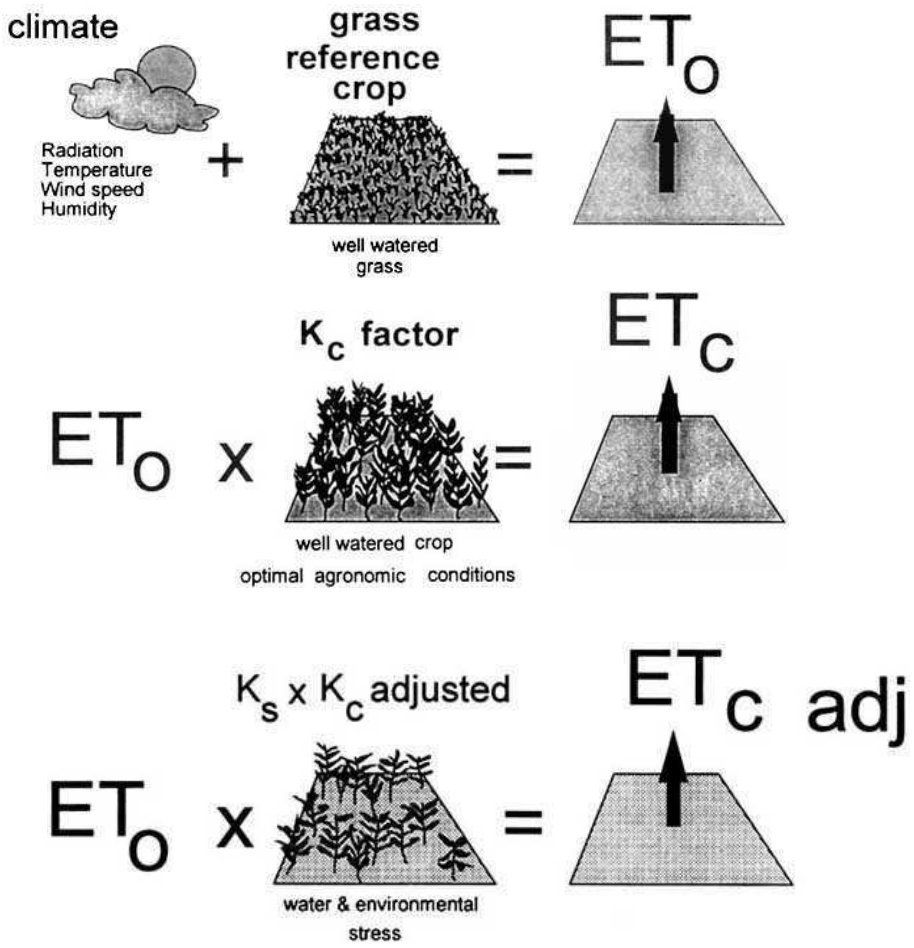
Bewässerungstechnik in der Landwirtschaft

Pflanzenwasserbedarf

Wolfram Spreer

FAO Irrigation and Drainage Paper No. 56



Potential reference (grass) evapotranspiration (ET_0)

Potential crop evapotranspiration (ET_c)

Actual (adjusted) crop evapotranspiration ($ET_{c\ adj}$)

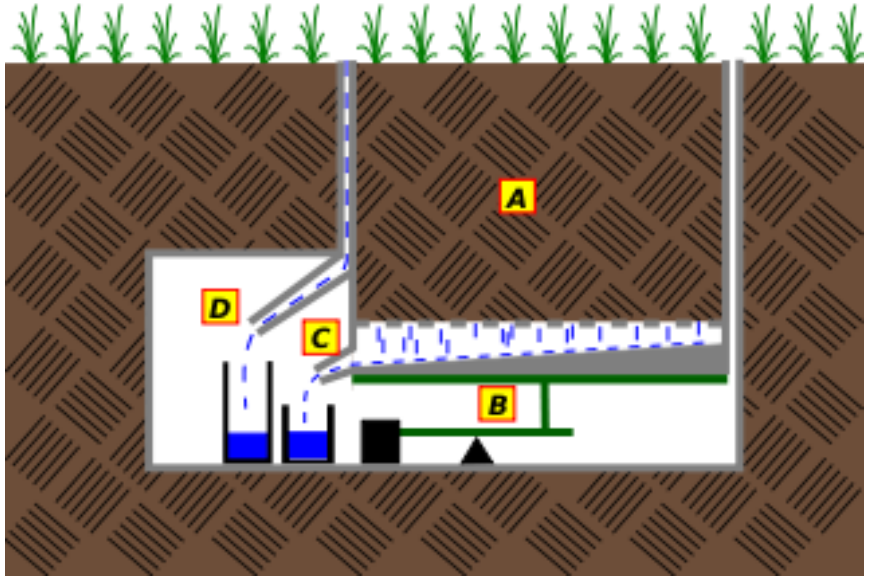
http://www.fao.org/3/X0490E/x0490e00.htm#Contents

FAO IDP 56

Lysimeter zur Bestimmung der Evapotranspiration

Lysimeter zur Bestimmung der Evapotranspiration

- Wägung eines Bodenblocks
- Messung der Versickerungsverluste
- Fakultativ: Bodenfeuchtesensoren
- Kontinuierliche Aufzeichnung

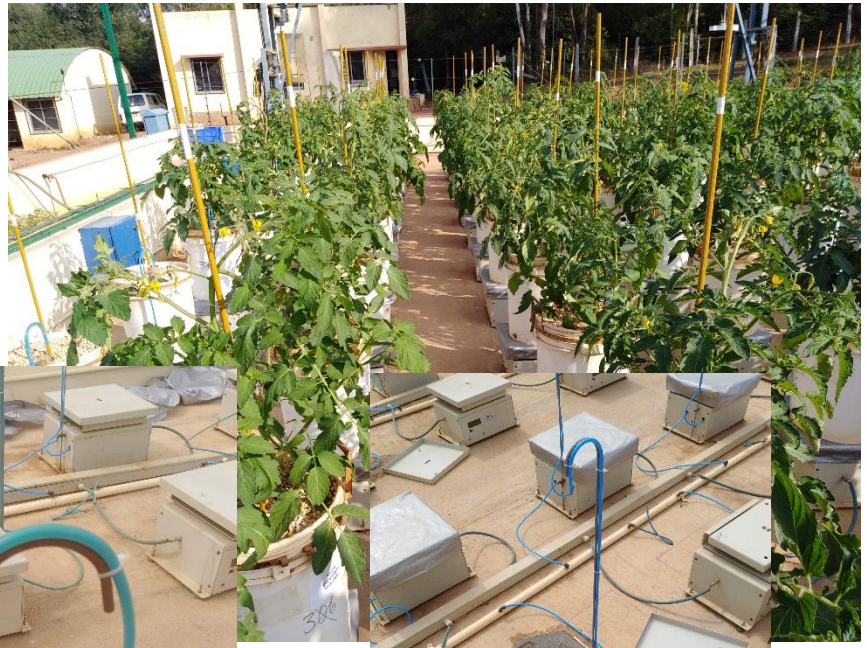


Lysimeter Zürich, Reckenholz

Lysimeter Zürich, Reckenholz

Wie wird Evapotranspiration bestimmt?

Lysimeter Einheit mit Wägzelle



mode
chstur

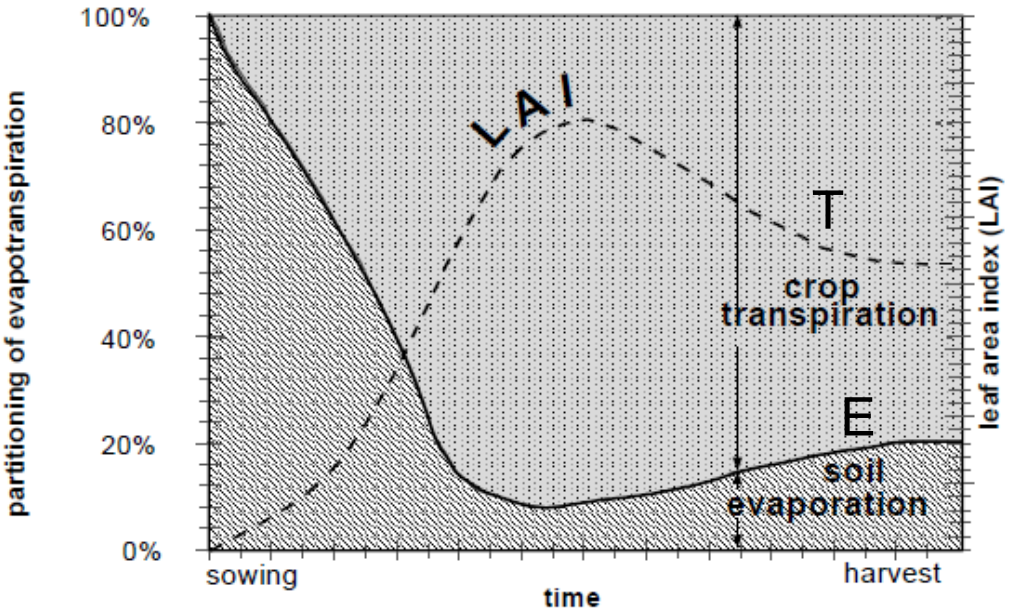
und

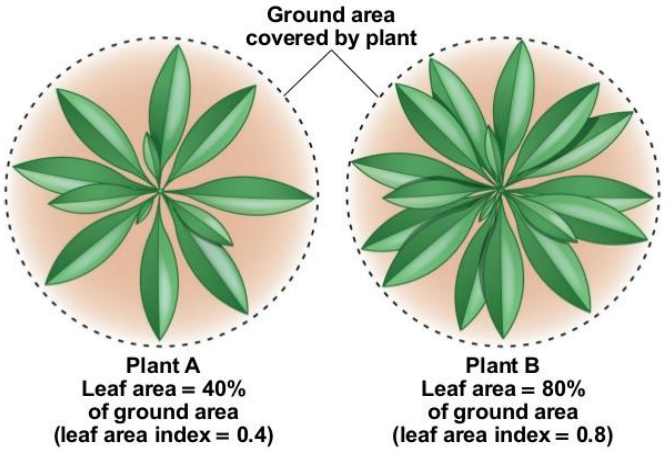
Individuelle Bewässerung

Kalibrierung

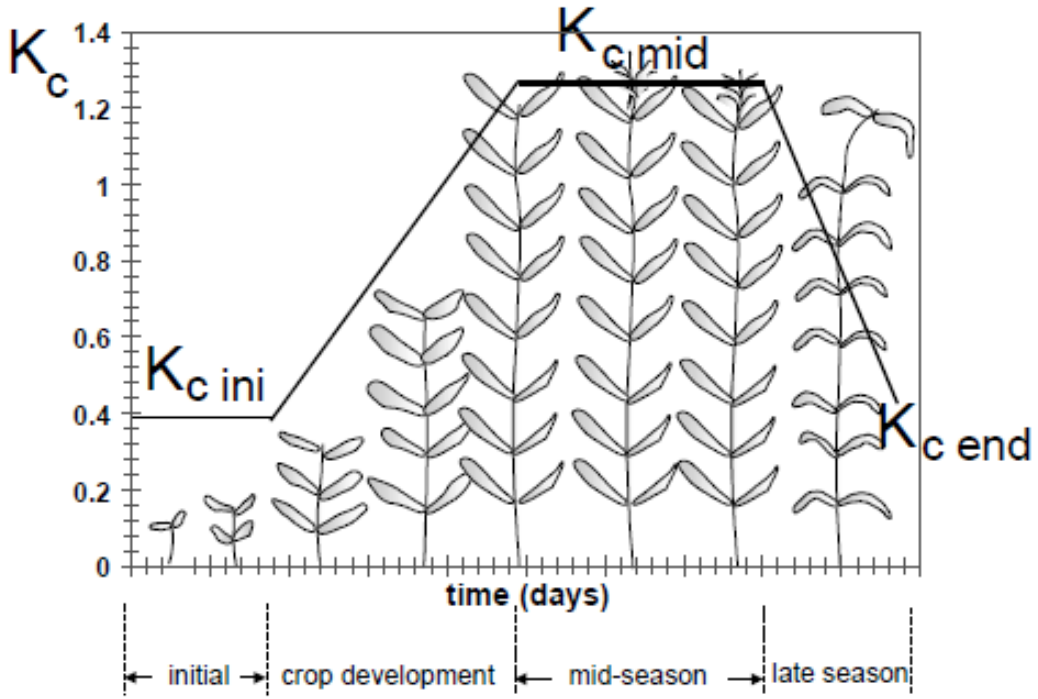
Evapotranspiration ET

- E Evaporation passive Wasserverdunstung einer Bodenoberfläche
- T Transpiration aktive Wasserverdunstung einer Pflanze





