Irrigation Scheduling Methods Applicable to the Southern Coast of Puerto Rico

Dr. Eric Harmsen
Professor, Dept. of Agricultural and Biosystems Eng., Univ. of Puerto Rico-Mayagüez
Eric.harmsen@upr.edu
(787)955-5102

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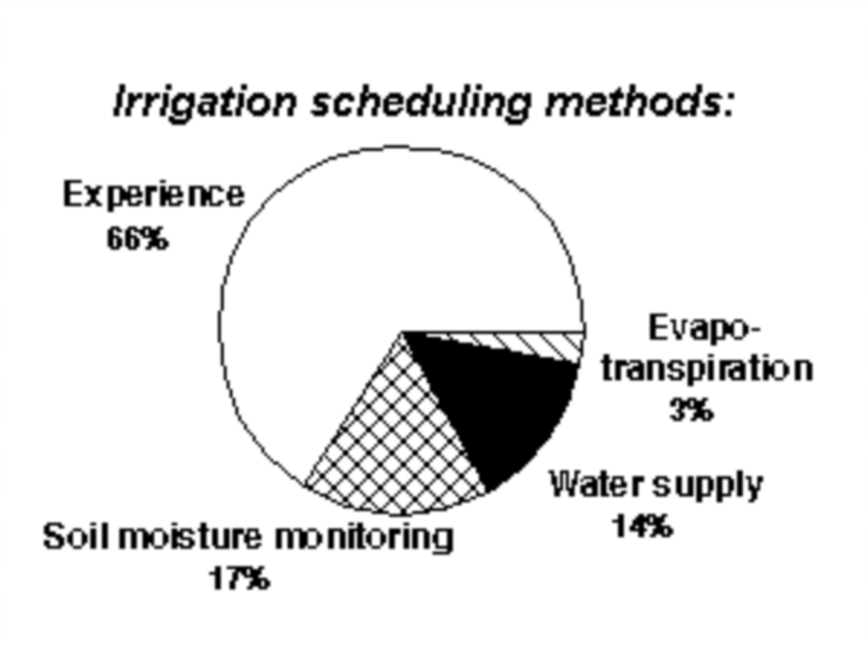
ACKNOWLEDGEMENT

- Colegio de Ciencias Agrícolas, Universidad de Puerto Rico
- USDA Hatch Project (H-402)
- NOAA-CREST
  (grant #NA11SEC4810004)

Irrigation Scheduling - What is the problem?

- There is anecdotal evidence that most farmers do not use scientific methods for scheduling irrigation



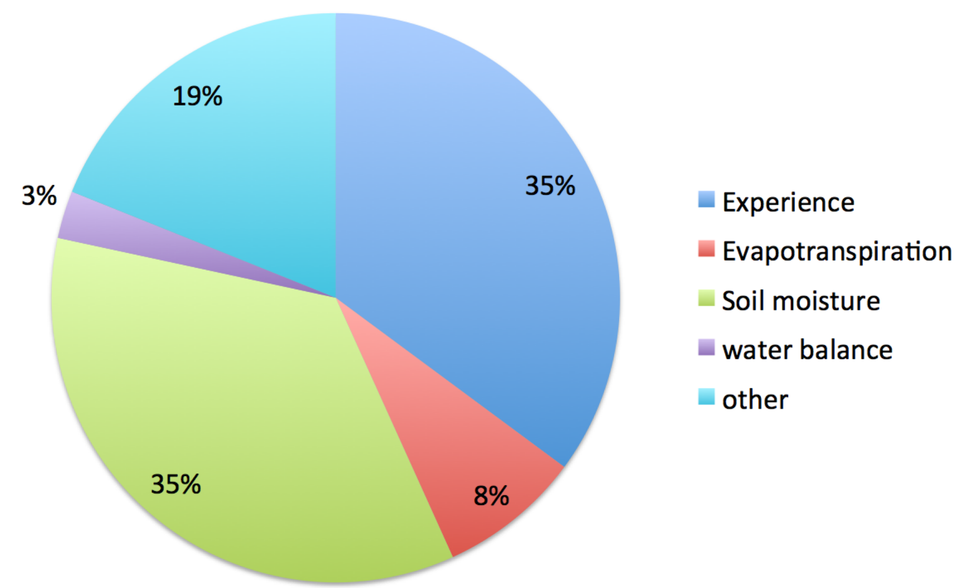
Data from Idaho, USA

http://www.webpages.uidaho.edu/~karenl/wq/wqbr/wqbr26.html

What can be done on the farm scale to increase efficiency and reduce waste?

IRRIGATION SCHEDULING: the process used by irrigation system managers (farmers) to determine the correct frequency and duration of watering. (wikipedia.org)

Irrigation Scheduling Methods used in Puerto Rico (preliminary data)



Definition

- What is irrigation scheduling***?*** ***Irrigation Scheduling*** is the process used by irrigation system managers (farmers) to determine the **correct frequency and duration** of watering. (wikipedia.org)

Why do we care?

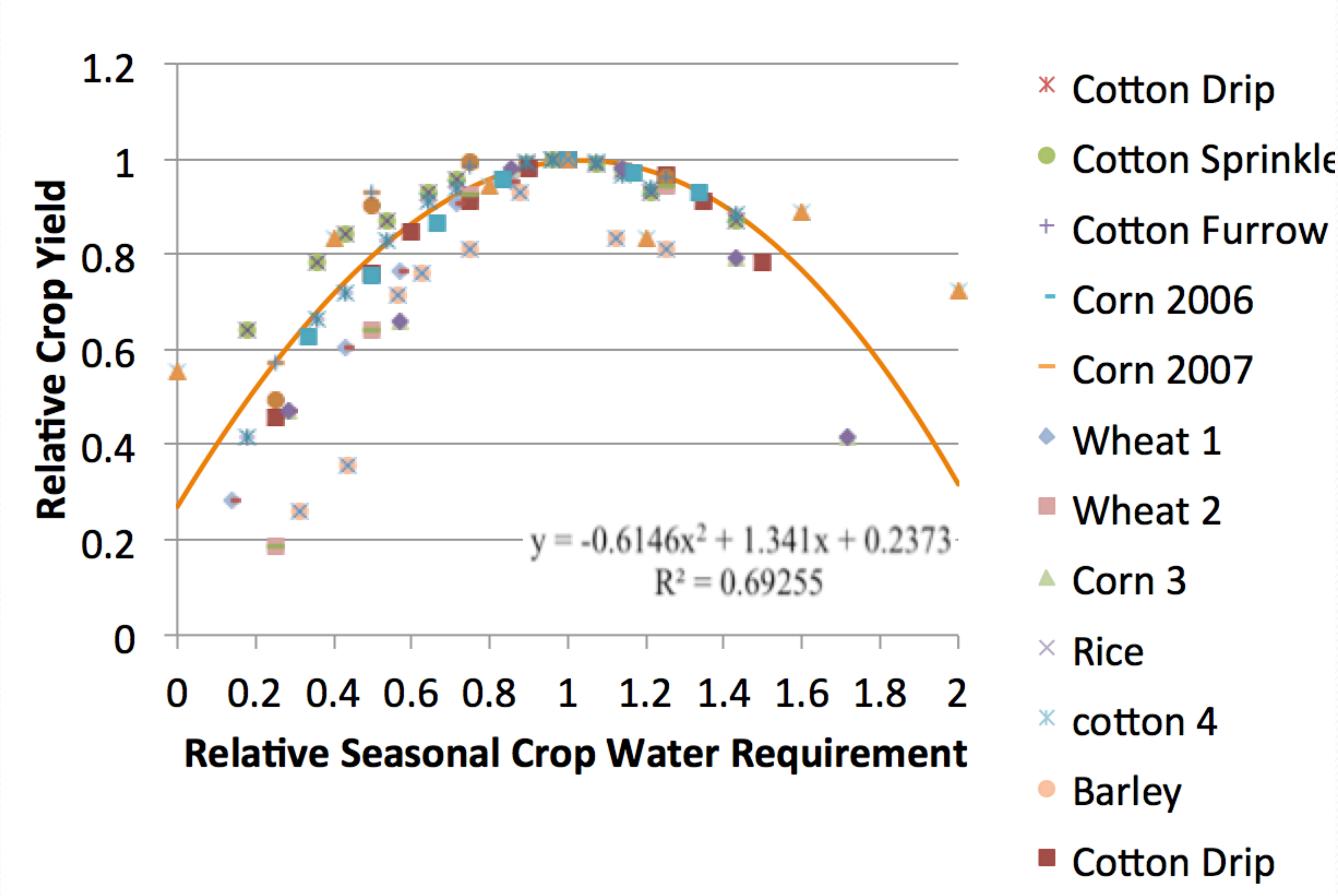
Over application of water

- Leads to the waste of
  - water
  - energy
  - chemicals
  - money
  - may lead to the contamination of ground and surface waters.
  - leaching of fertilizers past the root zone
  - water logging
  - lower crop yields.

Under-application of water

- Leads to
  - crop water stress
  - Reduced crop yield
  - loss of revenue to the grower

Relationship between relative crop yield and relative seasonal crop water requirement applied



How much money are we talking about?

	Relative Irrigation Applied						
	0.4	0.5	0.8	1.0	1.3	1.5	1.8
Cultivo*	**$ Lost / Cuerda**						
Gandules	47	32	10	0	12	35	69
Pepinillo	111	76	25	0	15	56	124
Repollo	256	174	57	0	21	103	247
Sandia	293	199	65	0	23	114	277
Platanos y Guineos, Plantilla	318	216	71	0	24	122	299
Calabaza	390	265	87	0	27	146	359
Cebolla	543	369	121	0	34	195	490
Pimiento	578	393	129	0	36	206	519
Barenjena	757	514	169	0	44	264	670
Platanos y Guineos, Reton~o	1,006	684	225	0	76	388	945
Melon, Cantaloupe y Honeydew	1,027	698	229	0	56	352	899
Raices y Tuberculos	1,041	707	232	0	57	356	911

*Based model budget data from the *Conjunto Tecnológico, UPR Experment Station*

Objective

- To review several important soil and water concepts related to irrigation management
- To introduce several methods of scheduling irrigation

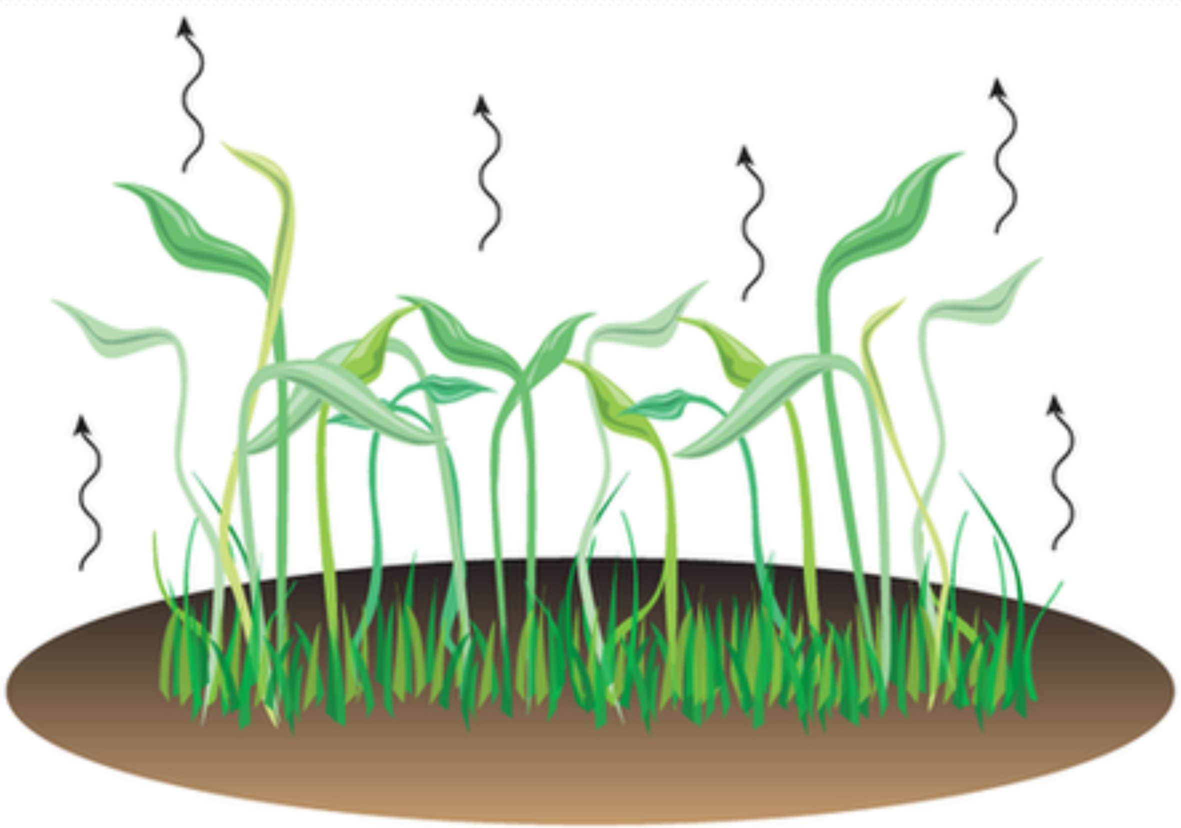
METHODS

- Experience Method
- Evapotranspiration Method
- Soil Moisture Method
- Water balance method

