Use of Satellite Imagery to assist with Irrigation Scheduling

Tom Trout
USDA-ARS, Ft. Collins, CO, USA

Lee Johnson, NASA Ames, CA
Forrest Melton, NASA, Ames, CA
Dong Wang, ARS, Fresno, CA

Water Management Research Unit
Fort Collins, CO

USDA ARS
United States Department of Agriculture
Agricultural Research Service

Irrigation Scheduling

- When to irrigate
- How much water to apply

Irrigation Scheduling Approaches

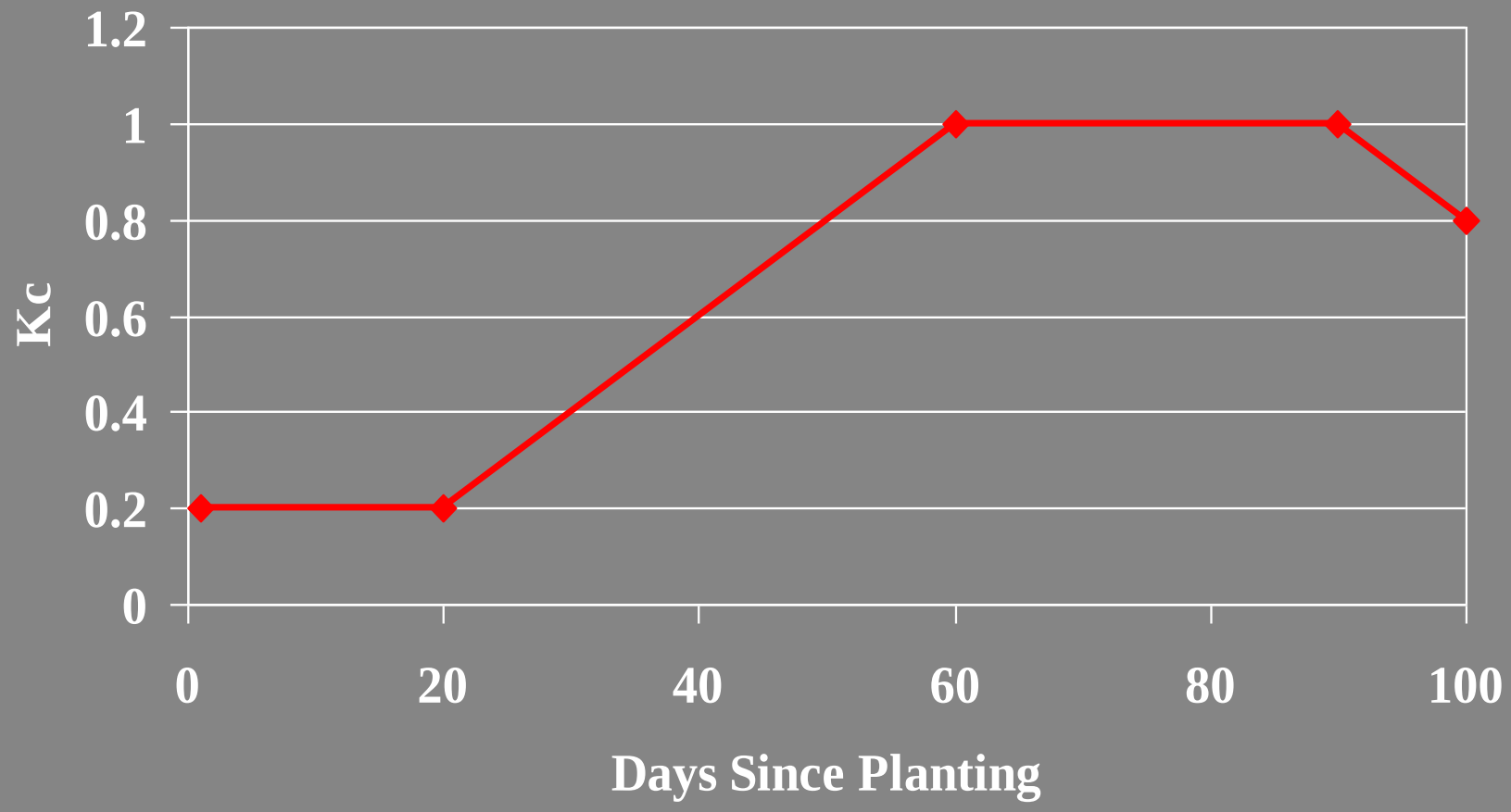
- Soil Water Deficit
- Plant Stress Indicators
- Estimated Water Use (ET)

Weather-Based Irrigation Scheduling

ETc = Kc x ETo

- ETc = Crop Water Use
- ETo = Reference ET
  - From ET weather stations (CIMIS, CoAgMet, Agrimet)
- Kc = Crop Coefficient

Standard Kc Curve



Crop Coefficient, Kc??

- "Standard" curves don't hold for non-standard conditions
  - Varieties
  - Planting seasons
  - Planting densities/configurations

Full Cover - Kc-mid

Annual Crops

Orchards

Vineyards

Ground Cover: Corn 7/31/2008

Tmnt 1: 91%

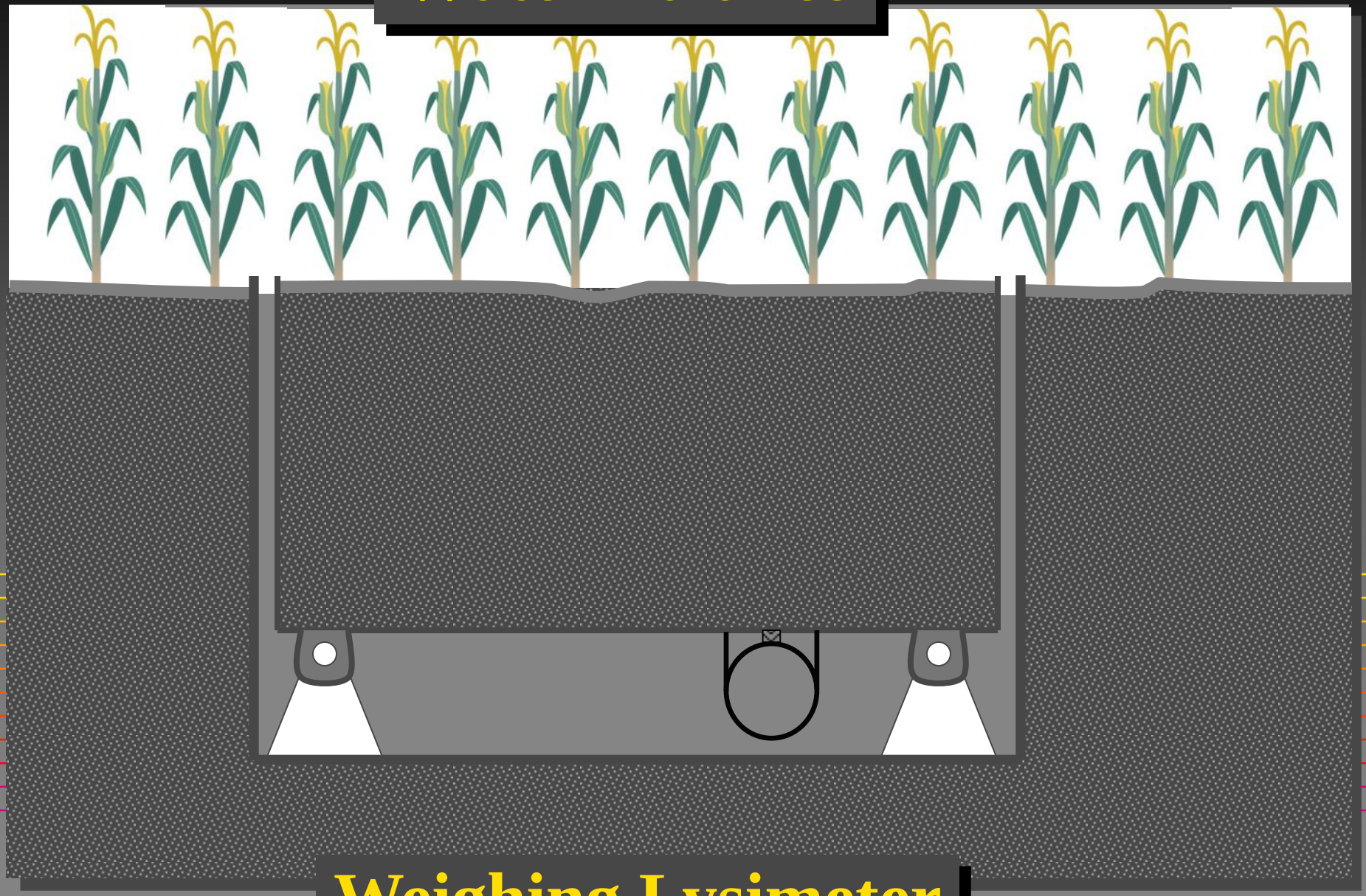
Tmnt 6: 63%

Kc (Kcb) is related to Light Interception *(Ground Cover)*

Develop Relationship between Ground Cover and Kcb for Horticultural Crops

$$K_{cb} = ET_c / ET_o$$

Water Balance



Weighing Lysimeter


Pepper 05

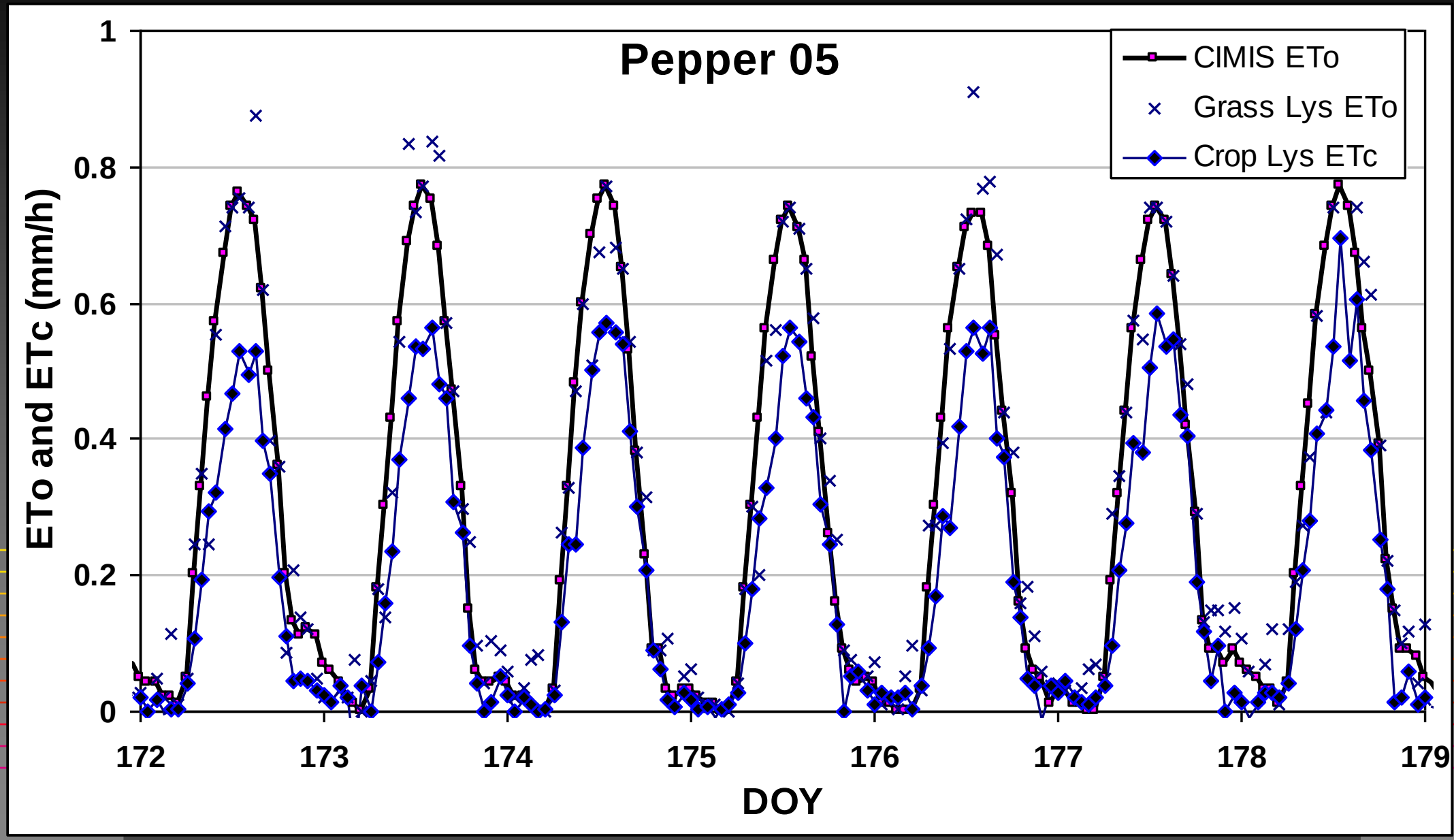
USDA-ARS Lysimeter
Five Points, CA

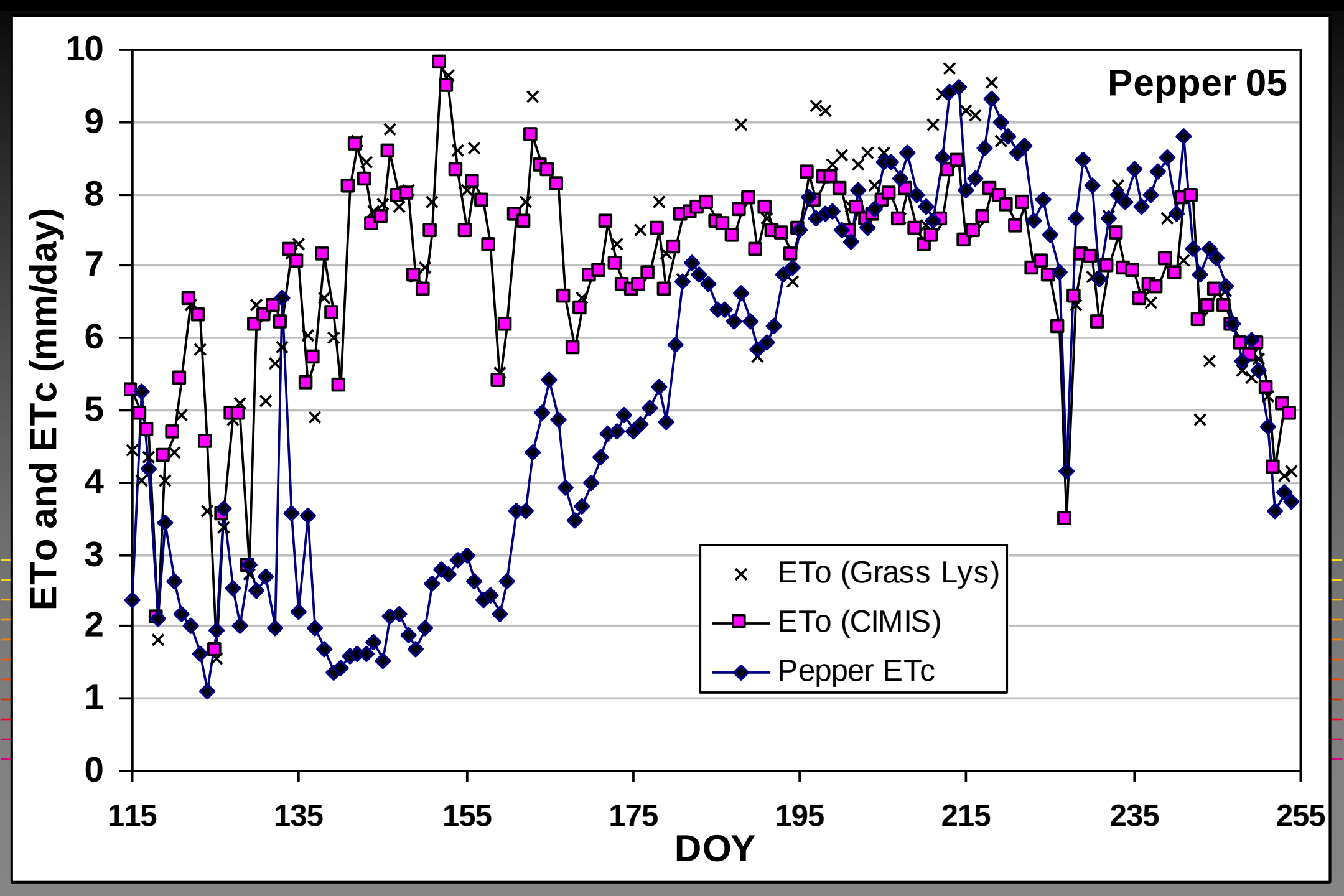

USDA-ARS Lysimeter
Five Points, CA

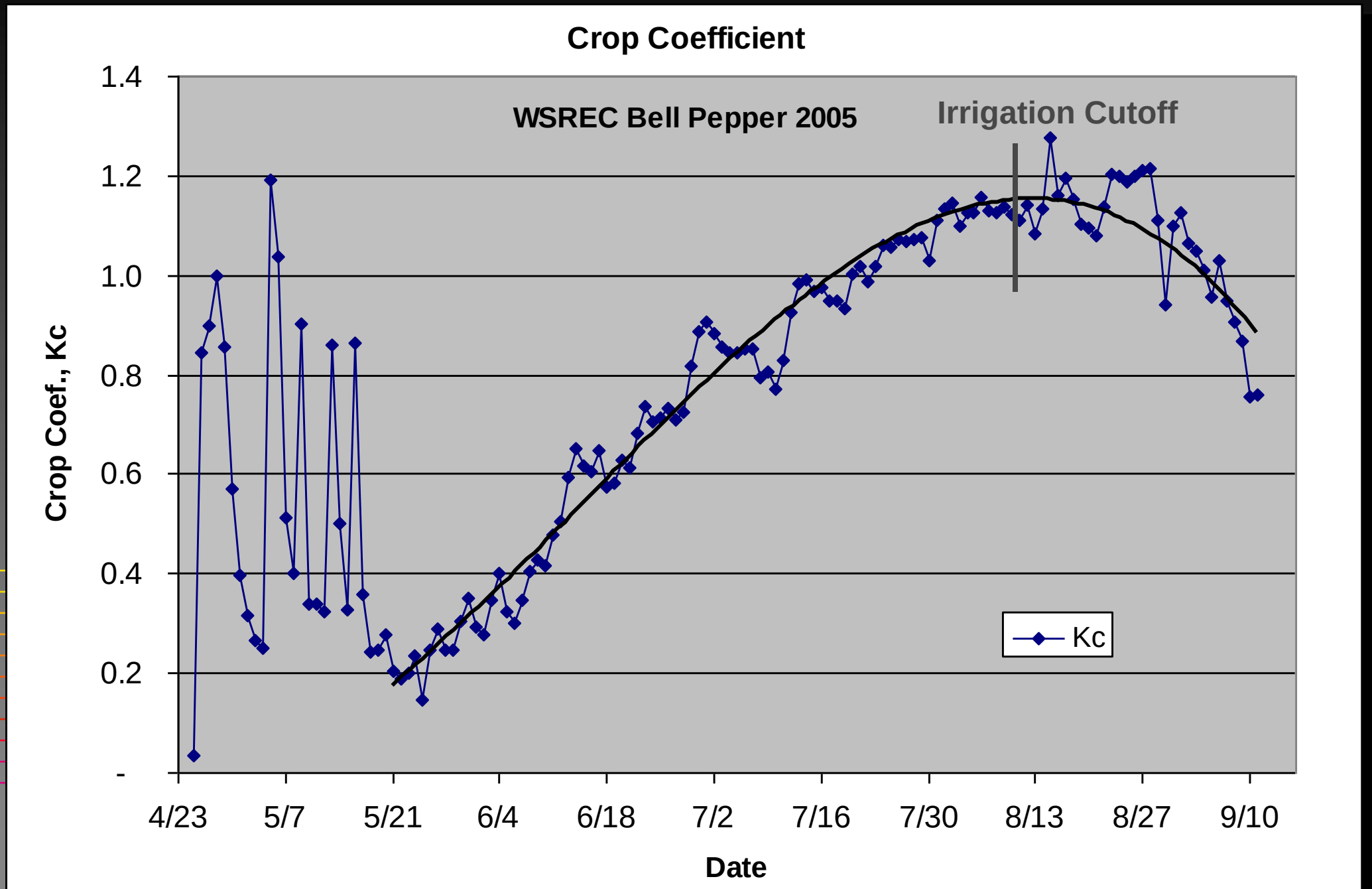
USDA-ARS Lysimeter
Five Points, CA

Pepper 05


Pepper 05


Pepper 05
CIMIS ETo
Grass Lys ETo
Crop Lys ETc
ETo and ETc (mm/h)
1
0.8
0.6
0.4
0.2
0
172
173
174
175
176
177
178
179
DOY