K_c-Wert im Verlauf der Bestandsentwicklung



$$ET_c = K_c \cdot ET_0$$

I	Initial stage:	Aussaat bis 10% Bodenbedeckung
II	Development stage:	…bis Ende vegetatives Wachstums (Blüte)
II	Mid-season stage:	…bis Reife
IV	Late season stage:	…bis Ernte (Seneszenz)

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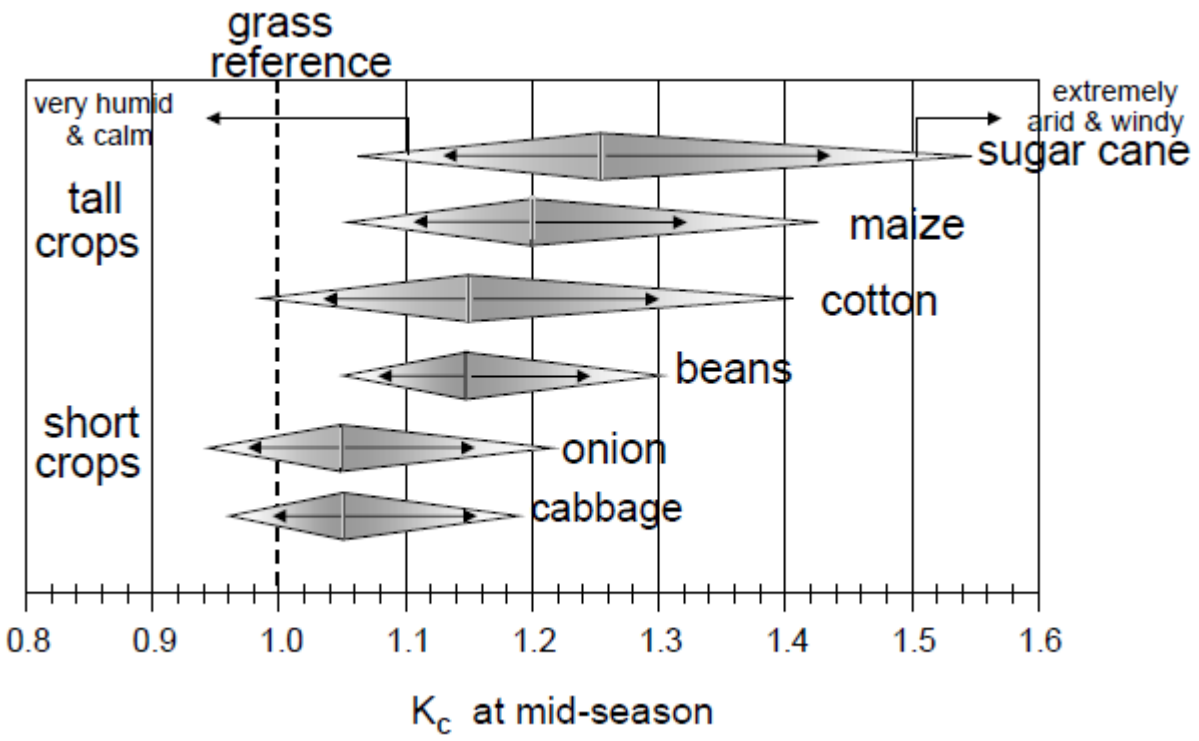
K_c Werte für unterschiedliche Pflanzenarten

$$ET_c = K_c \cdot ET_0$$



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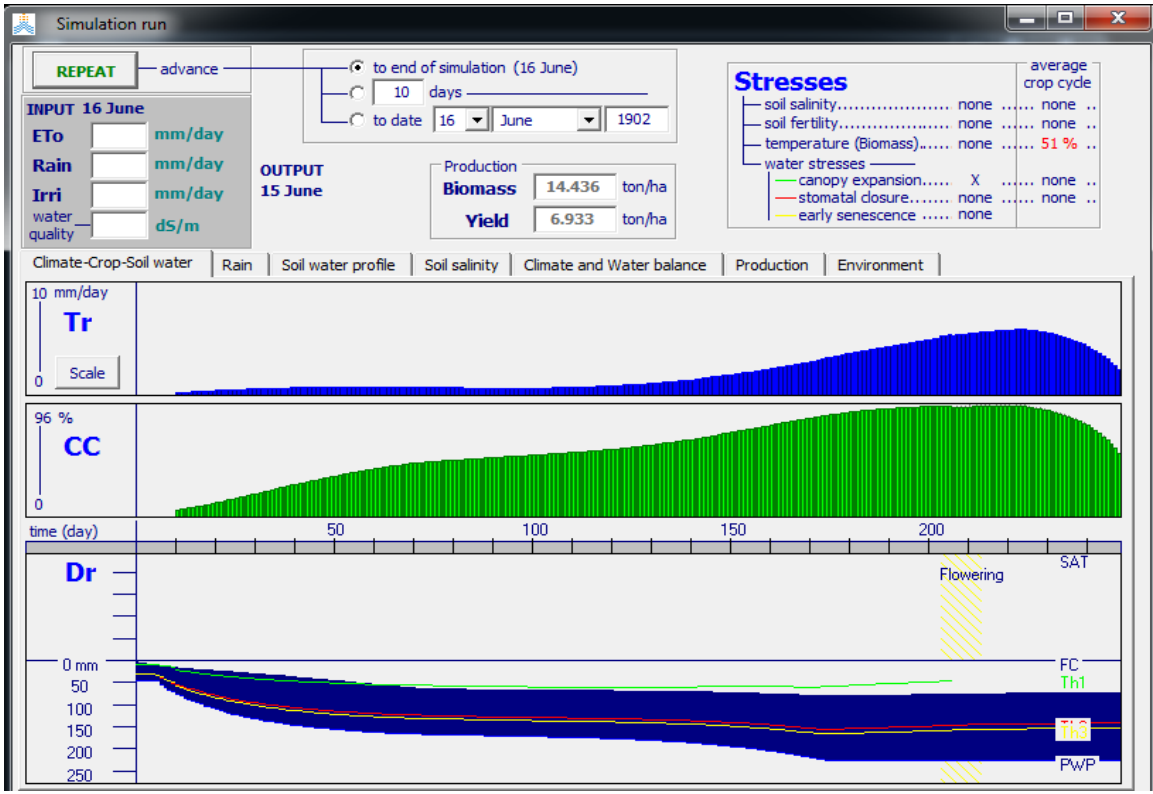
Kulturentwicklung mit AquaCrop

Simulation using growing degree days

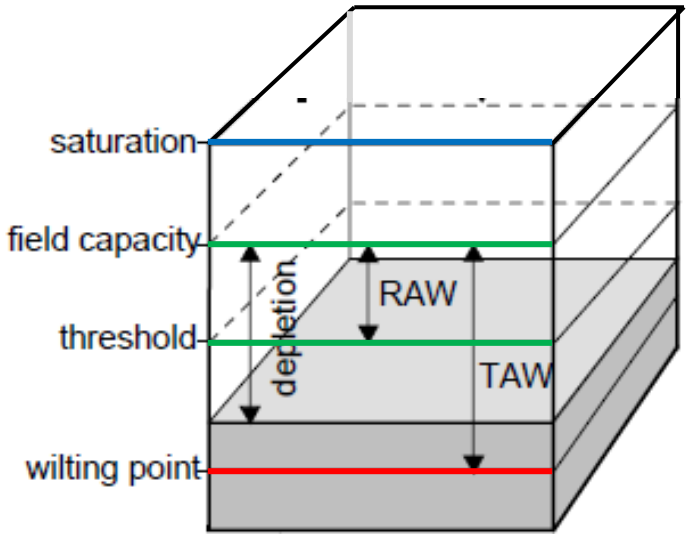
GDD = [(Tmax + Tmin)/2] - Tb

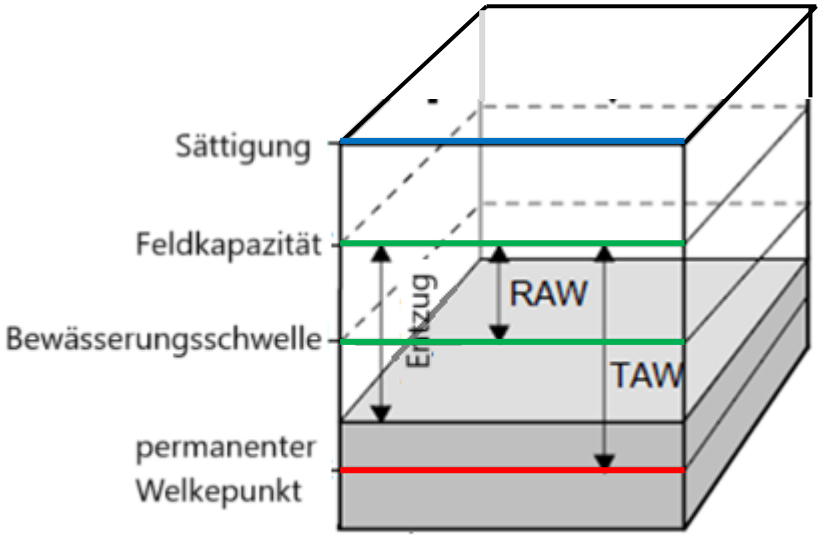
Tmax: maximum daily temperature
Tmin: minimum daily temperature
Tb: base temperature
(Cao and Moss, 1989)



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

Wasserstress





RAW	Readily available water
TAW	Total available water

RAW	stressfrei pflanzenverfügbares Wasser
TAW	gesamtes pflanzenverfügbares Wasser