Experience Method

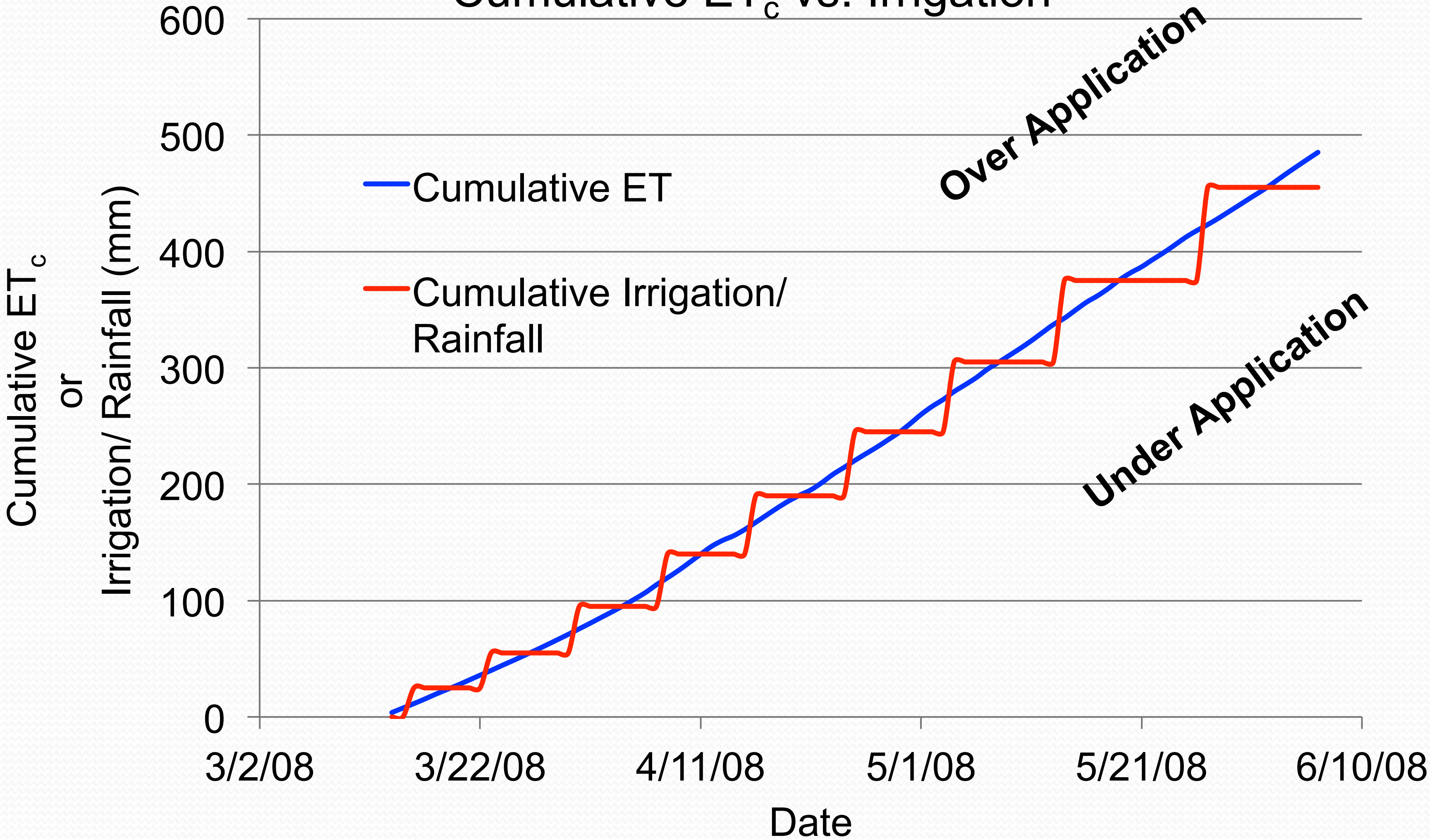
- “I apply 1 inch of water to my crop every week.”
- “The soil looks dry so I am going to irrigate.”
- “The crop looks stressed so I am going to irrigate.”

Evapotranspiration (ET) Method



http://www.google.com.pr/imgres?imgurl=https://s.campbellsci.com/images/9-6563.png&imgrefurl=https://www.campbellsci.com/blog/

Cumulative ET_c vs. Irrigation



Weather stations can provide rainfall, soil moisture and evapotranspiration

Evapotranspiration (ET) Method 1. Simple method (if you are currently not doing anything).

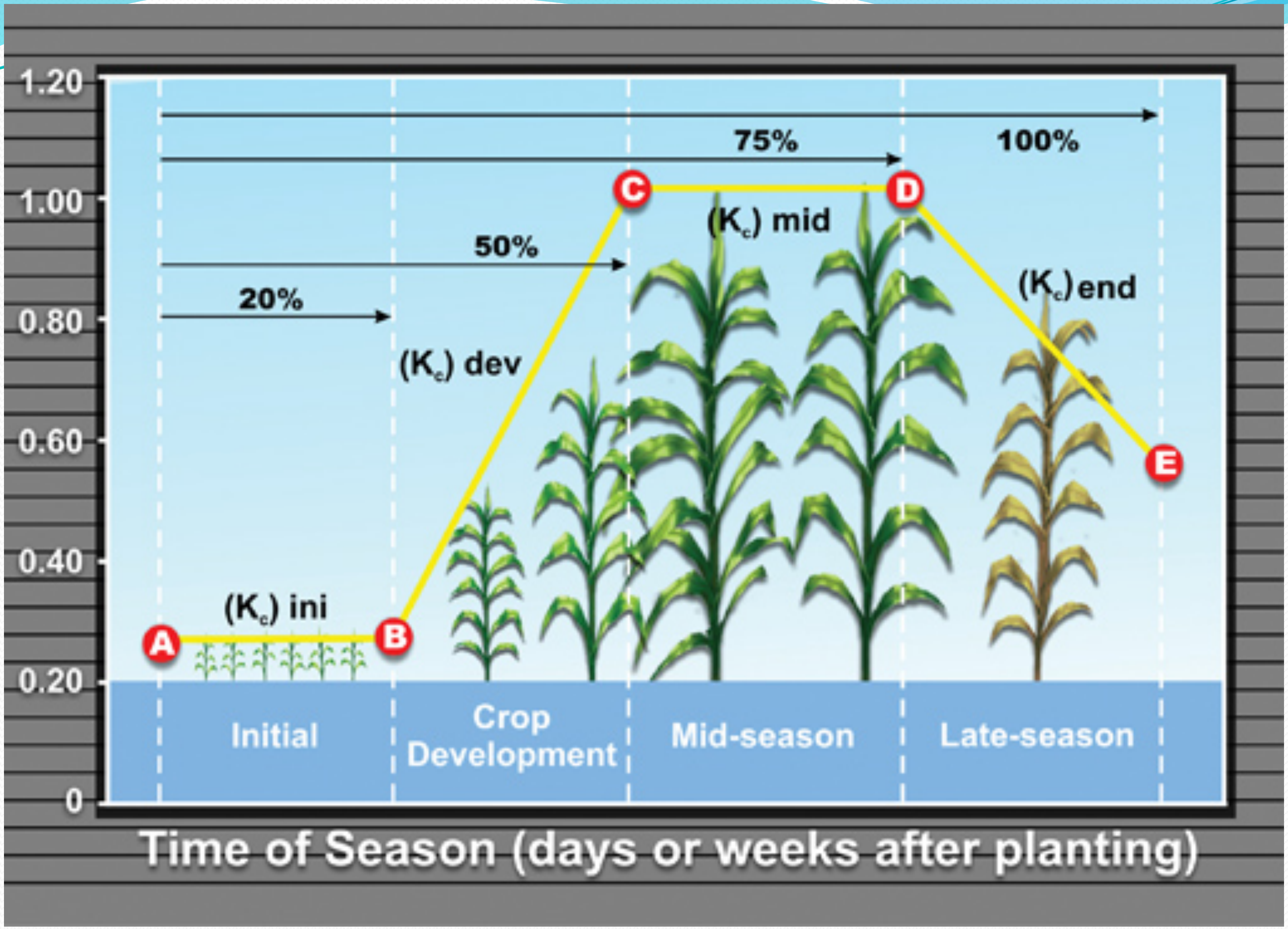
http://www.fao.org/docrep/s2022e/s2022e02.htm

TABLE 1. AVERAGE DAILY WATER NEEDS (mm) OF STANDARD GRASS DURING IRRIGATION SEASON

Climatic zone	Mean daily temperature		
	low	medium	high
	(less than 15°C)	(15-25°C)	(more than 25°C)
Desert/arid	4-6	7-8	9-10
Semi arid	4-5	6-7	8-9
Sub-humid	3-4	5-6	7-8
Humid	1-2	3-4	5-6

CROP WATER NEEDS IN PEAK PERIOD OF VARIOUS FIELD CROPS AS COMPARED TO STANDARD GRASS

Column 1	Column 2	Column 3	Column 4	Column 5
-30%	**-10%**	**same as standard grass**	**+ 10%**	**+20%**
citrus	cucumber	carrots	barley	paddy rice
olives	radishes	crucifers (cabbage, cauliflower, broccoli, etc.)	beans	sugarcane
grapes	squash	lettuce	maize	banana
		melons	flax	nuts & fruit trees with cover crop
		onions	small grains	
		peanuts	cotton	
		peppers	tomato	
		spinach	eggplant	
		tea	lentils	
		grass	millet	
		cacao	oats	
		coffee	peas	
		clean cultivated nuts & fruit trees e.g. apples	potatoes	
			safflower	
			sorghum	
			soybeans	
			sugarbeet	
			sunflower	
			tobacco	
			wheat	



http://www.ianrpubs.unl.edu/epublic/live/g1994/build/graphics/g1994-2.jpg

Example of simple ET method

- Crop: Sugar cane
- Location: Aguada, Puerto Rico
- Area: 50 cuerda
- Determine the irrigation requirement for one week during the peak of the growing season.
- Pump flow rate is 1000 gpm
- Irrigate once every 4 days
- Assume irrigation system is 75% efficient

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		peanuts	cotton	
		peppers	tomato	
		spinach	eggplant	
		tea	lentils	
		grass	millet	
		cacao	oats	
		coffee	peas	
		clean cultivated nuts & fruit trees e.g. apples	potatoes	
			safflower	
			sorghum	
			soybeans	
			sugarbeet	
			sunflower	
			tobacco	
			wheat	

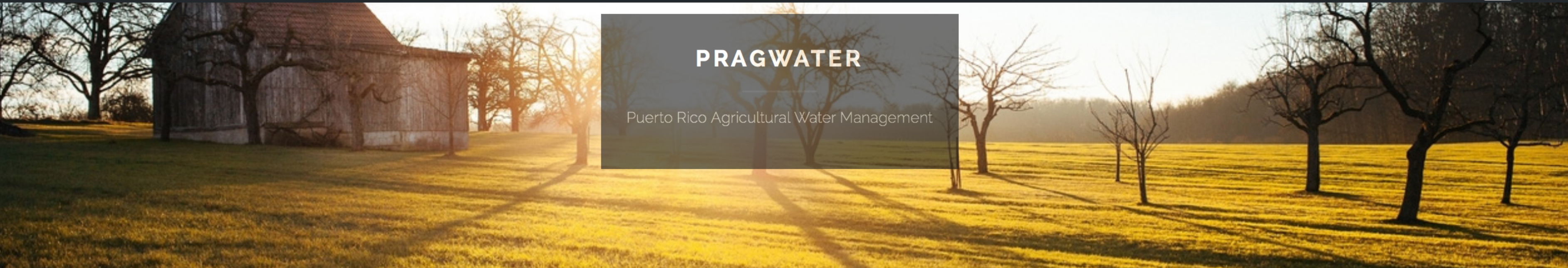
Calculations

- From Table 1: Water need for standard grass is 7 mm
- From table 2: add 20%.
  - 1.2 x 7 mm/day x 4 days = **33.6 mm**
- Calculate total gallons:
  - 33.6 mm x 50 cuerda x 1044 / 0.75

  = **2.3 million gallons**
- Pumping time:
  - (2,300,000 gal/1000 gal/min) /60 min/hr = **38.3 hours**

Evapotranspiration Method
2. Web-based ET method

- http://pragwater.com/daily-reference-evapotranspiration-eto-for-puerto-rico-hispaniola-and-jamaica/



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SIMPLE IRRIGATION SCHEDULING TOOL FOR PUERTO RICO

MARCH 29, 2012 / PRAGWATER / EDIT

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NOAA-CREST

Map and data products available on this webpage were developed by the NOAA-CREST team at UPRM under NOAA/EPP grant # NA11SEC4810004

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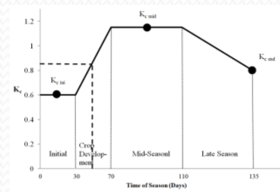
http://pragwater.com/2012/03/29/simple-irrigation-scheduling-tool-for-puerto-rico/

Web-based method for irrigation scheduling in PR

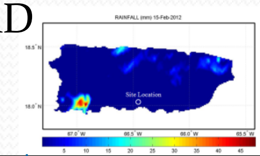
Start

Define problem (location, farm size, crop, etc.)

