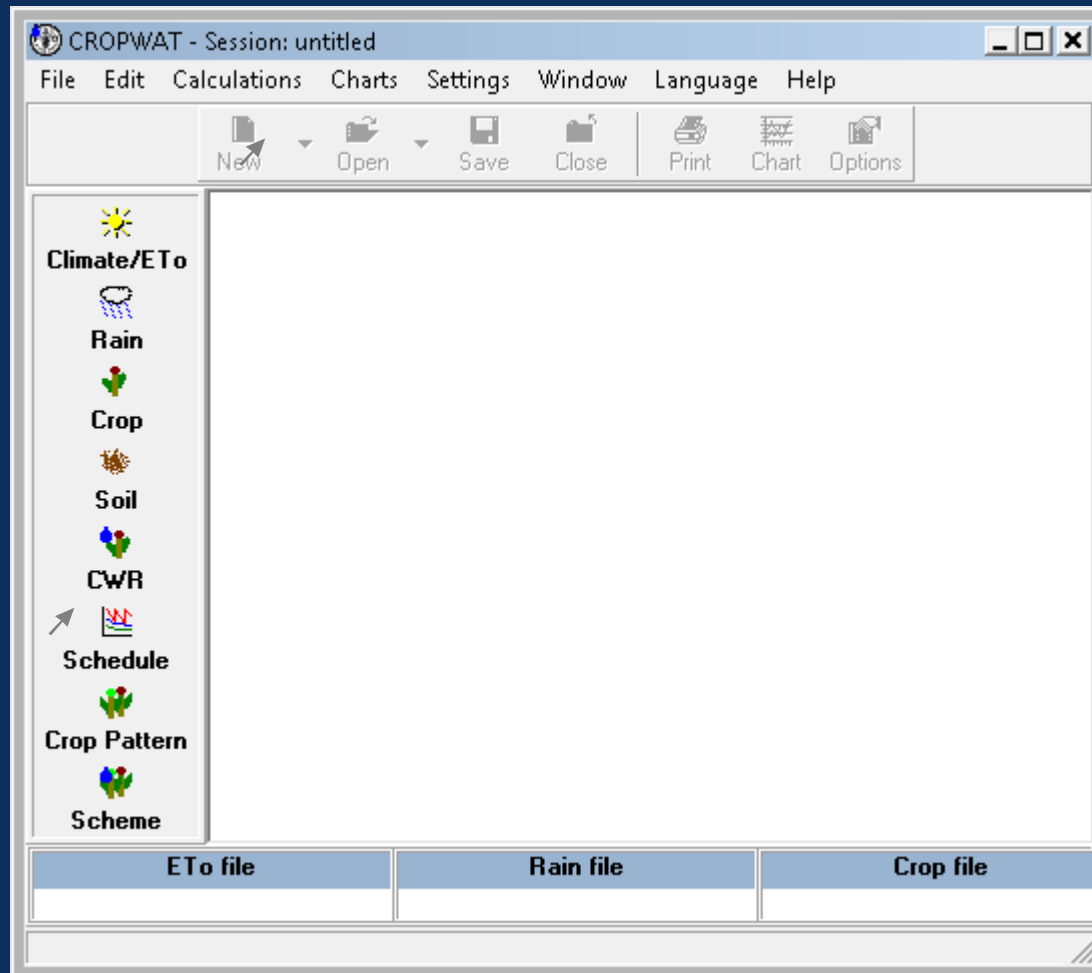
2. Irrigation schedule option – input



Schedule



2. Irrigation schedule option – output



Schedule



2. Irrigation schedule option - output

Crop irrigation schedule

ETo station GRONINGEN-AP-EELD **Crop** Sugarbeet **Planting date** 10/04 **Yield red.**
Rain station GRONINGEN-AP-EELD **Soil** Medium (loam) **Harvest date** 06/10 **0.0 %**

Table format:
 Irrigation schedule
 Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr
			mm	fract.	mm/day	%	mm	mm	mm	mm
10 Apr	1	Init	0.0	1.00	0.5	1	0.0	0.5	0.0	0.0
11 Apr	2	Init	0.0	1.00	0.6	1	0.0	1.1	0.0	0.0
12 Apr	3	Init	0.0	1.00	0.6	2	0.0	1.8	0.0	0.0
13 Apr	4	Init	7.6	1.00	0.6	1	0.0	0.6	0.0	0.0
14 Apr	5	Init	0.0	1.00	0.6	1	0.0	1.2	0.0	0.0
15 Apr	6	Init	0.0	1.00	0.6	2	0.0	1.8	0.0	0.0
16 Apr	7	Init	0.0	1.00	0.6	2	0.0	2.5	0.0	0.0
17 Apr	8	Init	7.6	1.00	0.6	1	0.0	0.6	0.0	0.0
18 Apr	9	Init	0.0	1.00	0.6	1	0.0	1.2	0.0	0.0