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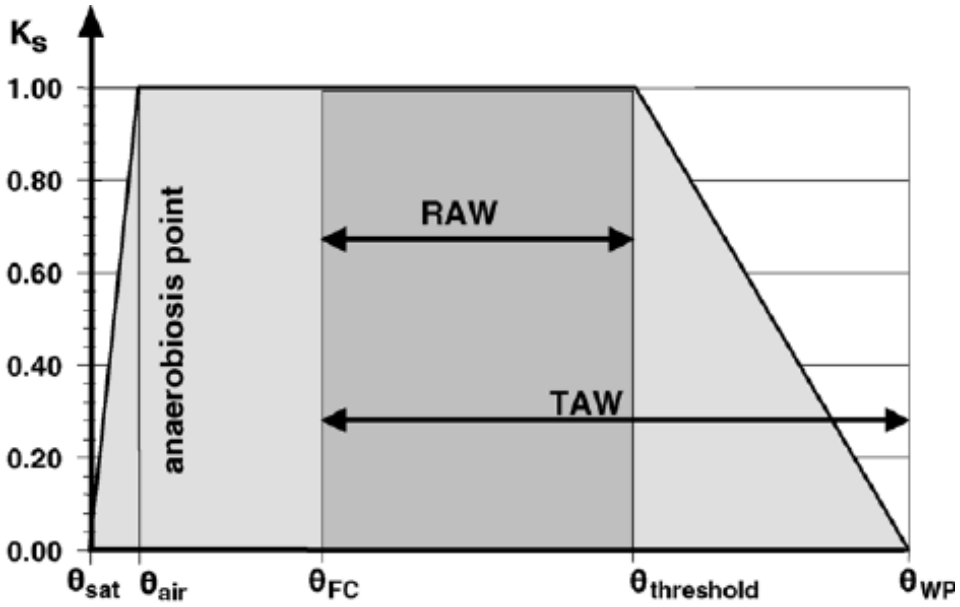
Water stress coefficient K_s

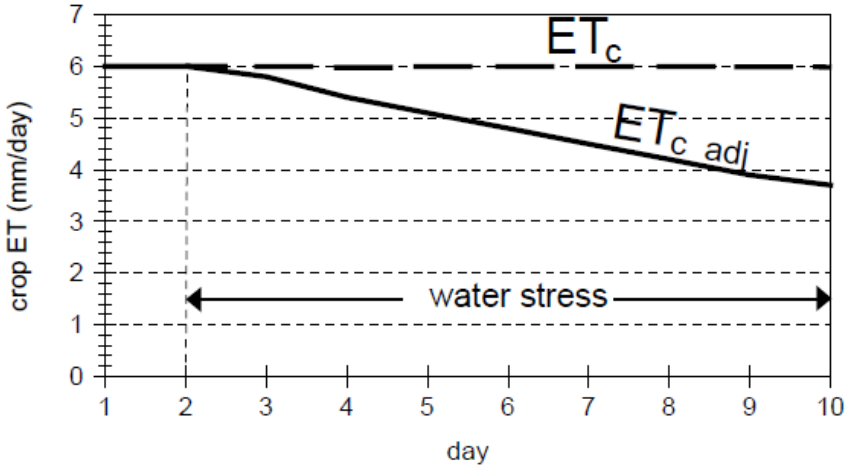


$$ET_{c\,adj} = K_s \cdot K_c \cdot ET_0$$

Θ	Bodenwassergehalt, m³/m³
Θ_{sat}	Boden mit Wasser gesättigt, Pflanze leidet an Luftmangel
Θ_{air}	ausreichend Luft in Poren verfügbar
Θ_{FC}	Field capacity, Bodenwasser bewegt sich nicht mehr durch Schwerkraft nach unten
Θ_{thr}	Threshold, Pflanze zeigt erste Symptome von Trockenstress
Θ_{WP}	Wilting point, Pflanze stirbt ab

Raes et al, 2006

Yield response factor K_y



$$ET_{c\,adj} = K_s \cdot K_c \cdot ET_0$$

$$\frac{Y_m - Y_a}{Y_m} = K_y \cdot \frac{ET_c - ET_{c\,adj}}{ET_c}$$

Y_m	maximal erzielbarer Ertrag
Y_a	tatsächlich erzielter Ertrag
K_y	yield response factor

http://www.fao.org/3/i2800e/i2800e02.pdf

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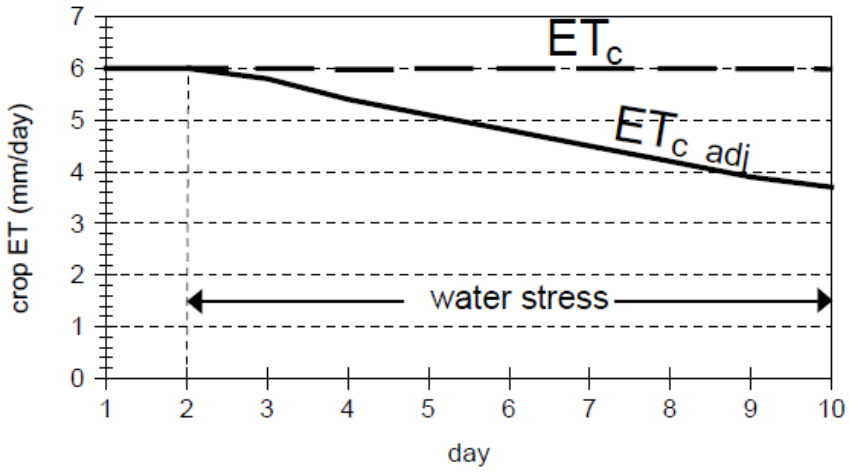
Yield response factor K_y



$$ET_{c\,adj} = K_s \cdot K_c \cdot ET_0$$

$$\frac{Y_m - Y_a}{Y_m} = K_y \cdot \frac{ET_c - ET_{c\,adj}}{ET_c}$$

Seasonal yield response functions from FAO Irrigation and Drainage Paper No. 33.

Crop	K_y	Crop	K_y
Alfalfa	1.1	Potato	1.1
Banana	1.2-1.35	Safflower	0.8
Beans	1.15	Sorghum	0.9
Cabbage	0.95	Soybean	0.85
Citrus	1.1-1.3	Spring Wheat	1.15
Cotton	0.85	Sugarbeet	1.0
Grape	0.85	Sugarcane	1.2
Groundnet	0.70	Sunflower	0.95
Maize	1.25	Tomato	1.05
Onion	1.1	Watermelon	1.1
Peas	1,15	Winter wheat	1.05
Pepper	1.1		

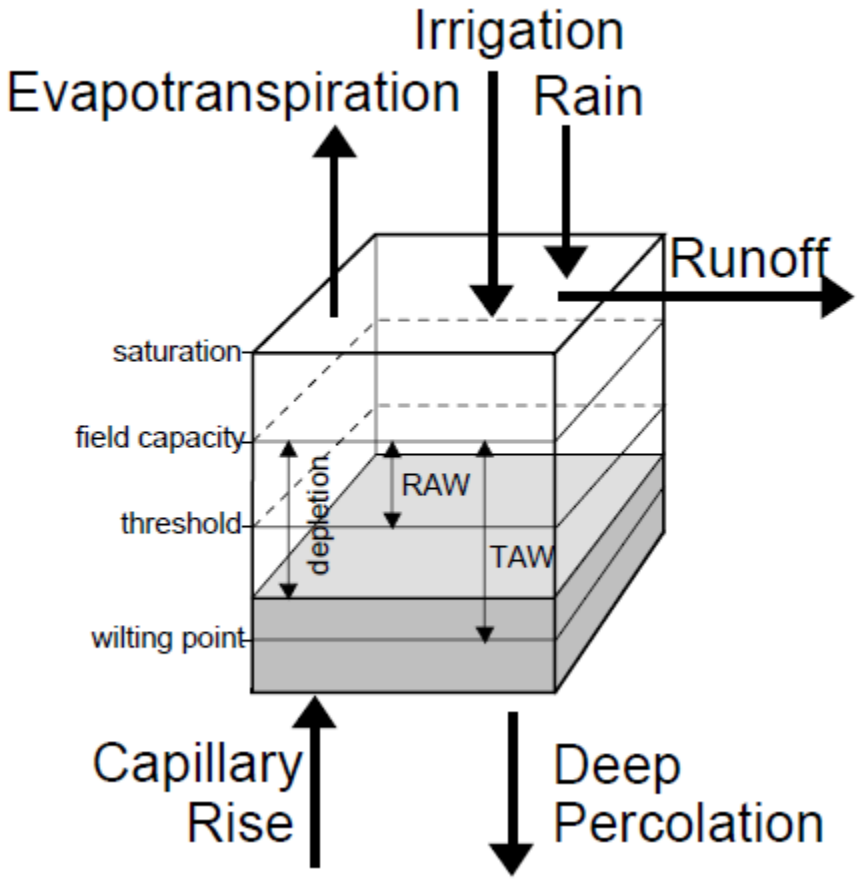
FAO IDP 33

Bodenwasserhaushalt im CROPWAT Modell

$$I + P + CR = ET_{c\ adj} + RO + DP$$

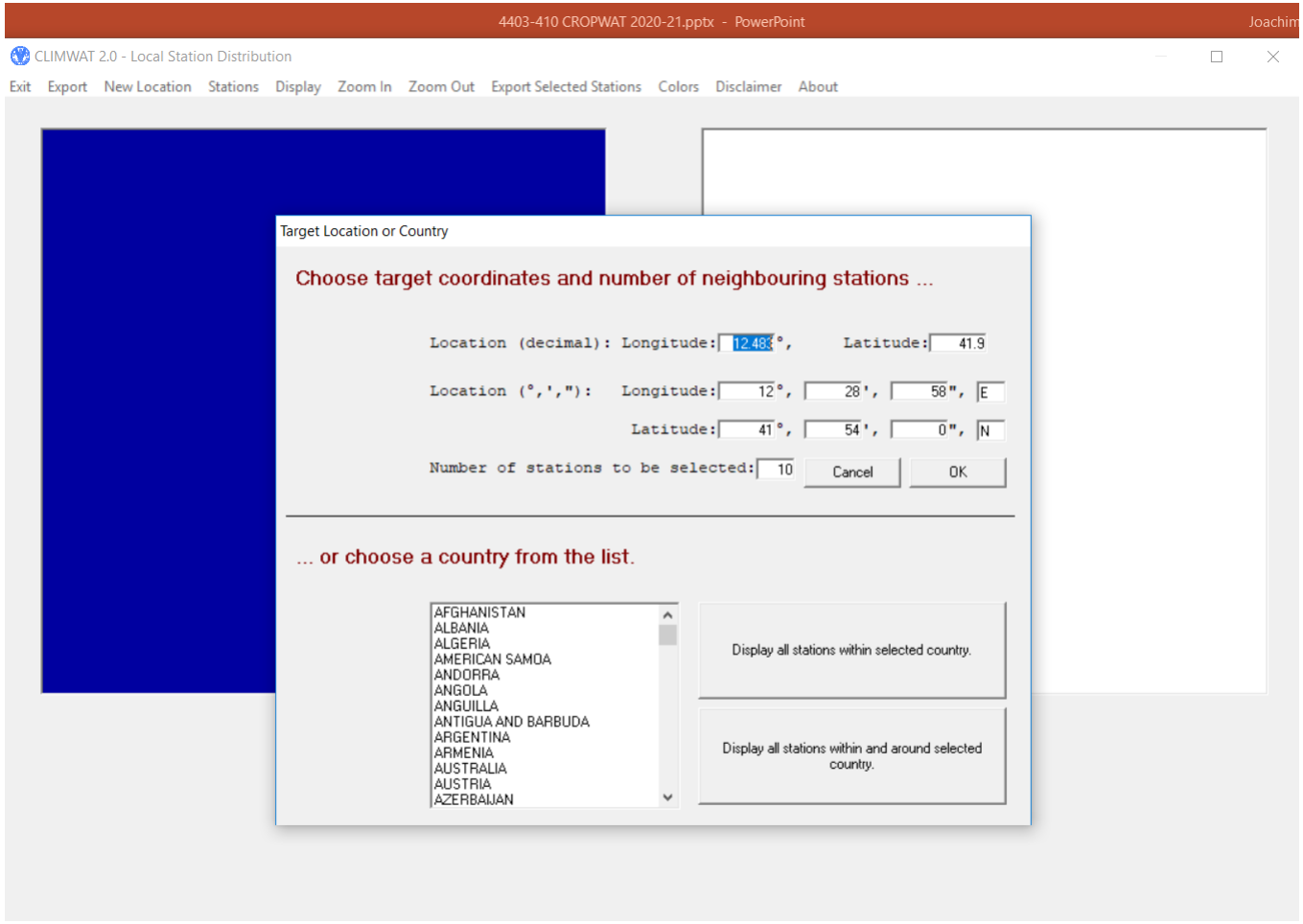
$$I = ET_{c\ adj} + RO + DP - P\ - CR$$

I	Irrigation
P	Precipitation
CR	Capillary rise
$ET_{c\ adj}$	Evapotranspiration
RO	Run-off
DP	Deep percolation