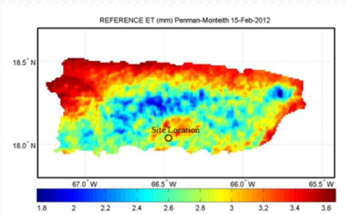
Determine average K_c for the time period



Determine rainfall from onsite gauge or NEXRAD



Determine ET_o



Estimate Crop Water Requirement

$$ET_c = K_c\,ET_o$$

Estimate Irrigation Requirement and required hours of pumping

Harmsen E.W., 2012. TECHNICAL NOTE: A Simple Web-Based Method for Scheduling Irrigation in Puerto Rico J. Agric. Univ. P.R. 96 (3-4) 2012.

Detailed Example

- Determine the irrigation requirement for the 5 day period, February 15-19, 2012, for a tomato crop in Juana Diaz, Puerto Rico.

Required Hyperlinks

Length of Growth Stages (Table 11) and Crop Coefficients (Table 12)	**http://www.fao.org/docrep/X0490E/x0490e00.htm**
Daily Reference Evapotranspiration (ETo)	http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/rainfall
Daily NEXRAD Rainfall for Puerto Rico	http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/reference_ET/

Step 1. Information used in example problem.

Location	Juana Diaz, Puerto Rico
Site Latitude	18.02 degrees N
Site Longitude	66.52 degrees W
Site Elevation above sea level	21 m
Crop	Tomato
Planting Date	1-Jan-12
Rainfall information	A rain gauge is not available on or near the farm
Type of irrigation	Drip
Irrigation system efficiency	85%
Field Size	10 acres
Pump capacity	300 gallons per minute

Step 2. Crop growth stage and crop coefficient data for example problem.

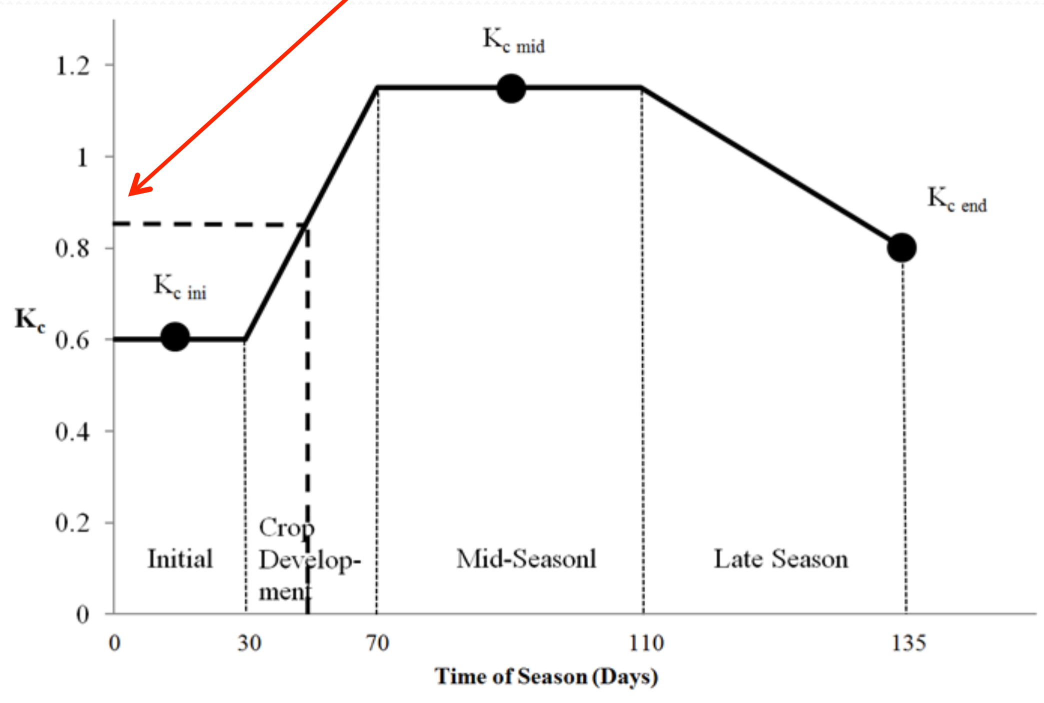
http://www.fao.org/docrep/X0490E/x0490e00.htm

Tomato Growth Stages and Crop Coefficients

Initial Crop Growth Stage	30 days
Crop Development Growth Stage	40 days
Mid-Season Growth Stage	40 days
Late-Season Growth Stage	25 days
Total Length of Season	135 days
$K_{c\ ini}$	0.6
$K_{c\ mid}$	1.15
$K_{c\ end}$	0.8

Crop Coefficient

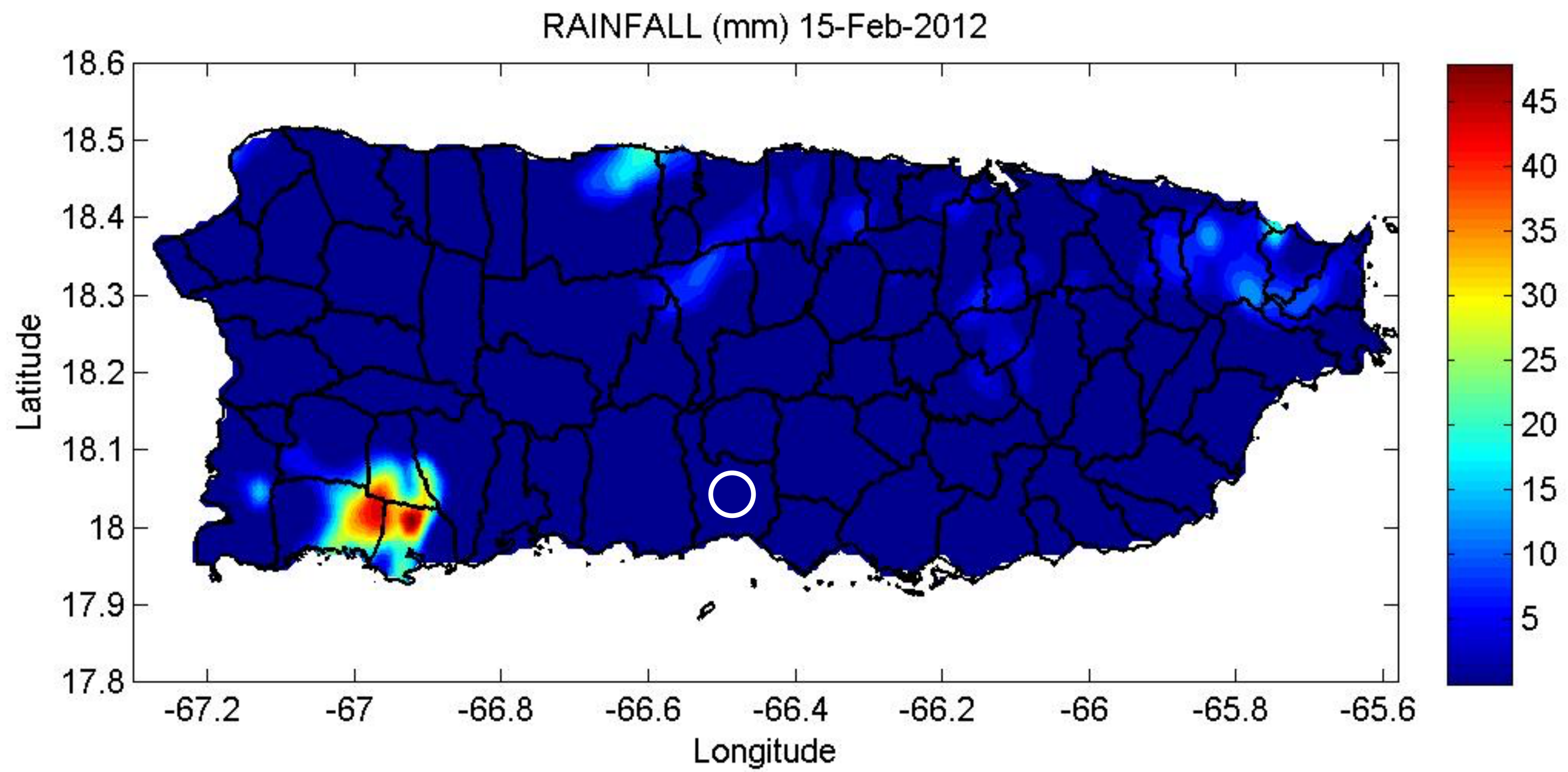
- The averge K_c value of 0.85 for the five day period was obtained.



Crop coefficient curve for the example problem. The heavy dashed line applies to the example problem with day of season 46-50 (i.e., Feb 15-19) corresponding to an approximate crop coefficient of 0.85 (vertical axis).

Step 3. Rainfall

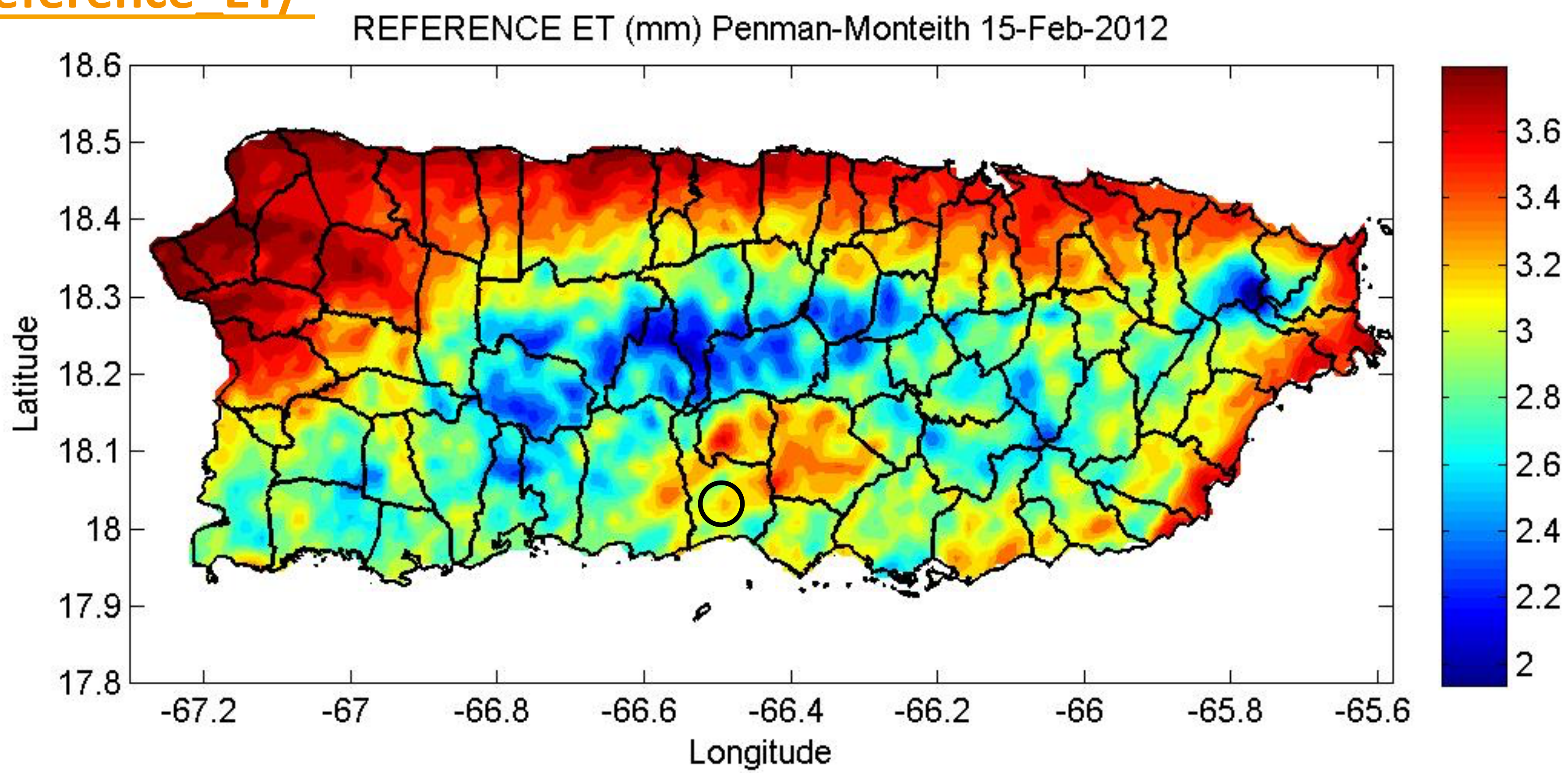
http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/rainfall/



- Inspection of the rainfall maps at the URL provided indicates that there was no rainfall during the five day period.

