Irrigation Scheduling

Eric Harmsen
Department of Agricultural and Biosystems Engineering

eharmsen@uprm.edu

http://academic.uprm.edu/abe/PRAGWATER

Irrigation Scheduling

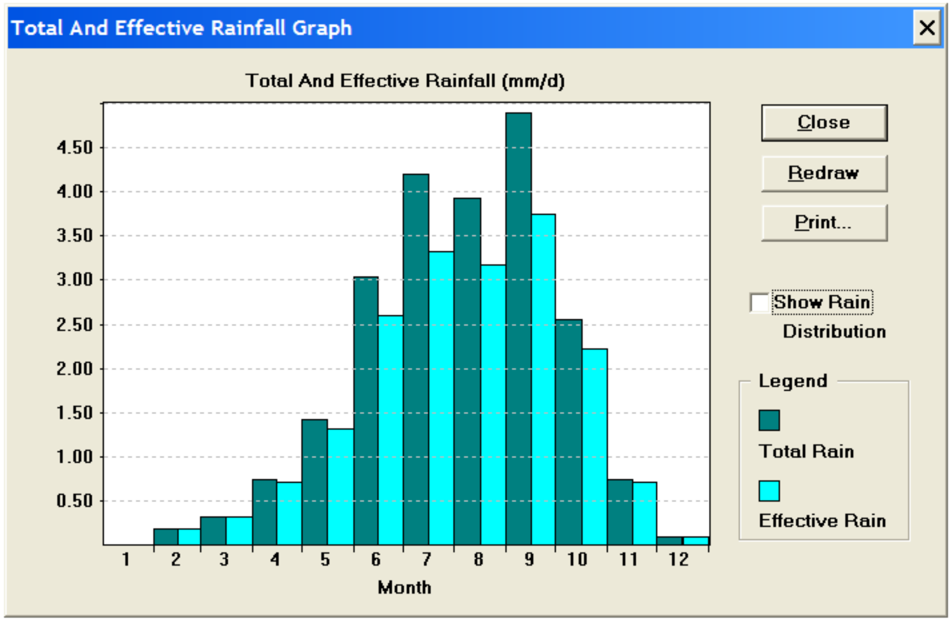
- Irrigation scheduling is the decision of when and how much water to apply to a field.
- Its purpose is to maximize irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level.
- Irrigation scheduling saves water and energy.
- All irrigation scheduling procedures consist of monitoring indicators that determine the need for irrigation.

(http://www.ext.colostate.edu/PUBS/crops/04708.html)