Totals

Total gross irrigation	0.0 mm	Total rainfall	383.0 mm
Total net irrigation	0.0 mm	Effective rainfall	319.5 mm
Total irrigation losses	0.0 mm	Total rain loss	63.4 mm
Actual water use by crop	380.3 mm	Moist deficit at harvest	60.8 mm
Potential water use by crop	380.3 mm	Actual irrigation requirement	60.8 mm
Efficiency irrigation schedule	- %	Efficiency rain	83.4 %
Deficiency irrigation schedule	0.0 %		

Yield reductions

Stagelabel	A	B	C	D	Season
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2. Irrigation schedule option - output

CROPWAT - Session: untitled

File Edit Calculations Charts Settings Window Language Help

New Open Save Close Print Chart Options

Crop irrigation schedule

ETo station: GRONINGEN-AP-EELD Crop: Sugarbeet Planting date: 10/04 Yield red.: 0.0 %
 Rain station: GRONINGEN-AP-EELD Soil: Medium (loam) Harvest date: 06/10

Table format:
 Irrigation schedule
 Daily soil moisture balance

Timing: Irrigate at critical depletion
 Application: Refill soil to field capacity
 Field eff. 70 %

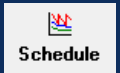
Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr
			mm	fract.	mm/day	%	mm	mm	mm	mm
10 Apr	1	Init	0.0	1.00	0.5	1	0.0	0.5	0.0	0.0
11 Apr	2	Init	0.0	1.00	0.6	1	0.0	1.1	0.0	0.0
12 Apr	3	Init	0.0	1.00	0.6	2	0.0	1.8	0.0	0.0
13 Apr	4	Init	7.6	1.00	0.6	1	0.0	0.6	0.0	0.0
14 Apr	5	Init	0.0	1.00	0.6	1	0.0	1.2	0.0	0.0
15 Apr	6	Init	0.0	1.00	0.6	2	0.0	1.8	0.0	0.0
16 Apr	7	Init	0.0	1.00	0.6	2	0.0	2.5	0.0	0.0
17 Apr	8	Init	7.6	1.00	0.6	1	0.0	0.6	0.0	0.0
18 Apr	9	Init	0.0	1.00	0.6	1	0.0	1.2	0.0	0.0

Totals

Total gross irrigation	0.0	mm	Total rainfall	383.0	mm
Total net irrigation	0.0	mm	Effective rainfall	319.5	mm
Total irrigation losses	0.0	mm	Total rain loss	63.4	mm
Actual water use by crop	380.3	mm	Moist deficit at harvest	60.8	mm
Potential water use by crop	380.3	mm	Actual irrigation requirement	60.8	mm
Efficiency irrigation schedule	-	%	Efficiency rain	83.4	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Stagelabel	A	B	C	D	Season





2. Irrigation schedule option - output

Rainfed conditions

$$ET_{green} (irr = 0) = ET_{tot} (irr = 0)$$

$$ET_{blue} (irr = 0) = 0$$

Irrigated conditions

$$ET_{green} (irr = 1) = ET_{green} (irr = 0)$$

$$ET_{blue} (irr = 1) = ET_{tot} (irr = 1) - ET_{green} (irr = 0)$$

Rainfed scenario ($irr = 0$)

CROPWAT options
Non-rice crop scheduling

Scheduling criteria for non-rice crops

Irrigation timing
No irrigation (rainfed) [v]
No irrigation (only rainfall)

Irrigation application
Refill soil to field capacity [v]

Irrigation efficiency
Irrigation efficiency: 70 %

Save as default Reset to FAO defaults OK Cancel Help

Irrigated scenario ($irr = 1$)

CROPWAT options
Non-rice crop scheduling

Scheduling criteria for non-rice crops

Irrigation timing
Irrigate at critical depletion [v]
Irrigation at 100% critical depletion

Irrigation application
Refill soil to field capacity [v]
Refill soil moisture content to 100% field capacity

Irrigation efficiency
Irrigation efficiency: 70 %

Save as default Reset to FAO defaults OK Cancel Help





2. Irrigation schedule option – output – Medium soil

Rainfed scenario ($irr = 0$)

Rainfed conditions

$$ET_{green}(irr = 0) = ET_{tot}(irr = 0)$$

$$ET_{blue}(irr = 0) = 0$$

Crop irrigation schedule

ETo station: GRONINGEN-AP-EELD Crop: Sugarbeet Planting date: 10/04 Yield red.: 0.0 %
 Rain station: GRONINGEN-AP-EELD Soil: Medium (loam) Harvest date: 06/10