Step 4. Reference Evapotranspiration (ET_o)

http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/reference_ET/



- Inspection of the ET_o maps at the URL provided above indicates that there was 16.1 mm of ET_o during the five day period.

Step 5. Crop Water Requirement

- The crop water requirement (ET_c) for the five day period can now be estimated as follows:

$$ET_c = K_c\, ET_o = (0.85)(16.1 \text{ mm}) = 13.\ 7 \text{ mm}$$

Step 6. Calculation of Irrigation Requirement and duration of pumping

- Using D = ET_c = 13.7 mm
- A = 10 acres
- Q = 300 gallons per minute
- eff = 0.85, yields:

- Irrigation Requirement (volume)

13.7 mm x 10 cuerda x 1044 / 0.85

= **168,260 gallons**

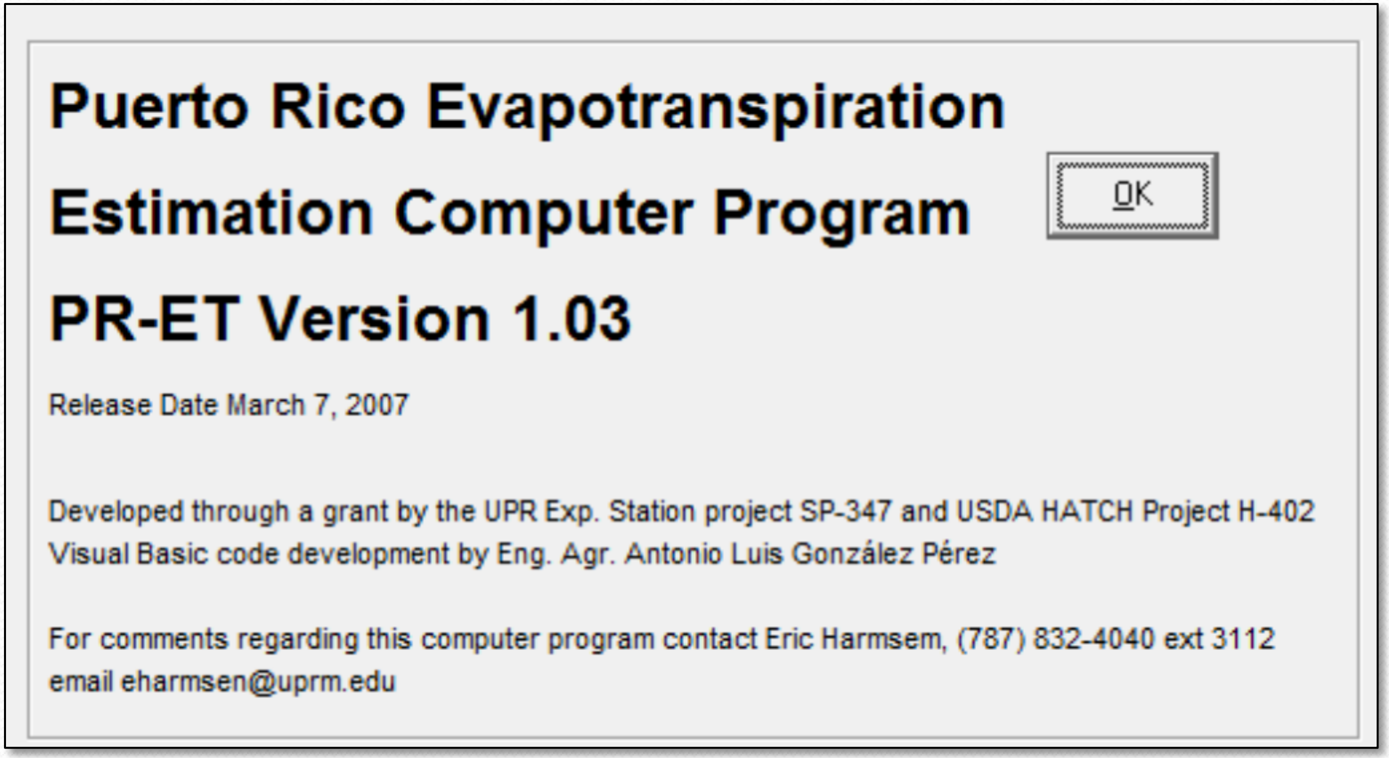
- Pumping time:

(168,260 gal/300 gal/min) /60 min/hr = **9.35 hours**

Web-based Irrigation Scheduling Tool

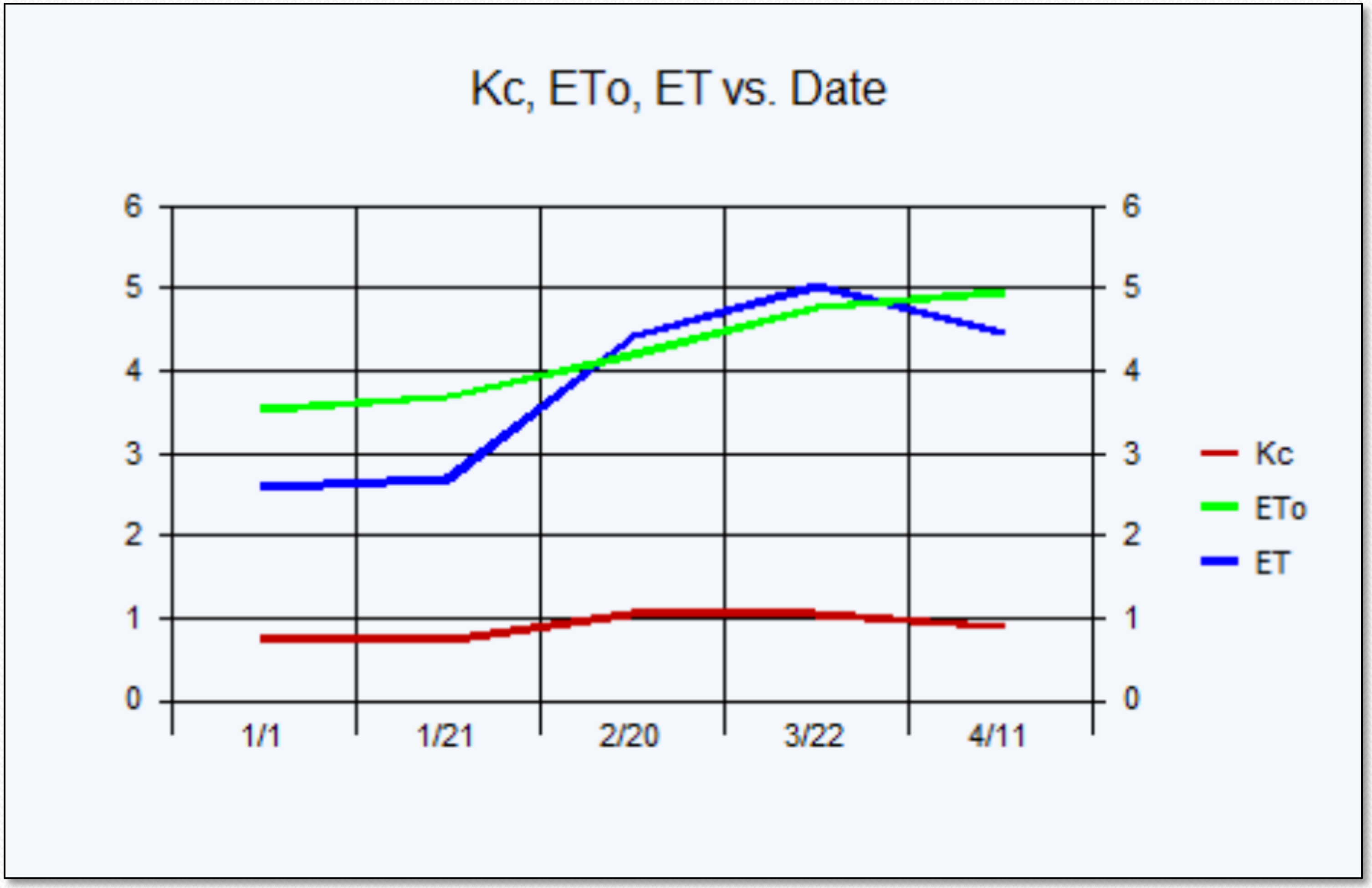
- Students from the Computer Engineering Department are developing ***desktop and mobile apps*** of the web-based irrigation scheduling procedure.
- The user will be able to create an account, which will remember the user irrigation history
- Everything will be automated
- The apps should be ready for use in approximately 3 months.