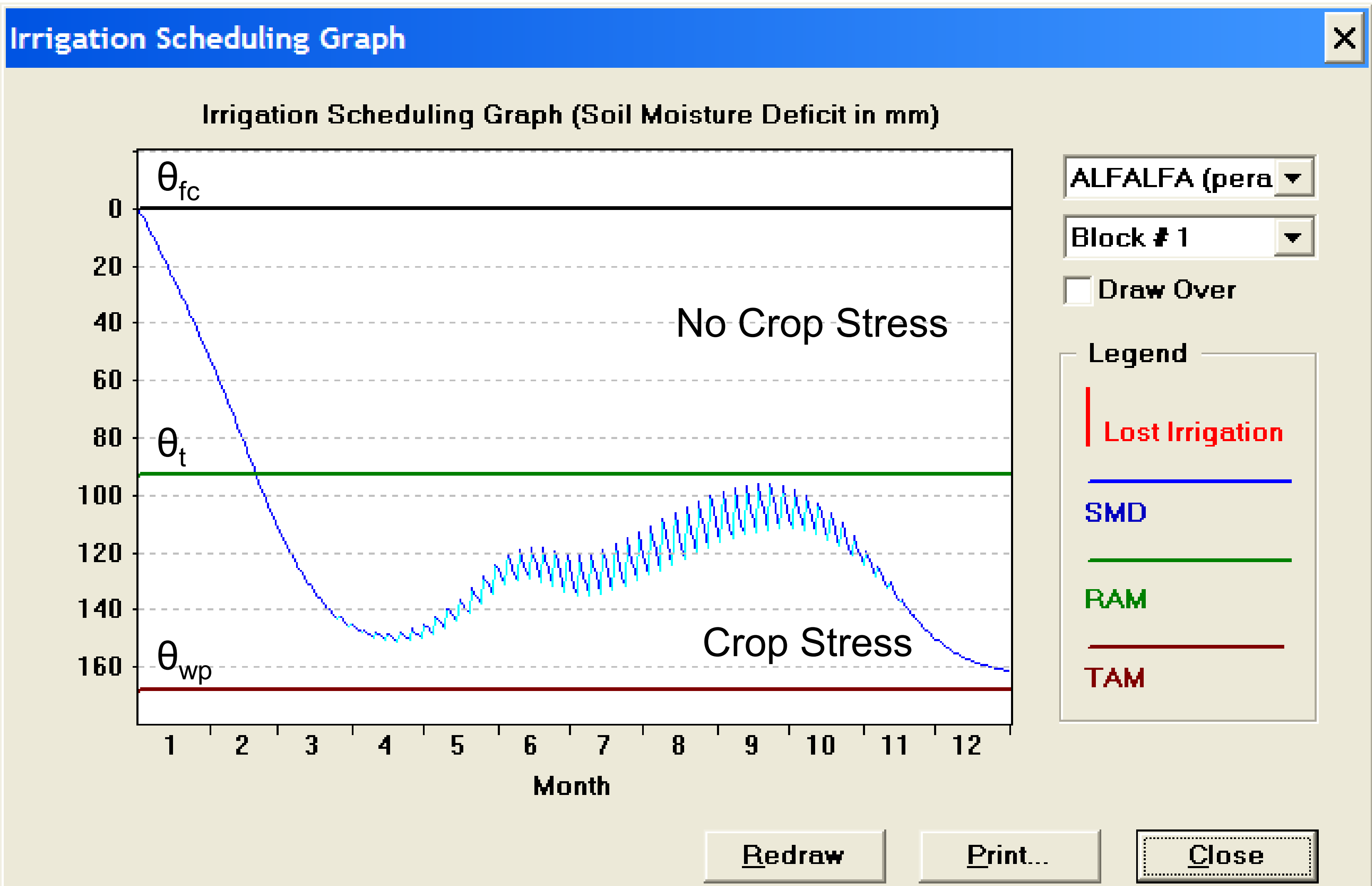
Need for Irrigation Scheduling Example

- Kurnool, India
- Crop: Alfalfa
- Soil texture: Medium

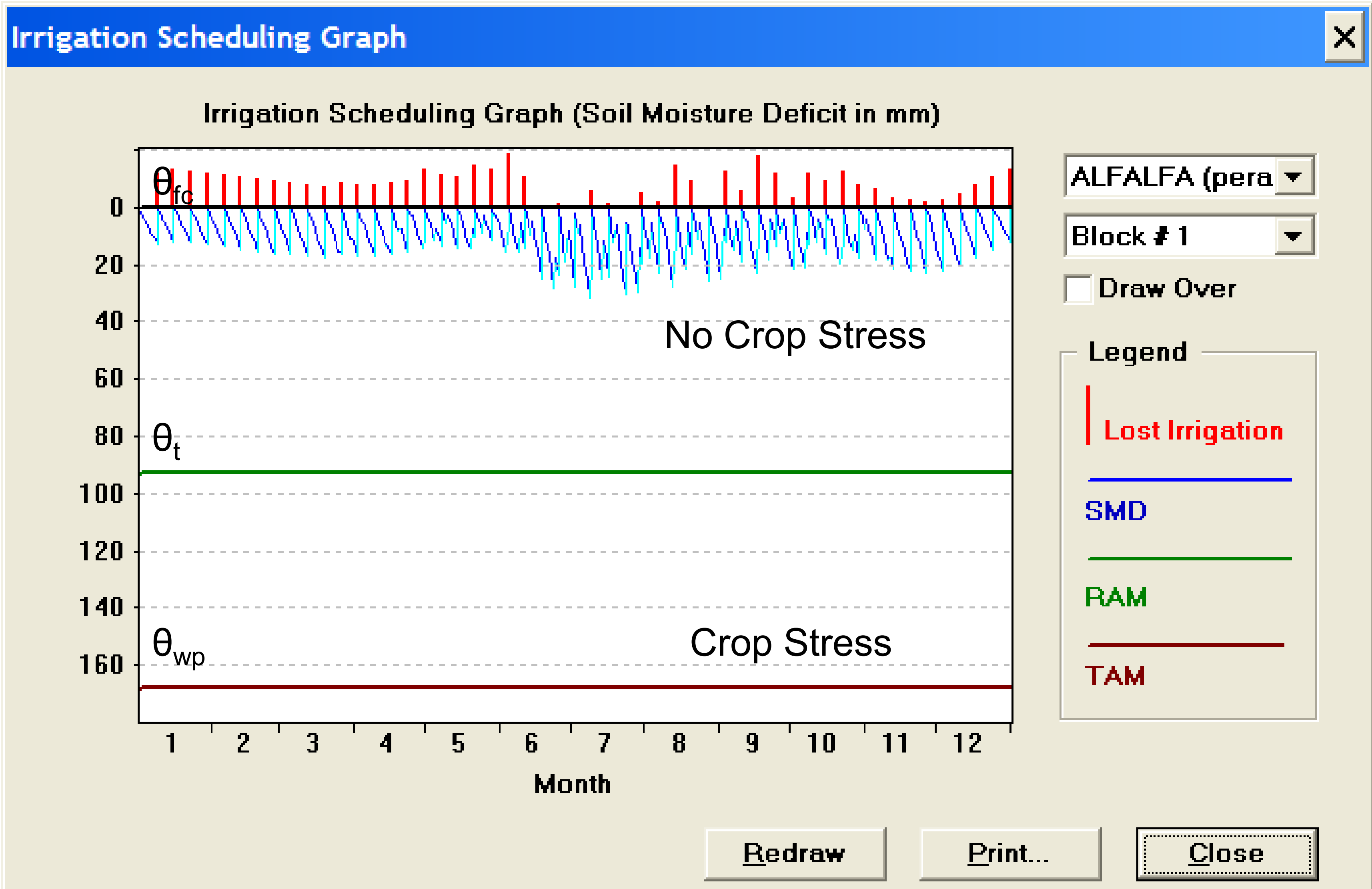
Rainfall 675 mm/year



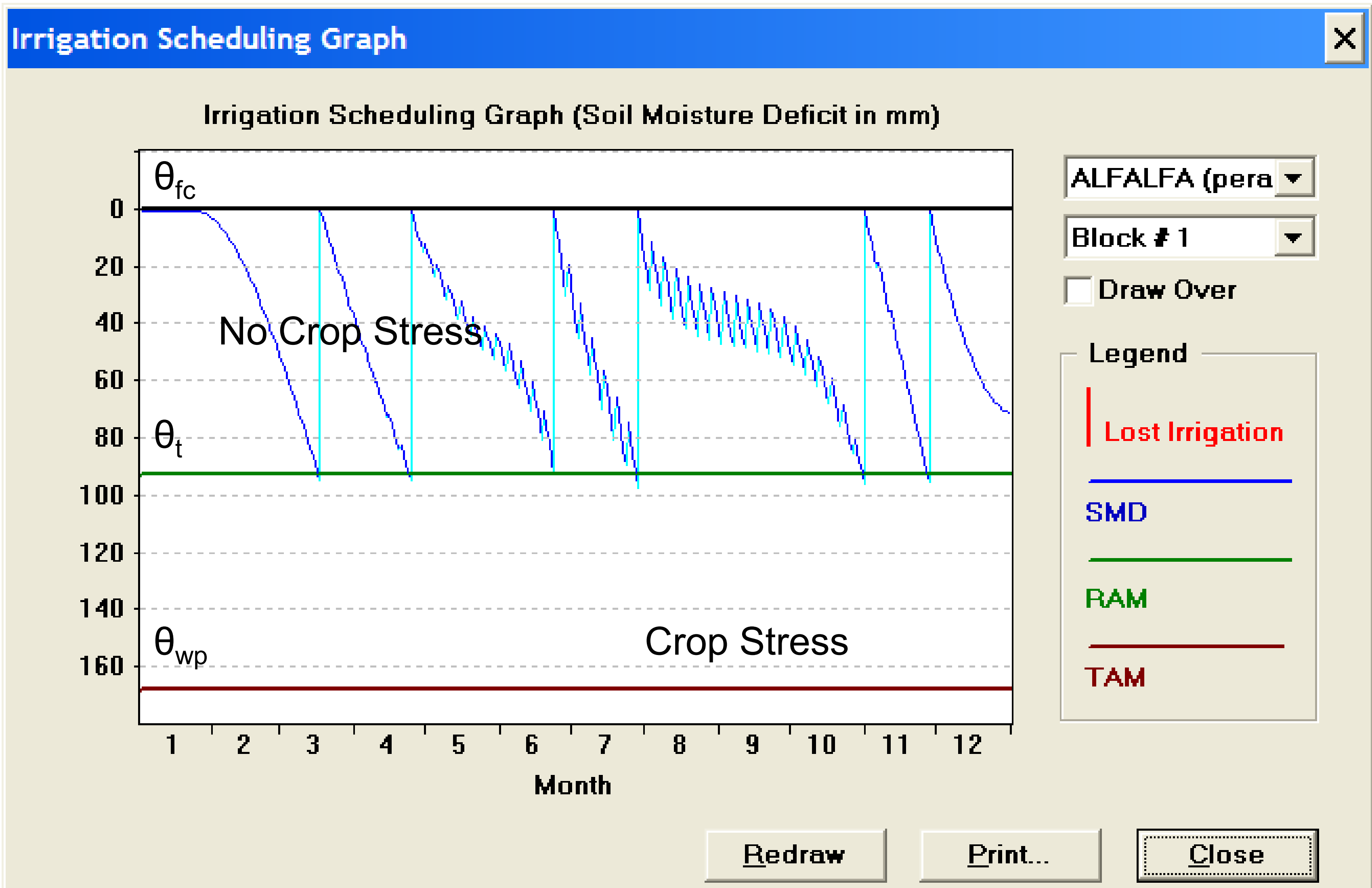
No irrigation during the year



1 inch of irrigation per week



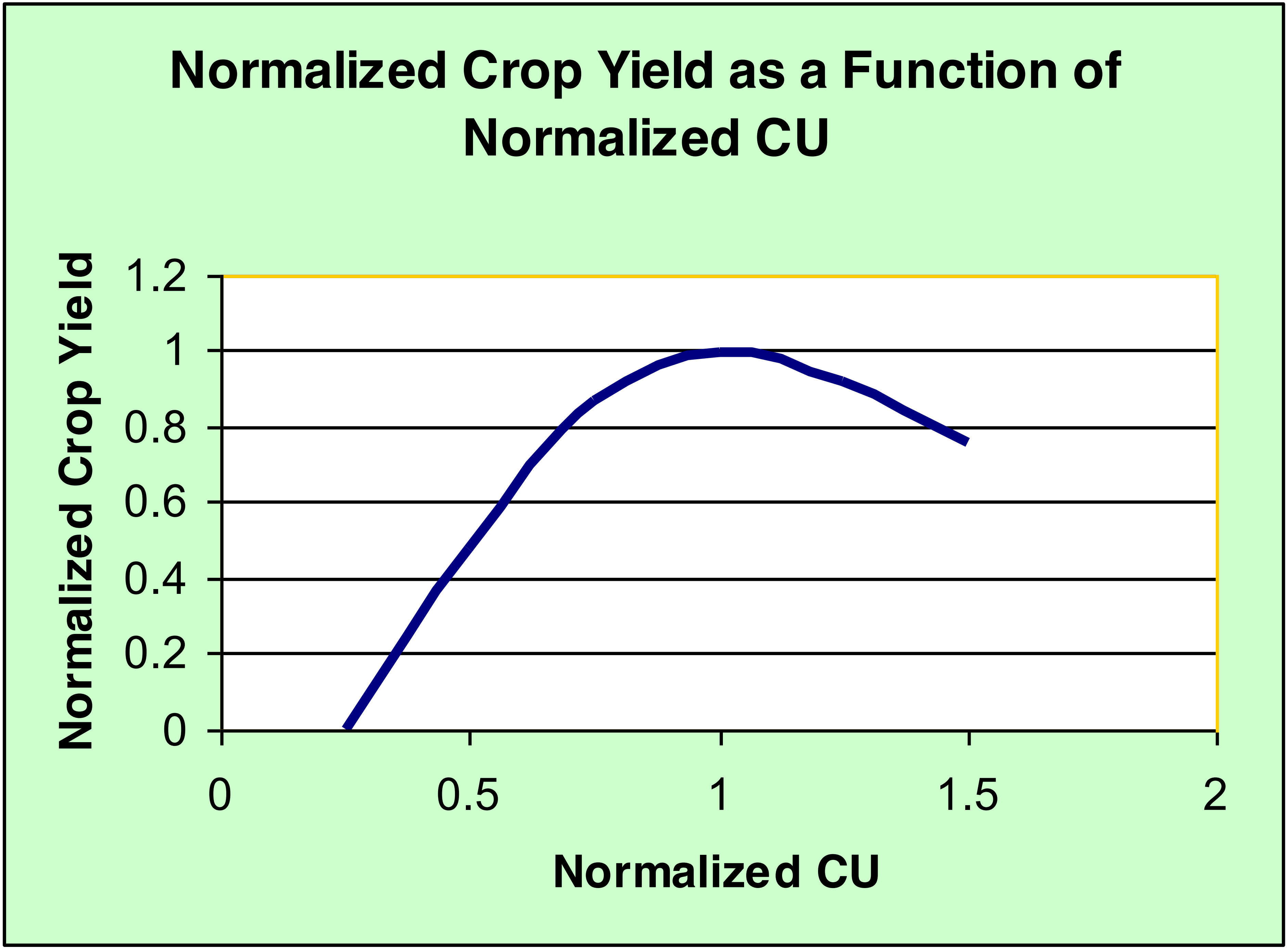
Irrigate when soil moisture reaches critical level



Why is Knowing the Correct Consumptive Use Important?

The Cost of Over-Applying Irrigation Water

- Assume the following:
  - Small 10-acre farm grows pumpkin
  - Estimated CU for season = 500 mm
  - Actual potential CU for season = 400 mm
  - Overall cost of water = $30/acre-ft (considering only: cost of water and electricity)
  - Assume the normalized yield vs. CU curve in the next slide is applicable.
  - Net income from a typical Calibaza crop = $1,800/acre.



Normalized Crop Yield as a Function of Normalized CU
Normalized Crop Yield
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
Normalized CU

Example continued

- Results:
  - Excess water applied = 100 mm = 1.07million gallons = 3 acre-ft (lost to groundwater)
  - Normalized CU = 1.25, therefore normalized yield = 0.9 (or 0.1 loss)