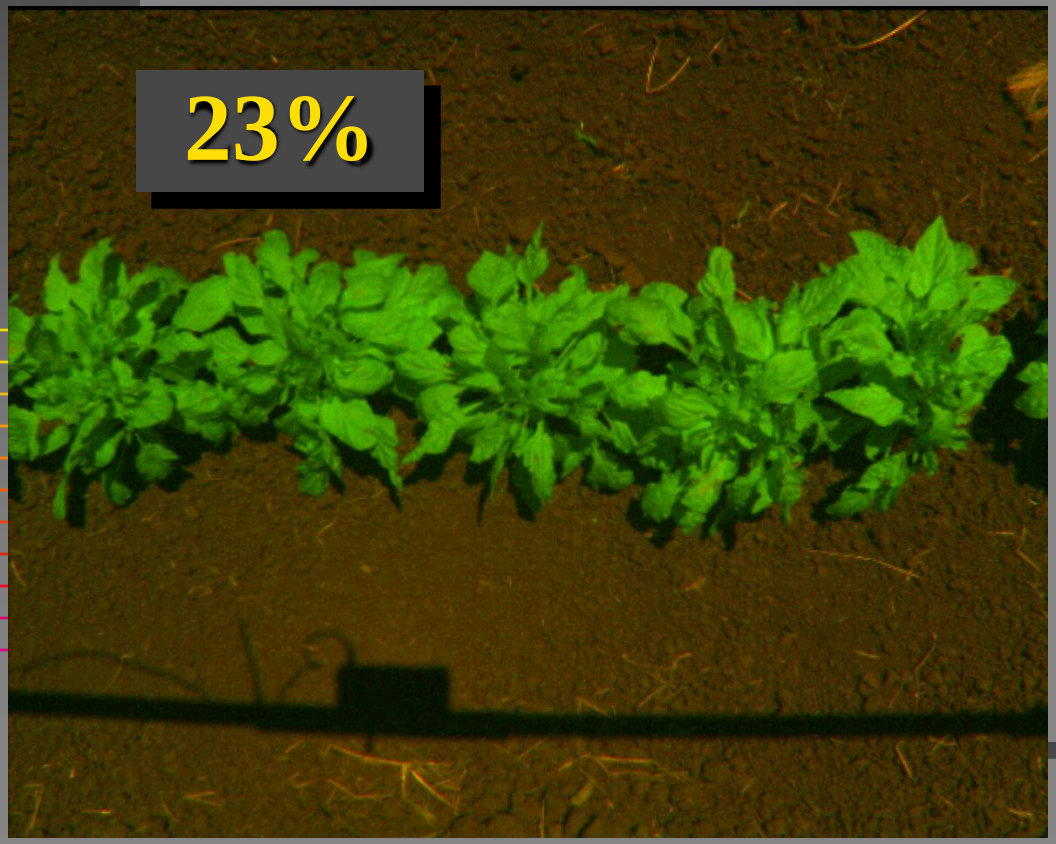

Pepper 05
ETo and ETc (mm/day)
DOY
ETo (Grass Lys)
ETo (CIMIS)
Pepper ETc
0
1
2
3
4
5
6
7
8
9
10
115
135
155
175
195
215
235
255

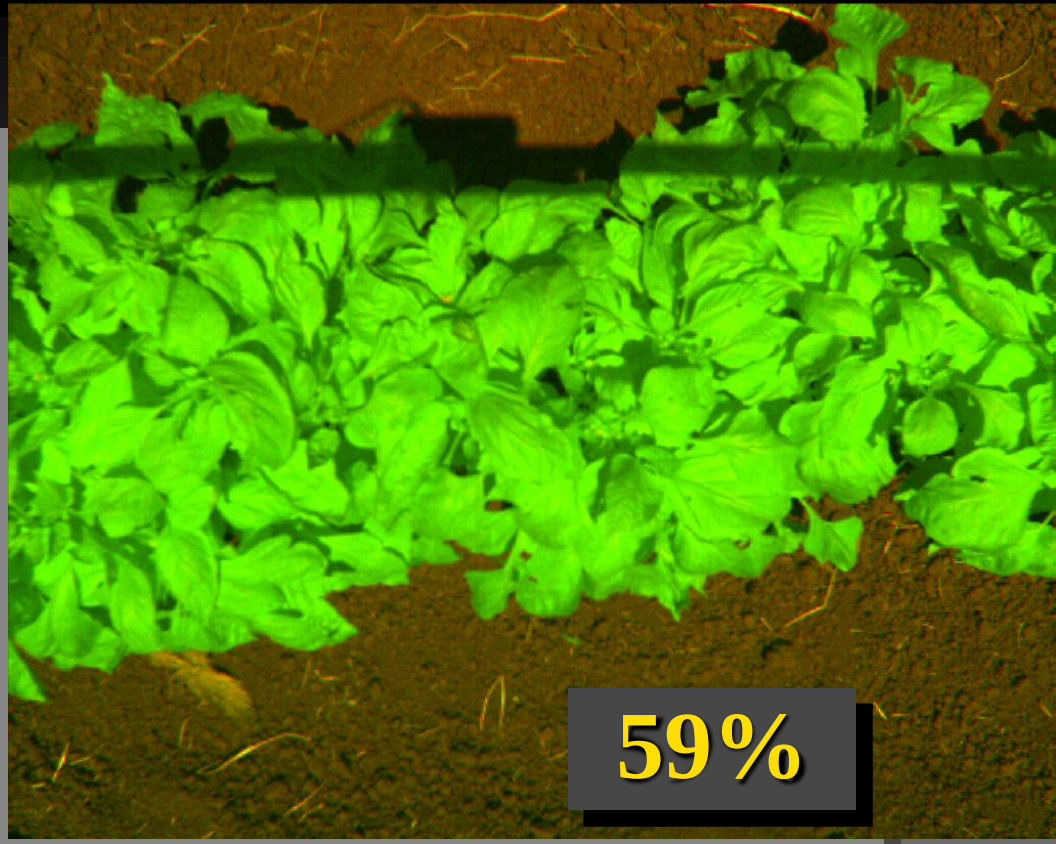

Crop Coefficient
WSREC Bell Pepper 2005
Irrigation Cutoff
Crop Coef., Kc
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-
4/23
5/7
5/21
6/4
6/18
7/2
7/16
7/30
8/13
8/27
9/10
Date
Kc

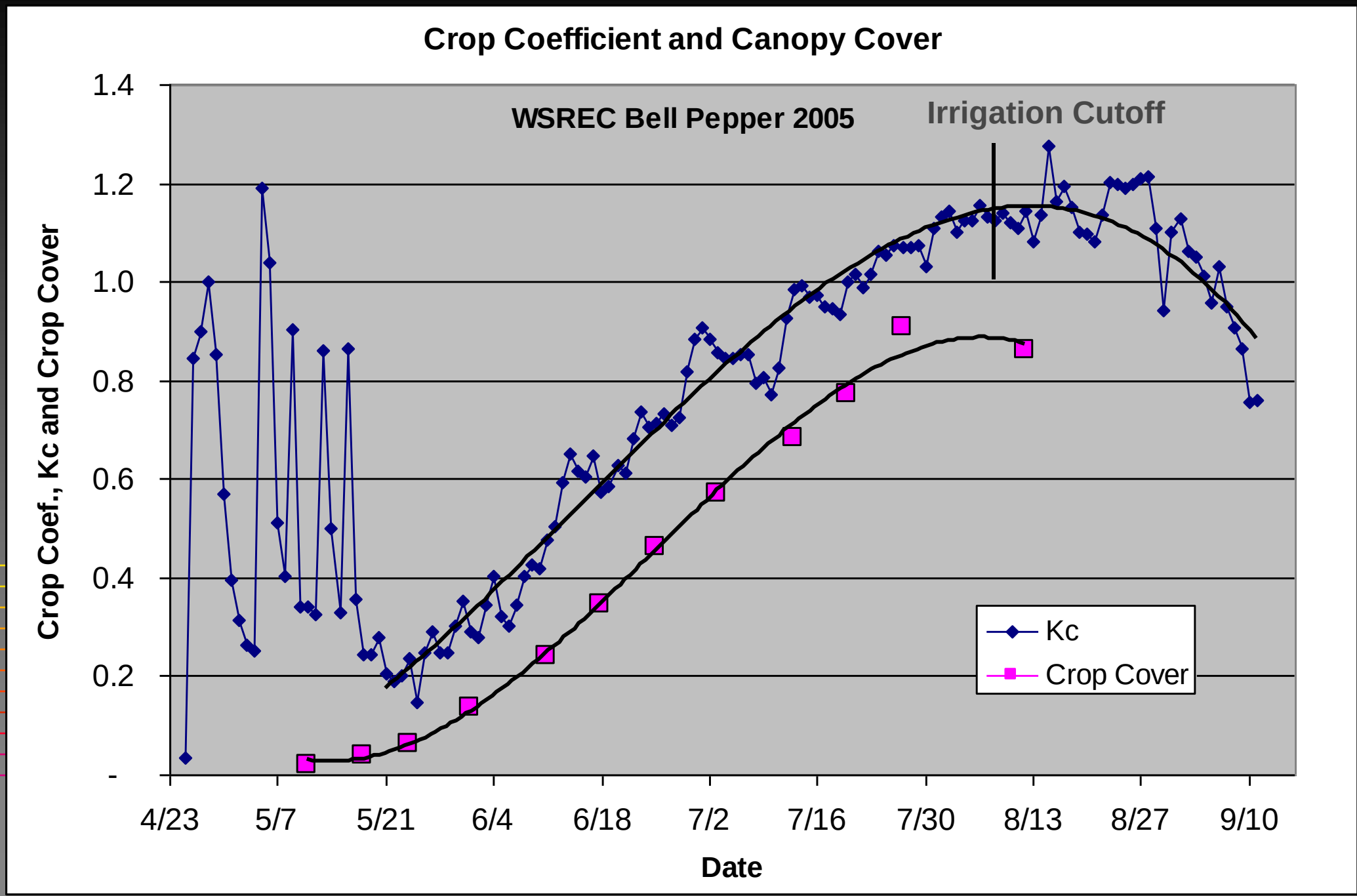
Photographing Canopy Size

TetraCam ADC

Pepper Ground Cover

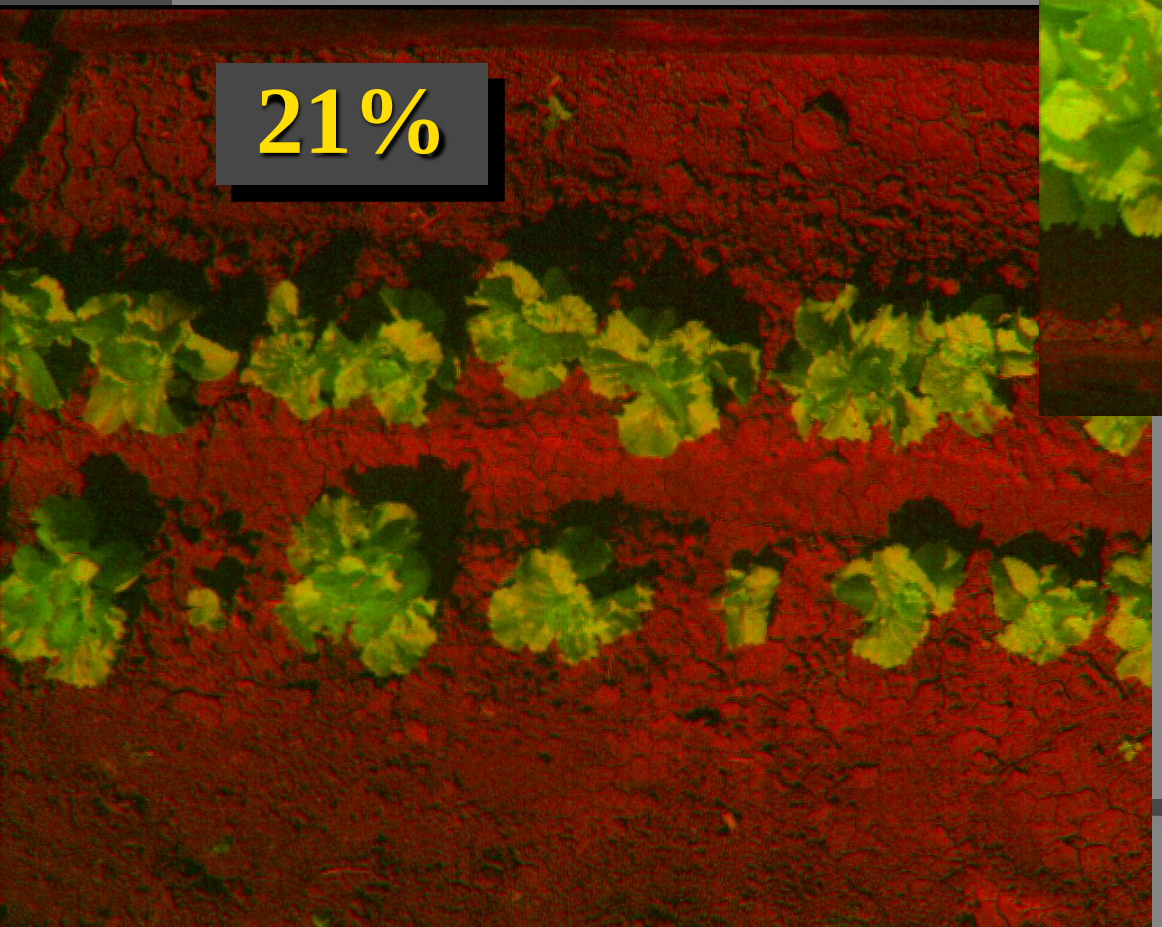


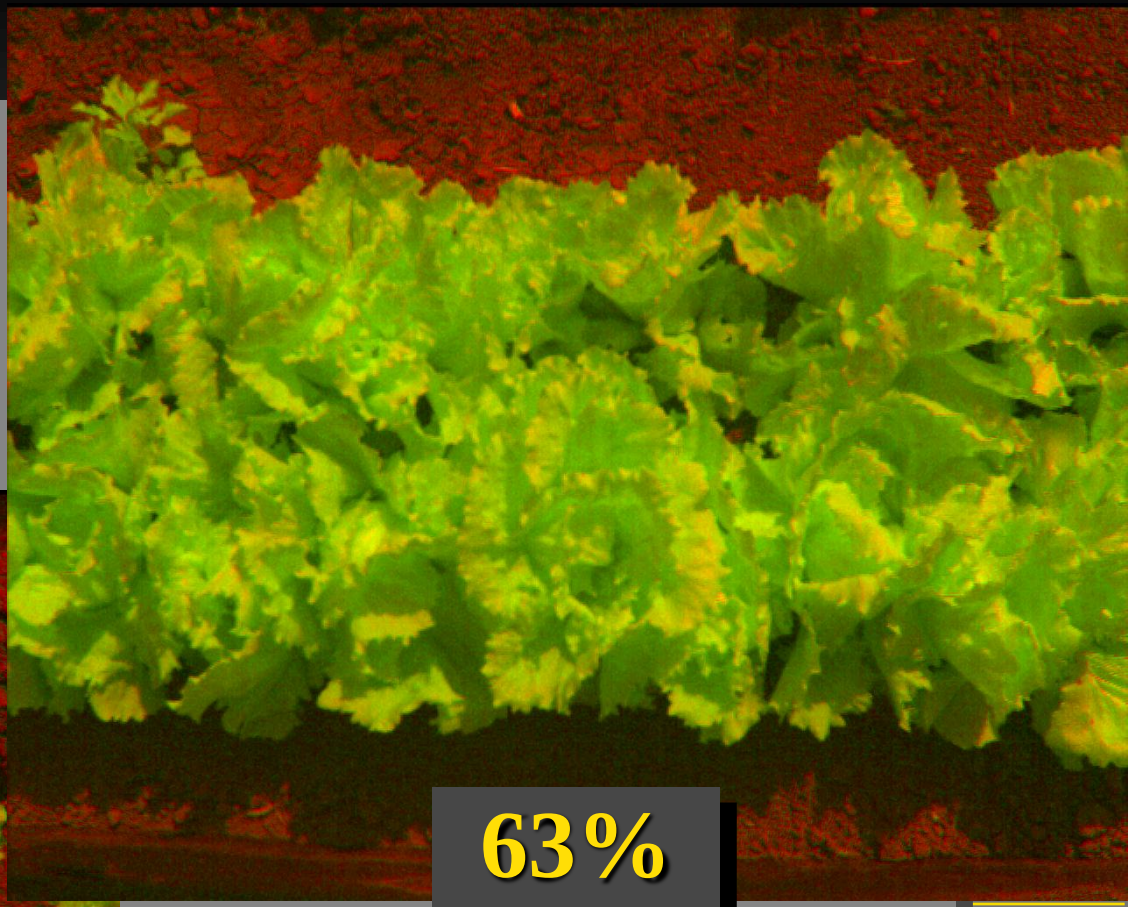


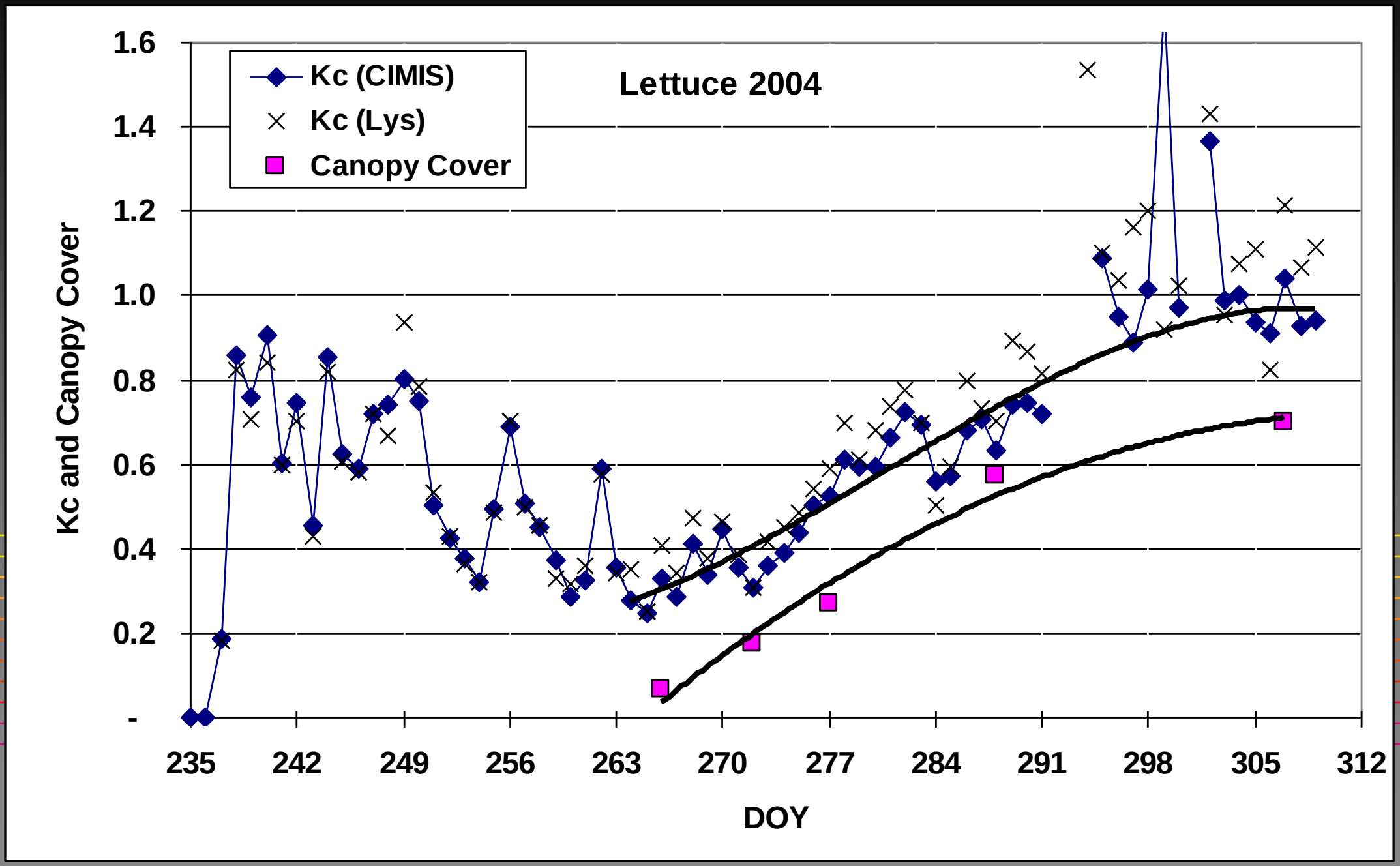

Crop Coefficient and Canopy Cover
WSREC Bell Pepper 2005
Irrigation Cutoff
Crop Coef., Kc and Crop Cover
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-
4/23
5/7
5/21
6/4
6/18
7/2
7/16
7/30
8/13
8/27
9/10
Date
Kc
Crop Cover


Lettuce 04

Lettuce Canopy Cover





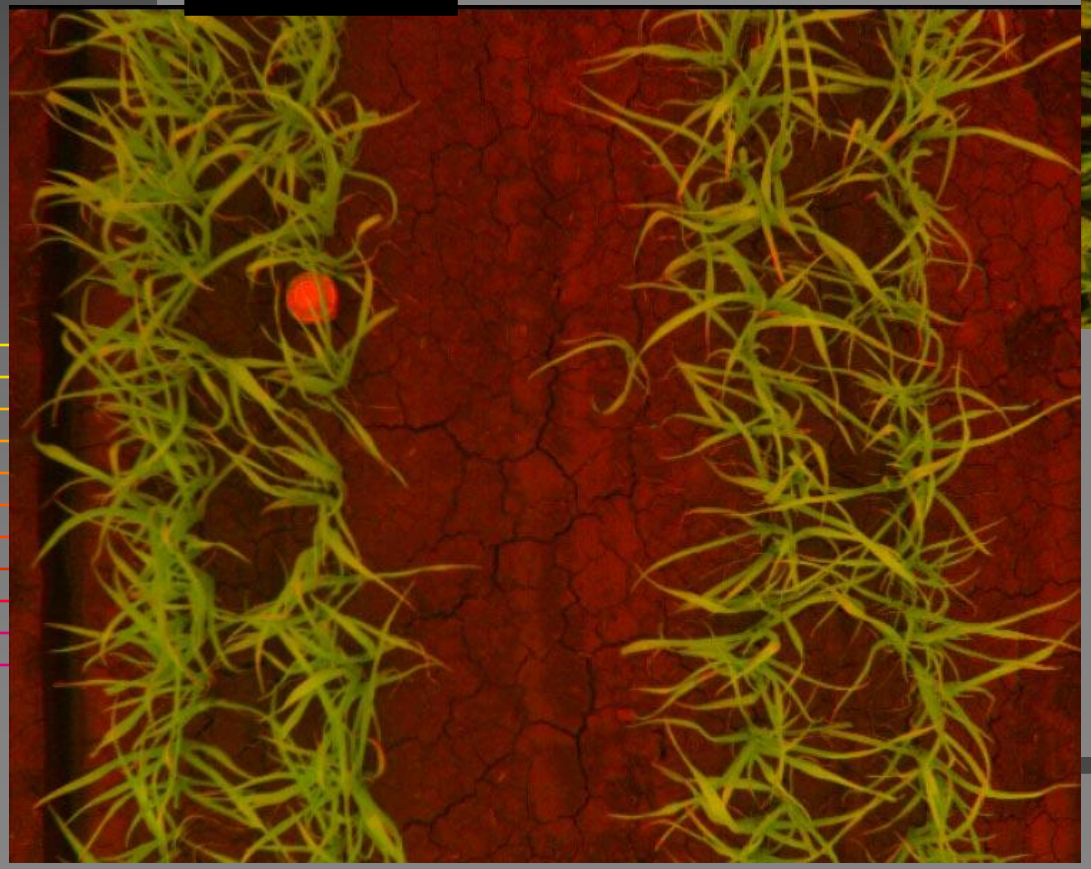

Lettuce 2004
Kc (CIMIS)
Kc (Lys)
Canopy Cover
Kc and Canopy Cover
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-
235
242
249
256
263
270
277
284
291
298
305
312
DOY