Puerto Rico Evapotranspiration Computer Program



http://pragwater.com/crop-water-use/

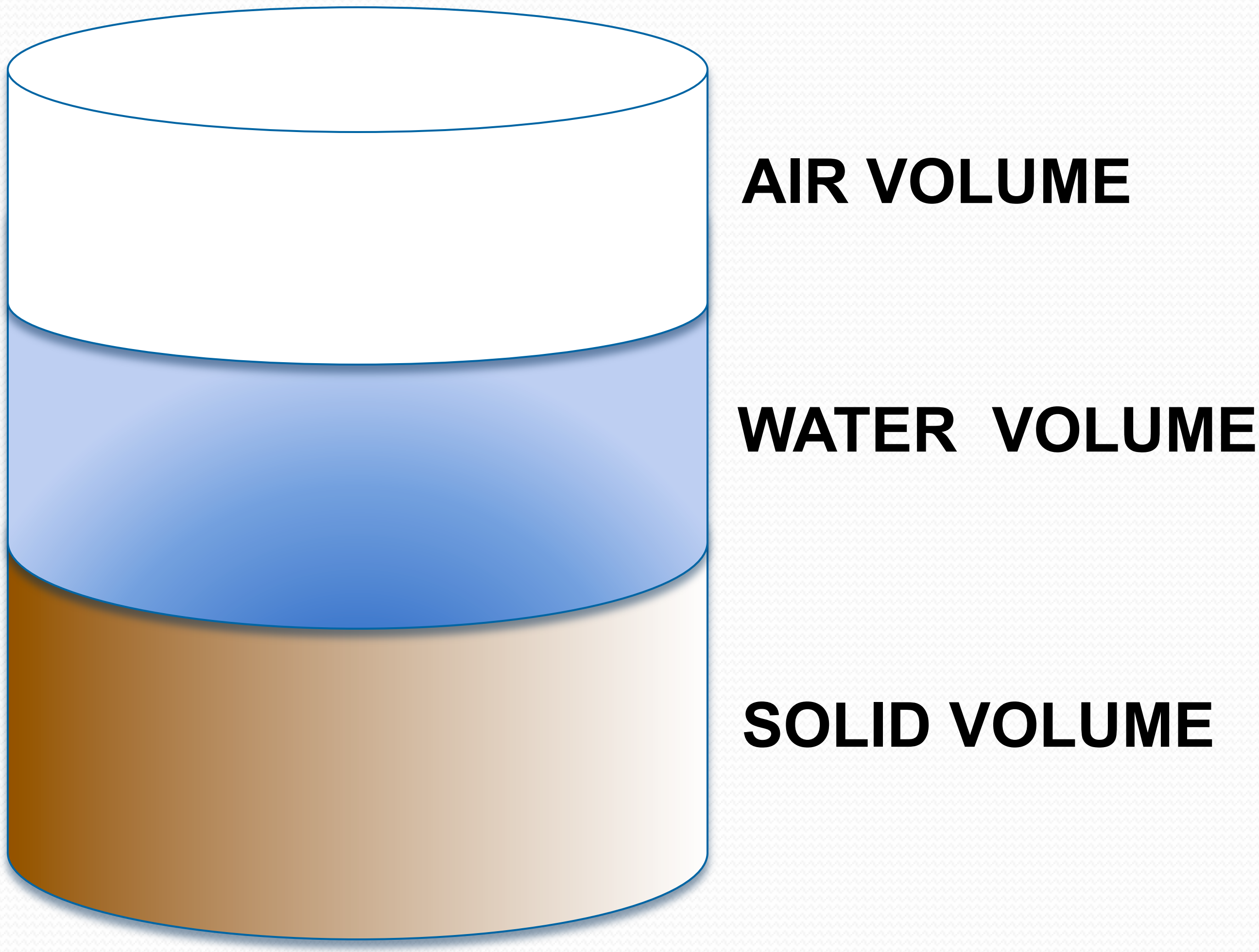
PRET



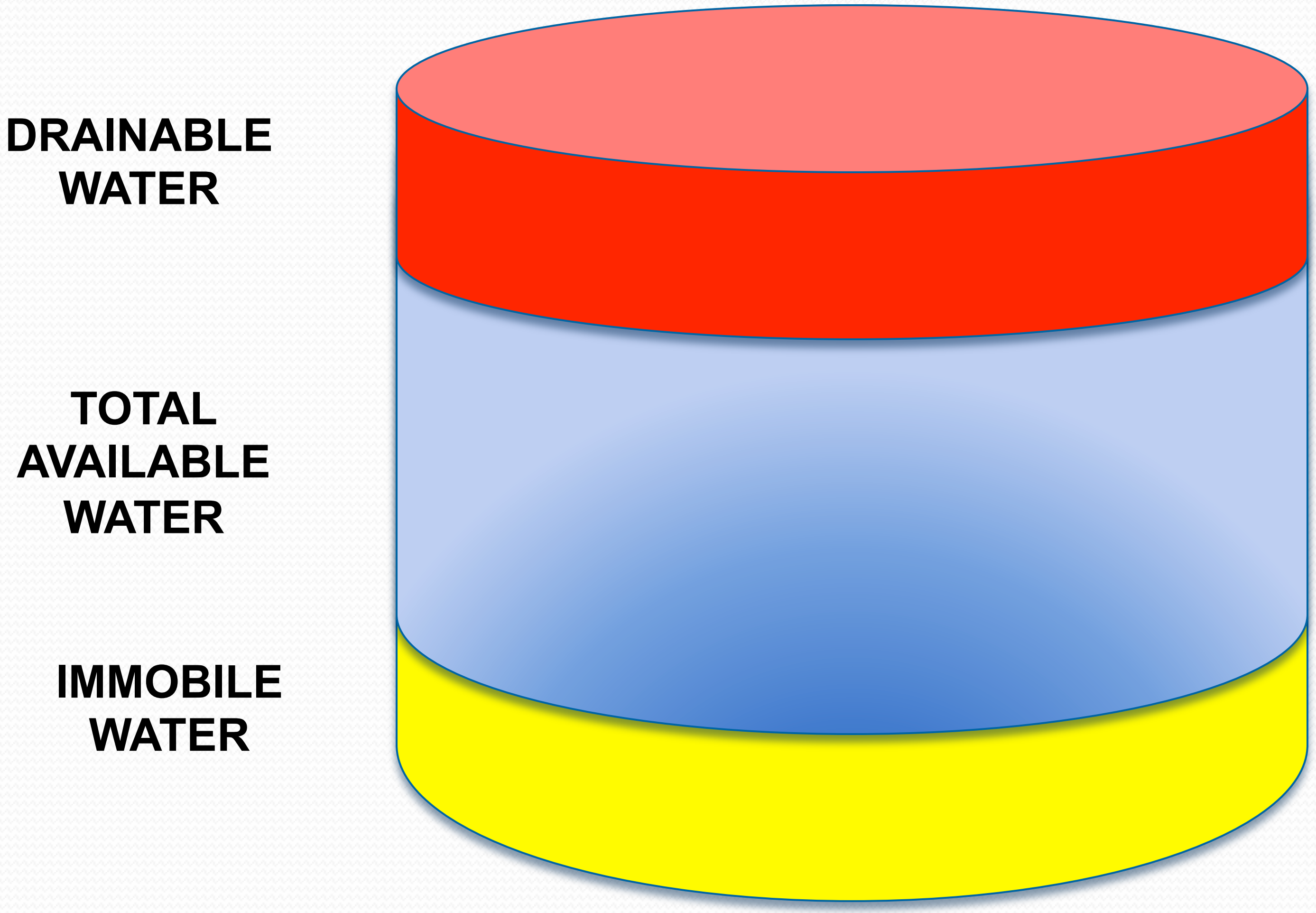
Soil Moisture Methods

Maintain soil water between θ_{FC} and θ_t

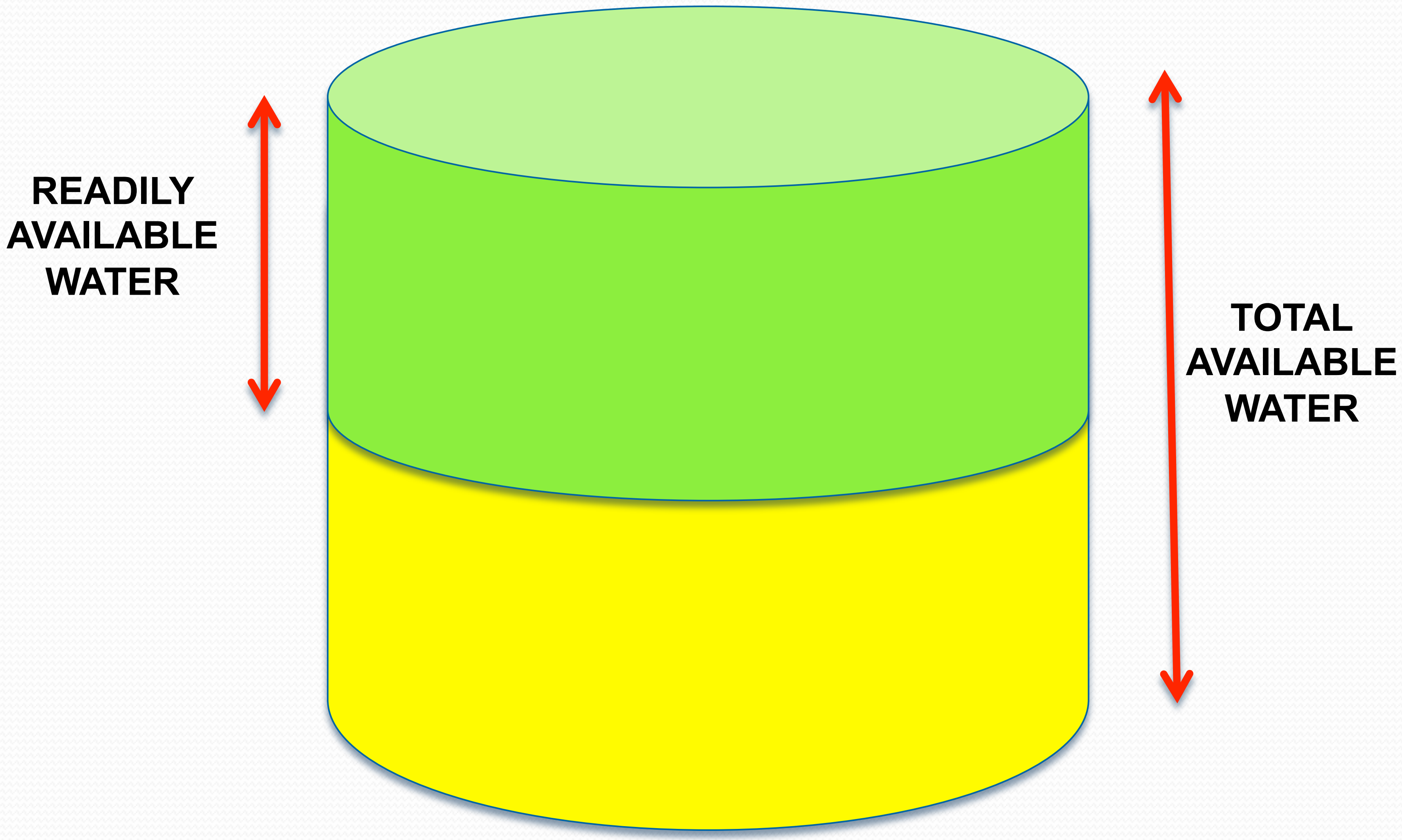
Soil Water Reservoir



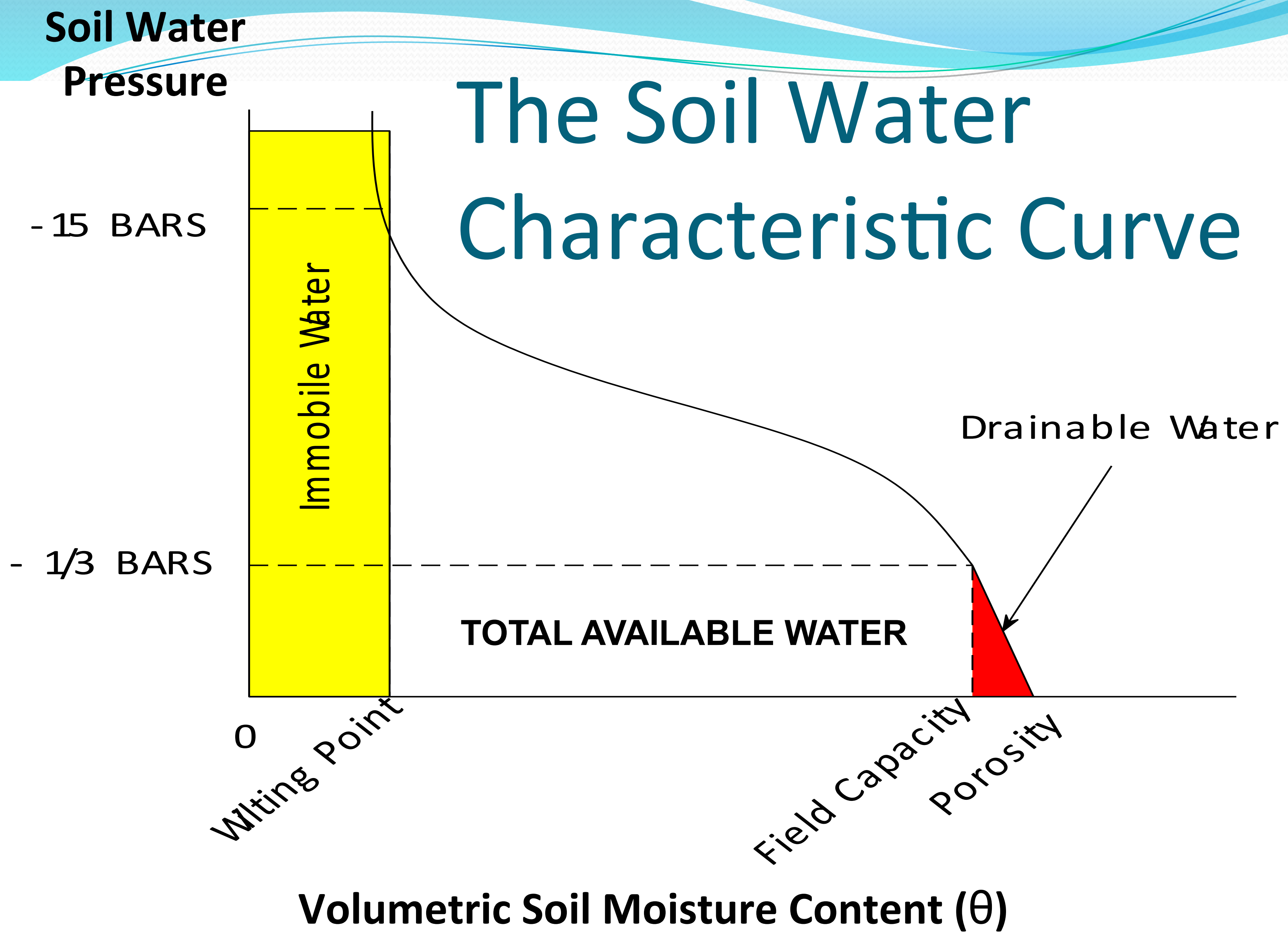
Water Volume



Total Available Water



The Soil Water Characteristic Curve



Total Available Water

$$TAW = \theta_{FC} - \theta_{WP}$$

where

θ_{FC} = Volumetric moisture content a the field capacity

θ_{WP} = Wilting point volumetric moisture content.