  - Potential $ LOST = cost of water + lost yield = 3 ac-ft x $30/ac-ft + [0.1*$1,800/ac] x 10 ac = $1890
  - Agr. Chemicals are leached to groundwater (cost was not included in calcluation). Groundwater was potentially contaminated

Cost of Under-Applying Irrigation Water

- Assume the following:
  - Same pumpkin farm (10-acres)
  - Estimated CU for season = 300 mm
  - Actual potential CU for season = 400 mm
  - Assume the normalized yield vs. CU curve is applicable.
  - Net income of a typical Calibaza crop = $1,800/acre.

Example continued

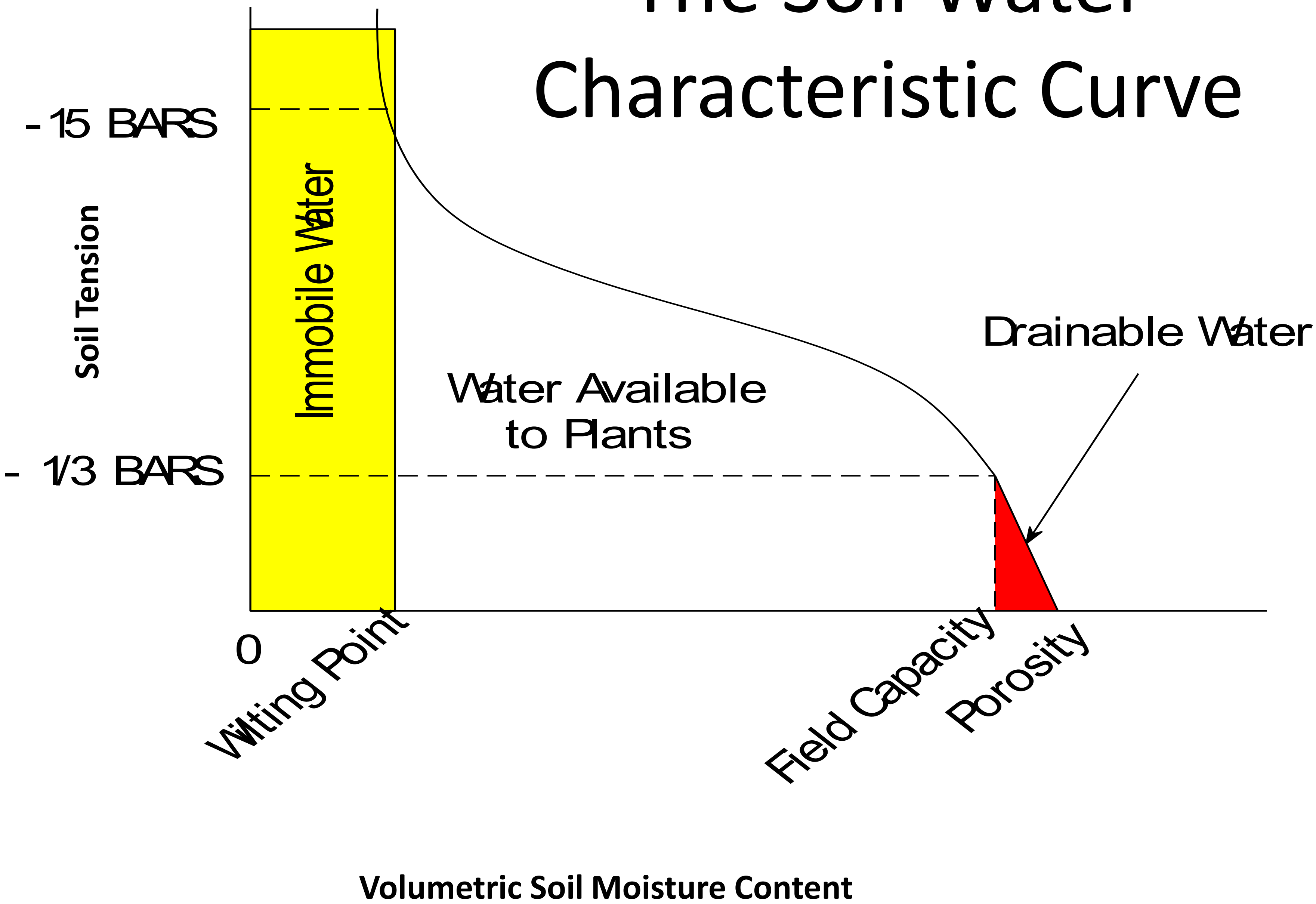
Results:

- Water deficit = 100 mm
- With a normalized CU of 0.82, the normalized yield = 0.85 (or 0.15 loss)
- Potential $ LOST = lost yield = [0.15*$1,800/ac] x 10 ac = $2,700

Conclusions from Examples

- The potential value of the crop may be significantly reduced by over or under-application irrigation water.
- When water is over-applied, in addition to the reducing the potential value of the crop, certain costs are also wasted (water, fuel, chemicals, etc.)
- Over application of water can lead to degradation of ground and surface waters.