Garlic

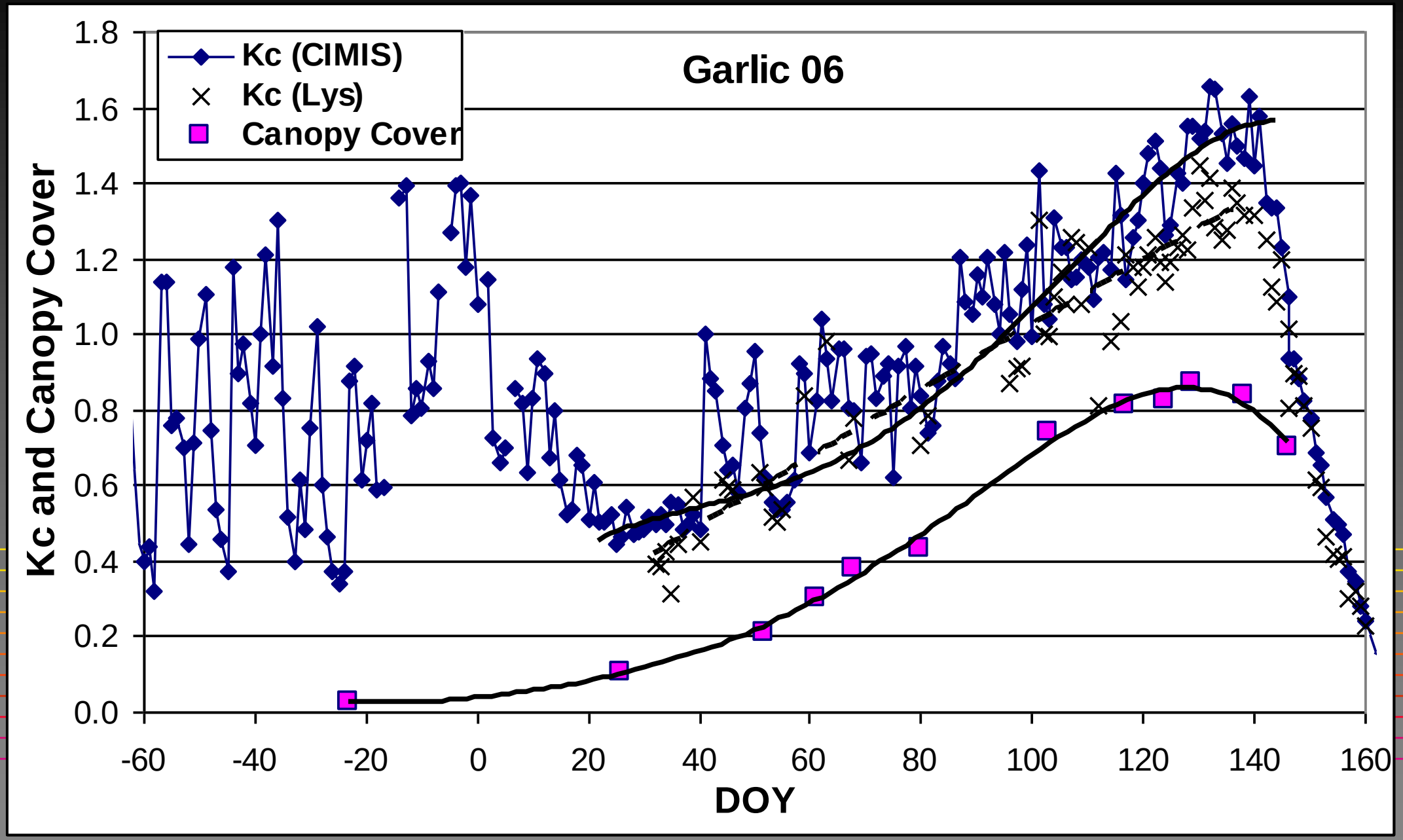
Garlic 06

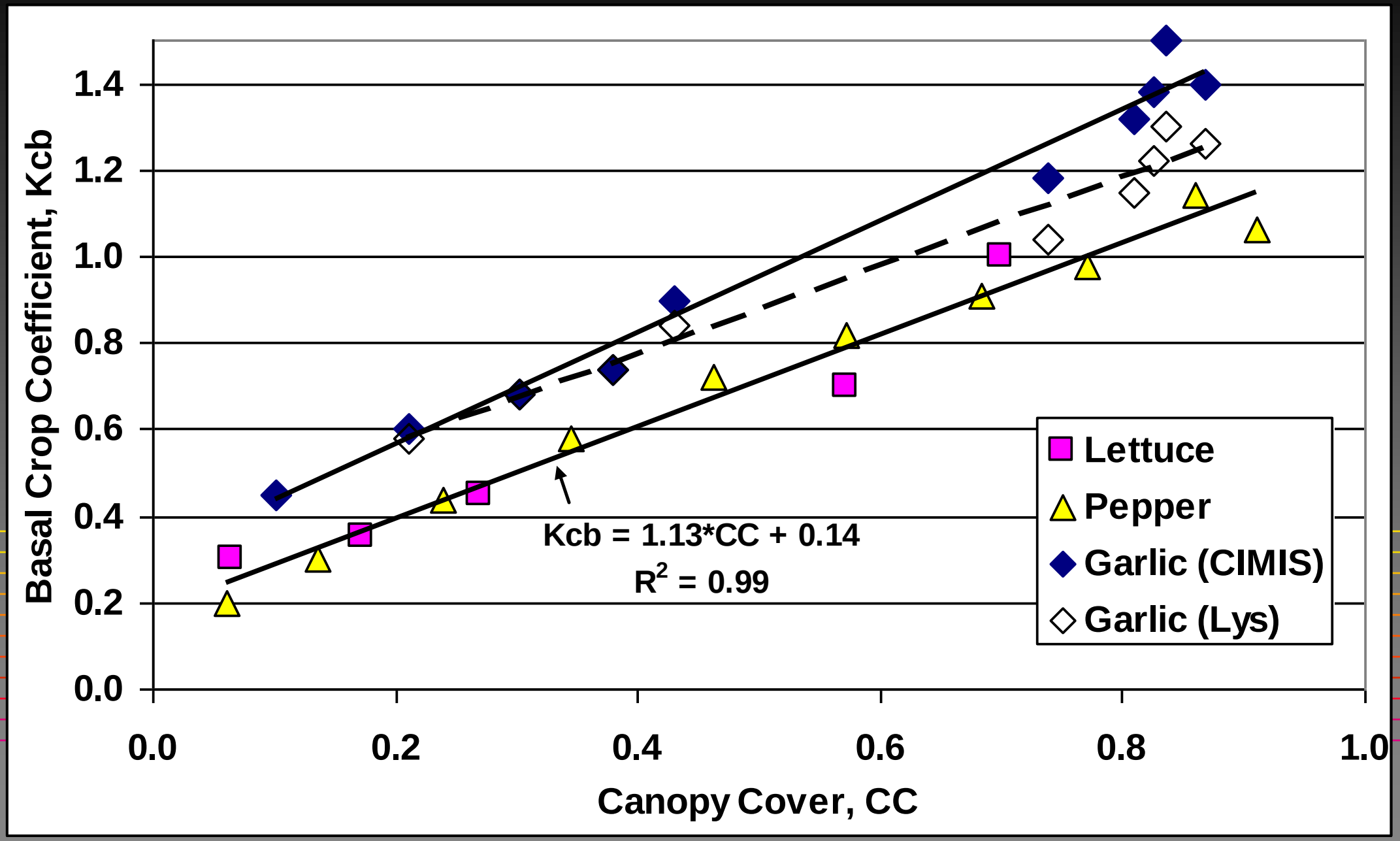
Garlic Canopy Cover

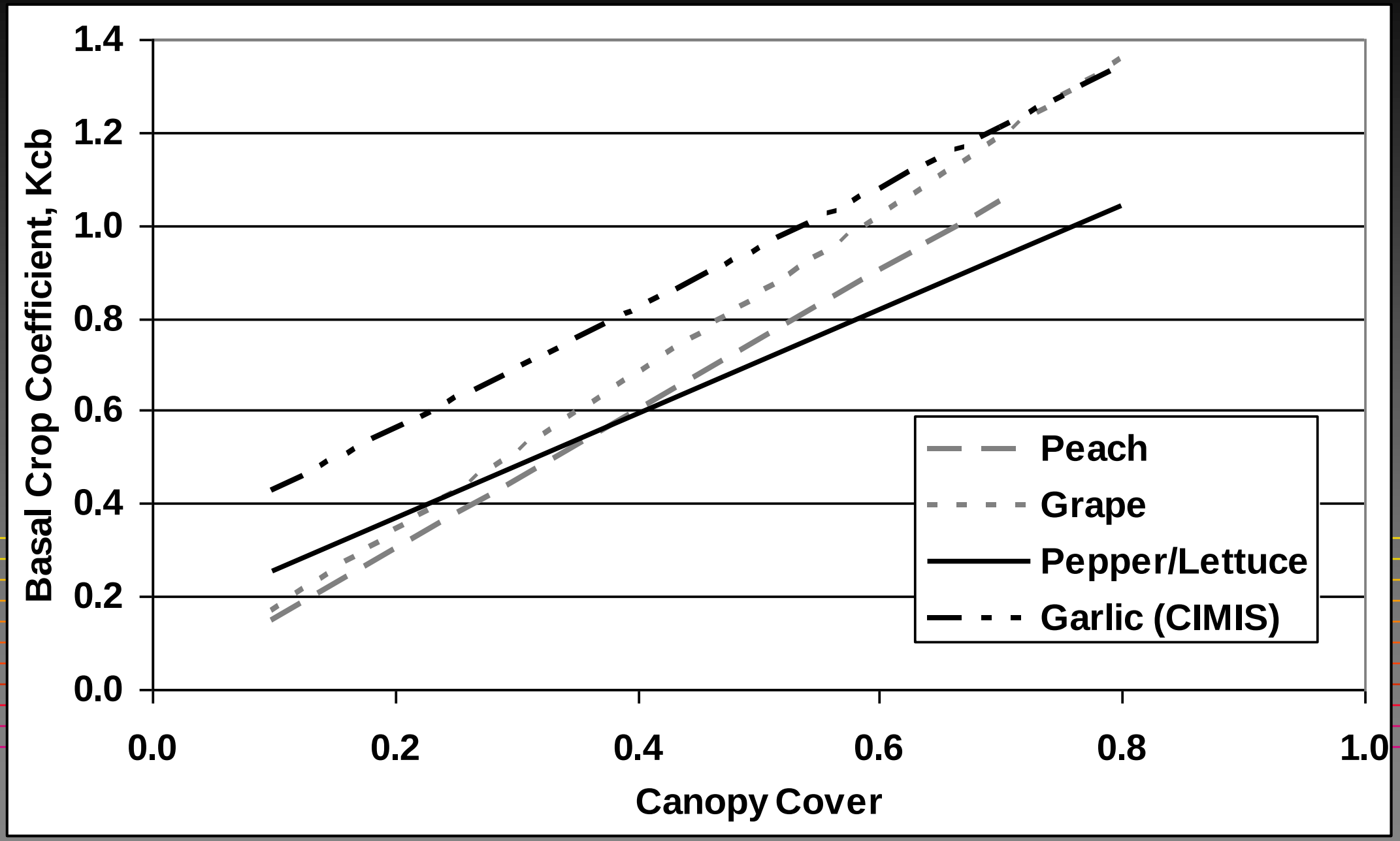
30%

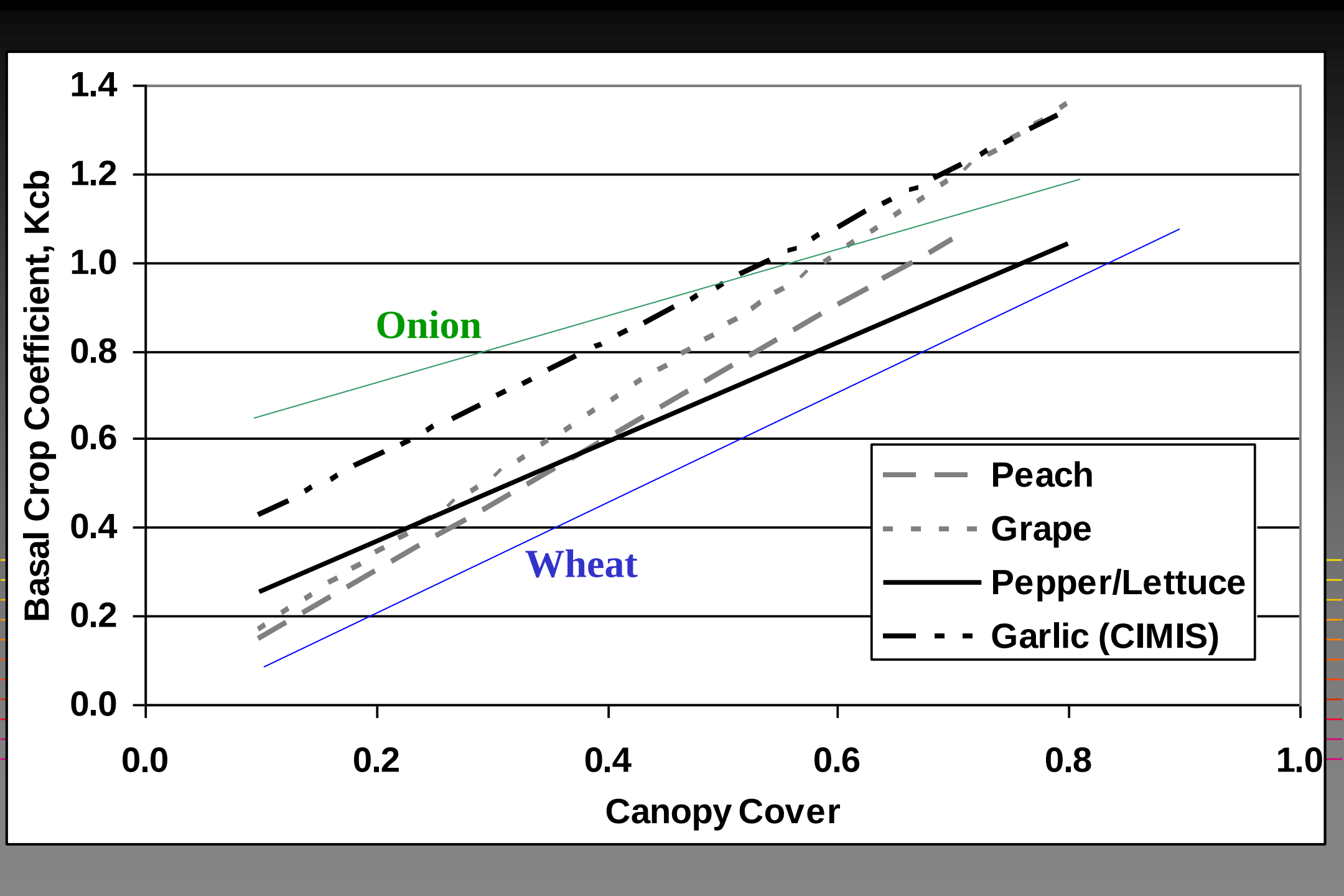


63%


Garlic 06
Kc (CIMIS)
Kc (Lys)
Canopy Cover
Kc and Canopy Cover
DOY
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-60
-40
-20
0
20
40
60
80
100
120
140
160


Basal Crop Coefficient, Kcb
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Canopy Cover, CC
Kcb = 1.13*CC + 0.14
R2 = 0.99
Lettuce
Pepper
Garlic (CIMIS)
Garlic (Lys)


Basal Crop Coefficient, Kcb
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Canopy Cover
Peach
Grape
Pepper/Lettuce
Garlic (CIMIS)


Basal Crop Coefficient, Kcb
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Canopy Cover
Onion
Wheat
Peach
Grape
Pepper/Lettuce
Garlic (CIMIS)

Irrig Sci (2009) 28:17–34
DOI 10.1007/s00271-009-0182-z

ORIGINAL PAPER

Estimating crop coefficients from fraction of ground cover and height

Richard G. Allen · Luis S. Pereira

Received: 13 May 2009 / Accepted: 15 July 2009 / Published online: 16 September 2009

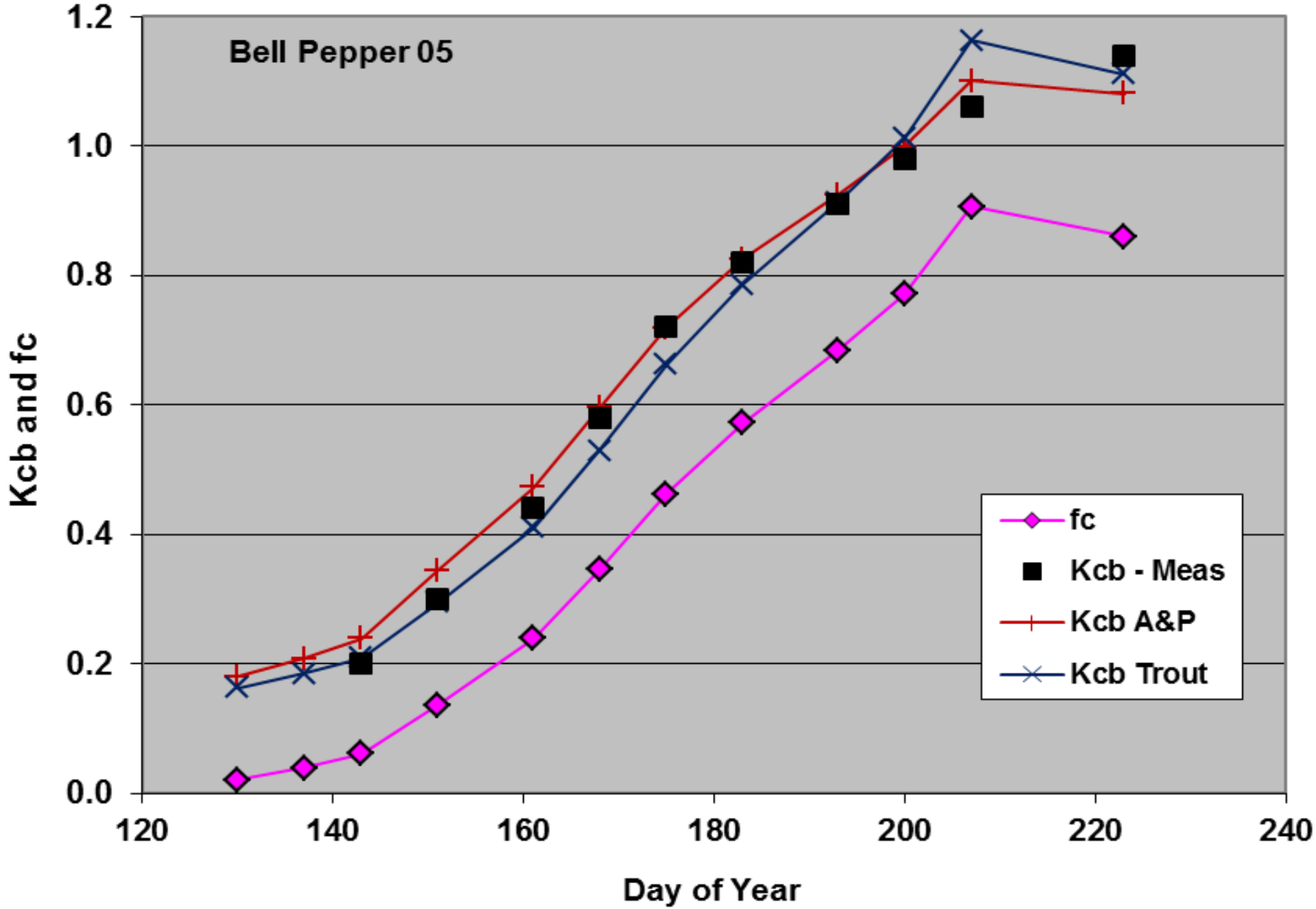
Abstract The FAO-56 procedure for estimating the crop coefficient K_c as a function of fraction of ground cover and