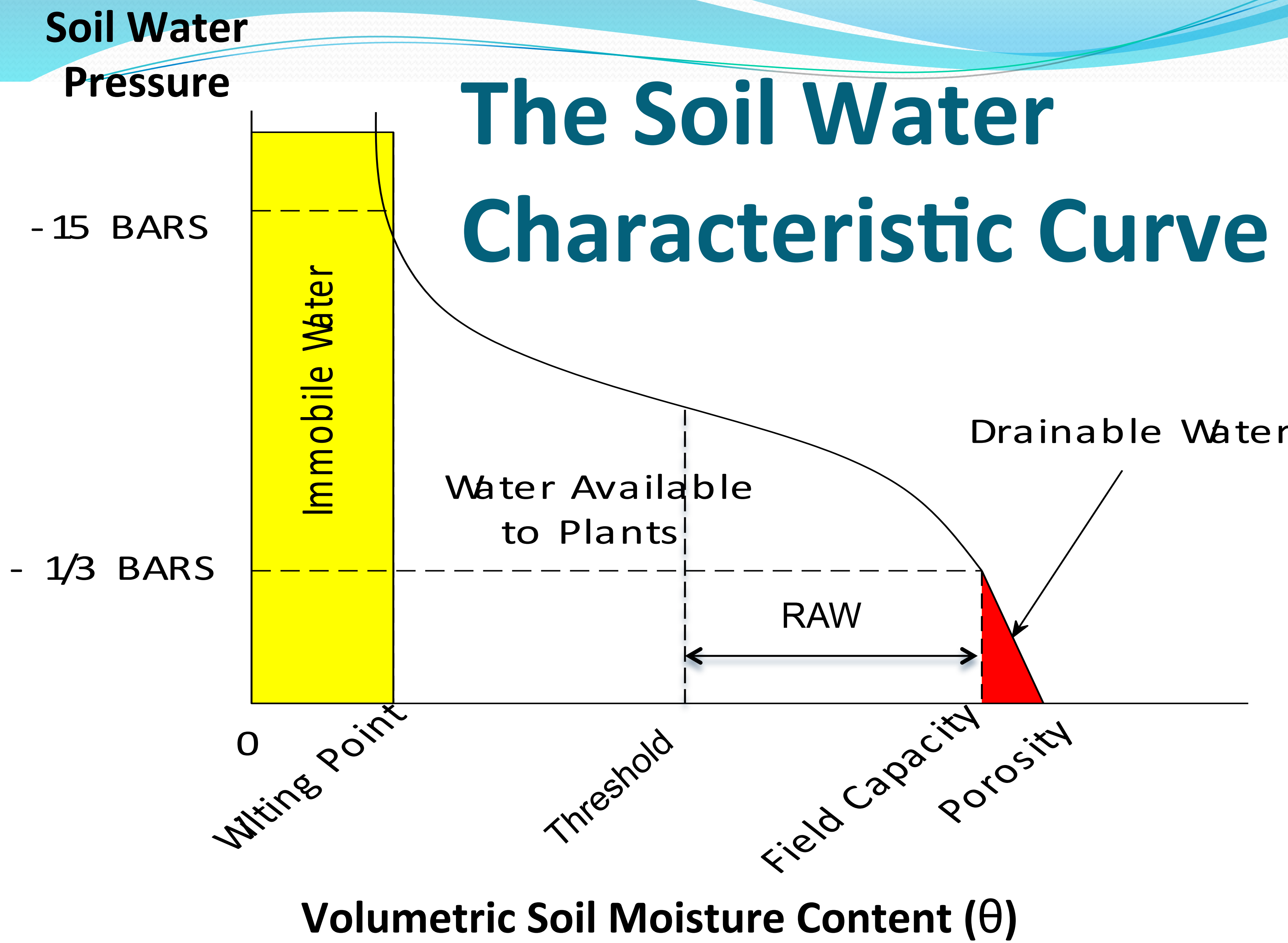
Representative Physical Properties of Soils

Soil Texture	Total Pore Space (% by vol)	Apparent Specific Gravity, A_s	Field Capacity, FC_v (% by vol)	Permanent Wilting, PWP_v (% by vol)	Available Water (mm/m)
Sandy loam	39	1.58	16	7	80
	(37–40)	(1.56–1.59)	(11–22)	(3–12)	(50–110)
Sandy clay loam	41	1.57	26	16	100
	(38–42)	(1.53–1.60)	(20–32)	(13–19)	(70–120)
Loam	42	1.55	25	12	130
	(40–43)	(1.50–1.58)	(18–31)	(7–16)	(110–150)
Silt loam	43	1.52	29	11	180
	(40–46)	(1.44–1.59)	(16–36)	(3–16)	(130–230)
Silt	40	1.58	29	6	230
	(39–42)	(1.55–1.61)	(25–32)	(4–8)	(210–250)
Silty clay loam	47	1.40	37	20	180
	(45–50)	(1.33–1.47)	(34–40)	(17–22)	(160–200)
Clay loam	44	1.47	34	20	140
	(42–47)	(1.41–1.53)	(30–37)	(17–22)	(130–160)
Clay	49	1.35	42	28	140
	(44–56)	(1.19–1.32)	(36–47)	(23–33)	(130–150)

Note: Numbers are rounded, and normal ranges are shown in parentheses.

Source: Saxton (2005).

The Soil Water Characteristic Curve



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 20% to 65%
- RAW is estimated from the following formula:

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

Management Allowed Deficit (MAD)

Crop	Maximum Root Depth[1] (m)	Depletion Fraction[2] (for ET ≃ 5 mm/day) MAD
a. Small Vegetables		
Broccoli	0.4-0.6	0.45
Brussel Sprouts	0.4-0.6	0.45
Cabbage	0.5-0.8	0.45
Carrots	0.5-1.0	0.35
Cauliflower	0.4-0.7	0.45
Celery	0.3-0.5	0.20
Garlic	0.3-0.5	0.30
Lettuce	0.3-0.5	0.30
Onions - dry	0.3-0.6	0.30
- green	0.3-0.6	0.30
- seed	0.3-0.6	0.35
Spinach	0.3-0.5	0.20
Radishes	0.3-0.5	0.30

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!

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

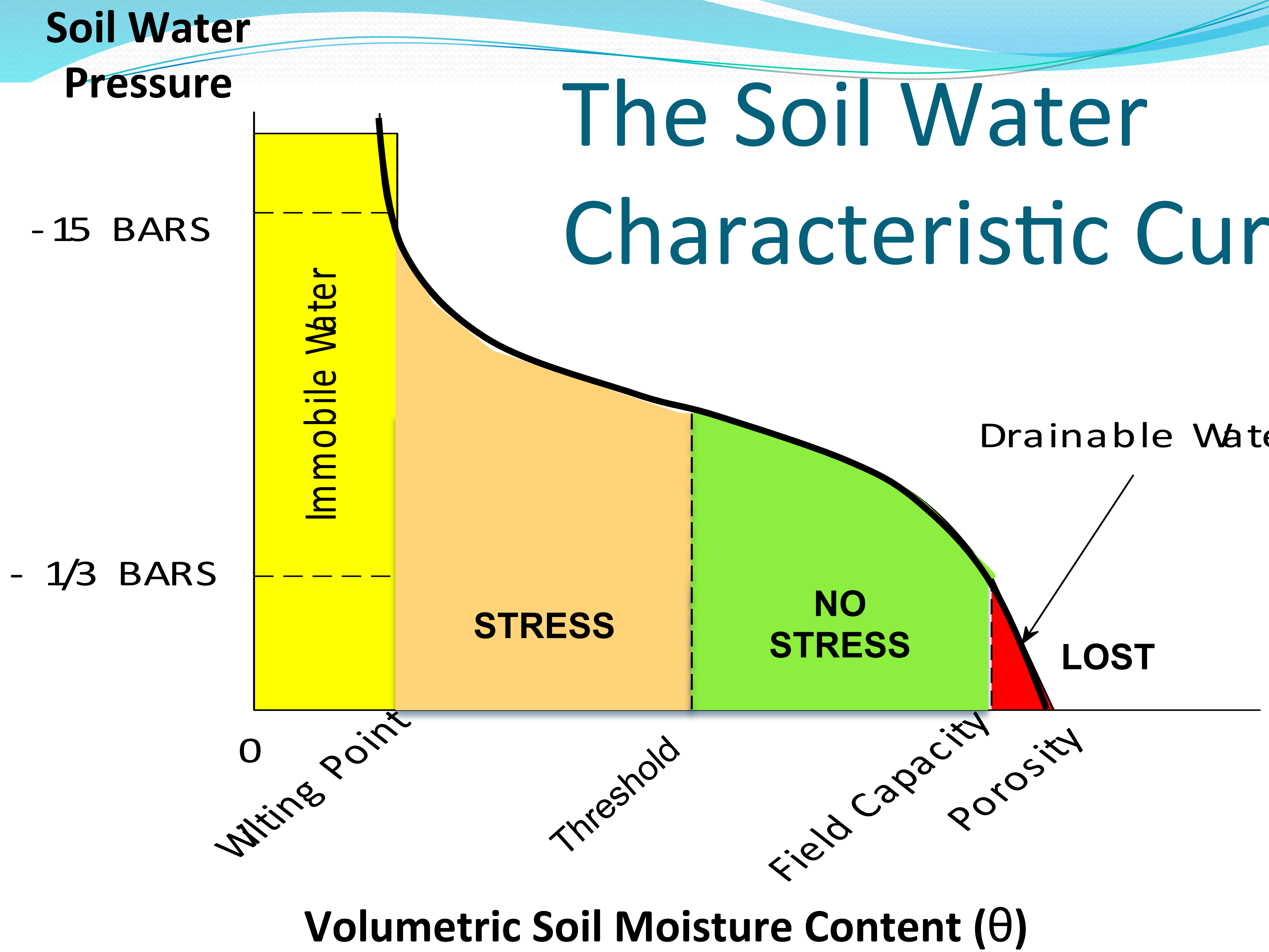
where

θ_t = threshold moisture content

θ_{FC} = field capacity moisture content

RAW = readily available water

The Soil Water Characteristic Curve



Maintain soil water between θ_{FC} and θ_t

Soil Moisture Method

- **Perhaps the best method because it considers the readily available water in the soil.**

- **Gravimetric method**
- **Electrical method**
- **Tensiometers**
- **Water balance method**

Gravimetric Soil Sampling

Time Domain Reflectometry

TDR

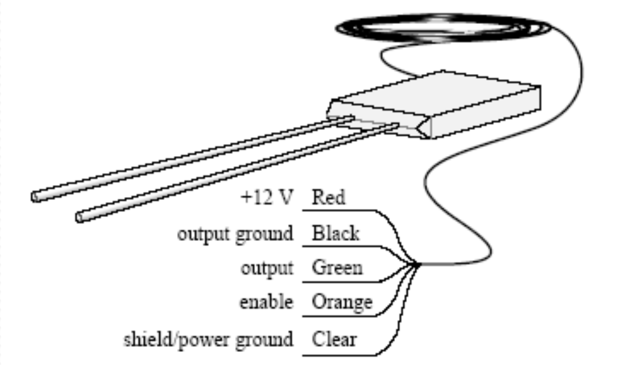
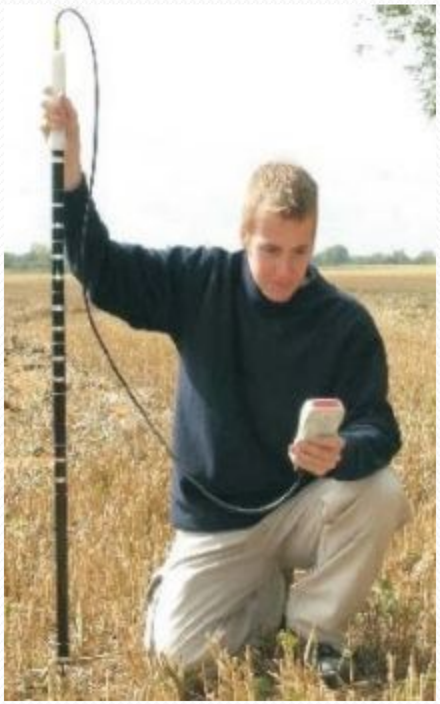
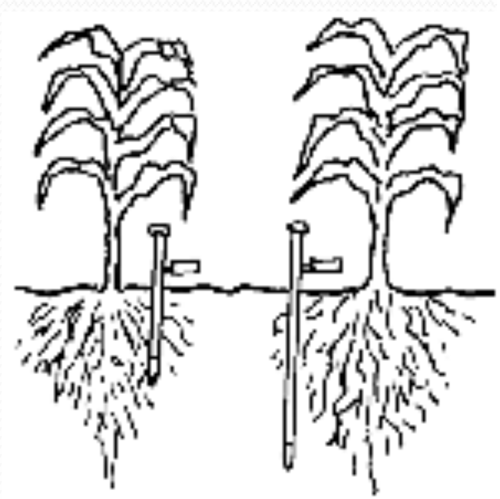