The Soil Water Characteristic Curve



Water Balance (checkbook)Method

$$\theta_2 = R + Irr - RO - ET_{c\ adj} - PERC + \theta_1$$

θ_2 = volumetric moisture content at time 2

θ_1 = volumetric moisture content at time 1

R = effective rainfall

RO = runoff

PERC = water that percolates past the root zone

Crop Water Use (ET_{cadj})

- The rate of water use by the crops can be estimated as follows

$$ET_c = K_c\ ET_o$$

$$ET_{cadj} = K_s\ ET_c$$

Where

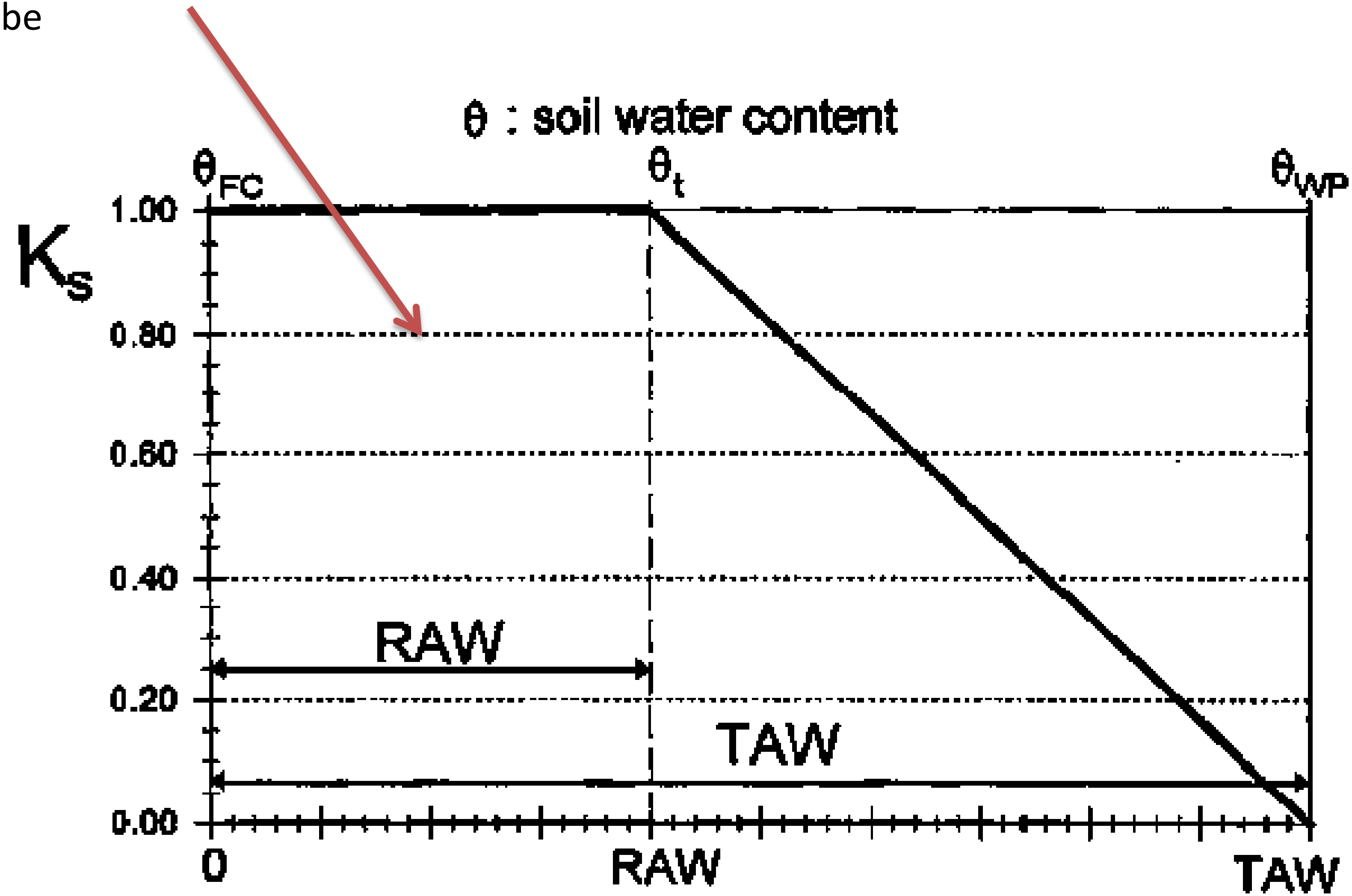
ET_o = Reference Evapotranspiration

K_c = Evapotranspiration Crop Coefficient

K_s = Crop Stress Factor

Crop Stress Factor

This is where
Your soil should
be



Readily Available Water

- Plants can only remove a portion of the available water before growth and yield are affected. This portion is the “readily available water” (RAW).
- For most crops RAW is between 40% to 65%
- RAW is estimated from the following formula:

$$RAW = (MAD)\ (TAW)$$

Management Allowed Deficit (MAD) and Rooting Depths of Various Crops

Crop	*MAD*	*Rooting Depth* *ft*	*m*
Alfalfa	0.55	3–10	1.0–3.0
Banana	0.35	2–3	0.5–0.9
Barley	0.55	3–5	1.0–1.5
Beans	0.45	1–2	0.5–0.7
Beets	0.5	2–3	0.6–1.0
Cabbage	0.45	1–2	0.4–0.5
Sunflower	0.45	3–5	0.8–1.5
Sweet potatoes	0.65	3–5	1.0–1.5
Tomatoes	0.4	2–5	0.7–1.5
Vegetables	0.2	1–2	0.3–0.6
Wheat	0.55	3–5	1.0–1.5

Source: Doorenbos, J. and W. O. Pruitt (1977). Reprinted with permission from Food and Agriculture Organization of the United Nations.

Threshold Moisture Content, θ_t

- If the soil moisture content falls below θ_t , the crop will go into stress and you will loss crop yield!