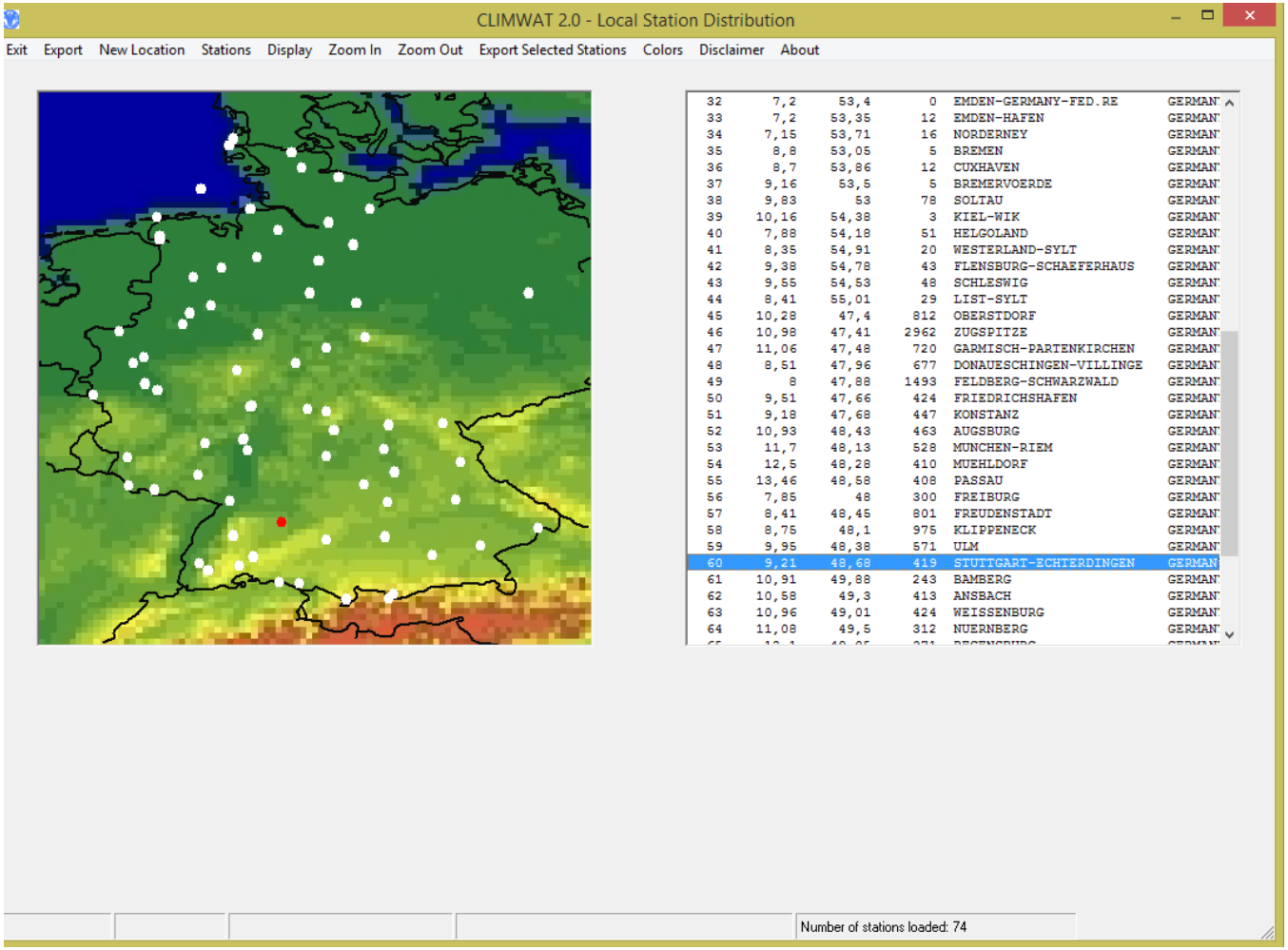


FAO IDP 56

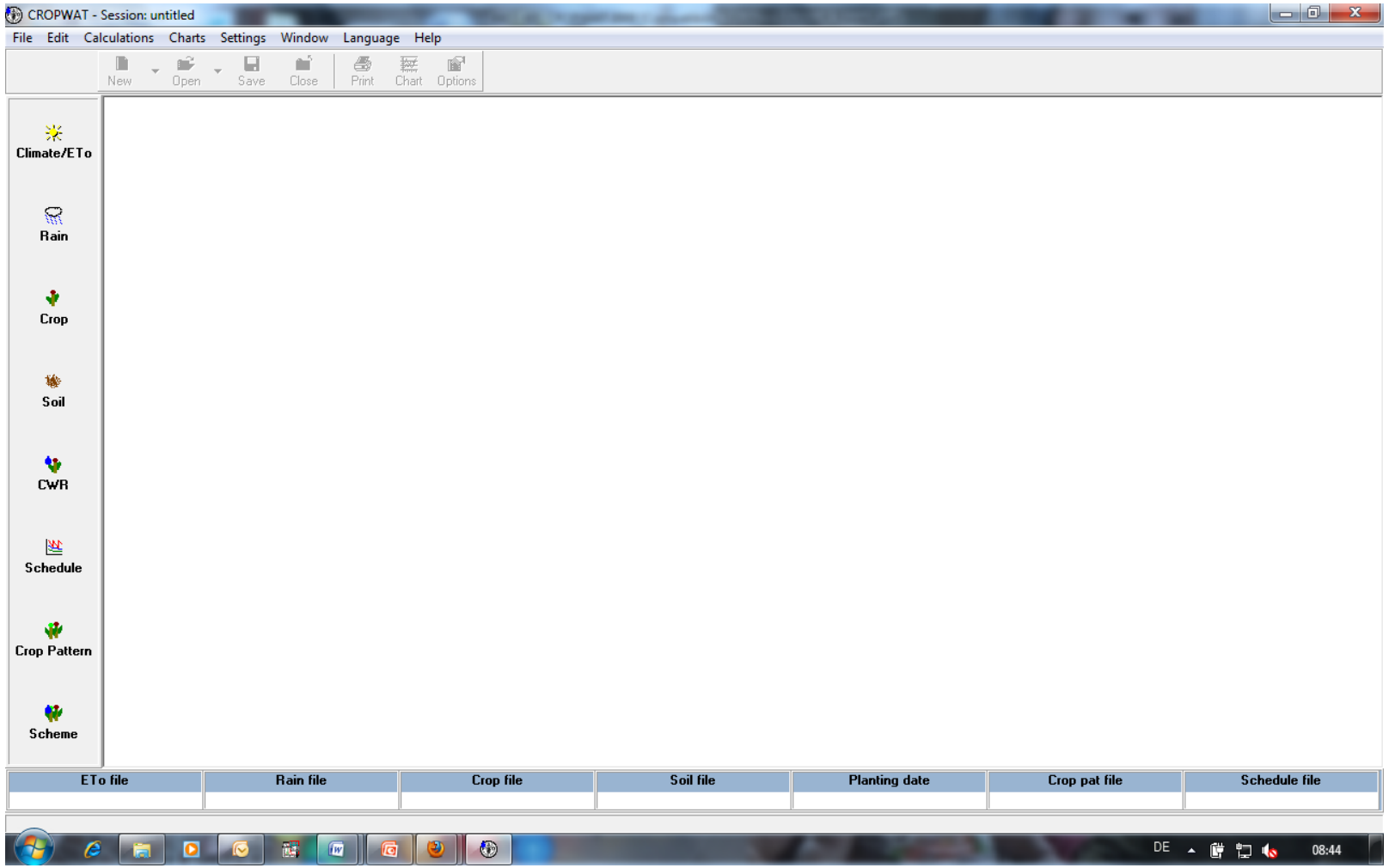
CLIMWAT


4403-410 CROPWAT 2020-21.pptx - PowerPoint
Joachim
CLIMWAT 2.0 - Local Station Distribution
Exit Export New Location Stations Display Zoom In Zoom Out Export Selected Stations Colors Disclaimer About
Target Location or Country
Choose target coordinates and number of neighbouring stations ...
Location (decimal): Longitude: 12.483 °, Latitude: 41.9
Location (°,',"): Longitude: 12 °, 28 ', 58 ", E
Latitude: 41 °, 54 ', 0 ", N
Number of stations to be selected: 10
Cancel
OK
... or choose a country from the list.
AFGHANISTAN
ALBANIA
ALGERIA
AMERICAN SAMOA
ANDORRA
ANGOLA
ANGUILLA
ANTIGUA AND BARBUDA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
Display all stations within selected country.
Display all stations within and around selected country.

CLIMWAT


CLIMWAT 2.0 - Local Station Distribution
Exit
Export
New Location
Stations
Display
Zoom In
Zoom Out
Export Selected Stations
Colors
Disclaimer
About
32 7,2 53,4 0 EMDEN-GERMANY-FED.RE GERMAN
33 7,2 53,35 12 EMDEN-HAFEN GERMAN
34 7,15 53,71 16 NORDERNEY GERMAN
35 8,8 53,05 5 BREMEN GERMAN
36 8,7 53,86 12 CUXHAVEN GERMAN
37 9,16 53,5 5 BREMERVOERDE GERMAN
38 9,83 53 78 SOLTAU GERMAN
39 10,16 54,38 3 KIEL-WIK GERMAN
40 7,88 54,18 51 HELGOLAND GERMAN
41 8,35 54,91 20 WESTERLAND-SYLT GERMAN
42 9,38 54,78 43 FLENSBURG-SCHAEFERHAUS GERMAN
43 9,55 54,53 48 SCHLESWIG GERMAN
44 8,41 55,01 29 LIST-SYLT GERMAN
45 10,28 47,4 812 OBERSTDORF GERMAN
46 10,98 47,41 2962 ZUGSPITZE GERMAN
47 11,06 47,48 720 GARMISCH-PARTENKIRCHEN GERMAN
48 8,51 47,96 677 DONAUESCHINGEN-VILLINGE GERMAN
49 8 47,88 1493 FELDBERG-SCHWARZWALD GERMAN
50 9,51 47,66 424 FRIEDRICHSHAFEN GERMAN
51 9,18 47,68 447 KONSTANZ GERMAN
52 10,93 48,43 463 AUGSBURG GERMAN
53 11,7 48,13 528 MUNCHEN-RIEM GERMAN
54 12,5 48,28 410 MUEHLDORF GERMAN
55 13,46 48,58 408 PASSAU GERMAN
56 7,85 48 300 FREIBURG GERMAN
57 8,41 48,45 801 FREUDENSTADT GERMAN
58 8,75 48,1 975 KLIPPENECK GERMAN
59 9,95 48,38 571 ULM GERMAN
60 9,21 48,68 419 STUTTGART-ECHTERDINGEN GERMAN
61 10,91 49,88 243 BAMBERG GERMAN
62 10,58 49,3 413 ANSBACH GERMAN
63 10,96 49,01 424 WEISSENBURG GERMAN
64 11,08 49,5 312 NUERNBERG GERMAN
Number of stations loaded: 74