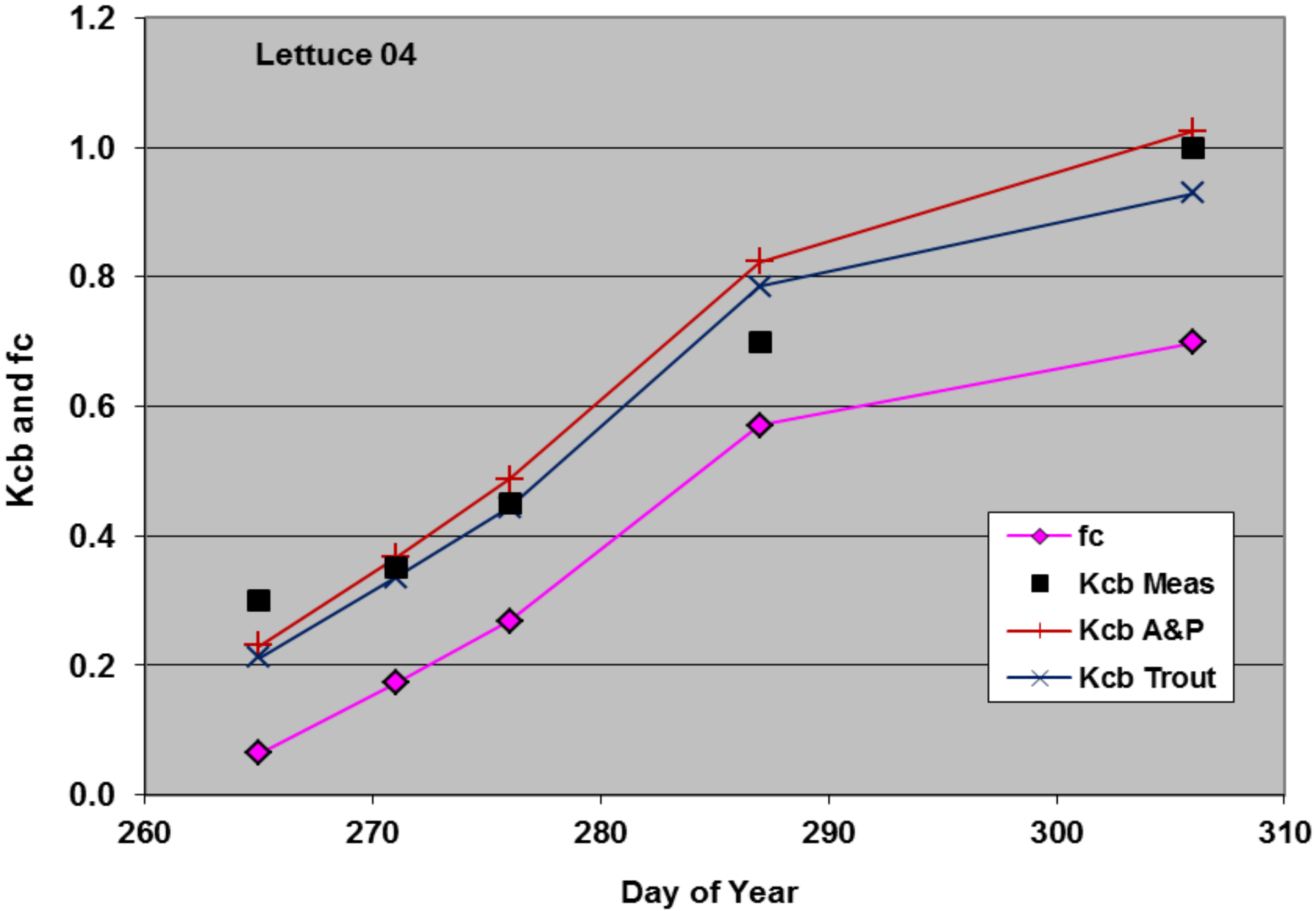
- **Kcb min = 0.15**
- **Kcb full = Fr(min(1+0.1h,1.2))+[0.04(u-2)-.004(RH-45]*(h/3)$^{0.3}$)**

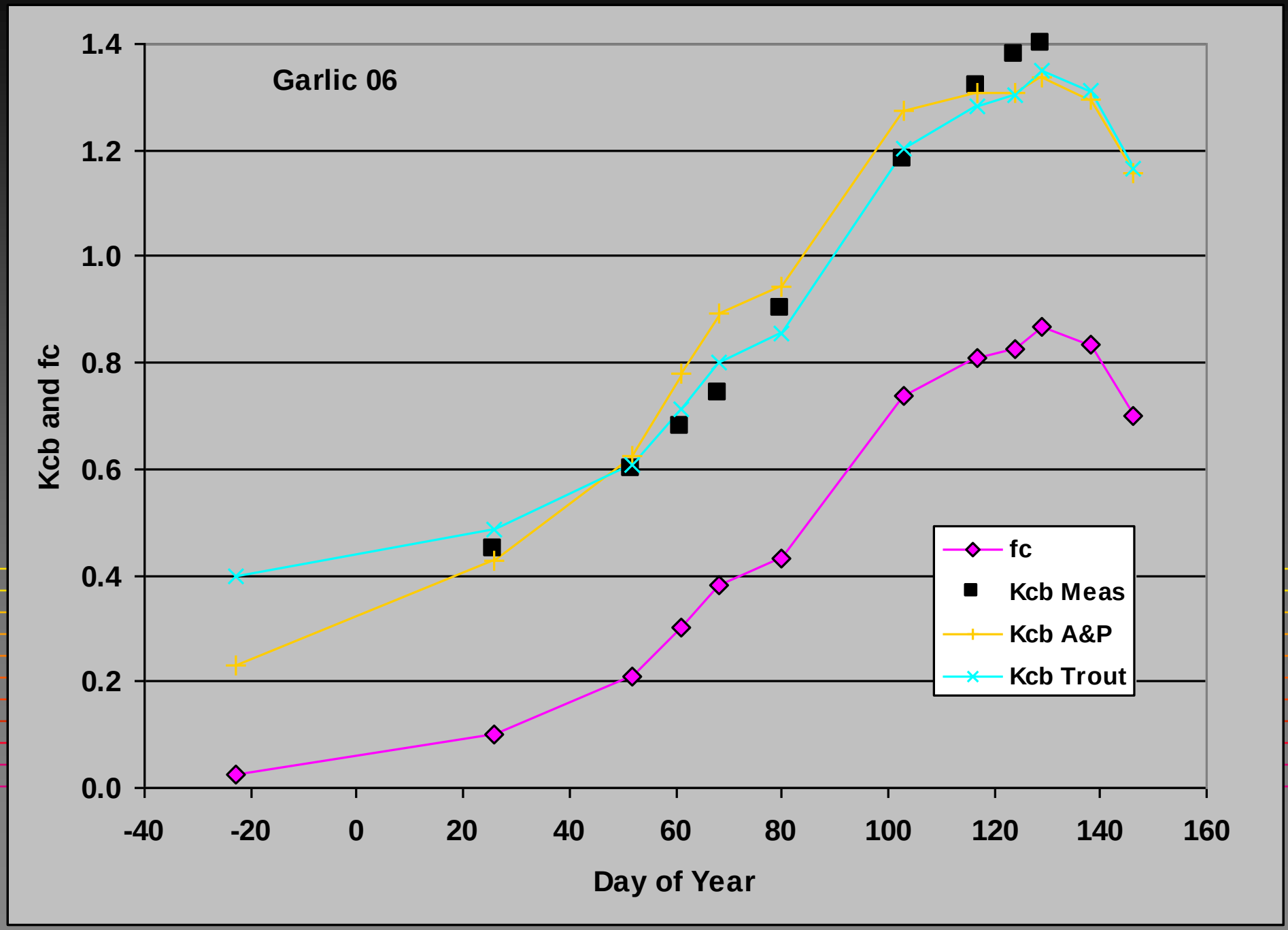
surface is dry. $K_{cb\ full}$ is estimated primarily as a function of crop height. $K_{cb\ full}$ can be adjusted for tree crops by multiplying by a reduction factor (F_r) estimated using a

Introduction

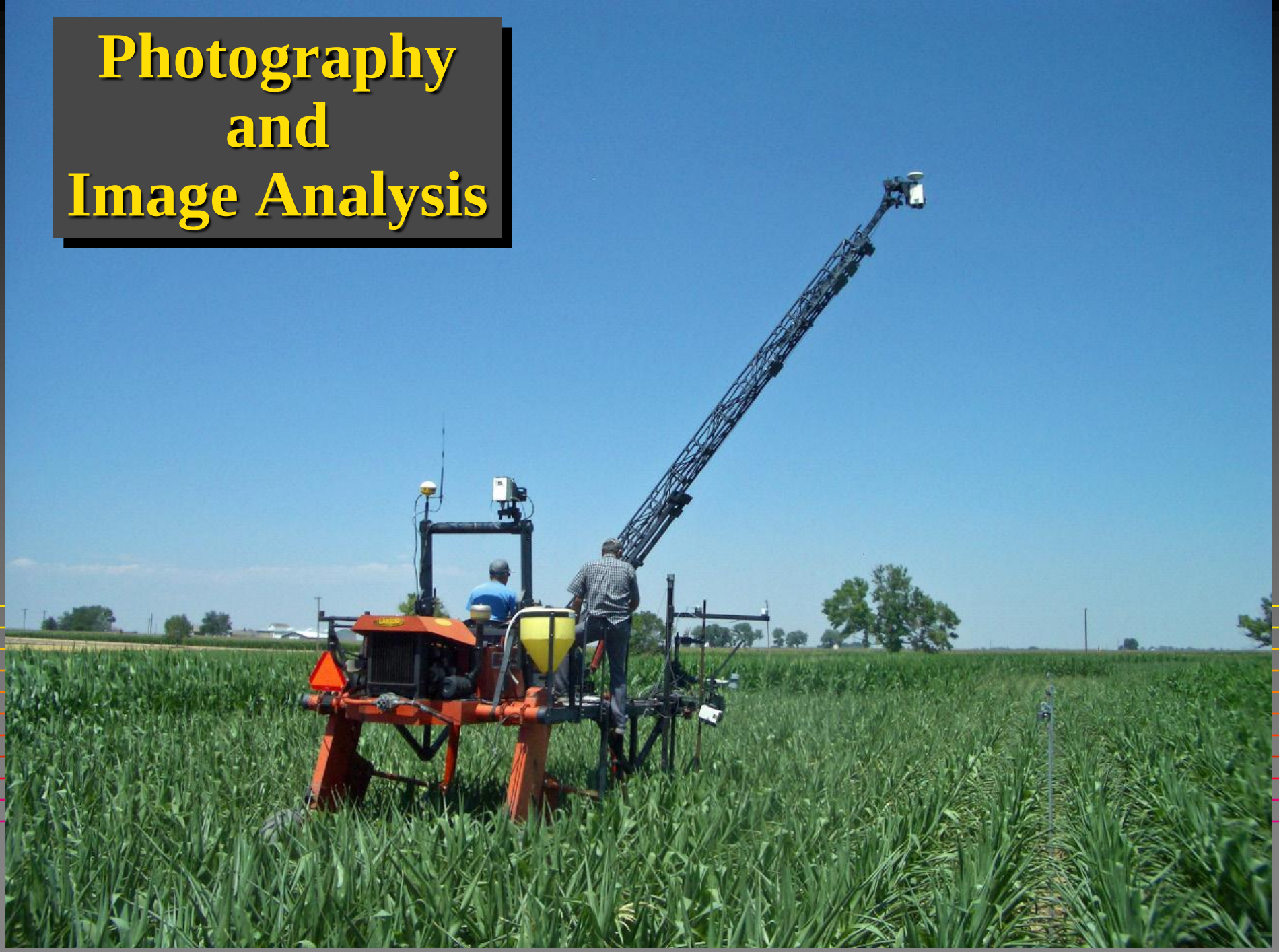
estimate by a crop coefficient that represents the relative rate of ET from a specific crop and condition to that of the reference. The reference condition is generally ET from a


Bell Pepper 05
Kcb and fc
Day of Year
1.2
1.0
0.8
0.6
0.4
0.2
0.0
120
140
160
180
200
220
240
fc
Kcb - Meas
Kcb A&P
Kcb Trout


Lettuce 04
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Kcb and fc
260
270
280
290
300
310
Day of Year
fc
Kcb Meas
Kcb A&P
Kcb Trout


Garlic 06
Kcb and fc
Day of Year
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-40
-20
0
20
40
60
80
100
120
140
160
fc
Kcb Meas
Kcb A&P
Kcb Trout

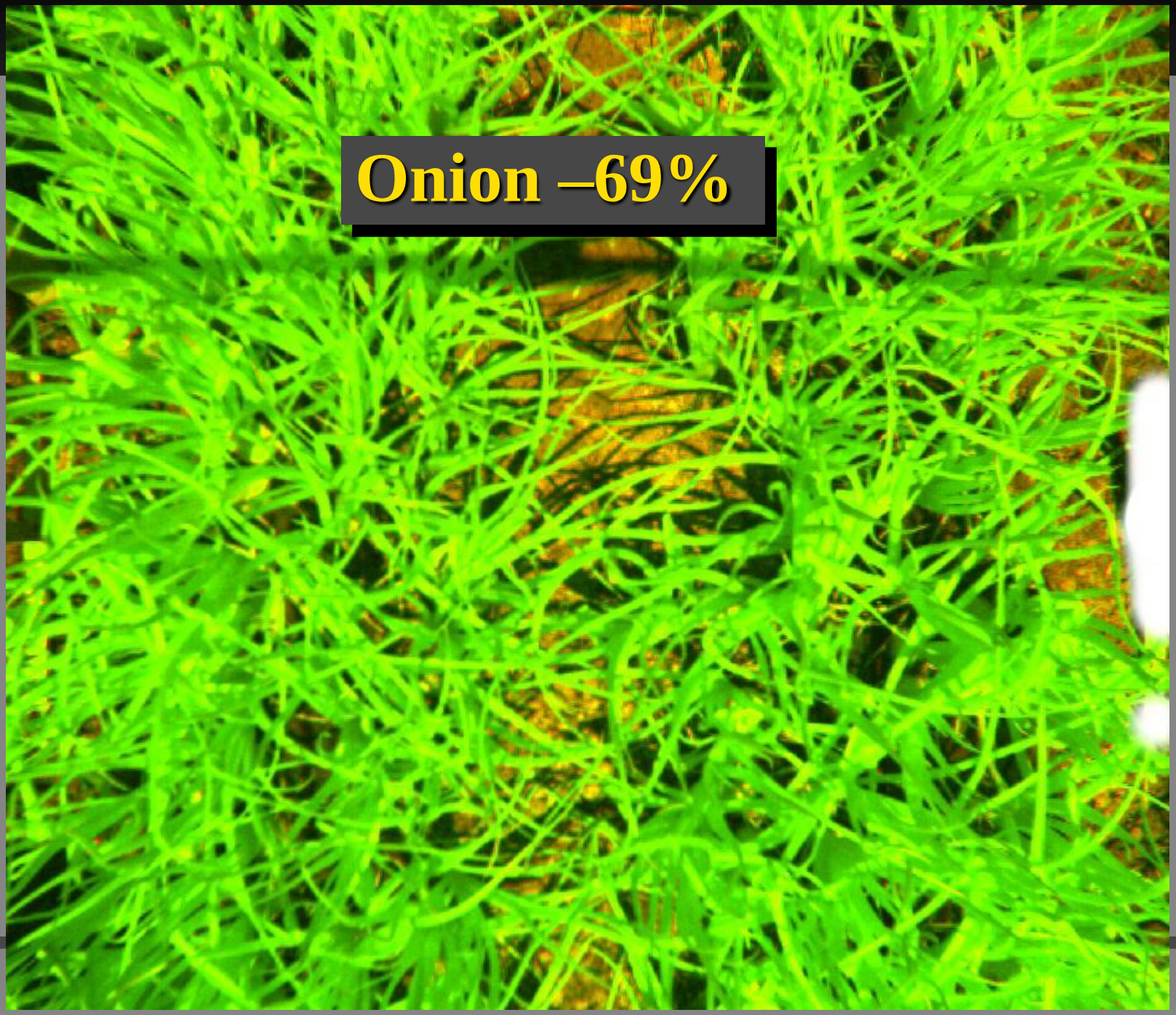
Photography and Image Analysis



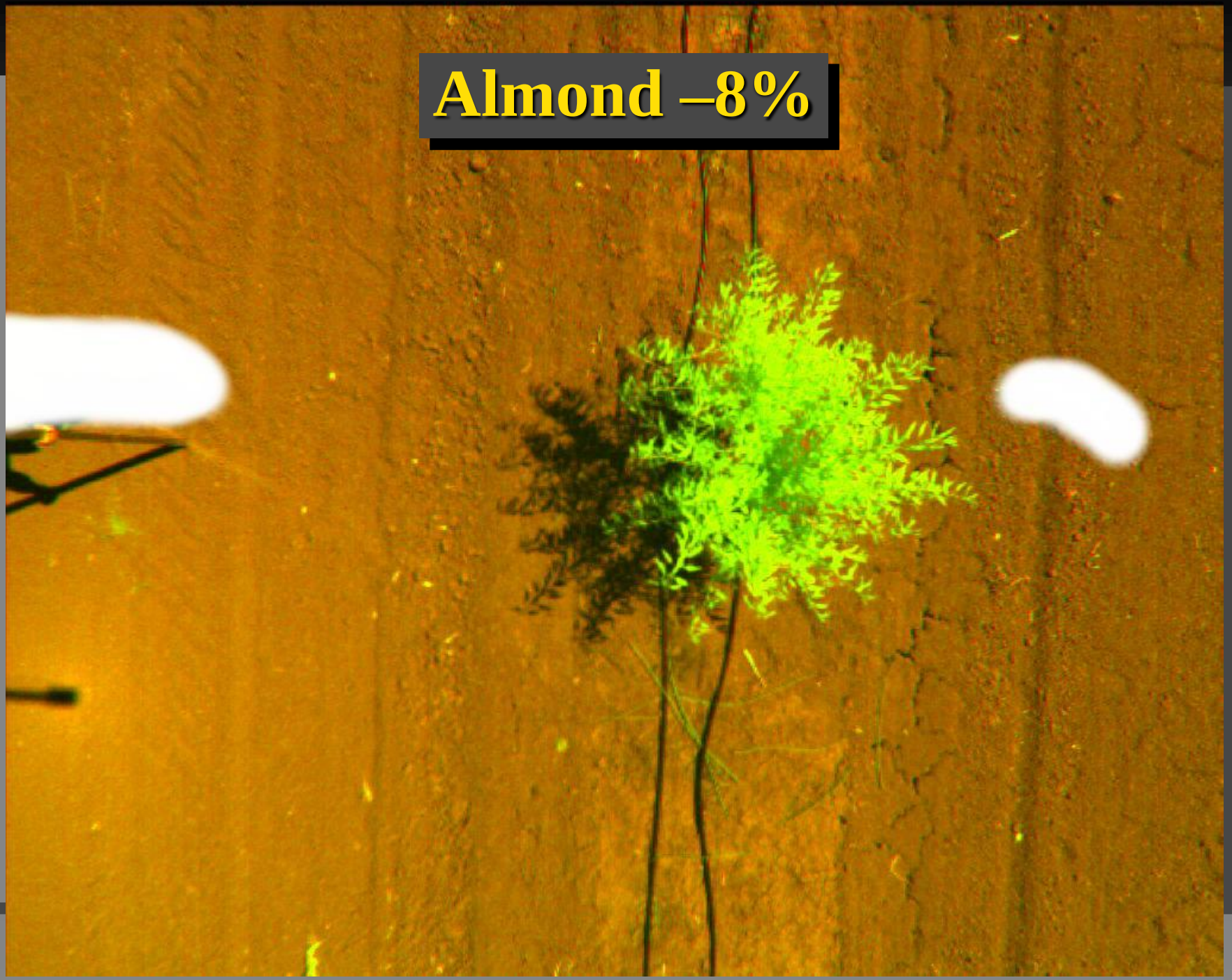
Dimensional fc


Landsat 5
San Joaquin Valley


Onions
Fractional Ground Cover – Red/NIR Camera (Tetracam)
Surface Soil Water Content (Wet/Dry)
Weed (non-crop) cover