$$\theta_t = \theta_{FC} - RAW$$

where

θ_t = threshold moisture content

θ_{FC} = field capacity moisture content

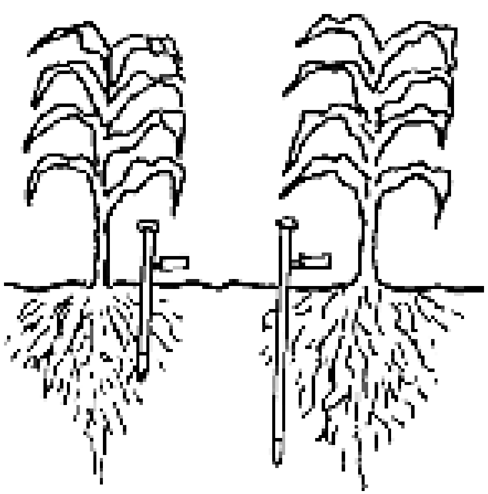
RAW = readily available water

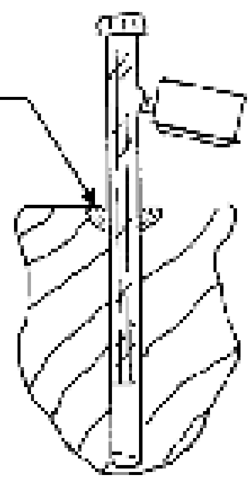
Volumetric Moisture Content

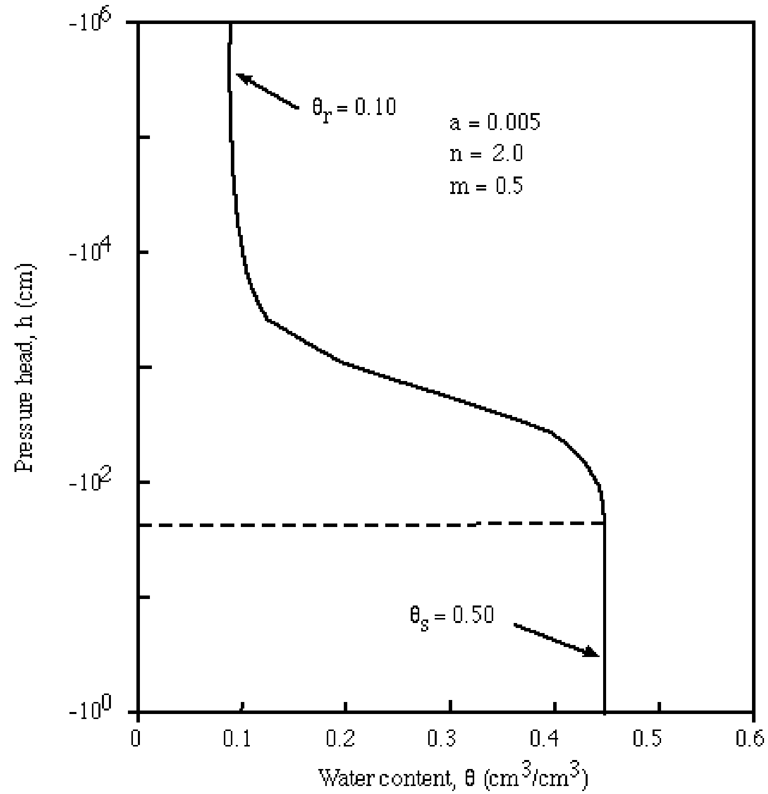
- Gravimetric Method (undisturbed core)
- Gravimetric Method (disturbed samples)
- Tensiometers
- Time Domain Reflectivity (TDR)
- Conductance
- Water balance method

Gravimetric Soil Sampling

Tensiometers







TDR

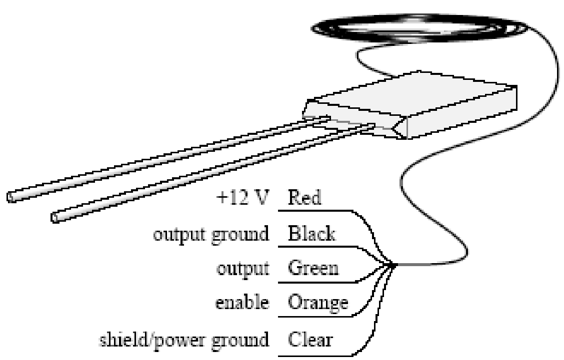
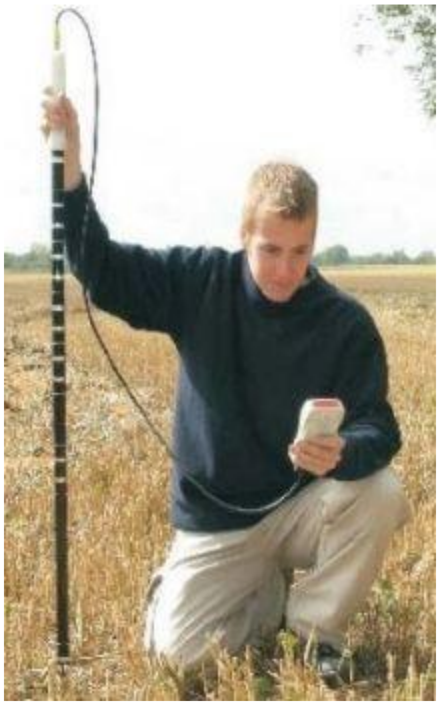


FIGURE 1. Water Content Reflectometer

Capacitance Method



Irrigation Scheduling Example

- Crop: Peppers
- Site: Isabela Experiment Station
- Soil: Coto Clay
- Irrigation: Drip with plastic mulch
- Scheduling method: Pan Evaporation
- Purpose of study: estimate deep percolation and N leaching

Estimating Nitrogen Leaching

$$L_{NO3} = 0.01\ \rho_b\ NO_3\ \ PERC\ /\ \theta_{vol}$$

$$L_{NH4} = 0.01\ \rho_b\ NH_4\ \ PERC\ /\ \theta_{vol}$$

Water Balance

$$Perc = (R\text{-}RO) + Irr - ET_c + \Delta S$$

Perc = **Deep percolation**

(R – RO) = **Rainfall – Runoff**

Irr = **Irrigation based on ET_{pan}**

ET_c = **Evapotranspiration based on Penman-Monteith method.**

ΔS = **Change in stored water**

$$IRR = ET_{pan} = K_c \, K_p \, E_{pan}$$

$IRR = ET_{pan}$ = Evapotranspiration based on pan

K_c = Crop coefficient

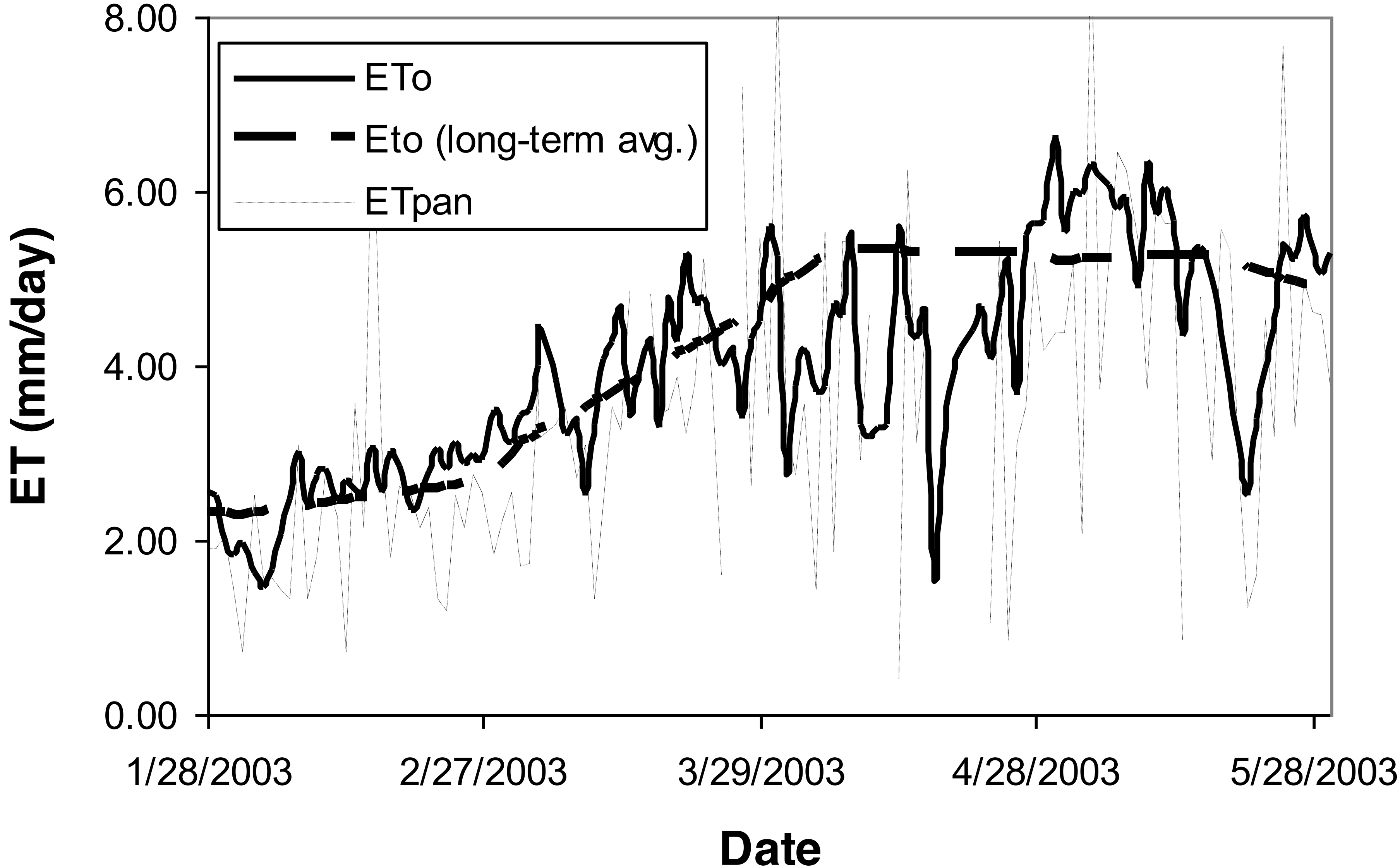
K_p = Pan coefficient

E_{pan} = Pan evaporation

$ET_c = K_c\ ET_o$

ET_c =	Evapotranspiration based on Penman-Monteith method.
K_c =	Calibrated crop coefficient
ET_o =	Reference evapotranspiration

Evapotranspiration – 2003 Season



http://academic.uprm.edu/abe/PRAGWATER

Puerto Rico Agricultural Water Management Website - Windows Internet Explorer

http://academic.uprm.edu/abe/PRAGWATER/

File Edit View Favorites Tools Help

Google finition irrigation scheduling Search Bookmarks Notebook Find Check Translate AutoFill AutoLink

Puerto Rico Agricultural Water Manageme...