CROPWAT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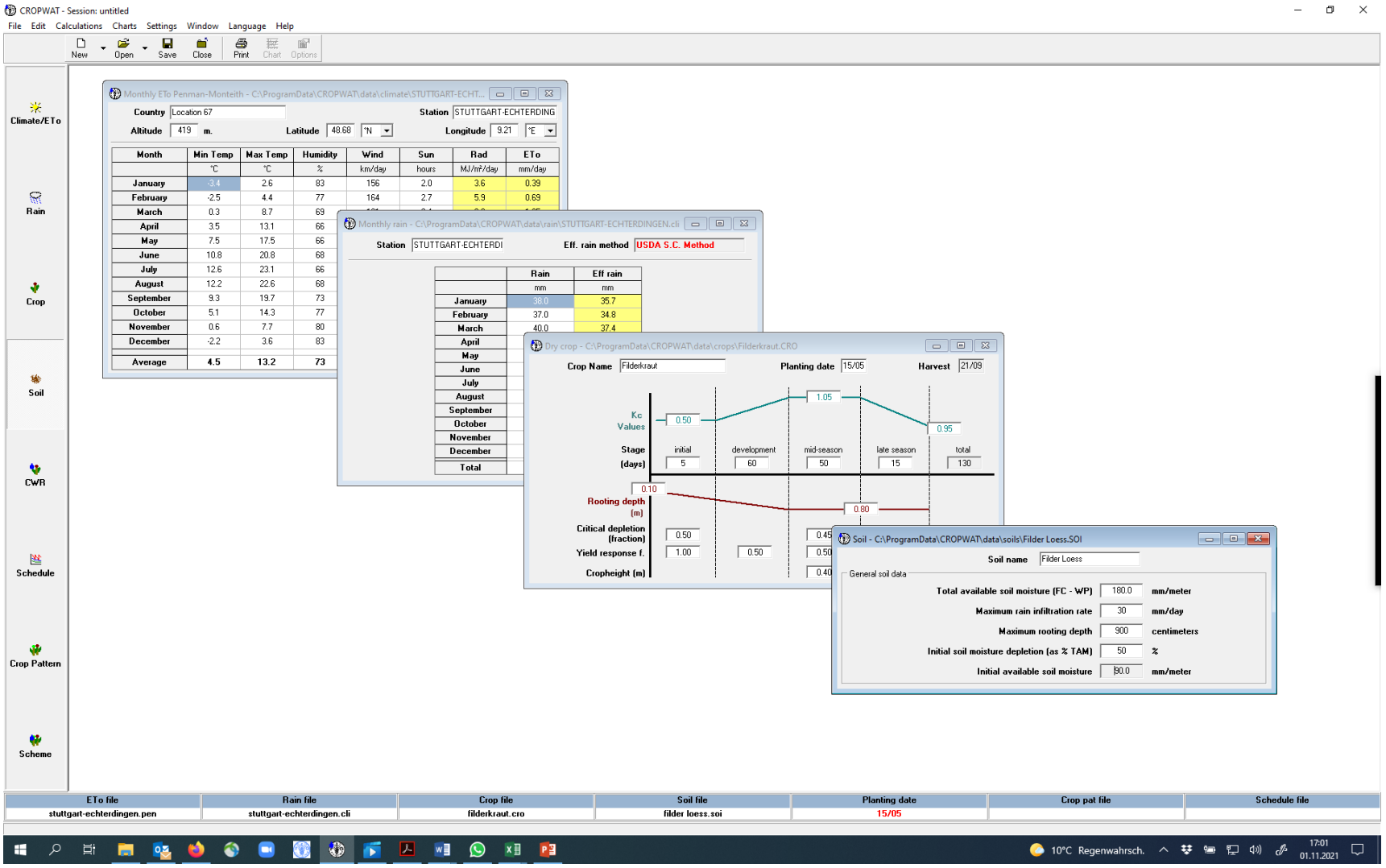
Climate/ETo
Rain
Crop
Soil
CWR
Schedule
Crop Pattern
Scheme
ETo file
Rain file
Crop file
Soil file
Planting date
Crop pat file
Schedule file
DE
08:44

CROPWAT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New Open Save Close Print Chart Options
Climate/ETo
Rain
Crop
Soil
CWR
Schedule
Crop Pattern
Scheme
Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\STUTTGART-ECHT...
Country Location 67
Station STUTTGART-ECHTERDING
Altitude 419 m.
Latitude 48.68 °N
Longitude 9.21 °E
Month | Min Temp | Max Temp | Humidity | Wind | Sun | Rad | ETo
°C | °C | % | km/day | hours | MJ/m²/day | mm/day
January -3.4 2.6 83 156 2.0 3.6 0.39
February -2.5 4.4 77 164 2.7 5.9 0.69
March 0.3 8.7 69
April 3.5 13.1 66
May 7.5 17.5 66
June 10.8 20.8 68
July 12.6 23.1 66
August 12.2 22.6 68
September 9.3 19.7 73
October 5.1 14.3 77
November 0.6 7.7 80
December -2.2 3.6 83
Average 4.5 13.2 73
Monthly rain - C:\ProgramData\CROPWAT\data\rain\STUTTGART-ECHTERDINGEN.cli
Station STUTTGART-ECHTERDI
Eff. rain method USDA S.C. Method
Rain | Eff rain
mm | mm
January 38.0 35.7
February 37.0 34.8
March 40.0 37.4
April
May
June
July
August
September
October
November
December
Total
Dry crop - C:\ProgramData\CROPWAT\data\crops\Filderkraut.CRO
Crop Name Filderkraut
Planting date 15/05
Harvest 21/09
Kc Values 0.50 1.05 0.95
Stage (days) initial 5 development 60 mid-season 50 late season 15 total 130
Rooting depth (m) 0.10 0.80
Critical depletion (fraction) 0.50 0.45
Yield response f. 1.00 0.50 0.50
Cropheight (m) 0.40
Soil - C:\ProgramData\CROPWAT\data\soils\Filder Loess.SOI
Soil name Filder Loess
General soil data
Total available soil moisture (FC - WP) 180.0 mm/meter
Maximum rain infiltration rate 30 mm/day
Maximum rooting depth 900 centimeters
Initial soil moisture depletion (as % TAM) 50 %
Initial available soil moisture 90.0 mm/meter
ETo file | Rain file | Crop file | Soil file | Planting date | Crop pat file | Schedule file
stuttgart-echterdingen.pen | stuttgart-echterdingen.cli | filderkraut.cro | filder loess.soi | 15/05
10°C Regenwahrsch. 17:01 01.11.2021

Climate, ET_0

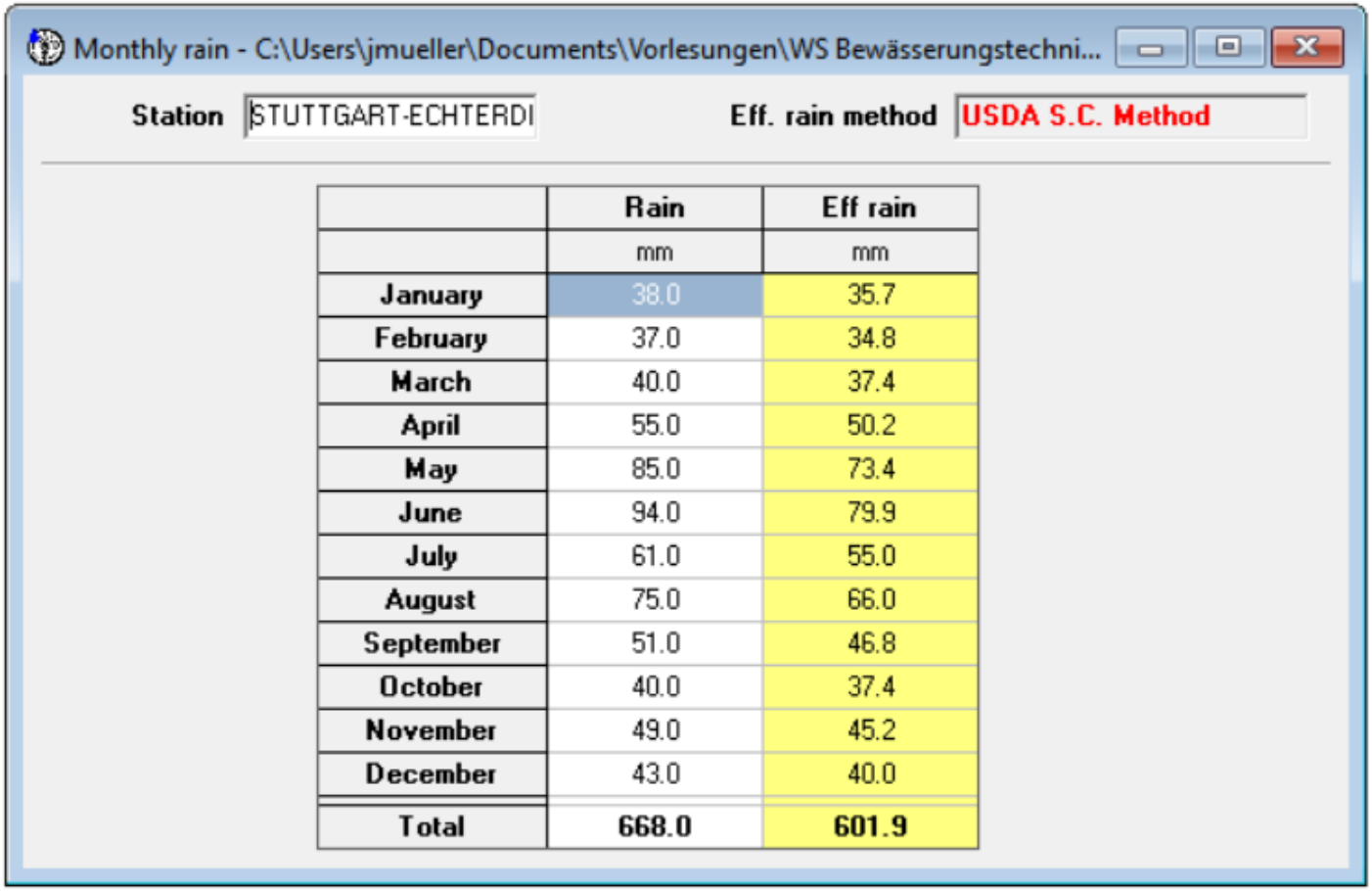
Monthly ETo Penman-Monteith - C:\Users\jmueller\Documents\Vorlesungen\WS Bewässerun...