Onion –69%


Small Almonds


Almond –8%

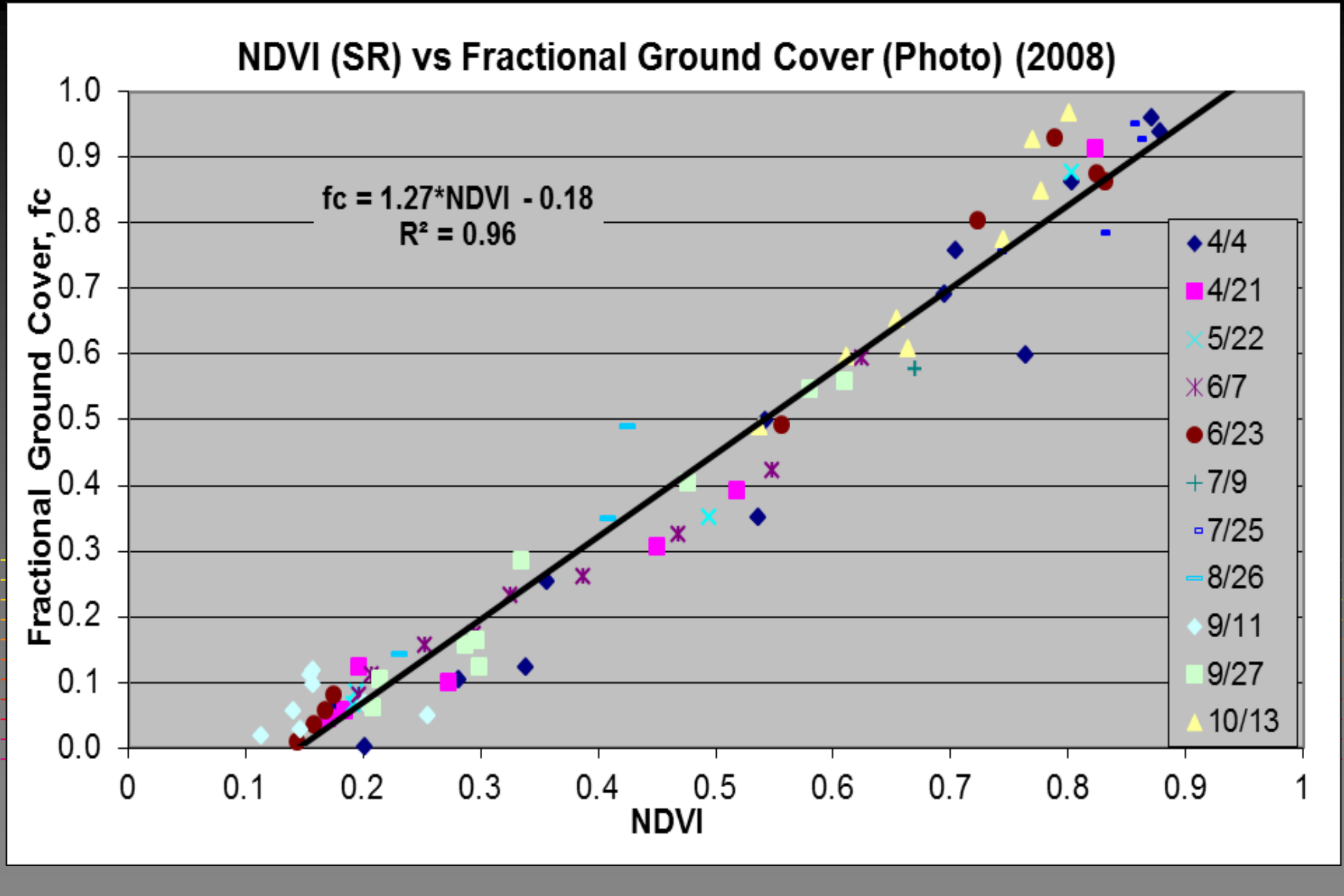
12 Measurement Dates, 2008

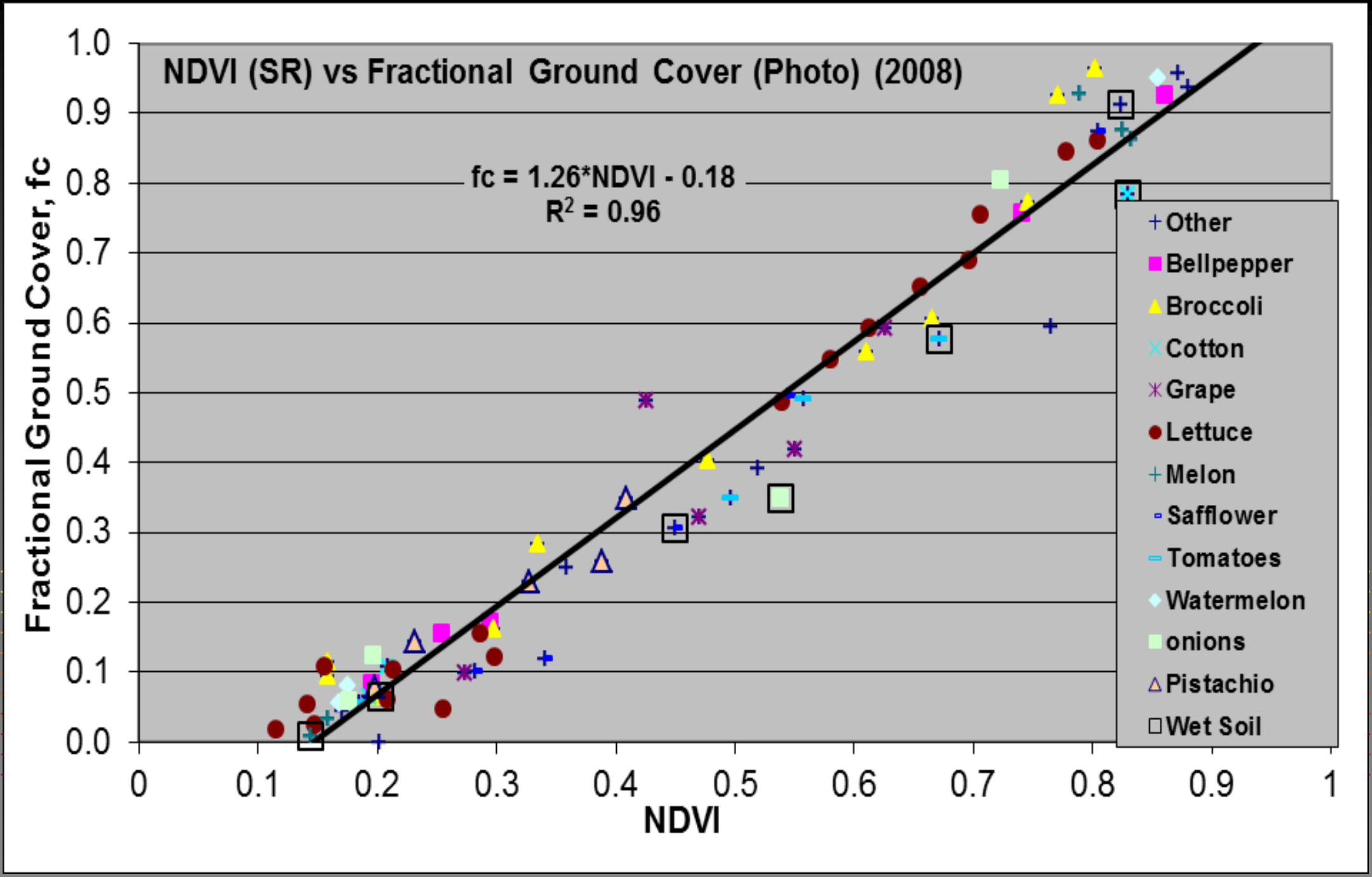
- 4/4, 4/21
- 5/6, 5/22
- 6/7, 6/23
- 7/9, 7/25
- 8/26
- 9/11, 9/27
- 10/13

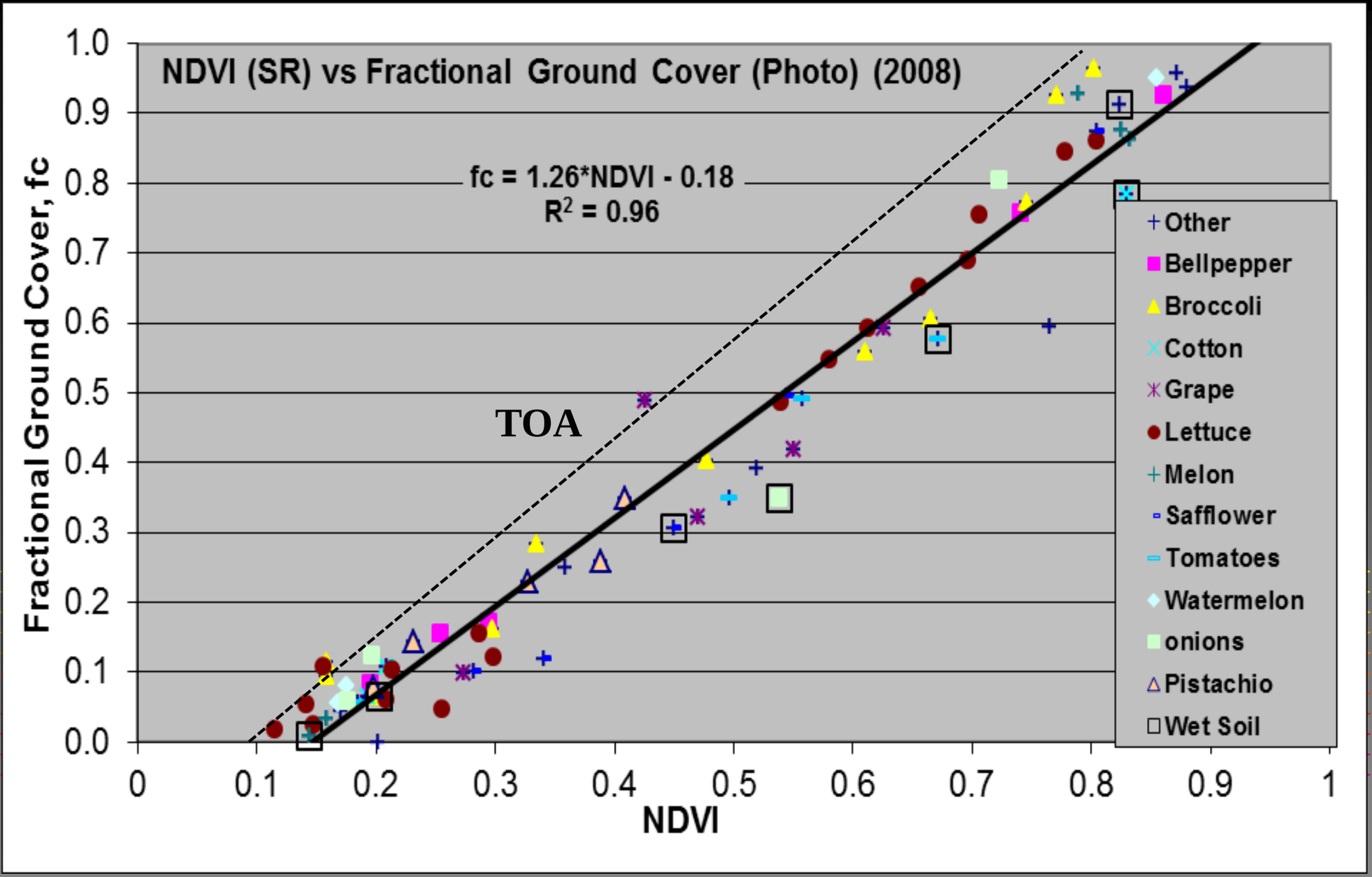
NDVI from Landsat 5 TM

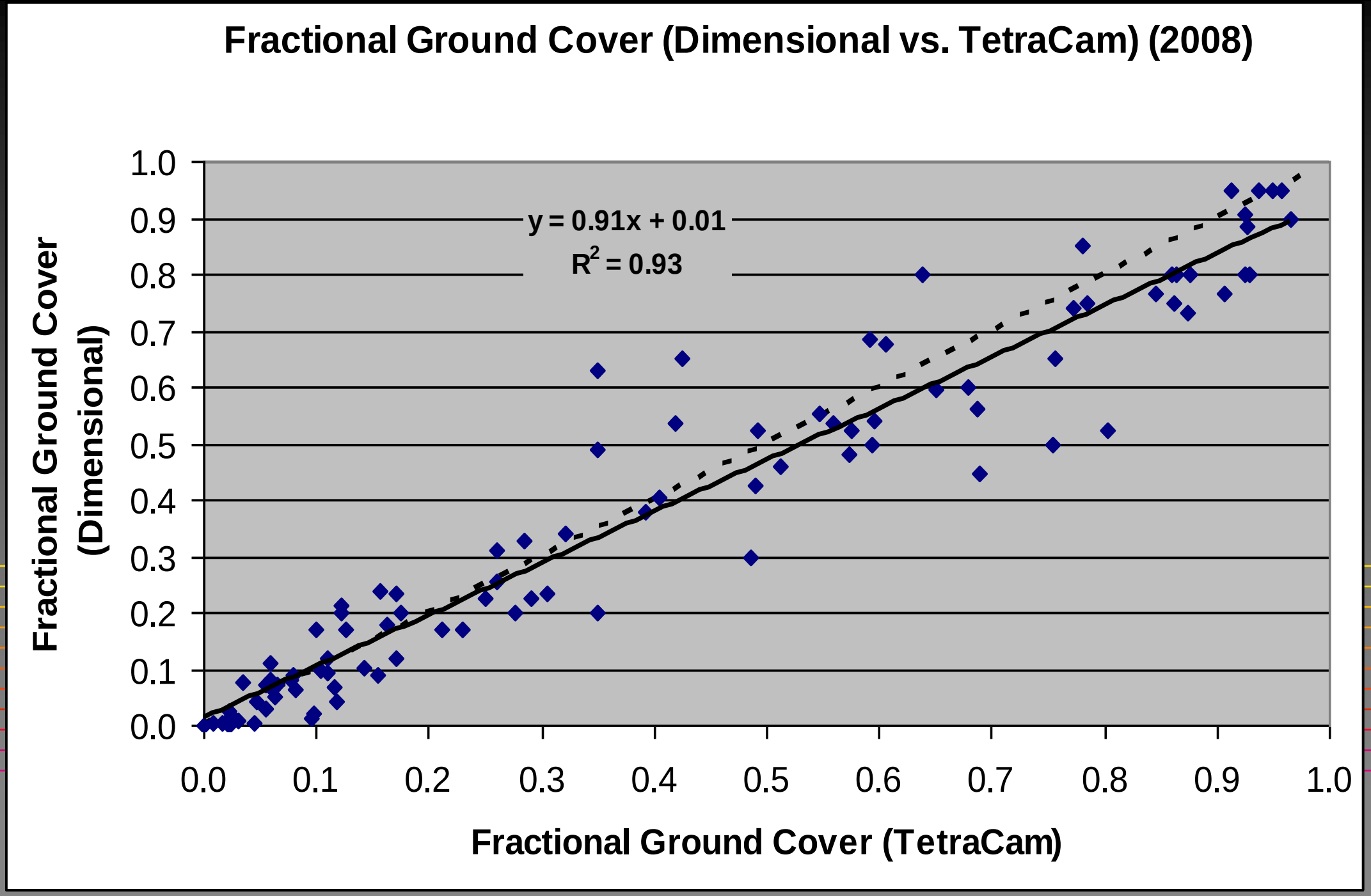
16 Crops

- Bell Pepper, Broccoli, Lettuce, Cantaloupe, Watermelon, Tomato, Garlic, Onion, Carrot
- Cotton, Safflower, Sugar Beet, Alfalfa
- Grape, Almond, Pistachio


NDVI (SR) vs Fractional Ground Cover (Photo) (2008)
fc = 1.27*NDVI - 0.18
R² = 0.96
Fractional Ground Cover, fc
NDVI
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
4/4
4/21
5/22
6/7
6/23
7/9
7/25
8/26
9/11
9/27
10/13


NDVI (SR) vs Fractional Ground Cover (Photo) (2008)
fc = 1.26*NDVI - 0.18
R2 = 0.96
Fractional Ground Cover, fc
NDVI
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Other
Bellpepper
Broccoli
Cotton
Grape
Lettuce
Melon
Safflower
Tomatoes
Watermelon
onions
Pistachio
Wet Soil

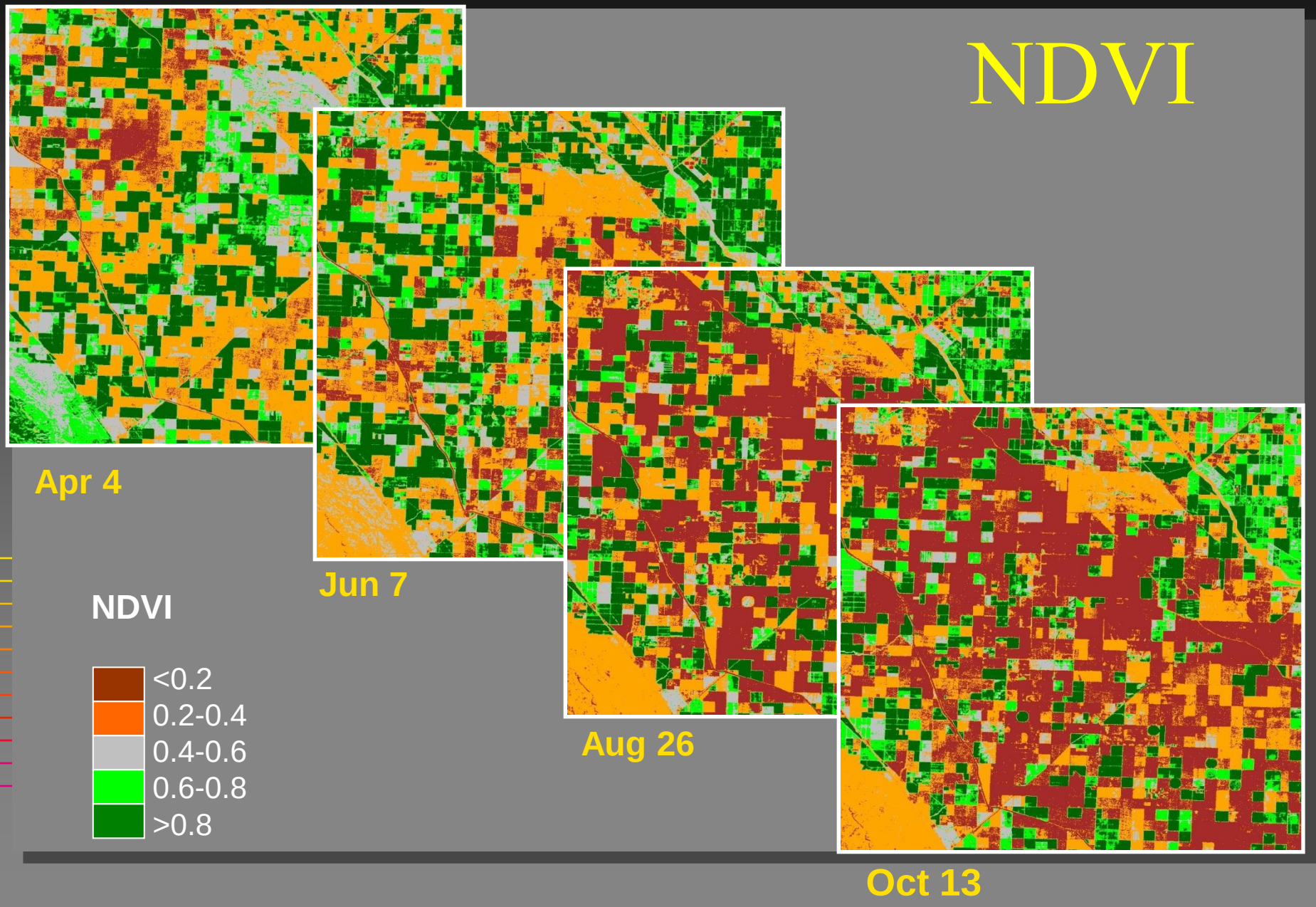

NDVI (SR) vs Fractional Ground Cover (Photo) (2008)
fc = 1.26*NDVI - 0.18
R2 = 0.96
TOA
Fractional Ground Cover, fc
NDVI
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Other
Bellpepper
Broccoli
Cotton
Grape
Lettuce
Melon
Safflower
Tomatoes
Watermelon
onions
Pistachio
Wet Soil

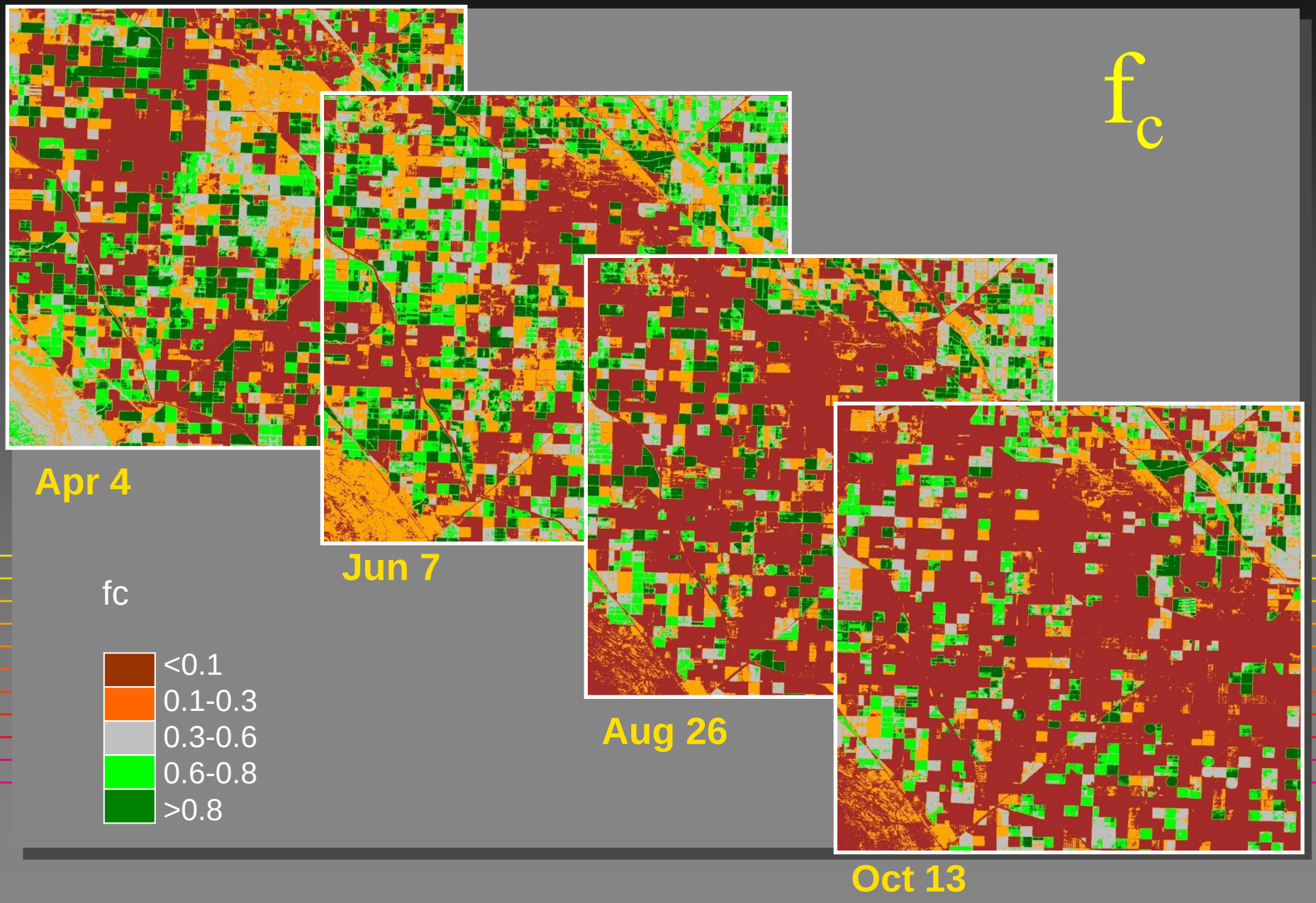

Fractional Ground Cover (Dimensional vs. TetraCam) (2008)
y = 0.91x + 0.01
R2 = 0.93
Fractional Ground Cover (Dimensional)
Fractional Ground Cover (TetraCam)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Conclusion