Agricultural Water Management in Puerto Rico

Page last updated
August 7, 2008

- Home Page
- Contact Information
- Research Activities
- Links
- Crop Water Use
- Software and Books

Welcome to the University of Puerto Rico Agricultural Water Management Website.

University of Puerto Rico-Mayagüez

The goal of this site is to facilitate the dissemination of information related to sound water management practices in Puerto Rico. Information is included on:

Selected Publications and Presentations
Research Activities
Irrigation Related Links
Crop Water Use
Software and Books

Department of Agricultural Engineering
University of Puerto Rico-Mayagüez Campus
P.O. Box 9030
Mayagüez, PR 00681-9030

This website was developed through a grant from the University of Puerto Rico Experiment Station (Grant SP-347)

NEW

- **Download Soil Water Management Spreadsheet**
- **PPT Presentation: Management of Soils under Microirrigation**
- **Evaluate your drip irrigation system with the Distribution Uniformity Graph**
- **Download PR-ET Verion 1.03!!**
- **PowerPoint presentation on Climate Change Impacts on Agriculture in Puerto Rico, presented at the Simposio de Ciencias 2007, UPR-Carolina**
- **Spanish language translation of FAO Irrigation and Drainage Paper no. 56 (Crop Evapotranspiration)!**
- **"Riego por Goteo" text book by Dr. Megh Goyal, download electronic version**
- **Links to climate change impacts on agriculture**