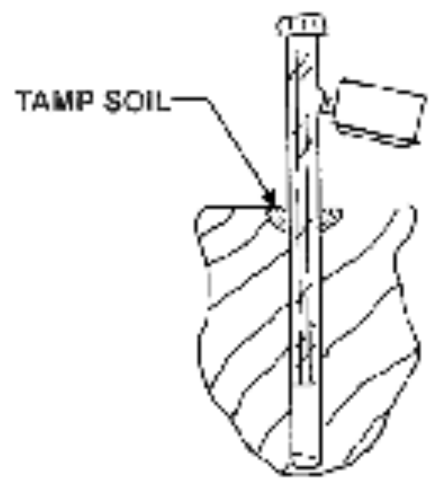
FIGURE 1. Water Content Reflectometer

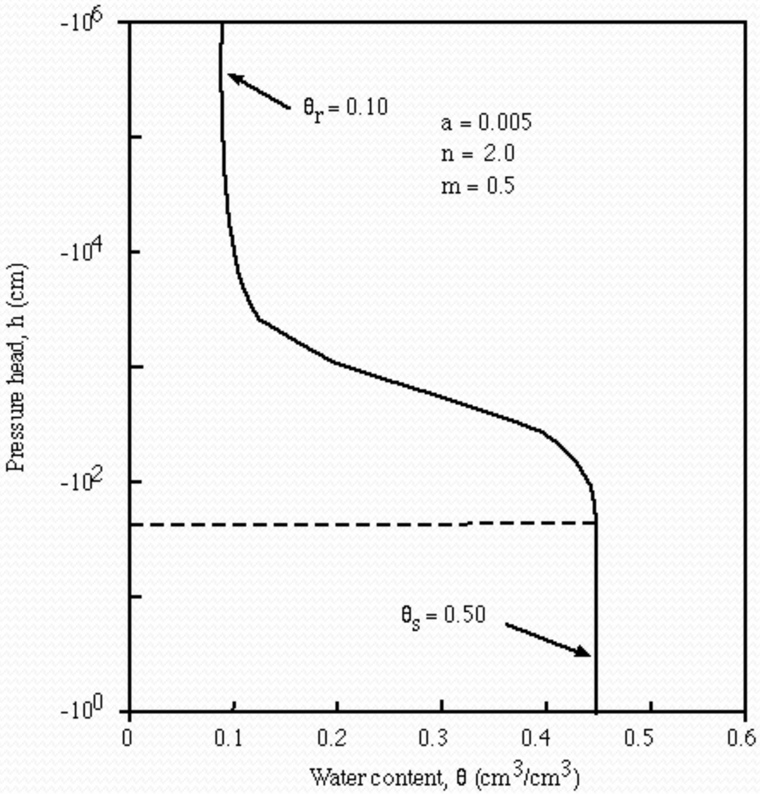
Capacitance Method

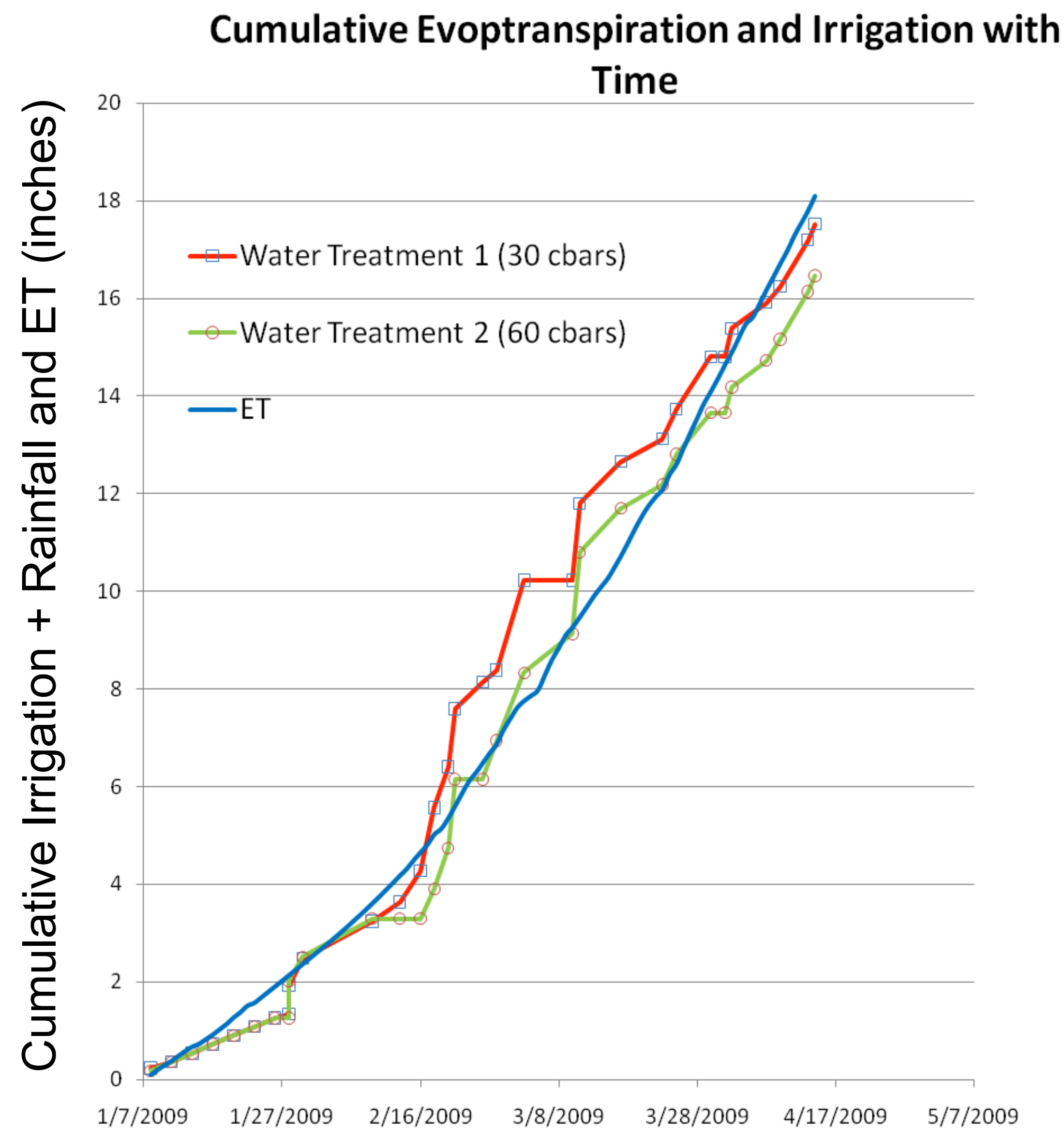


Tensiometers








Cumulative Evoptranspiration and Irrigation with Time
Cumulative Irrigation + Rainfall and ET (inches)
0
2
4
6
8
10
12
14
16
18
20
1/7/2009
1/27/2009
2/16/2009
3/8/2009
3/28/2009
4/17/2009
5/7/2009
Water Treatment 1 (30 cbars)
Water Treatment 2 (60 cbars)
ET

Maintain soil water between θ_{FC} and θ_t

Water Balance Method

$$\theta_{t2} = R + Irr - RO - ET_{c\ adj} - PERC + \theta_{t1}$$

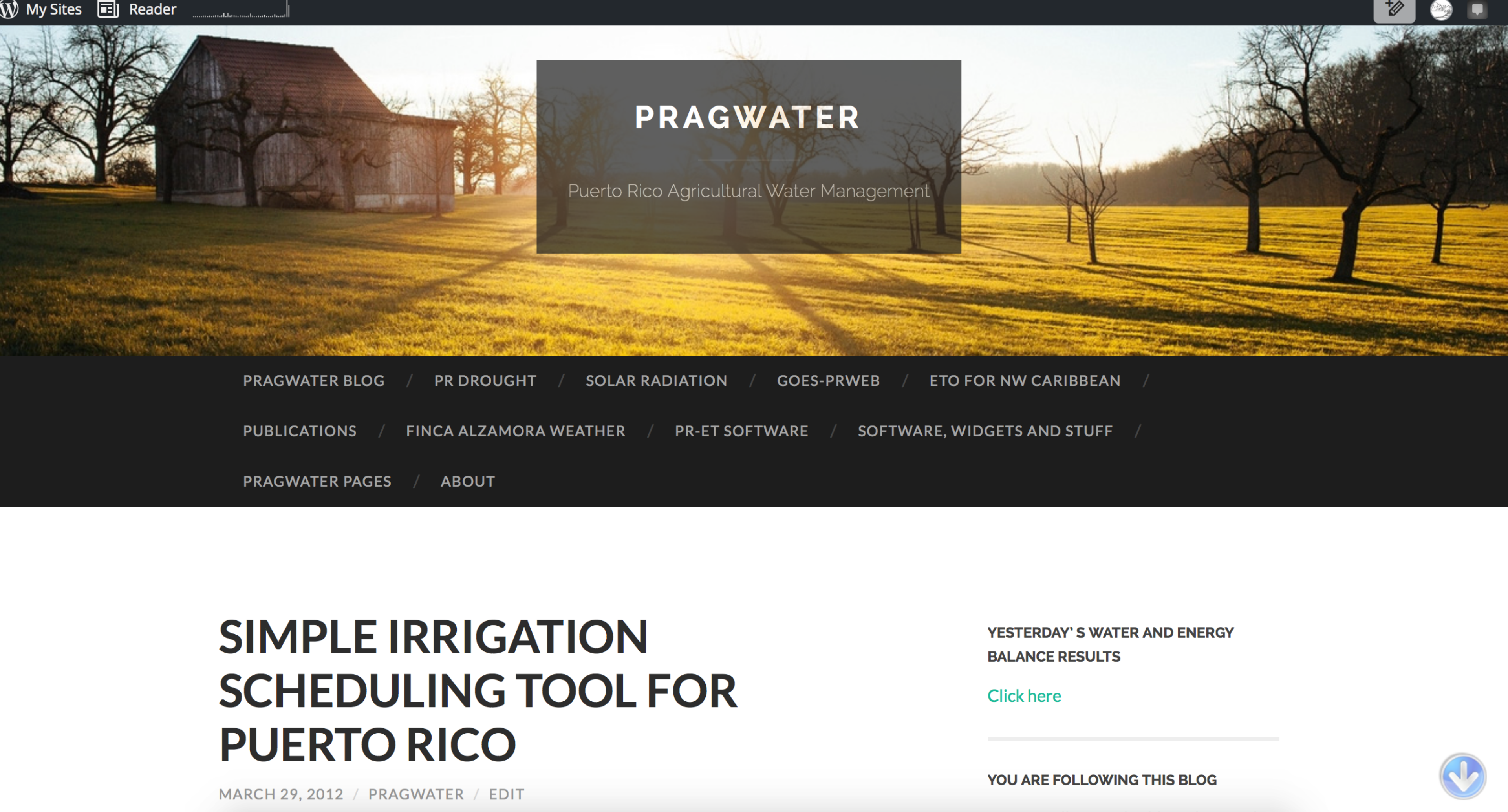
θ_{t2} = volumetric moisture content at time 2

θ_{t1} = volumetric moisture content at time 1

R = effective rainfall

RO = runoff

PERC = water that percolates past the root zone



http://pragwater.com/2011/12/17/a-simple-irrigation-scheduling-spreadsheet-program/