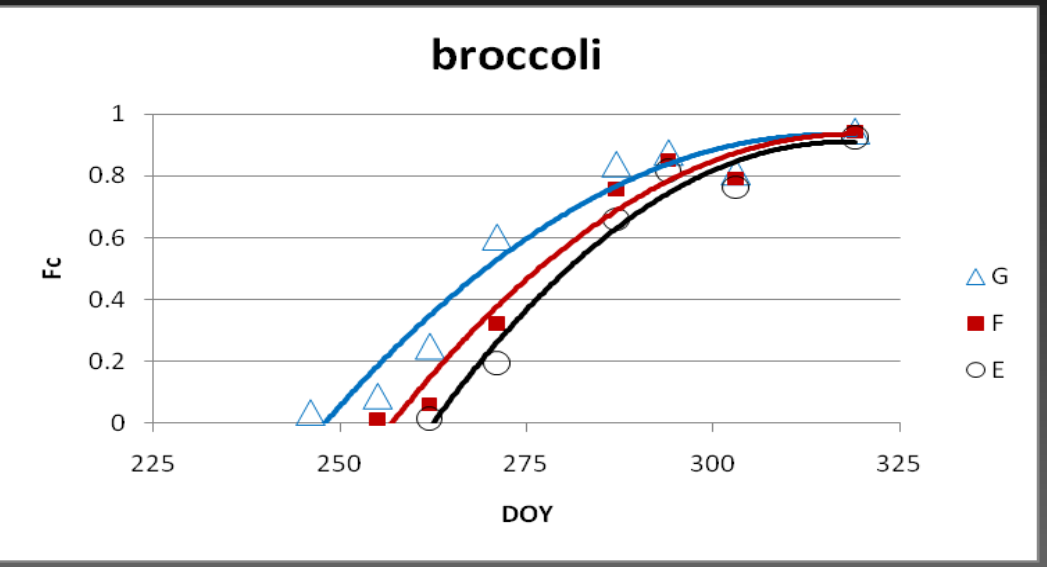
- You can estimate fractional ground cover from NDVI from Landsat imagery

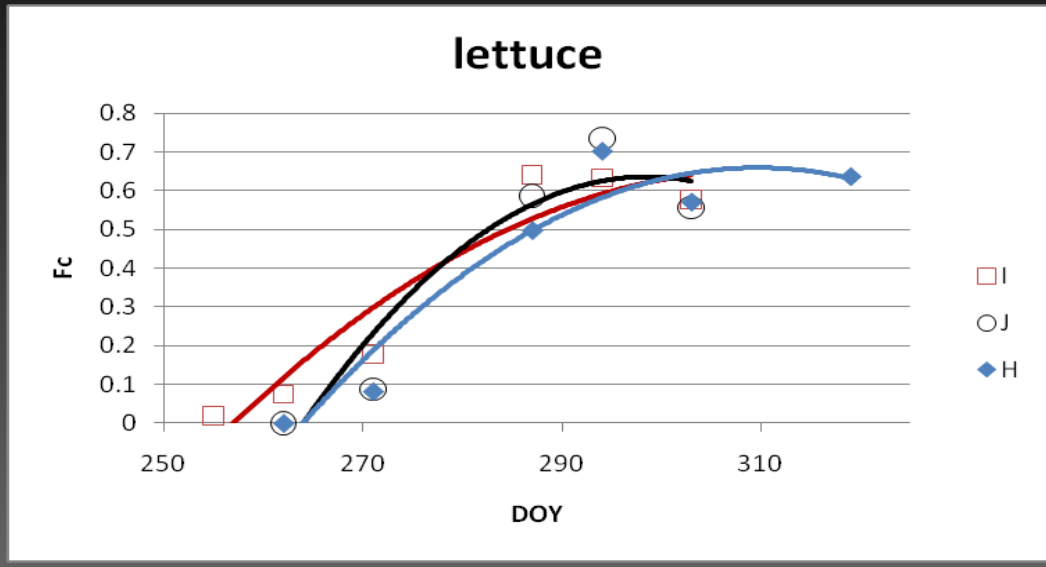
NDVI

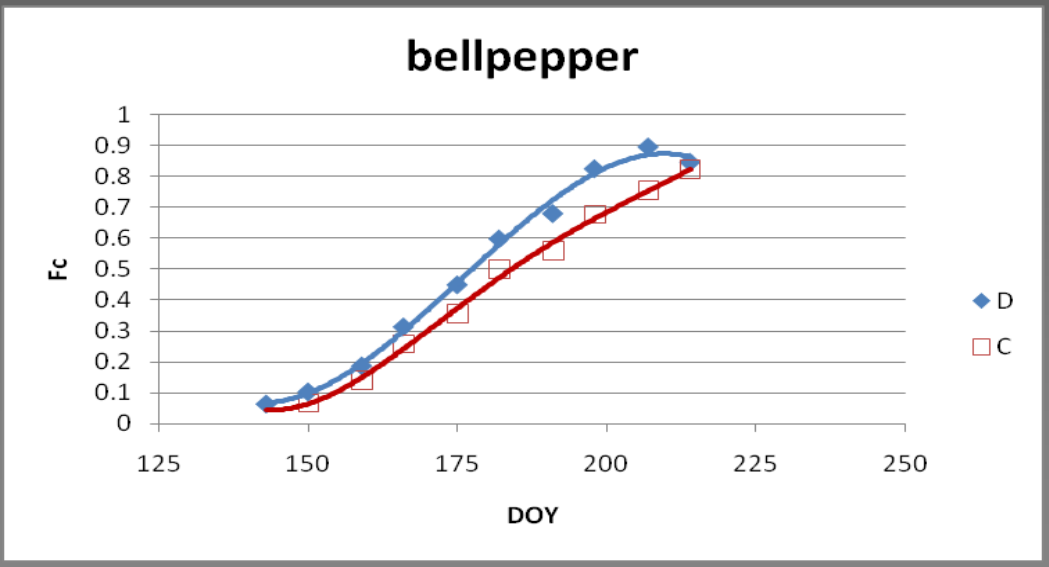


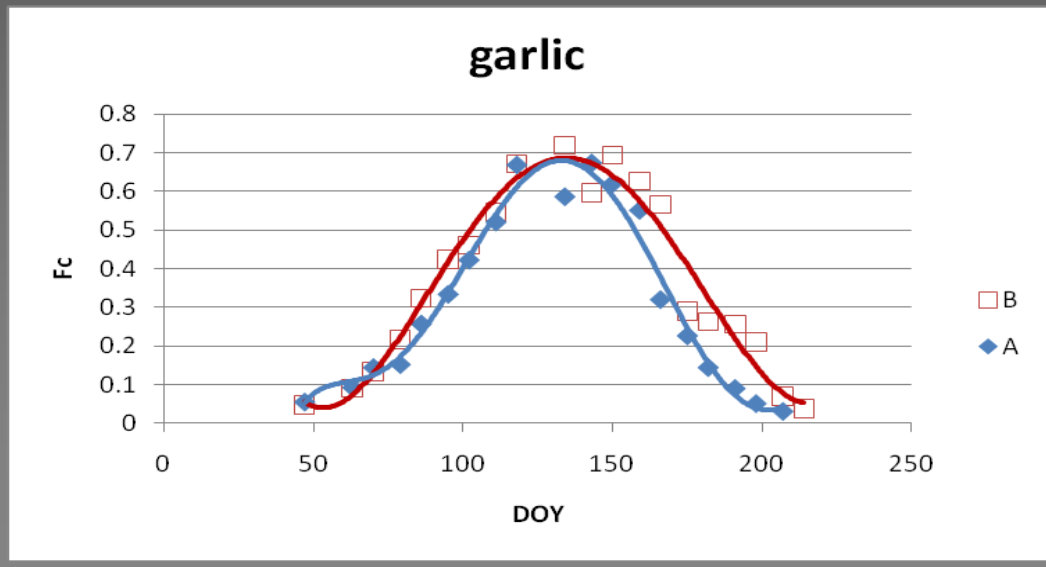

f_c
Apr 4
Jun 7
Aug 26
Oct 13
fc
<0.1
0.1-0.3
0.3-0.6
0.6-0.8
>0.8

Fractional cover

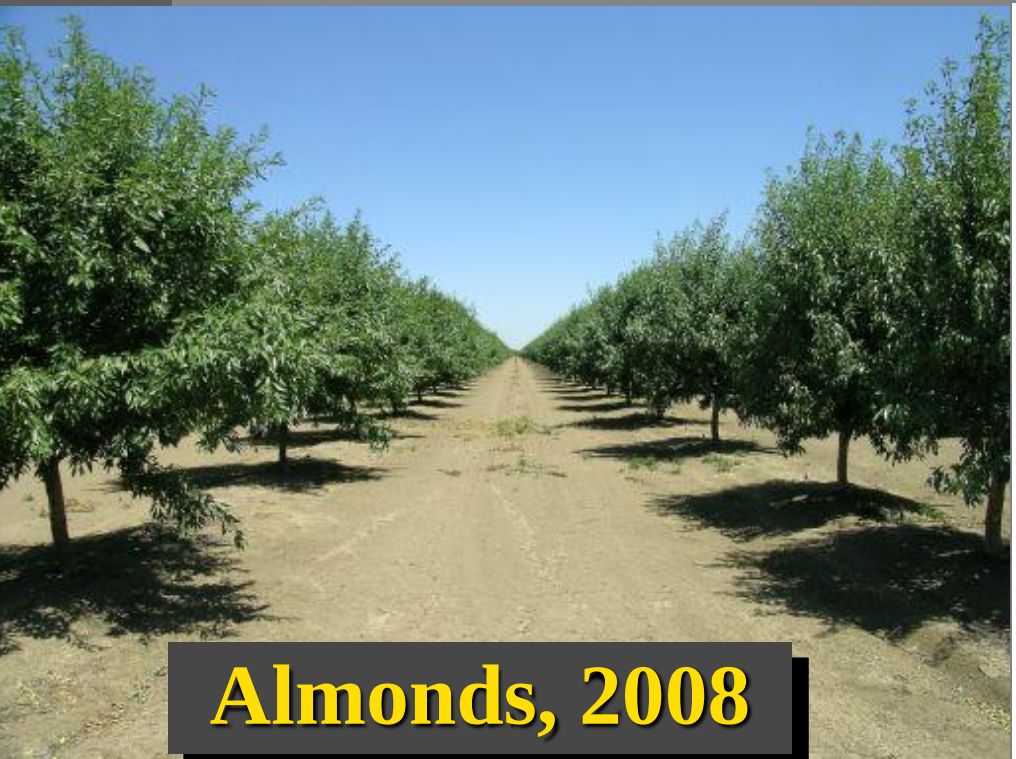




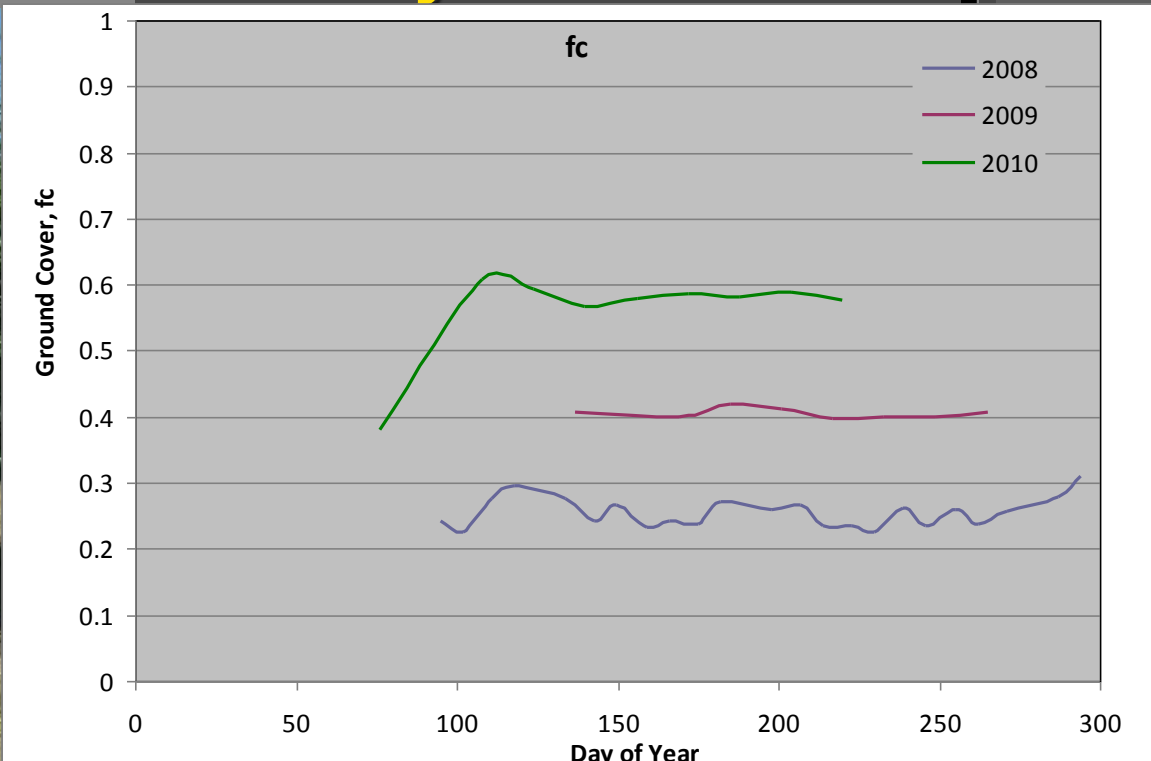




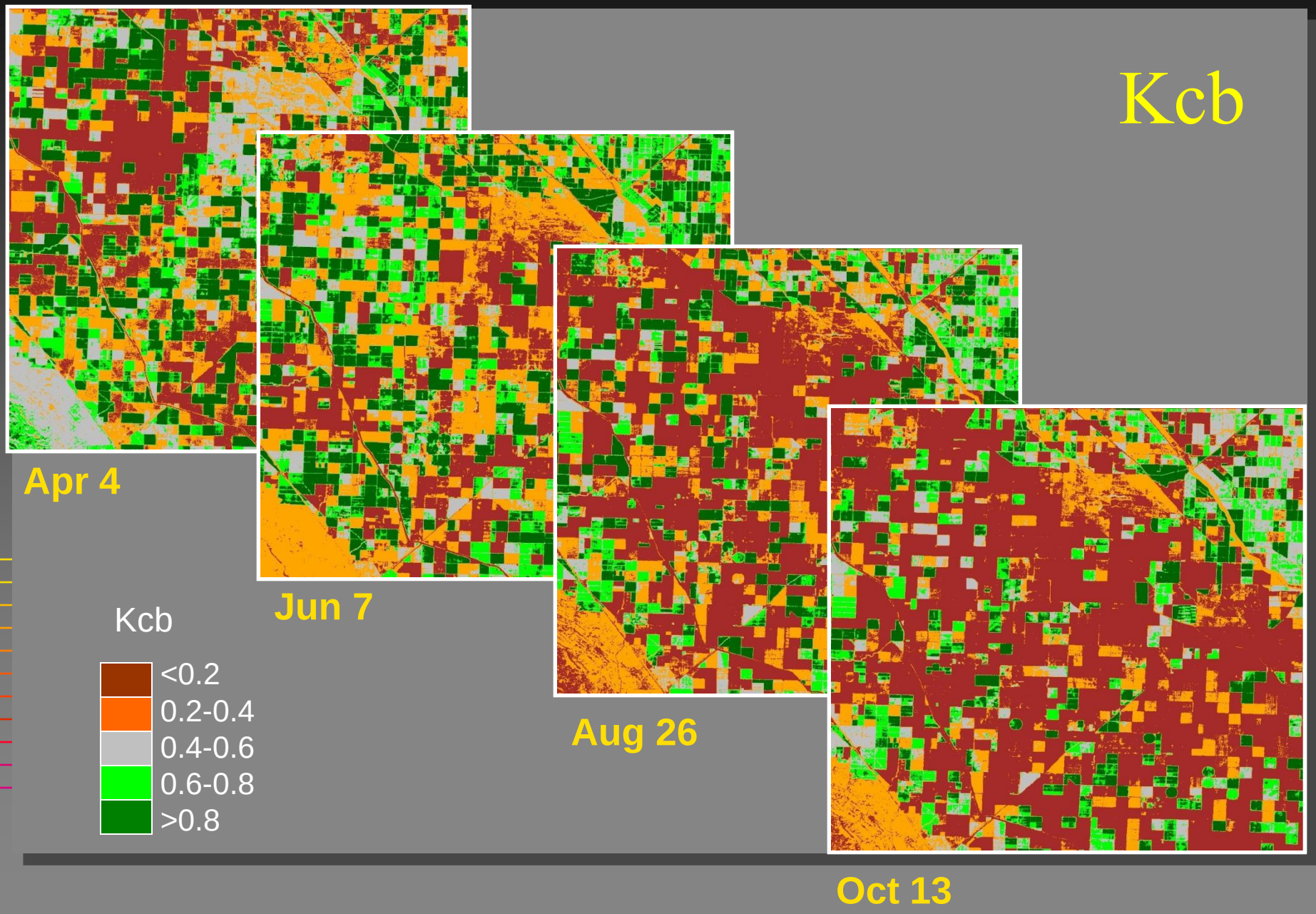
Multi-year Growth



Almonds, 2008



Kcb



Development of Reflectance-Based Crop Coefficients for Corn

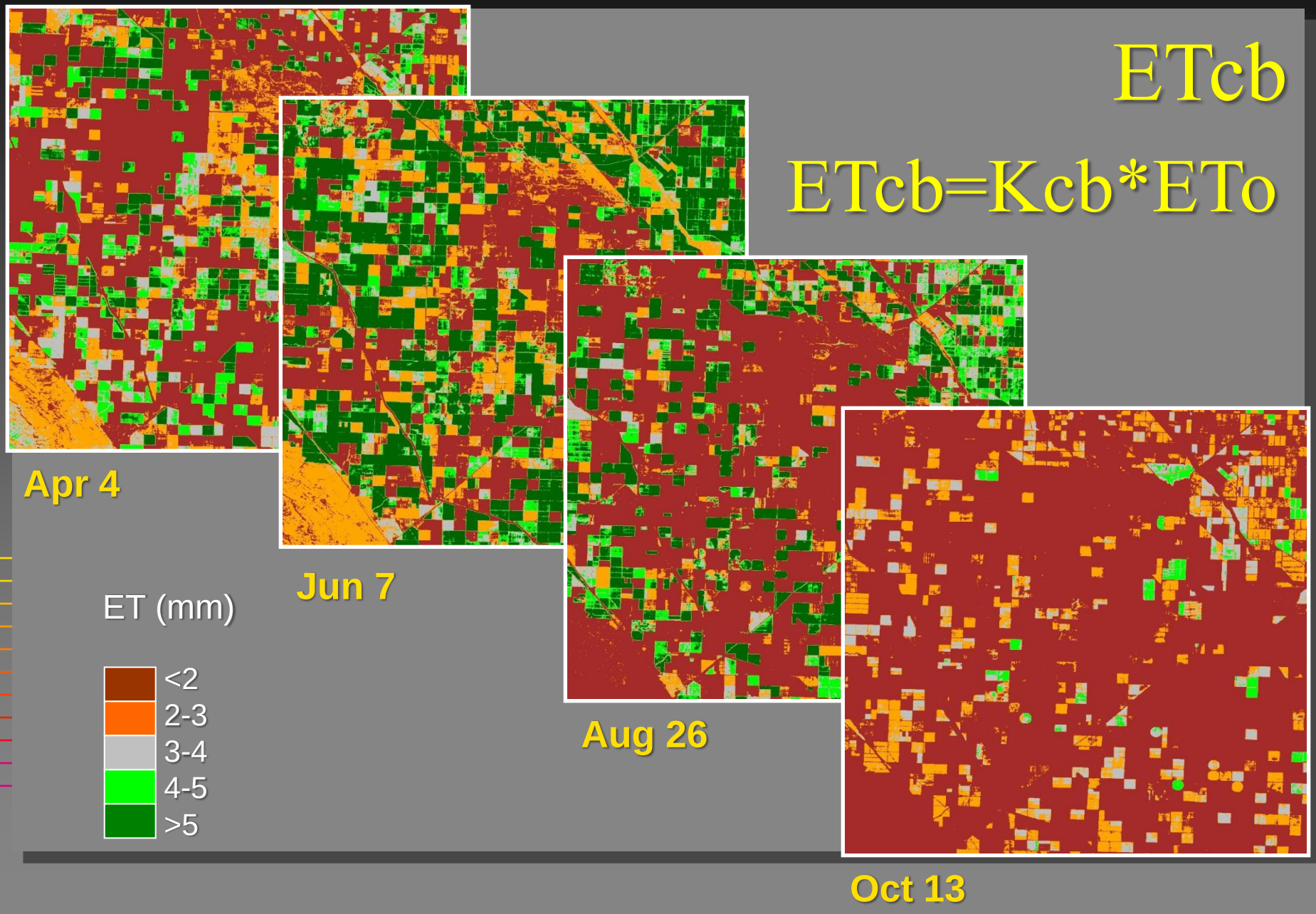
Transactions of the ASABE. 32(6) 1891-1900. 1990

Christopher M. U. Neale, Walter C. Bausch, Dale F. Heermann

ABSTRACT Concurrent measurements of reflected canopy radiation and the basal crop coefficient (Kcb) for corn were conducted throughout a season in order to develop a reflectance-based crop coefficient model. Reflectance was measured in Landsat Thematic Mapper bands TM3 (0.63 - 0.69 um) and TM4 (0.76 - 0.90 um) and used in the calculation of a vegetation index called the normalized difference vegetation index (NDVI).