Soil Water Management Spreadsheet

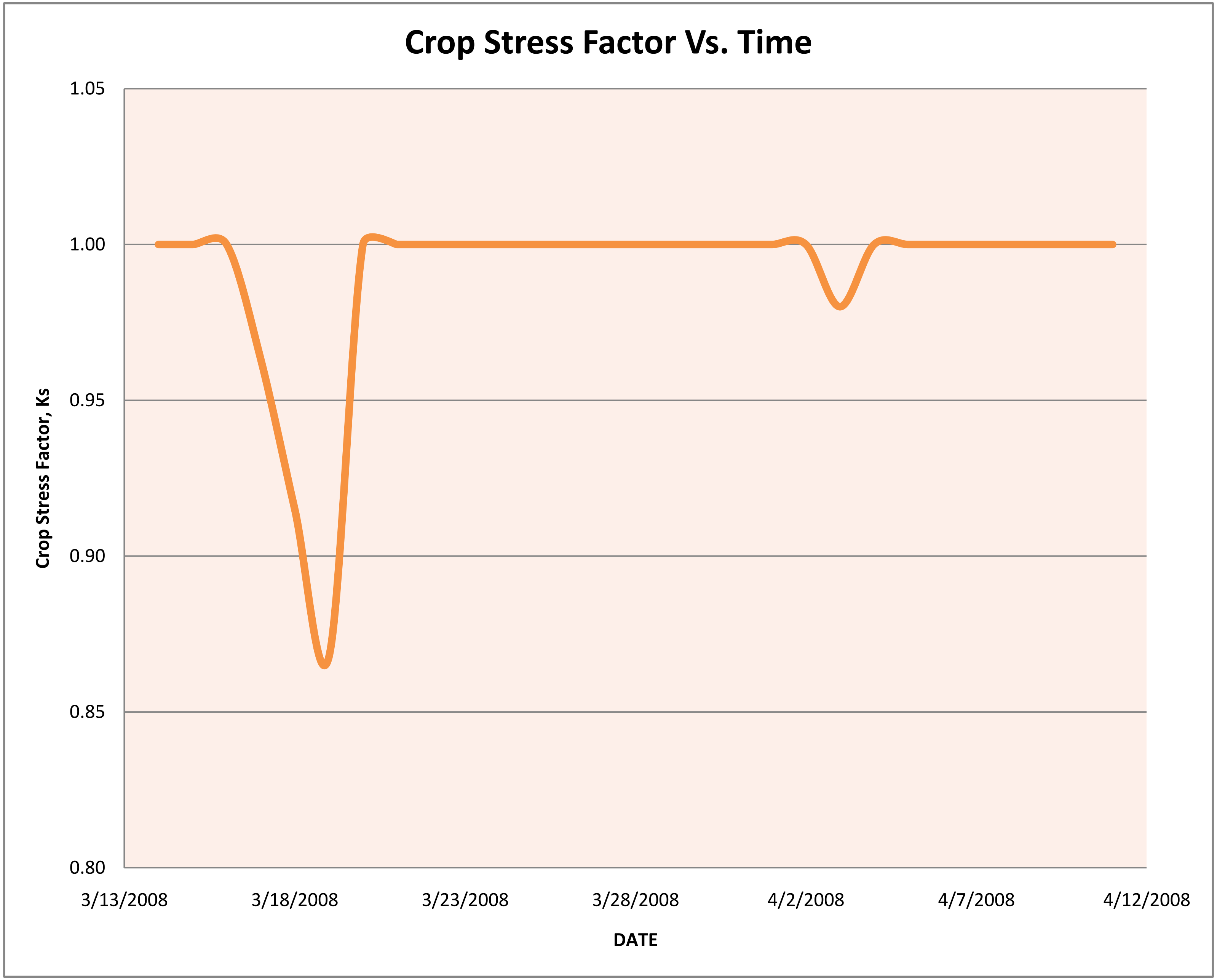
http://academic.uprm.edu/abe/PRAGWATER/

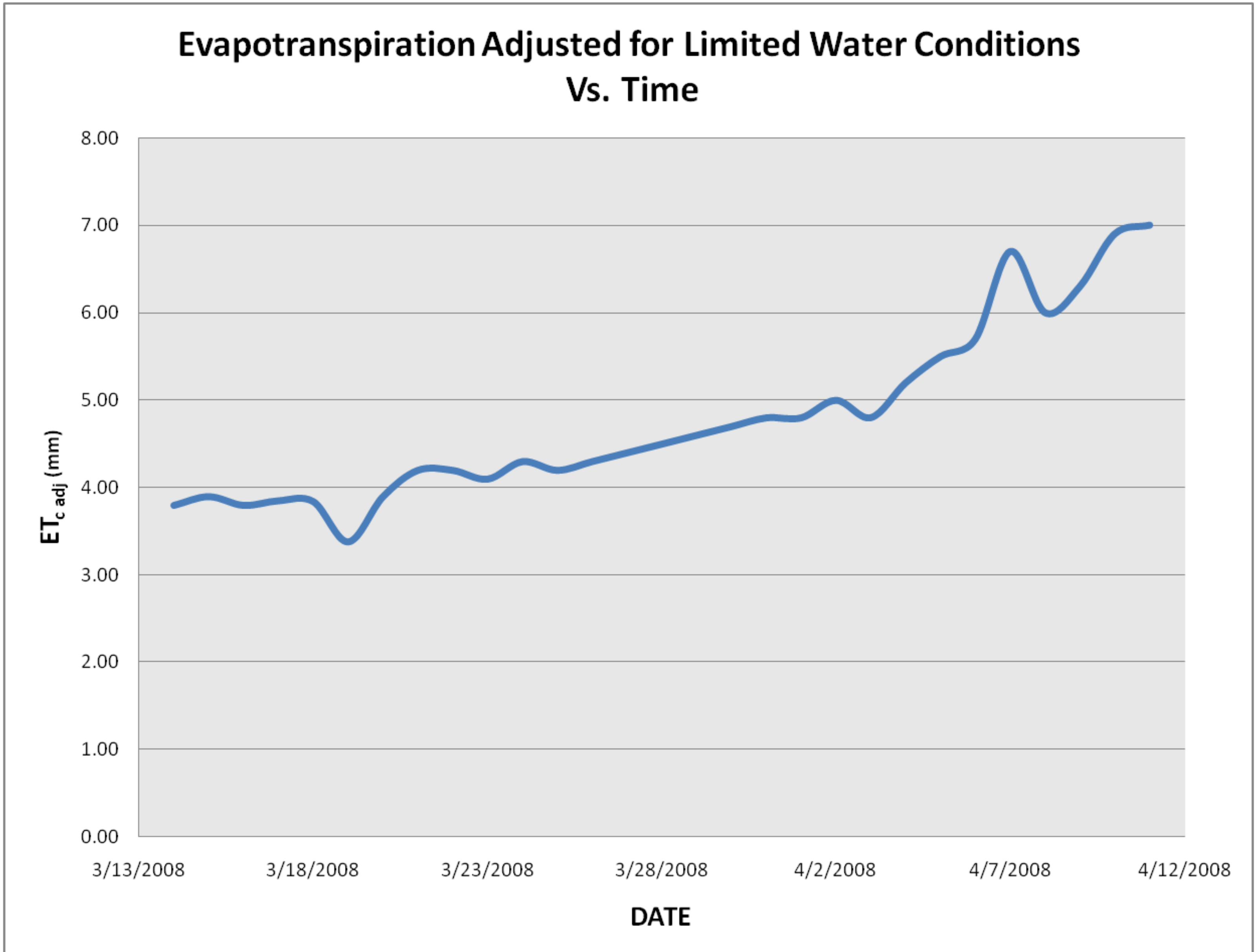
Date	Field Capacity	Wilting Point	Total Available Water	Root Depth	Management Allowed Deficit	Readily Available Moisture Content	Threshold Moisture Content	Moisture Content	Crop Stress Factor	Average Crop Evapotranspiration	Average Evapotranspiration Adjusted for Stress	Soil Water Deficit	Irrigation needed	Applied Irrigation or Rainfall	Did Stress Occur?
	FC	WP	TAW	RD	MAD	RAW	θ_t	θ	K_s	ET_c	$ET_{c\ adj}$				
	%	%	%	m	fraction	%	%	%		mm	mm	%	mm	mm	
3/14/2008	36	18	18	0.70	0.4	7.2	28.8	30.00	1.00	3.80	3.80	6.0	42	0	NO
3/15/2008	36	18	18	0.71	0.4	7.2	28.8	29.46	1.00	3.90	3.90	6.5	46	0	NO
3/16/2008	36	18	18	0.72	0.4	7.2	28.8	28.92	1.00	3.80	3.80	7.1	51	0	NO
3/17/2008	36	18	18	0.73	0.4	7.2	28.8	28.40	0.96	4.00	3.85	7.6	55	0	YES
3/18/2008	36	18	18	0.74	0.4	7.2	28.8	27.88	0.91	4.20	3.84	8.1	60	0	YES
3/19/2008	36	18	18	0.75	0.4	7.2	28.8	27.37	0.87	3.90	3.38	8.6	65	0	YES
3/20/2008	36	18	18	0.76	0.4	7.2	28.8	36.00	1.00	3.90	3.90	0.0	0	69	NO
3/21/2008	36	18	18	0.77	0.4	7.2	28.8	35.50	1.00	4.20	4.20	0.5	4	0	NO
3/22/2008	36	18	18	0.78	0.4	7.2	28.8	34.96	1.00	4.20	4.20	1.0	8	0	NO
3/23/2008	36	18	18	0.79	0.4	7.2	28.8	34.43	1.00	4.10	4.10	1.6	12	0	NO
3/24/2008	36	18	18	0.80	0.4	7.2	28.8	33.91	1.00	4.30	4.30	2.1	17	0	NO
3/25/2008	36	18	18	0.81	0.4	7.2	28.8	33.38	1.00	4.20	4.20	2.6	21	0	NO
3/26/2008	36	18	18	0.82	0.4	7.2	28.8	32.87	1.00	4.30	4.30	3.1	26	0	NO
3/27/2008	36	18	18	0.83	0.4	7.2	28.8	32.35	1.00	4.40	4.40	3.6	30	0	NO
3/28/2008	36	18	18	0.84	0.4	7.2	28.8	31.83	1.00	4.50	4.50	4.2	35	0	NO

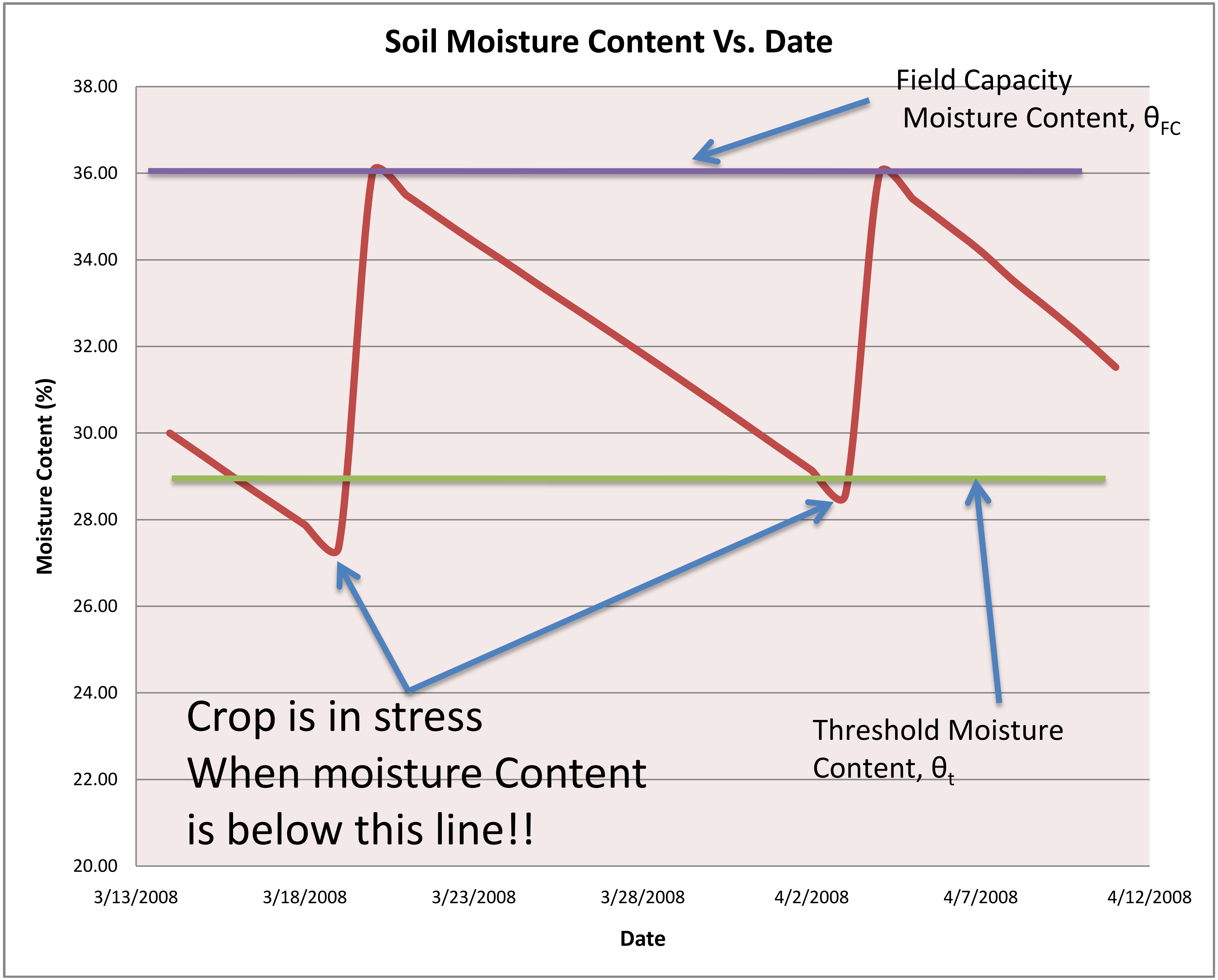
User must enter the yellow spreadsheet cells