Country: Location 60 | Station: STUTTGART-ECHTERDING

Altitude: 419 m. | Latitude: 48.68 °N | Longitude: 9.21 °E

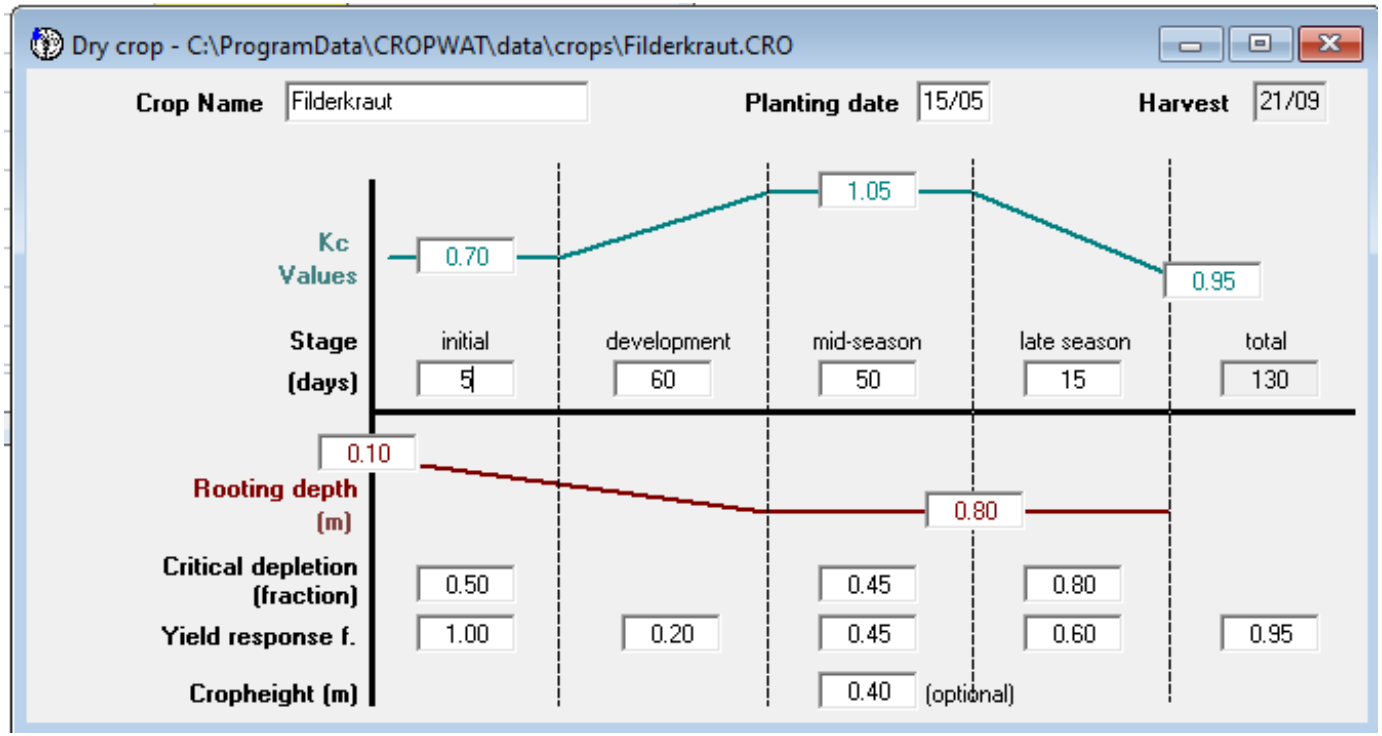
Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	m/s	hours	MJ/m²/day	mm/day
January	-3.4	2.6	83	1.8	2.0	3.6	0.39
February	-2.5	4.4	77	1.9	2.7	5.9	0.69
March	0.3	8.7	69	2.1	3.4	9.2	1.35
April	3.5	13.1	66	2.0	4.1	12.9	2.11
May	7.5	17.5	66	1.8	4.6	15.6	2.80
June	10.8	20.8	68	1.7	5.4	17.4	3.34
July	12.6	23.1	66	1.6	6.0	17.8	3.61
August	12.2	22.6	68	1.5	5.6	15.4	3.13
September	9.3	19.7	73	1.4	5.1	11.9	2.22
October	5.1	14.3	77	1.5	3.8	7.5	1.27
November	0.6	7.7	80	1.8	2.4	4.2	0.68
December	-2.2	3.6	83	1.9	1.9	3.1	0.41
Average	**4.5**	**13.2**	**73**	**1.8**	**3.9**	**10.4**	**1.83**

Effective precipitation (rain), P_{eff}

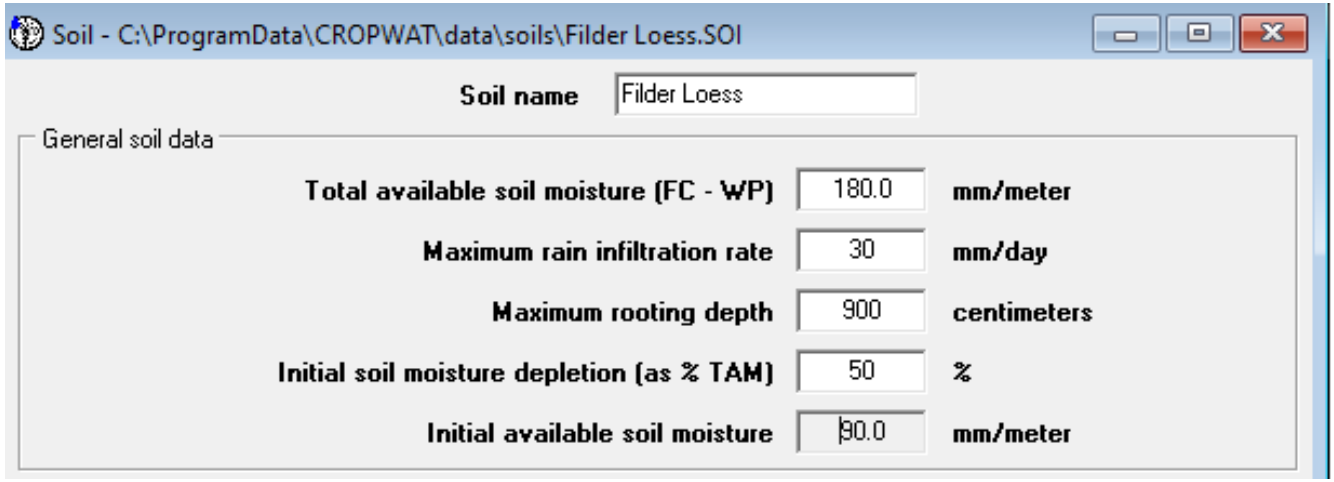


	Rain	Eff rain
	mm	mm
January	38.0	35.7
February	37.0	34.8
March	40.0	37.4
April	55.0	50.2
May	85.0	73.4
June	94.0	79.9
July	61.0	55.0
August	75.0	66.0
September	51.0	46.8
October	40.0	37.4
November	49.0	45.2
December	43.0	40.0
Total	668.0	601.9

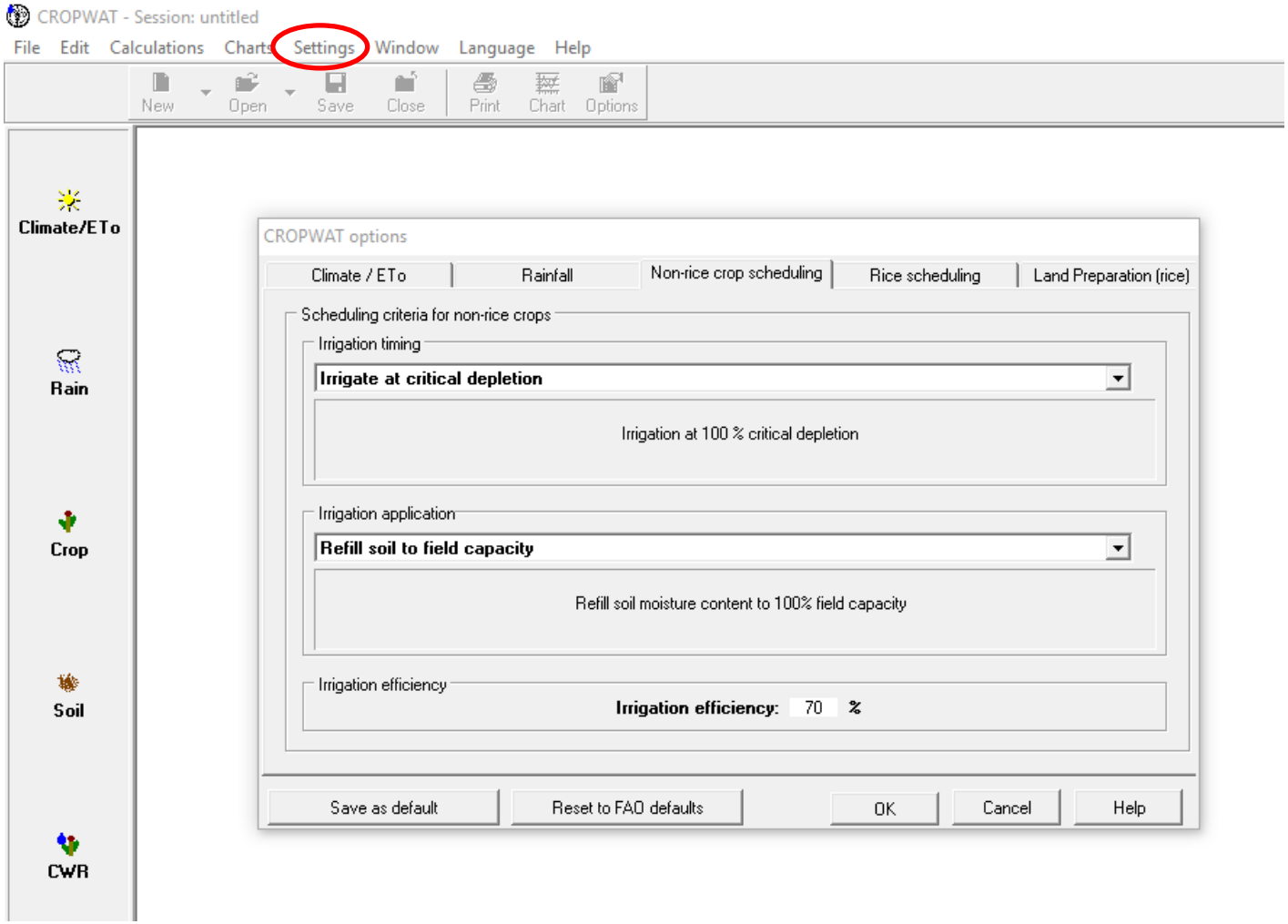
Crop


Dry crop - C:\ProgramData\CROPWAT\data\crops\Filderkraut.CRO
Crop Name
Filderkraut
Planting date
15/05
Harvest
21/09
Kc Values
0.70
1.05
0.95
Stage
(days)
initial
5
development
60
mid-season
50
late season
15
total
130
0.10
Rooting depth (m)
0.80
Critical depletion (fraction)
0.50
0.45
0.80
Yield response f.
1.00
0.20
0.45
0.60
0.95
Cropheight (m)
0.40
(optional)