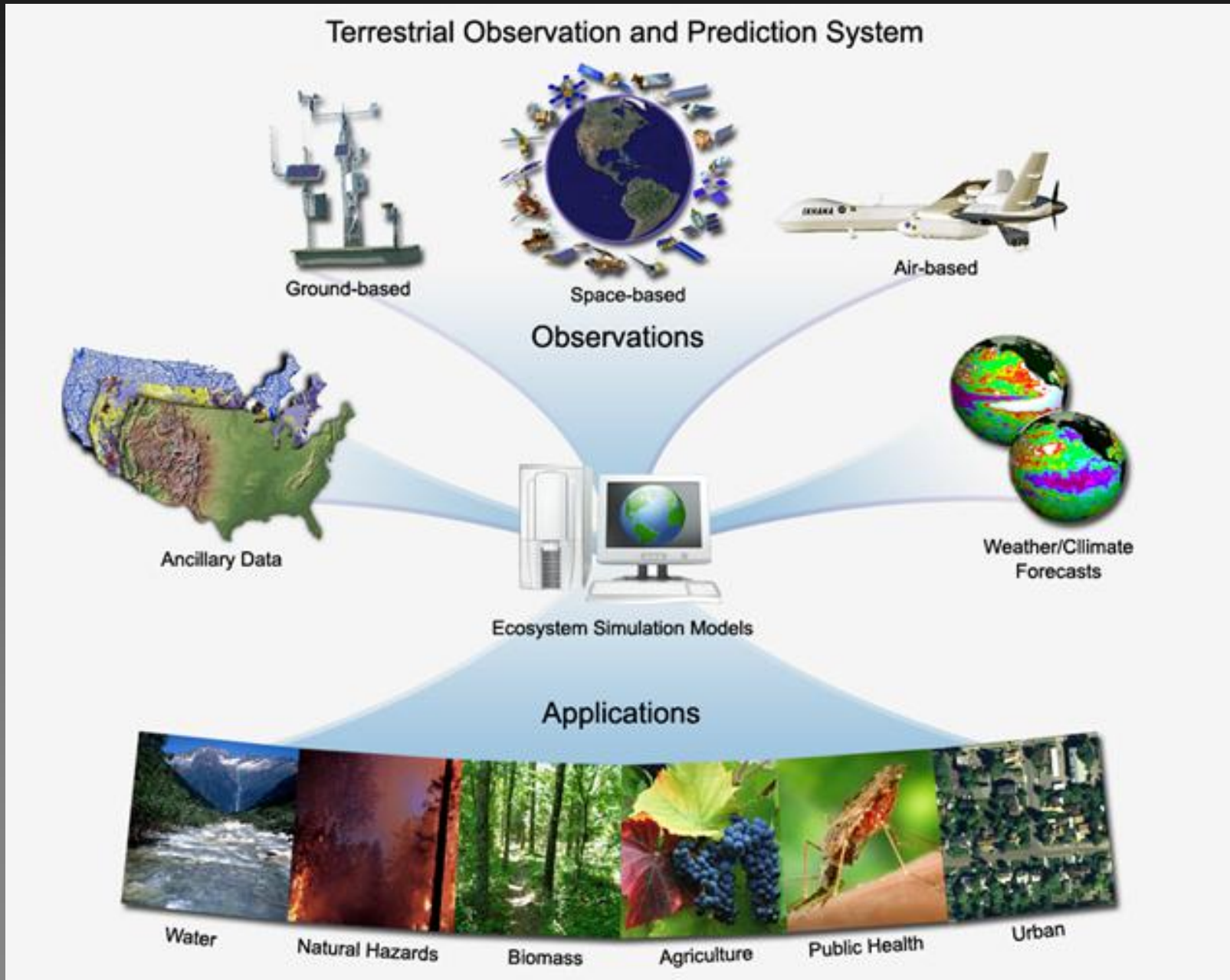
ETcb

ETcb=Kcb*ETo



NASA Modeling and Data Assimilation Framework: TOPS

- *Monitoring modeling, & forecasting at multiple scales*
- **TOPS provides solution to the data processing problem**
- **Previously used to support a wide range of applications**
- **Modular integration of component models**



Satellite Irrigation Management Support Project: TOPS - SIMS

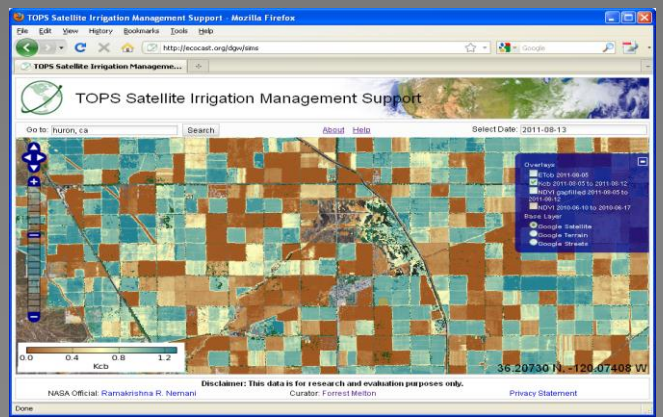
Processing Steps

- At sensor radiance
- LEDAPS
- Surface reflectance
- NDVI
- Fractional ground cover
- Kcb
- ETcb = Kcb * ETo

Satellite

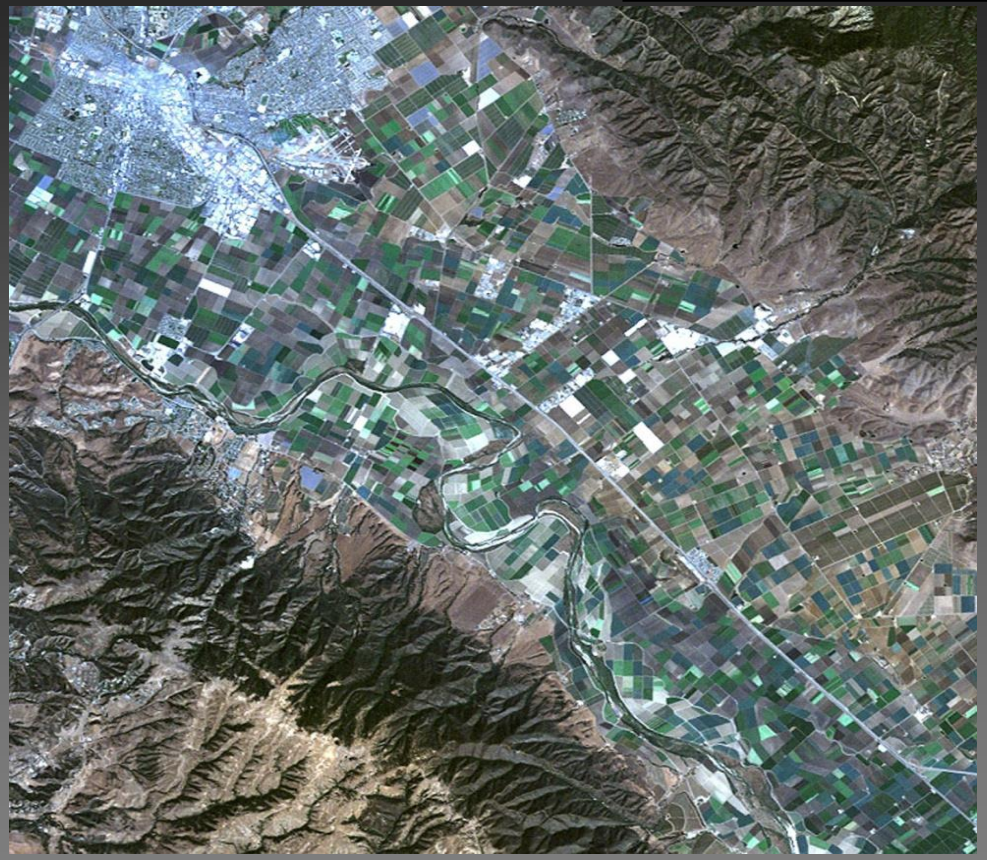
ET Weather Station

Processor



Web browser

Satellite Imagery



Landsat 5 and 7 (TM / ETM+)

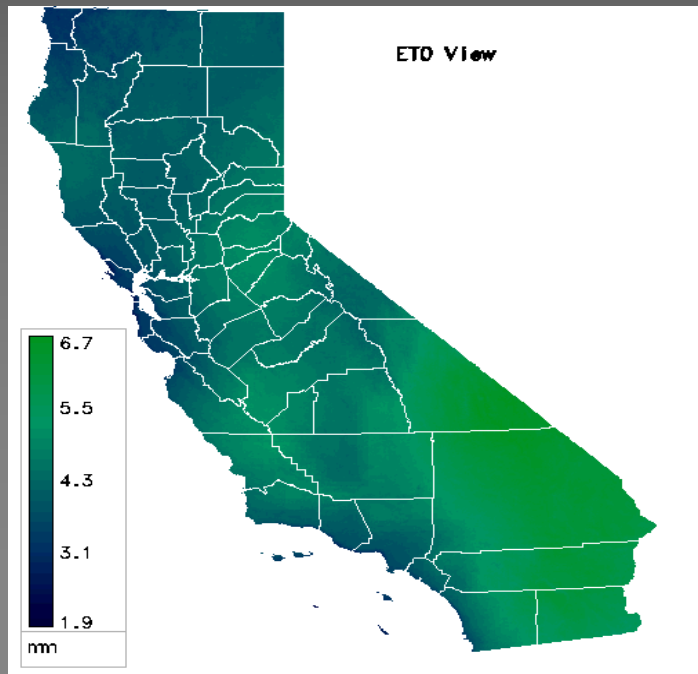
- **(30m / 0.1 Ha)**
- **Overpass – every 8 or 16 days**

Terra (MODIS)

- **(250m / 6 Ha)**
- **Overpass - daily**

Agricultural Weather Networks

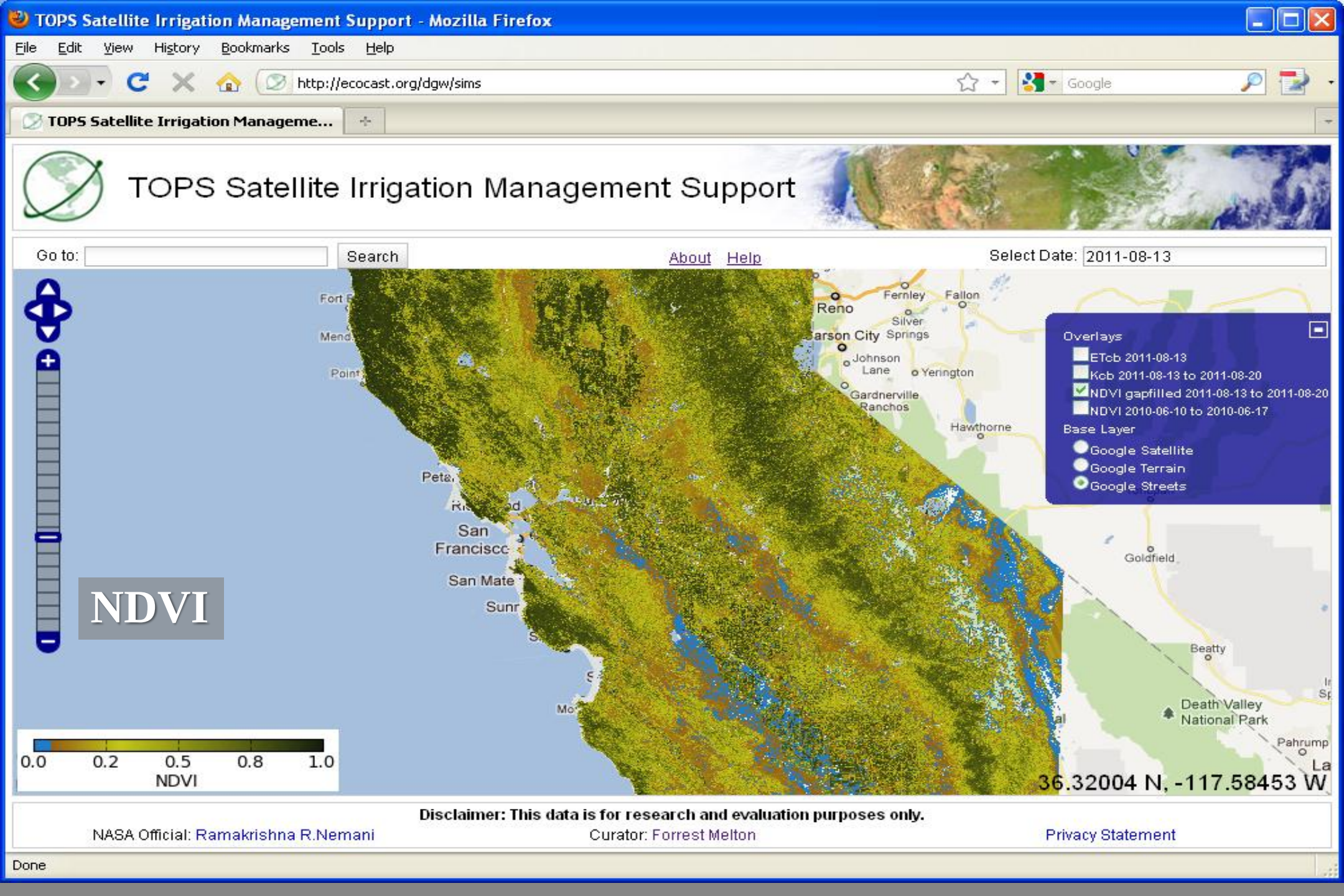
- California Irrigation Management Information System (CIMIS)
  - Operating since 1982
  - More than 139 stations currently providing daily measurements of ET_o
  - Spatial CIMIS data now available for CA; 2 km statewide grid, daily

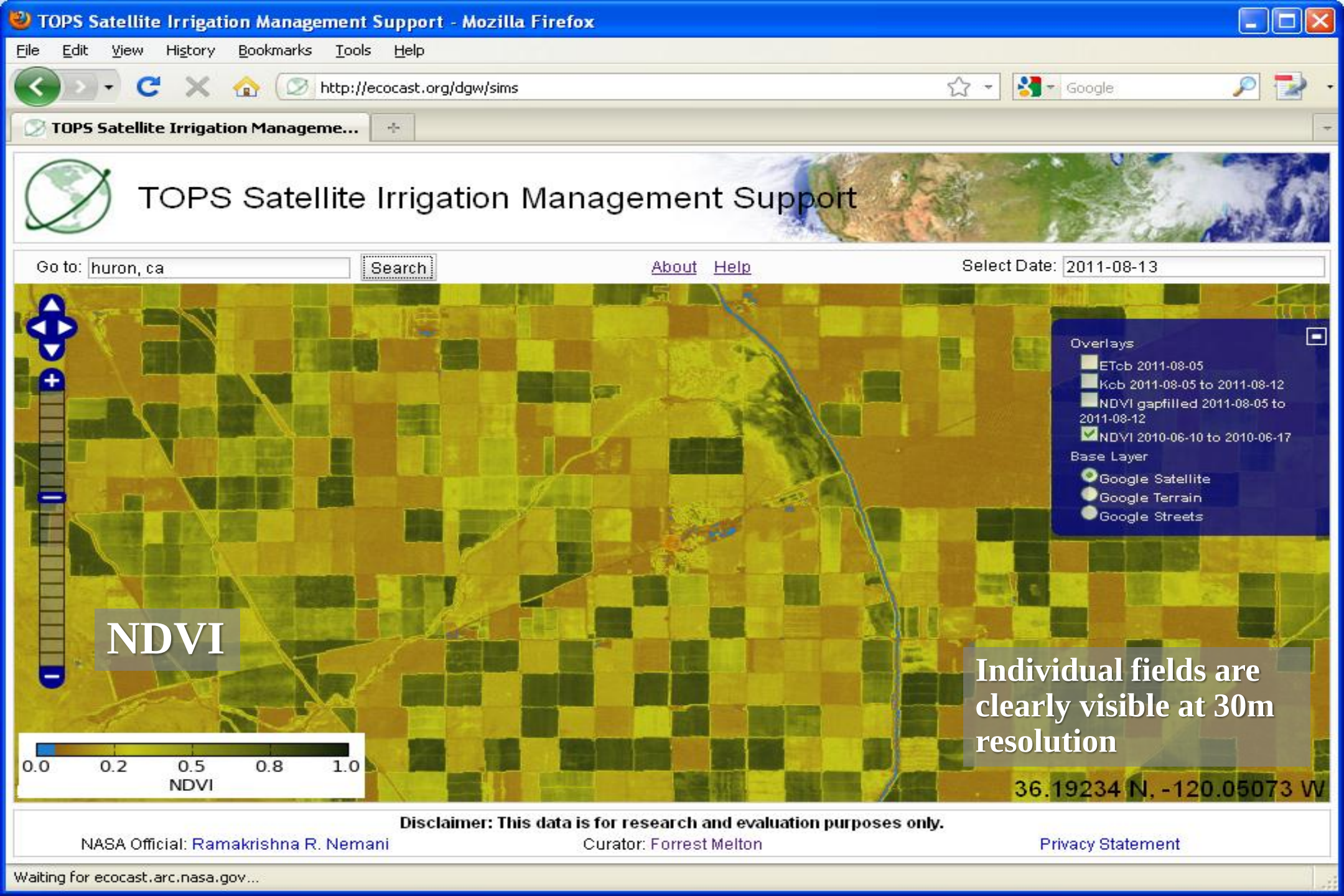


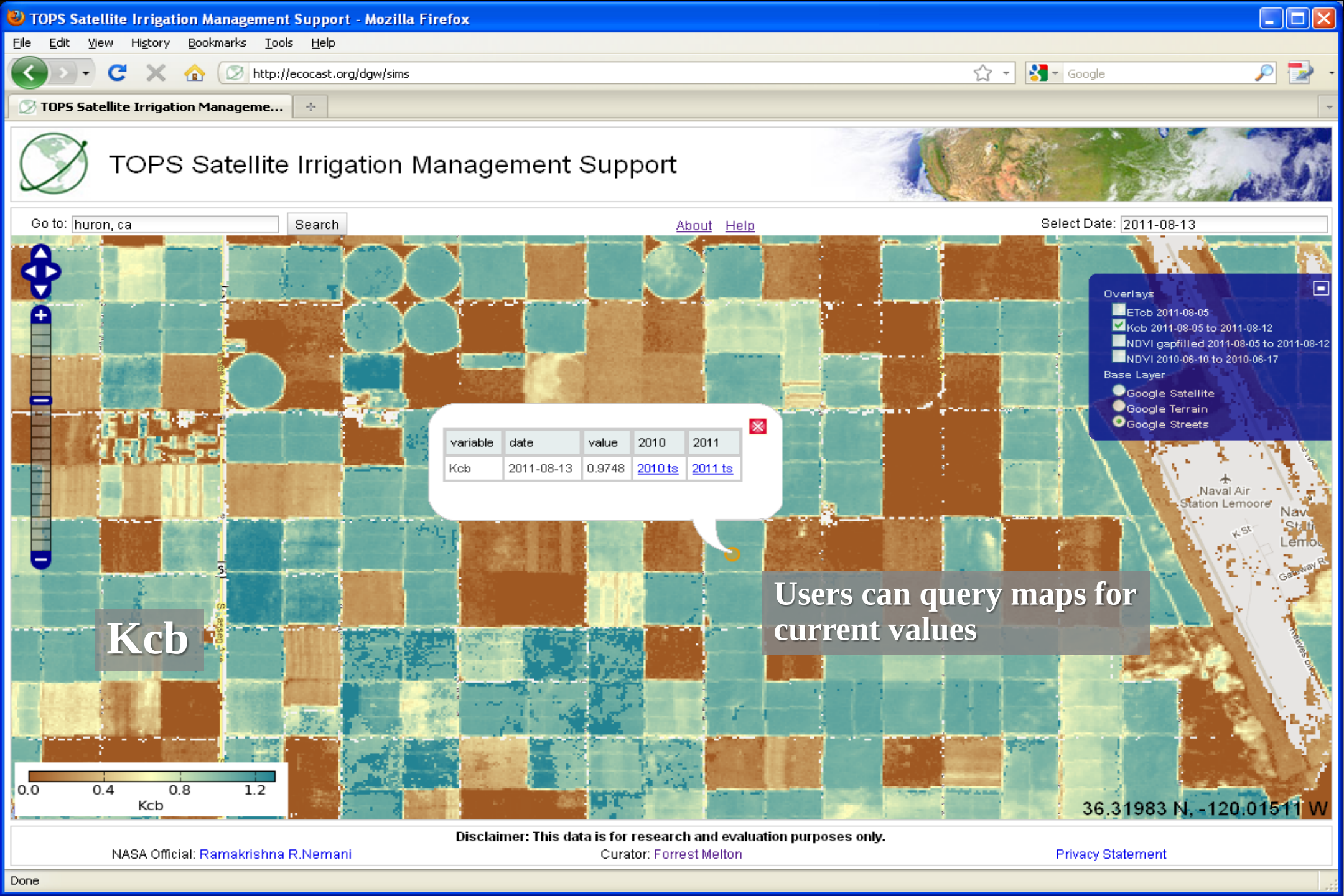
Spatial CIMIS ET_0
16 Sept 2010


TOPS Satellite Irrigation Management Support - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://ecocast.org/dgw/sims
TOPS Satellite Irrigation Manageme...
TOPS Satellite Irrigation Management Support
Go to:
Search
About Help
Select Date: 2011-08-13
Overlays
ETcb 2011-08-05
Kcb 2011-08-05 to 2011-08-12
NDVI gapfilled 2011-08-05 to 2011-08-12
NDVI 2010-06-10 to 2010-06-17
Base Layer
Google Satellite
Google Terrain
Google Streets
ETcb
http://ecocast.org/dgw/sims
Coverage includes ~6 million Ha of farmland (3.5 mil Ha irrigated) in the Central Valley and coastal agricultural valleys
0.0 0.1 0.2 0.3 0.4
ETcb(in)
35.56177 N, -112.29461 W
Disclaimer: This data is for research and evaluation purposes only.
NASA Official: Ramakrishna R.Nemani
Curator: Forrest Melton
Privacy Statement
Done