Date	Field Capacity	Wilting Point	Total Available Water	Root Depth	Management Allowed Deficit	Readily Available Moisture Content
	FC	WP	TAW	RD	MAD	RAW
	%	%	%	m	fraction	%
3/14/2008	36	18	18	0.70	0.4	7.2
3/15/2008	36	18	18	0.71	0.4	7.2
3/16/2008	36	18	18	0.72	0.4	7.2
3/17/2008	36	18	18	0.73	0.4	7.2
3/18/2008	36	18	18	0.74	0.4	7.2
3/19/2008	36	18	18	0.75	0.4	7.2
3/20/2008	36	18	18	0.76	0.4	7.2
3/21/2008	36	18	18	0.77	0.4	7.2
3/22/2008	36	18	18	0.78	0.4	7.2
3/23/2008	36	18	18	0.79	0.4	7.2
3/24/2008	36	18	18	0.80	0.4	7.2
3/25/2008	36	18	18	0.81	0.4	7.2
3/26/2008	36	18	18	0.82	0.4	7.2
3/27/2008	36	18	18	0.83	0.4	7.2

Threshold Moisture Content	Moisture Content	Crop Stress Factor	Average Crop Evapotranspiration	Average Evapotranspiration Adjusted for Stress
θ_t	θ	K_s	ET_c	$ET_{c\ adj}$
%	%		mm	mm
28.8	30.00	1.00	3.80	3.80
28.8	29.46	1.00	3.90	3.90
28.8	28.92	1.00	3.80	3.80
28.8	28.40	0.96	4.00	3.85
28.8	27.88	0.91	4.20	3.84
28.8	27.37	0.87	3.90	3.38
28.8	36.00	1.00	3.90	3.90
28.8	35.50	1.00	4.20	4.20
28.8	34.96	1.00	4.20	4.20
28.8	34.43	1.00	4.10	4.10
28.8	33.91	1.00	4.30	4.30
28.8	33.38	1.00	4.20	4.20
28.8	32.87	1.00	4.30	4.30
28.8	32.35	1.00	4.40	4.40


Crop Stress Factor Vs. Time
1.05
1.00
0.95
0.90
0.85
0.80
Crop Stress Factor, Ks
3/13/2008
3/18/2008
3/23/2008
3/28/2008
4/2/2008
4/7/2008
4/12/2008
DATE


Evapotranspiration Adjusted for Limited Water Conditions
Vs. Time
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
ET$_{c\ adj}$ (mm)
3/13/2008
3/18/2008
3/23/2008
3/28/2008
4/2/2008
4/7/2008
4/12/2008
DATE


Soil Moisture Content Vs. Date
Field Capacity
Moisture Content, θFC
Crop is in stress
When moisture Content
is below this line!!
Threshold Moisture
Content, θt
Moisture Cotent (%)
38.00
36.00
34.00
32.00
30.00
28.00
26.00
24.00
22.00
20.00
3/13/2008
3/18/2008
3/23/2008
3/28/2008
4/2/2008
4/7/2008
4/12/2008
Date

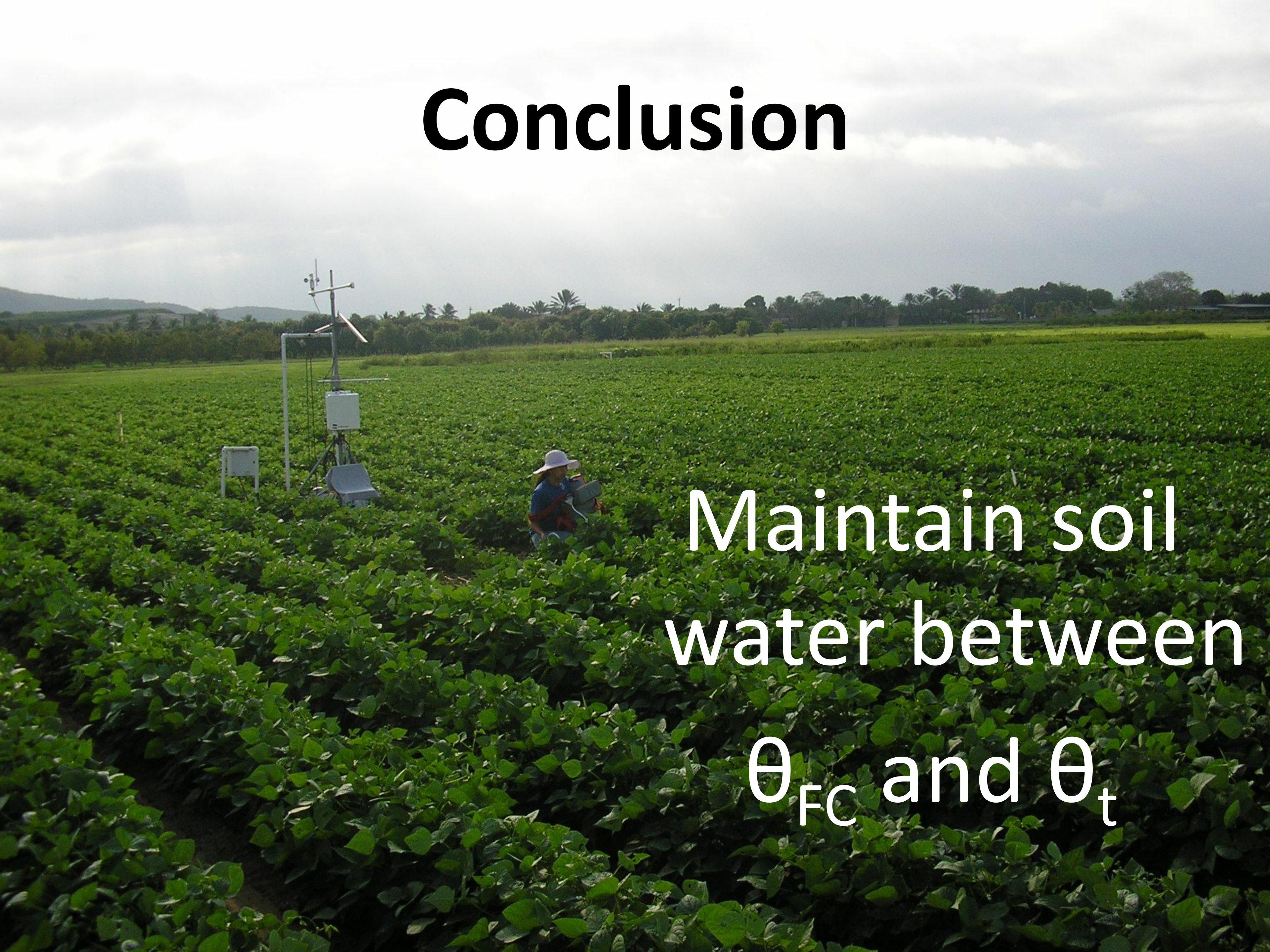
Soil Water Deficit	Irrigation needed	Applied Irrigation or Rainfall	Did Stress Occur?
%	mm	mm	
6.0	42	0	NO
6.5	46	0	NO
7.1	51	0	NO
7.6	55	0	YES
8.1	60	0	YES
8.6	65	0	YES
0.0	0	69	NO
0.5	4	0	NO
1.0	8	0	NO
1.6	12	0	NO
2.1	17	0	NO
2.6	21	0	NO
3.1	26	0	NO
3.6	30	0	NO

Crop Stress!

Irrigation Application Rate and Timing

Irrigation Needed	Field Area	Percent Wetted Area	Irrigation Efficiency	Volume of Water to Apply	Pump Manifold Flow Rate	Time to Apply Irrigation
mm	Acres	%	%	gallons	Gallons per Minute	Hours
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
69	5	50	90	204890	500	6.8
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0

Conclusion



Maintain soil water between θ_{FC} and θ_t