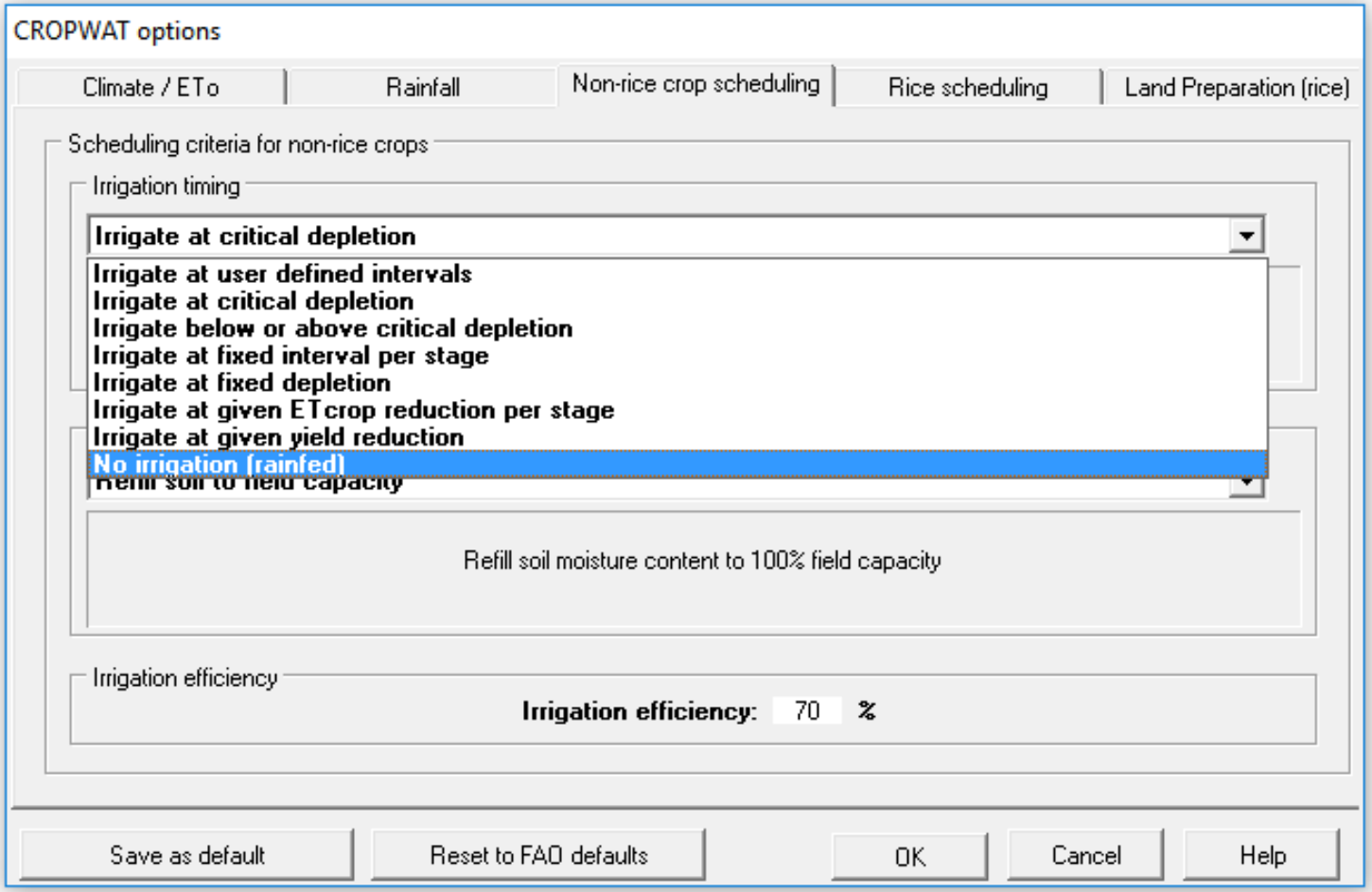
Bodenparameter



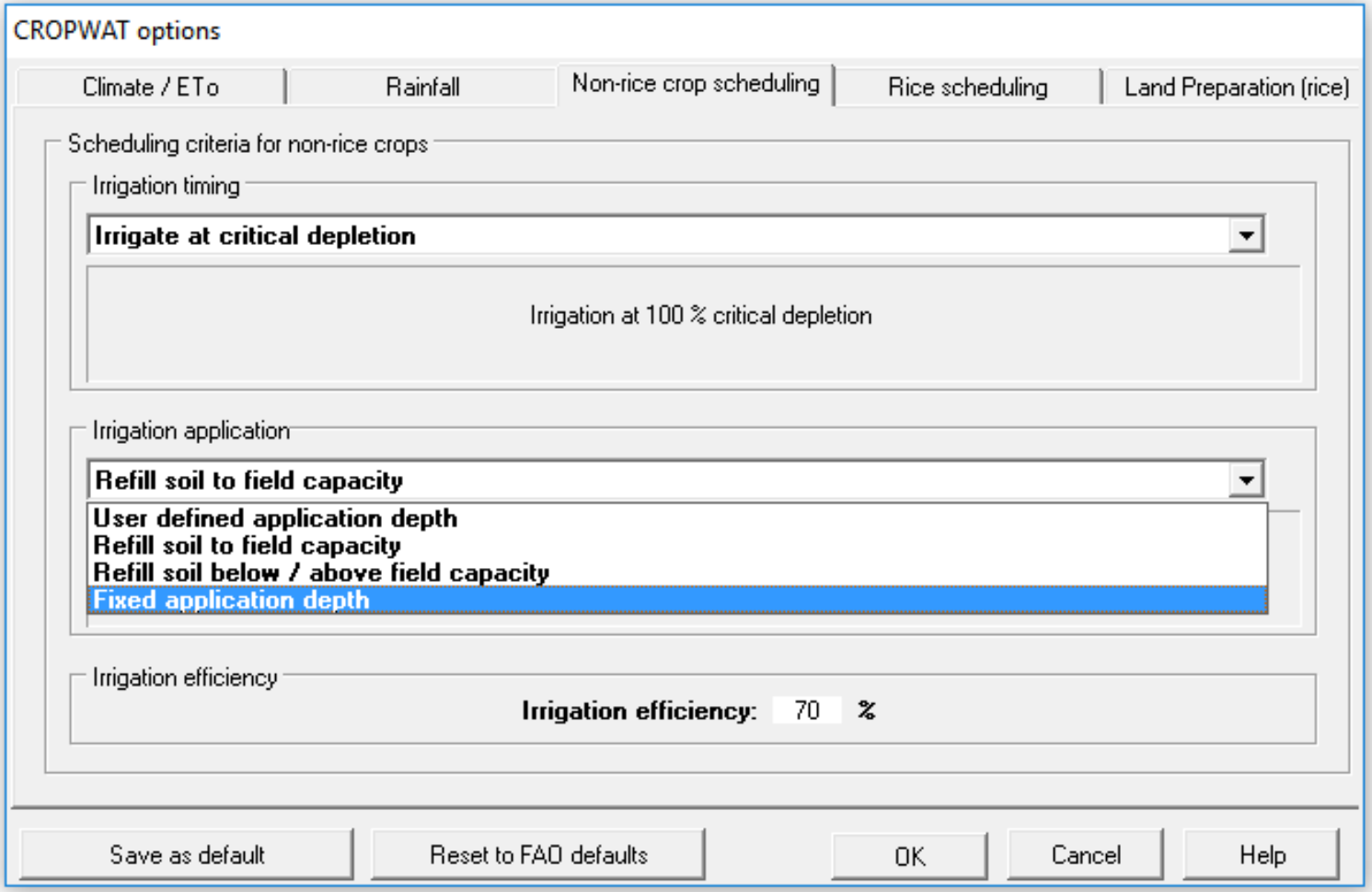
Scheduling criteria



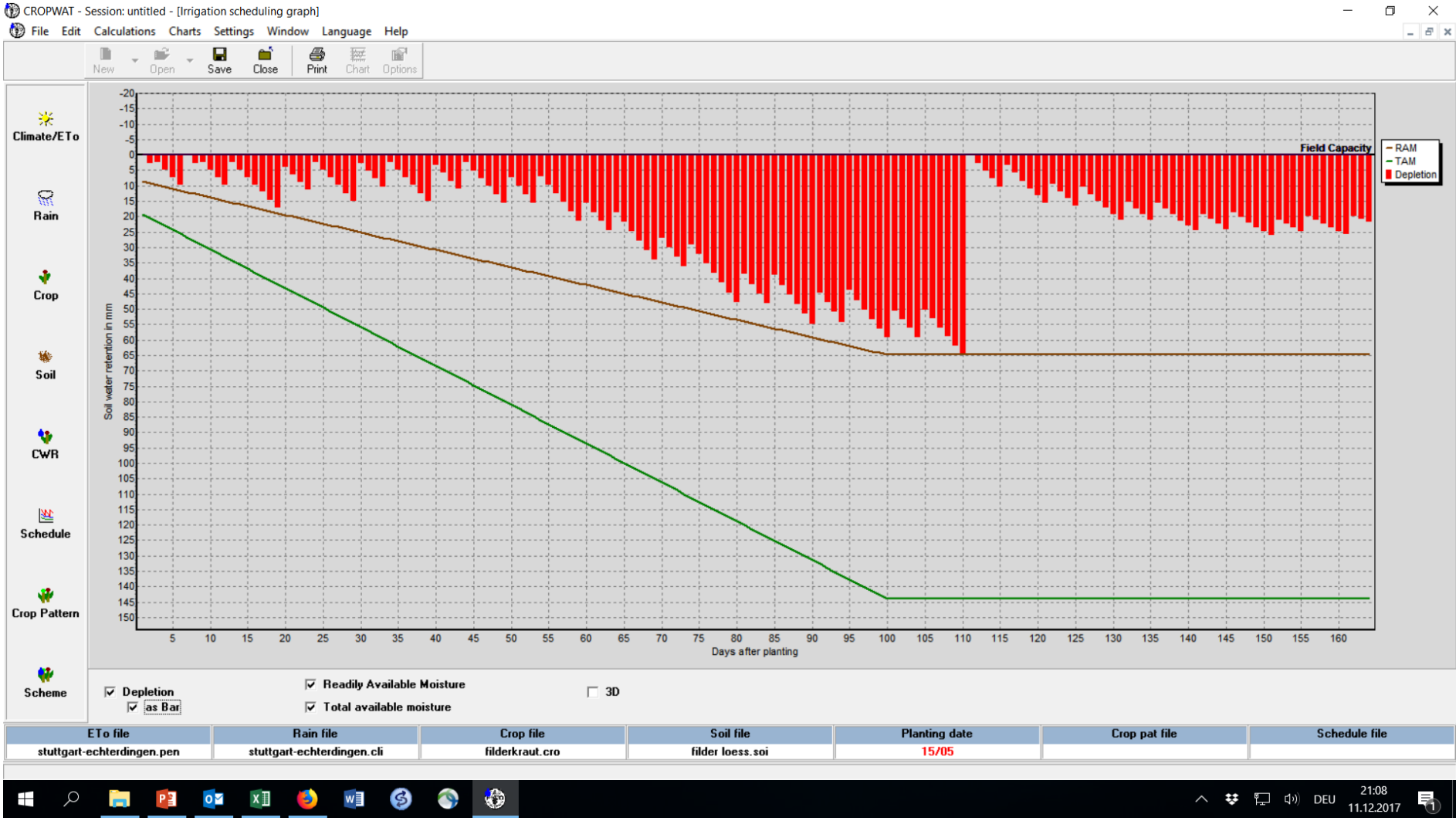
Irrigation timing



Irrigation application



Depletion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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
Soil water retention in mm
Days after planting
Field Capacity
RAM
TAM
Depletion
Depletion
as Bar
Readily Available Moisture
Total available moisture
3D
ETo file
Rain file
Crop file
Soil file
Planting date
Crop pat file
Schedule file
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DEU
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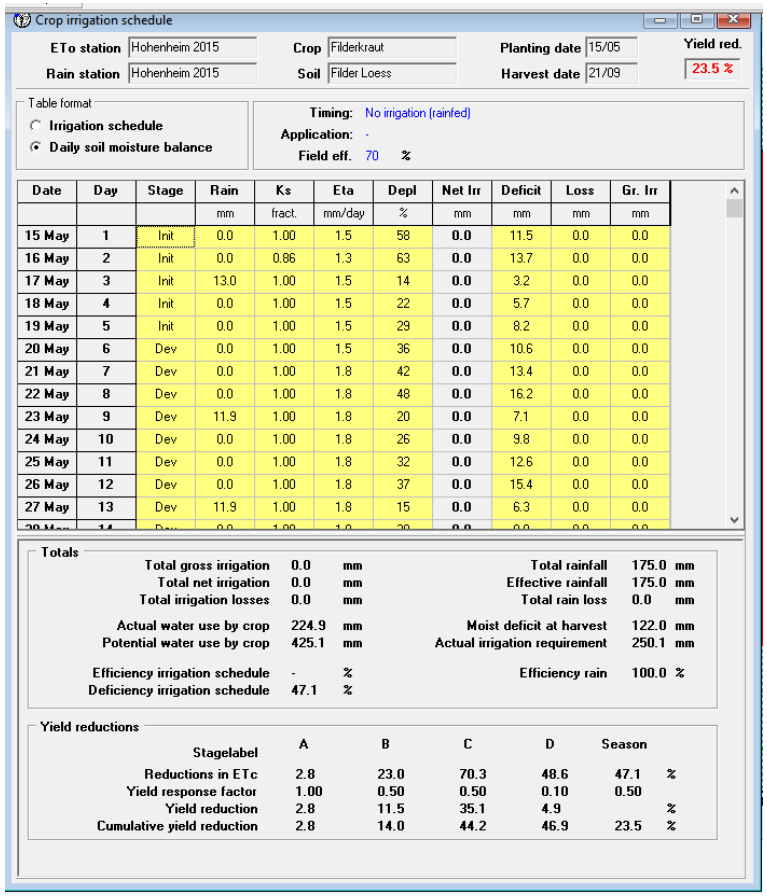
11.12.2017