Table format:
 Irrigation schedule
 Daily soil moisture balance

Timing: No irrigation (rainfed)
 Application: -
 Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr
			mm	fract.	mm/day	%	mm	mm	mm	mm
29 Sep	173	End	0.0	1.00	1.3	23	0.0	66.3	0.0	0.0
30 Sep	174	End	0.0	1.00	1.3	23	0.0	67.6	0.0	0.0
1 Oct	175	End	0.0	1.00	0.9	24	0.0	68.5	0.0	0.0
2 Oct	176	End	0.0	1.00	0.9	24	0.0	69.4	0.0	0.0
3 Oct	177	End	11.4	1.00	0.9	20	0.0	58.9	0.0	0.0
4 Oct	178	End	0.0	1.00	0.9	21	0.0	59.9	0.0	0.0
5 Oct	179	End	0.0	1.00	0.9	21	0.0	60.8	0.0	0.0
6 Oct	End	End	0.0	1.00	0.0	21				

Totals					
Total gross irrigation	0.0	mm	Total rainfall	383.0	mm
Total net irrigation	0.0	mm	Effective rainfall	319.5	mm
Total irrigation losses	0.0	mm	Total rain loss	63.4	mm
Actual water use by crop	380.3	mm	Moist deficit at harvest	60.8	mm
Potential water use by crop	380.3	mm	Actual irrigation requirement	60.8	mm
Efficiency irrigation schedule	-	%	Efficiency rain	83.4	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Stagelabel	A	B	C	D	Season





2. Irrigation schedule option – output – Medium soil

Irrigated scenario (*irr* = 1)

Crop irrigation schedule

ETo station: GRONINGEN-AP-EELD Crop: Sugarbeet Planting date: 10/04 Yield red.: 0.0 %
 Rain station: GRONINGEN-AP-EELD Soil: Medium (loam) Harvest date: 06/10

Table format:
 Irrigation schedule
 Daily soil moisture balance

Timing: Irrigate at critical depletion
 Application: Refill soil to field capacity
 Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr
			mm	fract.	mm/day	%	mm	mm	mm	mm
29 Sep	173	End	0.0	1.00	1.3	23	0.0	66.3	0.0	0.0
30 Sep	174	End	0.0	1.00	1.3	23	0.0	67.6	0.0	0.0
1 Oct	175	End	0.0	1.00	0.9	24	0.0	68.5	0.0	0.0
2 Oct	176	End	0.0	1.00	0.9	24	0.0	69.4	0.0	0.0
3 Oct	177	End	11.4	1.00	0.9	20	0.0	58.9	0.0	0.0
4 Oct	178	End	0.0	1.00	0.9	21	0.0	59.9	0.0	0.0
5 Oct	179	End	0.0	1.00	0.9	21	0.0	60.8	0.0	0.0
6 Oct	End	End	0.0	1.00	0.0	21				

Totals

Total gross irrigation	0.0	mm	Total rainfall	383.0	mm
Total net irrigation	0.0	mm	Effective rainfall	319.5	mm
Total irrigation losses	0.0	mm	Total rain loss	63.4	mm
Actual water use by crop	380.3	mm	Moist deficit at harvest	60.8	mm
Potential water use by crop	380.3	mm	Actual irrigation requirement	60.8	mm
Efficiency irrigation schedule	-	%	Efficiency rain	83.4	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Stagelabel	A	B	C	D	Season
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Irrigated conditions

$$ET_{green} (irr = 1) = ET_{green} (irr = 0)$$

$$ET_{blue} (irr = 1) = ET_{tot} (irr = 1) - ET_{green} (irr = 0)$$



2. Irrigation schedule option - output – Soil comparison

Light

Totals					
Total gross irrigation	110.4	mm	Total rainfall	383.0	mm
Total net irrigation	77.2	mm	Effective rainfall	300.0	mm
Total irrigation losses	0.0	mm	Total rain loss	83.0	mm
Actual water use by crop	380.3	mm	Moist deficit at harvest	3.1	mm
Potential water use by crop	380.3	mm	Actual irrigation requirement	80.4	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	78.3	%
Deficiency irrigation schedule	0.0	%			

Medium

Totals					
Total gross irrigation	0.0	mm	Total rainfall	383.0	mm
Total net irrigation	0.0	mm	Effective rainfall	319.5	mm
Total irrigation losses	0.0	mm	Total rain loss	63.4	mm
Actual water use by crop	380.3	mm	Moist deficit at harvest	60.8	mm
Potential water use by crop	380.3	mm	Actual irrigation requirement	60.8	mm
Efficiency irrigation schedule	-	%	Efficiency rain	83.4	%
Deficiency irrigation schedule	0.0	%			