Soil Water Management Spreadsheet

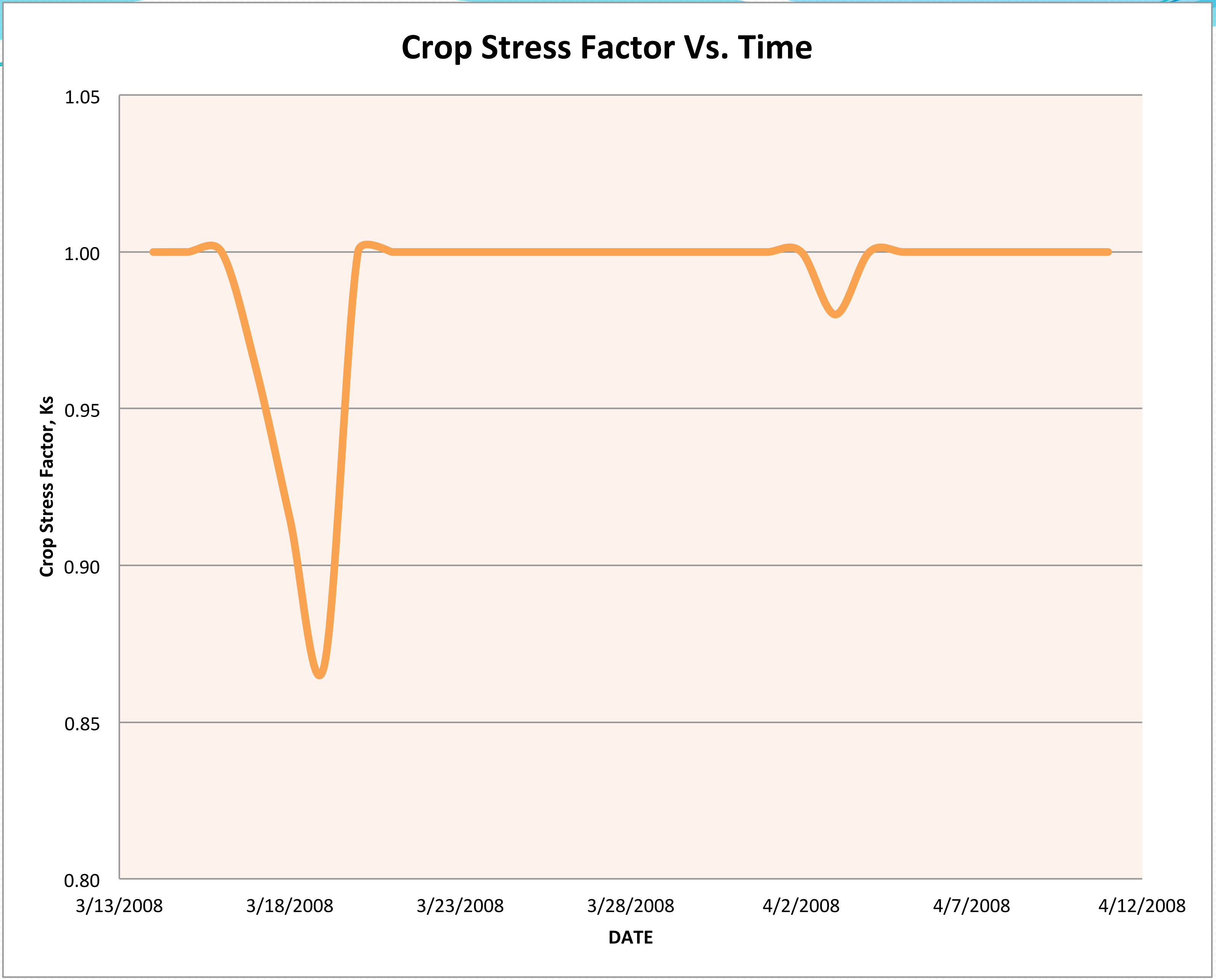
http://pragwater.com/2011/12/17/a-simple-irrigation-scheduling-spreadsheet-program/

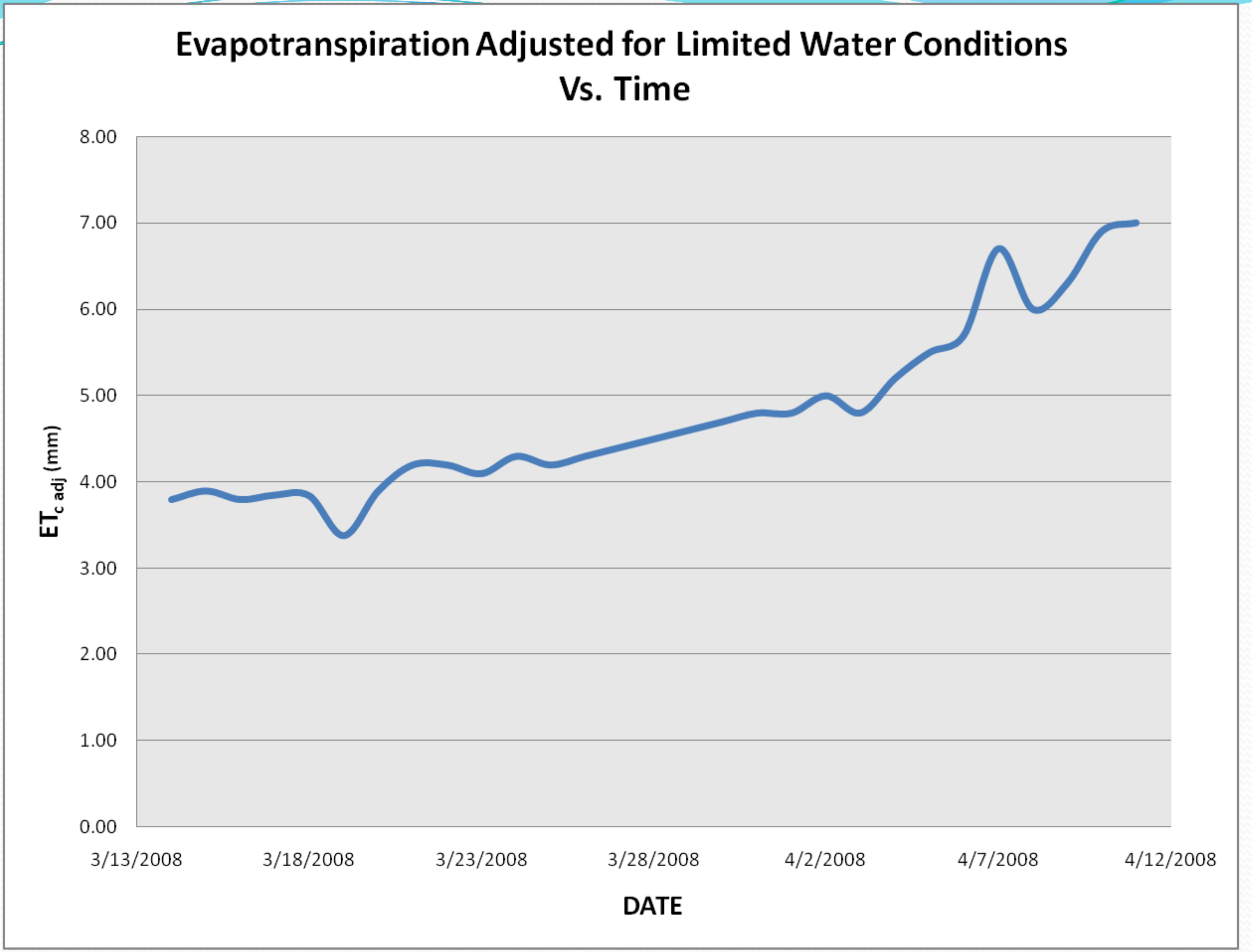
Date	Field Capacity	Wilting Point	Total Available Water	Root Depth	Management Allowed Deficit	Readily Available Moisture Content	Threshold Moisture Content	Moisture Content	Crop Stress Factor	Average Crop Evapotranspiration	Average Evapotranspiration Adjusted for Stress	Soil Water Deficit	Irrigation 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

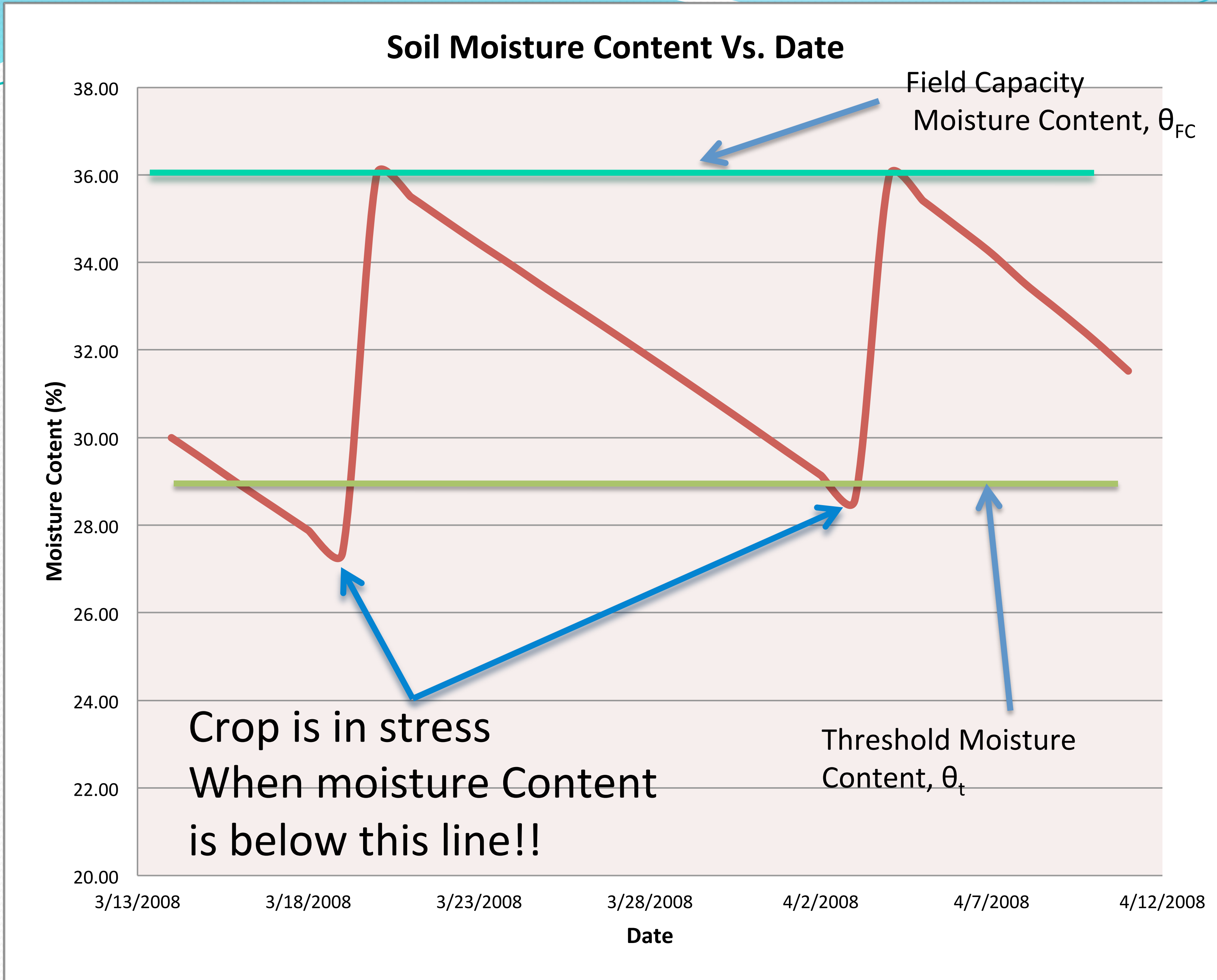
Date	Field Capacity	Wilting Point	Total Available Water	Root Depth	Management Allowed Deficit	Readily Available Moisture Content
	FC	WP	TAW	RD	MAD	RAW
	%	%	%	m	fraction	%
3/14/2008	36	18	18	0.70	0.4	7.2
3/15/2008	36	18	18	0.71	0.4	7.2
3/16/2008	36	18	18	0.72	0.4	7.2
3/17/2008	36	18	18	0.73	0.4	7.2
3/18/2008	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
Crop Stress Factor, Ks
1.05
1.00
0.95
0.90
0.85
0.80
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, θ_{FC}
38.00
36.00
34.00
32.00
30.00
28.00
26.00
24.00
22.00
20.00
Moisture Cotent (%)
Crop is in stress
When moisture Content
is below this line!!
Threshold Moisture
Content, θ_t
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

Soil moisture method

Maintain soil water between θ_{FC} and θ_t

Conclusions and Recommendations

- Currently, many farmers do not systematically schedule irrigation resulting in a loss of water, energy, chemicals and money.
- Available irrigation Scheduling methods include: evapotranspiration, soil moisture and water balance methods

Gracias!

For help with any of the methods covered in today's presentation, please contact me by email at eric.harmsen@upr.edu