Crop irrigation schedule



Crop irrigation schedule

ETo station: Hohenheim 2015 | Crop: Filderkraut | Planting date: 15/05 | Yield red.: 23.5 %
Rain station: Hohenheim 2015 | Soil: Filder Loess | Harvest date: 21/09

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
15 May	1	Init	0.0	1.00	1.5	58	0.0	11.5	0.0	0.0
16 May	2	Init	0.0	0.86	1.3	63	0.0	13.7	0.0	0.0
17 May	3	Init	13.0	1.00	1.5	14	0.0	3.2	0.0	0.0
18 May	4	Init	0.0	1.00	1.5	22	0.0	5.7	0.0	0.0
19 May	5	Init	0.0	1.00	1.5	29	0.0	8.2	0.0	0.0
20 May	6	Dev	0.0	1.00	1.5	36	0.0	10.6	0.0	0.0
21 May	7	Dev	0.0	1.00	1.8	42	0.0	13.4	0.0	0.0
22 May	8	Dev	0.0	1.00	1.8	48	0.0	16.2	0.0	0.0
23 May	9	Dev	11.9	1.00	1.8	20	0.0	7.1	0.0	0.0
24 May	10	Dev	0.0	1.00	1.8	26	0.0	9.8	0.0	0.0
25 May	11	Dev	0.0	1.00	1.8	32	0.0	12.6	0.0	0.0
26 May	12	Dev	0.0	1.00	1.8	37	0.0	15.4	0.0	0.0
27 May	13	Dev	11.9	1.00	1.8	15	0.0	6.3	0.0	0.0

Totals

Total gross irrigation	0.0	mm	Total rainfall	175.0 mm
Total net irrigation	0.0	mm	Effective rainfall	175.0 mm
Total irrigation losses	0.0	mm	Total rain loss	0.0 mm
Actual water use by crop	224.9	mm	Moist deficit at harvest	122.0 mm
Potential water use by crop	425.1	mm	Actual irrigation requirement	250.1 mm
Efficiency irrigation schedule	-	%	Efficiency rain	100.0 %
Deficiency irrigation schedule	47.1	%		

Yield reductions

Stagelabel	A	B	C	D	Season	
Reductions in ETc	2.8	23.0	70.3	48.6	47.1	%
Yield response factor	1.00	0.50	0.50	0.10	0.50	
Yield reduction	2.8	11.5	35.1	4.9		%
Cumulative yield reduction	2.8	14.0	44.2	46.9	23.5	%

Kumulative Ertragsminderung bei Trockenstress

$$\frac{Y_m - Y_a}{Y_m} = K_y \cdot \frac{ET_c - ET_a}{ET_c}$$

$$\frac{Y_a}{Y_m} = 1 - K_y \cdot \frac{ET_c - ET_a}{ET_c}$$

Y_m	Ertrag maximal
Y_a	Ertrag tatsächlich
ET_c	ET maximal
Et_a	ET tatsächlich
K_Y	Yield response factor
1…i	Wachstumsstadien

$$\left(\frac{Y_m - Y_a}{Y_m}\right)_i = 1 - \left(\frac{Y_{a,1}}{Y_{m,1}}\right) \cdot \left(\frac{Y_{a,2}}{Y_{m,2}}\right) \cdots \left(\frac{Y_{a,i}}{Y_{m,i}}\right) = 1 - \prod_1^i \left(\frac{Y_{a,i}}{Y_{m,i}}\right)$$

$$\left(\frac{Y_m - Y_a}{Y_m}\right)_i = 1 - \prod_1^i \left(1 - K_{y,i} \cdot \frac{ET_{c,i} - ET_{a,i}}{ET_{c,i}}\right)$$ Kumulative Ertragsminderung

$$\left(\frac{Y_a}{Y_m}\right)_i = \prod_1^i \left(1 - K_{y,i} \cdot \frac{ET_{c,i} - ET_{a,i}}{ET_{c,i}}\right)$$ Kumulativer relativer Ertrag

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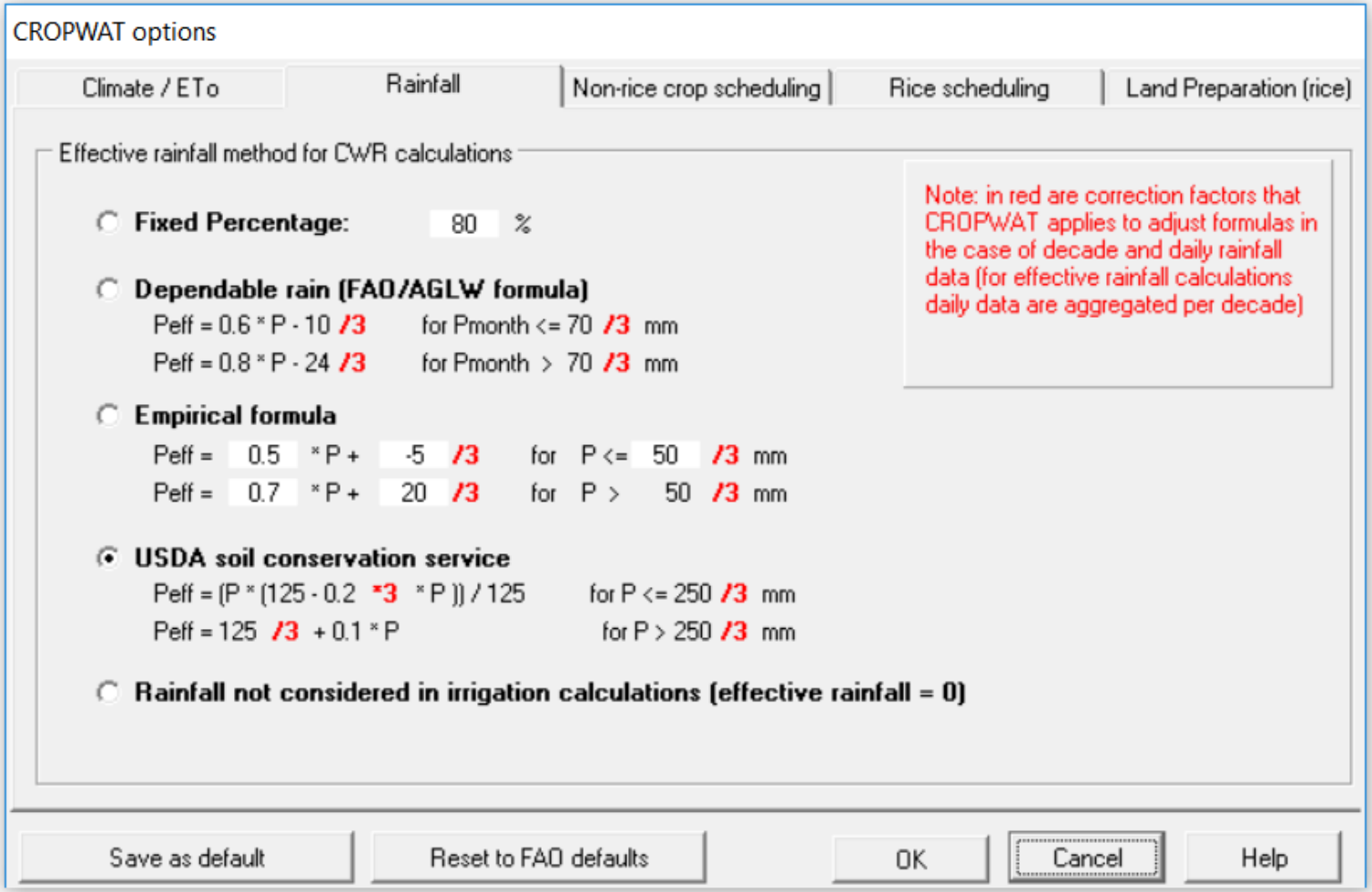
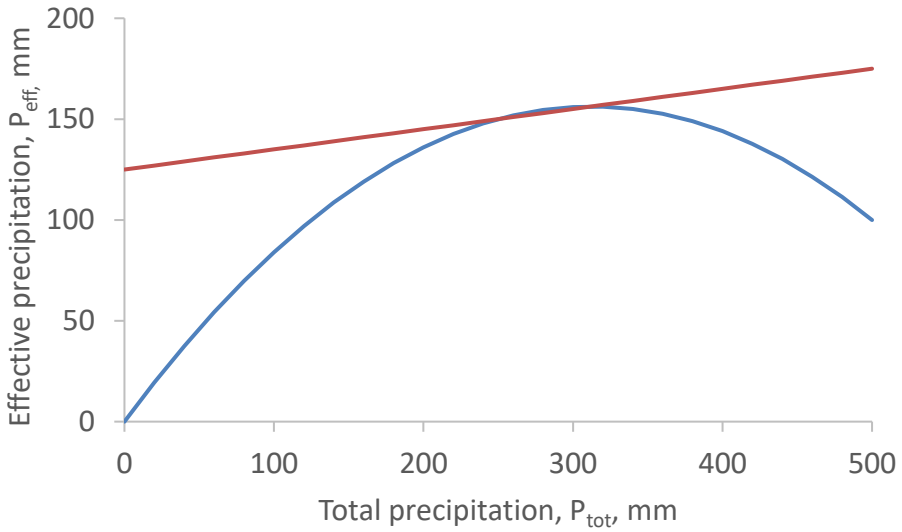
Effective precipitation (rain), P_{eff}



Effective precipitation (rain), P_{eff}

USDA Method

$$P_{eff} = \begin{cases} \dfrac{125 - 0.2 \cdot P_{tot}}{125} \cdot P_{tot};\ P_{tot} < 250\ mm \\ 125 + 0.1 \cdot P_{tot};\qquad P_{tot} \geq 250\ mm \end{cases}$$



P_{eff} effective precipitation, mm

P_{tot} total precipitation, mm

USDA Soil Conservation Service