Heavy

Totals					
Total gross irrigation	0.0	mm	Total rainfall	383.0	mm
Total net irrigation	0.0	mm	Effective rainfall	319.5	mm
Total irrigation losses	0.0	mm	Total rain loss	63.4	mm
Actual water use by crop	380.3	mm	Moist deficit at harvest	60.8	mm
Potential water use by crop	380.3	mm	Actual irrigation requirement	60.8	mm
Efficiency irrigation schedule	-	%	Efficiency rain	83.4	%
Deficiency irrigation schedule	0.0	%			





2. Irrigation schedule option - output – Soil comparison

CROPWAT option	ET _{green}	ET _{blue}	ET	CWU _{green}	CWU _{blue}	CWU	Y*	WF _{proc,green}	WF _{proc,blue}	WF _{proc}
	mm/period			m ³ /ha			ton/ha	m ³ /ton		
Light	336	44	380	3364	440	3803	59	57	7	64
Medium	380	0	380	3803	0	3803	59	64	0	64
Heavy	380	0	380	3803	0	3803	59	64	0	64

*IRS (1999-2006) for Northern Netherlands





Water footprint estimation

1. CWR option

ET_g	ET_b	ET	CWU_g	CWU_b	CWU	Y^*	$WF_{proc,green}$	$WF_{proc,blue}$	WF_{proc}
mm/period			m ³ /ha			ton/ha	m ³ /ton		
282	100	381	2816	995	3811	59	48	17	65

*IRS (1999-2006) for Northern Netherlands

2. Irrigation schedule option

CROPWAT option	ET_{green}	ET_{blue}	ET	CWU_{green}	CWU_{blue}	CWU	Y^*	$WF_{proc,green}$	$WF_{proc,blue}$	WF_{proc}
	mm/period			m ³ /ha			ton/ha	m ³ /ton		
Light	336	44	380	3364	440	3803	59	57	7	64
Medium	380	0	380	3803	0	3803	59	64	0	64
Heavy	380	0	380	3803	0	3803	59	64	0	64

*IRS (1999-2006) for Northern Netherlands

Average irrigated area varies from 1 to 19% (IIRB, 2004)



Grey water footprint

- volume of polluted freshwater that associates with the production of a product in its full supply-chain.
- calculated as the volume of water that is required to assimilate pollutants based on ambient water quality standards.



$$\blacktriangleright \text{WF}_{\text{proc, grey}} (\text{m}^3) = \frac{L}{(c_{\text{max}} - c_{\text{nat}})}$$

$$\blacktriangleright \text{WF}_{\text{proc, grey}} (\text{m}^3/\text{ton}) = \frac{L / (c_{\text{max}} - c_{\text{nat}})}{\text{Prod}}$$

L – Load of pollutants entering the water system (g/day)

c_{max} – Ambient water quality standard for the pollutant considered (g/m³)

c_{nat} – Natural concentration in the receiving water body (g/m³)

Prod – Production (ton/yr)



Grey water footprint

Source: Fertistat (FAO, 2009c)

The screenshot shows the Fertistat website interface. At the top, the FAO logo and text "FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS helping to build a world without hunger" are visible, along with "Plant Production and Protection Division". The main heading is "FertiStat Fertilizer Use Statistics". A navigation menu on the left includes: Home, Fertilizer Use Statistics, Download dataset, Publications, Related Sites, and Contact. The main content area is titled "Fertilizer Use Statistics" and includes language options: English | Français | Español. A text block explains the selection criteria: "This page provides 3 criteria for the selection of fertilizer use statistics. You may select more than one country by holding down the Ctrl key and clicking on the countries. FertiStat is still growing - if there is no data for the country-crop-year combination selected, please retry by dropping one of the selection criteria." Below this are three dropdown menus: "Country" (with options: Moldova, Republic of; Morocco; Myanmar; Netherlands), "Commodity" (with option: Beet), and "Year" (with option: All years). At the bottom of the search area are "Search!" and "Reset" buttons. The footer contains "Contact FertiStat" and "© FAO 2007".



Grey water footprint

Source: Fertistat (FAO, 2009c)

Grey component of the process water footprint for sugarbeet within the Northern Netherlands

Average fertilizer application rate*	Area**	Total fertilizer applied	Nitrogen leached to the water bodies 10%	US EPA (2009)	Total $WF_{proc, grey}$ sugar beet	Production**	$WF_{proc, grey}$ sugar beet
kg/ha	ha	ton/year	ton/year	mg/l	10^6 m ³ /year	ton	m ³ /ton
108	10887	1176	118	10	12	647176	18
*Fertistat (FAO, 2009c)							
**IRS (1999-2006) for Northern Netherlands							

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