TOPS Satellite Irrigation Management Support - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://ecocast.org/dgw/sims
TOPS Satellite Irrigation Manageme...
TOPS Satellite Irrigation Management Support
Go to: Search
About Help
Select Date: 2011-08-13
Geographic search
Date selection
Overlays
ETcb 2011-08-05
Kcb 2011-08-05 to 2011-08-12
NDVI gapfilled 2011-08-05 to 2011-08-12
NDVI 2010-06-10 to 2010-06-17
Base Layer
Google Satellite
Google Terrain
Google Streets
http://ecocast.org/dgw/sims
0.0 0.1 0.2 0.3 0.4
ETcb(in)
35.56177 N, -112.29461 W
Disclaimer: This data is for research and evaluation purposes only.
NASA Official: Ramakrishna R.Nemani
Curator: Forrest Melton
Privacy Statement
Done


TOPS Satellite Irrigation Management Support - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://ecocast.org/dgw/sims
TOPS Satellite Irrigation Manageme...
TOPS Satellite Irrigation Management Support
Go to:
Search
About Help
Select Date: 2011-08-13
Overlays
ETcb 2011-08-13
Kcb 2011-08-13 to 2011-08-20
NDVI gapfilled 2011-08-13 to 2011-08-20
NDVI 2010-06-10 to 2010-06-17
Base Layer
Google Satellite
Google Terrain
Google Streets
NDVI
0.0 0.2 0.5 0.8 1.0
NDVI
Reno
Fernley
Fallon
Silver Springs
Carson City
Johnson Lane
Yerington
Gardnerville Ranchos
Hawthorne
San Francisco
Goldfield
Beatty
Death Valley National Park
Pahrump
36.32004 N, -117.58453 W
Disclaimer: This data is for research and evaluation purposes only.
NASA Official: Ramakrishna R.Nemani
Curator: Forrest Melton
Privacy Statement
Done


TOPS Satellite Irrigation Management Support - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://ecocast.org/dgw/sims
Google
TOPS Satellite Irrigation Manageme...
TOPS Satellite Irrigation Management Support
Go to: huron, ca
Search
About Help
Select Date: 2011-08-13
Overlays
ETcb 2011-08-05
Kcb 2011-08-05 to 2011-08-12
NDVI gapfilled 2011-08-05 to 2011-08-12
NDVI 2010-06-10 to 2010-06-17
Base Layer
Google Satellite
Google Terrain
Google Streets
NDVI
0.0 0.2 0.5 0.8 1.0
NDVI
Individual fields are clearly visible at 30m resolution
36.19234 N, -120.05073 W
Disclaimer: This data is for research and evaluation purposes only.
NASA Official: Ramakrishna R. Nemani
Curator: Forrest Melton
Privacy Statement
Waiting for ecocast.arc.nasa.gov...


TOPS Satellite Irrigation Management Support - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://ecocast.org/dgw/sims
TOPS Satellite Irrigation Manageme...
TOPS Satellite Irrigation Management Support
Go to: huron, ca
Search
About Help
Select Date: 2011-08-13
Overlays
ETcb 2011-08-05
Kcb 2011-08-05 to 2011-08-12
NDVI gapfilled 2011-08-05 to 2011-08-12
NDVI 2010-06-10 to 2010-06-17
Base Layer
Google Satellite
Google Terrain
Google Streets
variable date value 2010 2011
Kcb 2011-08-13 0.9748 2010 ts 2011 ts
Users can query maps for current values
Kcb
0.0 0.4 0.8 1.2
Kcb
Naval Air Station Lemoore
36.31983 N, -120.01511 W
Disclaimer: This data is for research and evaluation purposes only.
NASA Official: Ramakrishna R.Nemani
Curator: Forrest Melton
Privacy Statement
Done

TOPS Satellite Irrigation Management Support - Mozilla Firefox

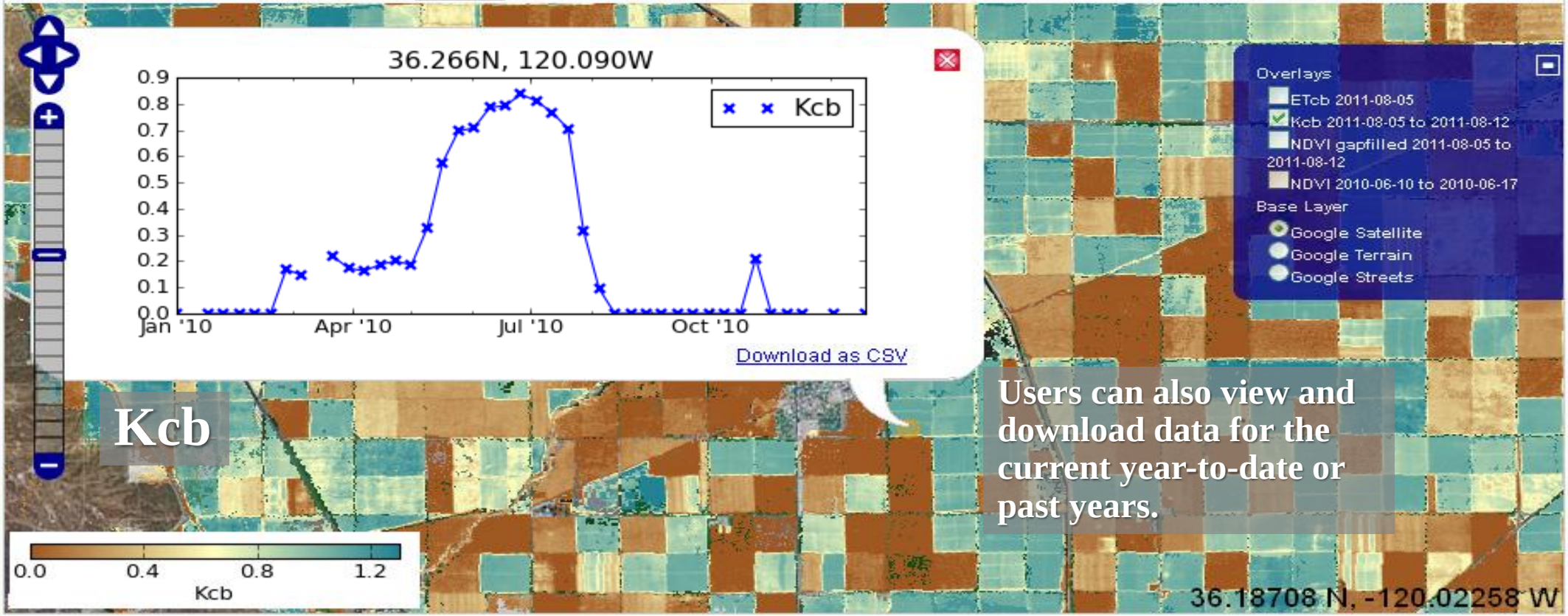
File Edit View History Bookmarks Tools Help

http://ecocast.org/dgw/sims

TOPS Satellite Irrigation Manageme...

TOPS Satellite Irrigation Management Support

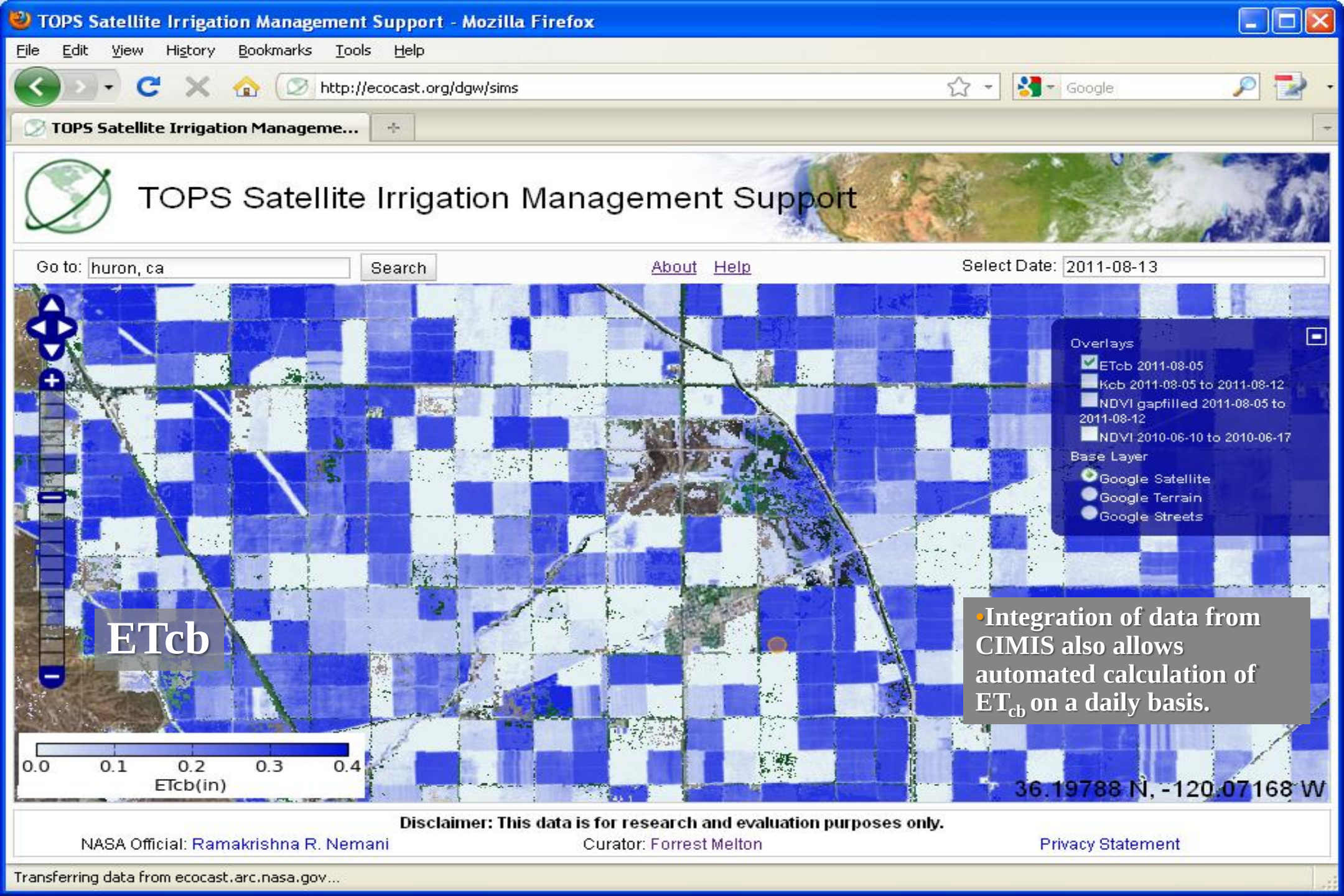
Go to: huron, ca Search About Help Select Date: 2011-08-13

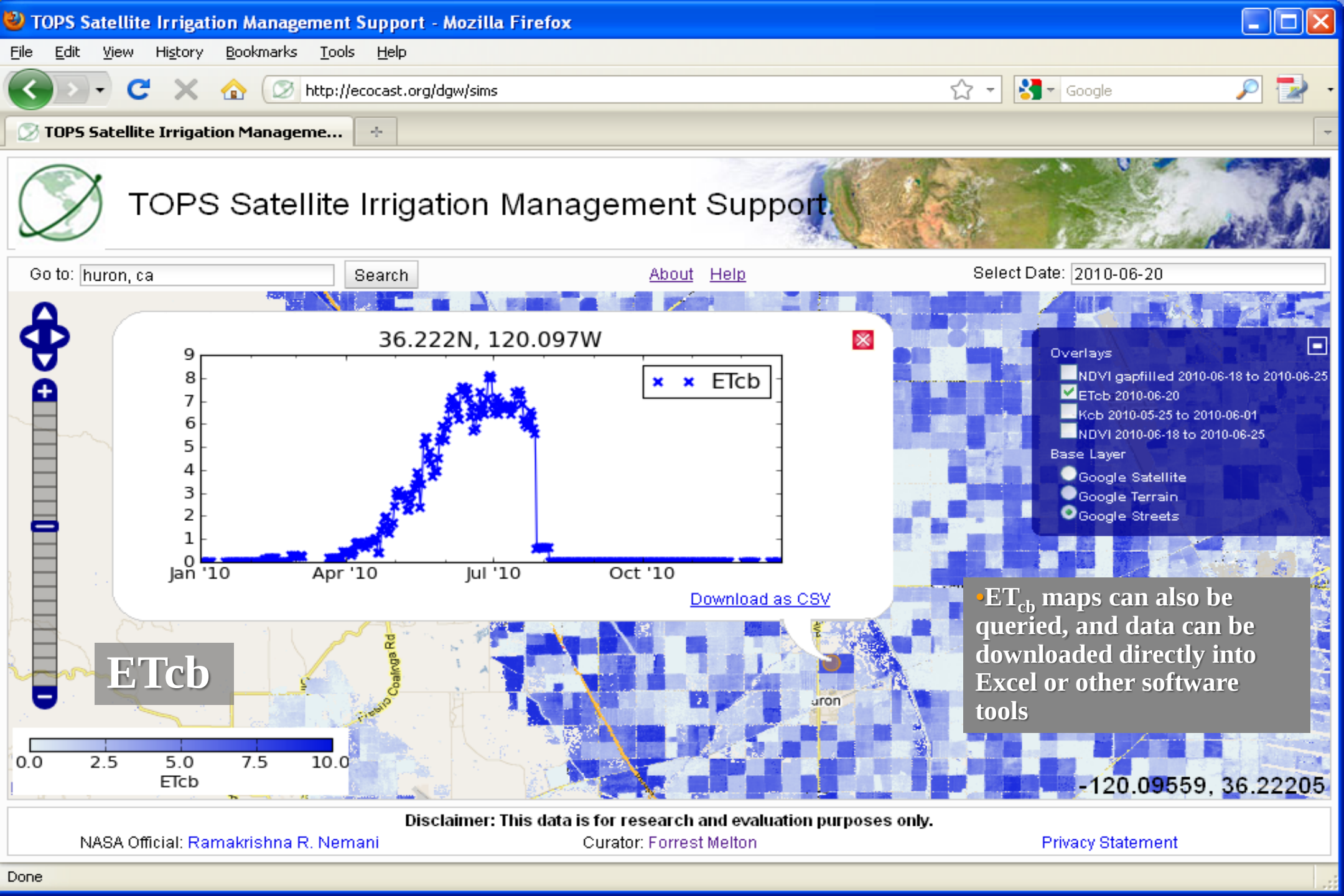


Disclaimer: This data is for research and evaluation purposes only.

NASA Official: Ramakrishna R. Nemani Curator: Forrest Melton Privacy Statement

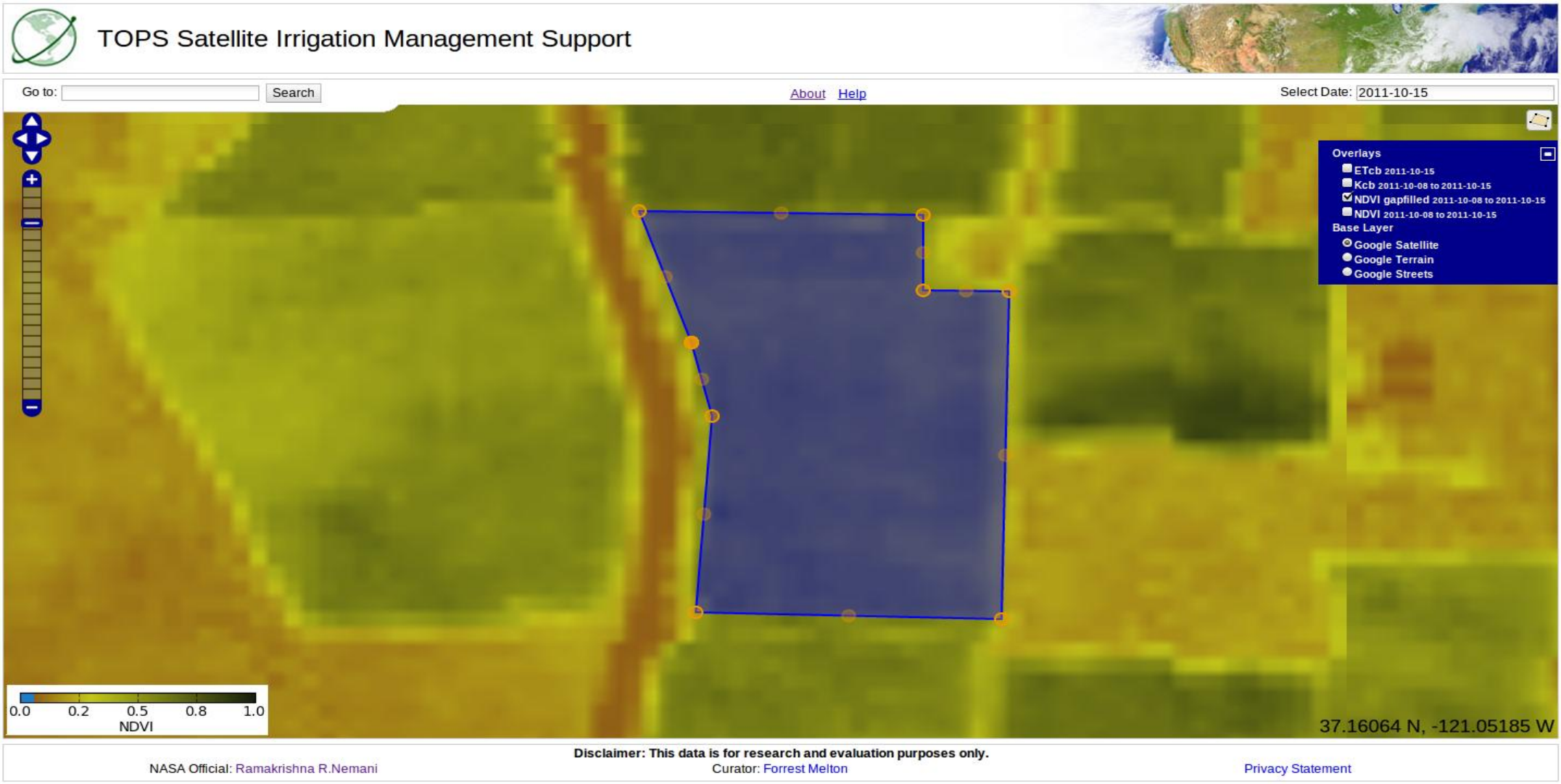
Done


TOPS Satellite Irrigation Management Support - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://ecocast.org/dgw/sims
Google
TOPS Satellite Irrigation Manageme...
TOPS Satellite Irrigation Management Support
Go to: huron, ca
Search
About Help
Select Date: 2011-08-13
Overlays
ETcb 2011-08-05
Kcb 2011-08-05 to 2011-08-12
NDVI gapfilled 2011-08-05 to 2011-08-12
NDVI 2010-06-10 to 2010-06-17
Base Layer
Google Satellite
Google Terrain
Google Streets
ETcb
•Integration of data from CIMIS also allows automated calculation of ET_{cb} on a daily basis.
0.0 0.1 0.2 0.3 0.4
ETcb(in)
36.19788 N, -120.07168 W
Disclaimer: This data is for research and evaluation purposes only.
NASA Official: Ramakrishna R. Nemani
Curator: Forrest Melton
Privacy Statement
Transferring data from ecocast.arc.nasa.gov...

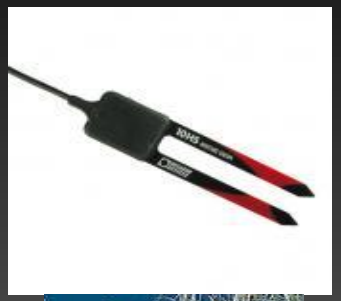

TOPS Satellite Irrigation Management Support - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://ecocast.org/dgw/sims
Google
TOPS Satellite Irrigation Manageme...
TOPS Satellite Irrigation Management Support
Go to: huron, ca
Search
About Help
Select Date: 2010-06-20
36.222N, 120.097W
ETcb
9
8
7
6
5
4
3
2
1
0
Jan '10
Apr '10
Jul '10
Oct '10
Download as CSV
Overlays
NDVI gapfilled 2010-06-18 to 2010-06-25
ETcb 2010-06-20
Kcb 2010-05-25 to 2010-06-01
NDVI 2010-06-18 to 2010-06-25
Base Layer
Google Satellite
Google Terrain
Google Streets
ETcb
•ETcb maps can also be queried, and data can be downloaded directly into Excel or other software tools
0.0 2.5 5.0 7.5 10.0
ETcb
-120.09559, 36.22205
Disclaimer: This data is for research and evaluation purposes only.
NASA Official: Ramakrishna R. Nemani
Curator: Forrest Melton
Privacy Statement
Done

Upcoming Features: 3–5 day ET forecasts

Upcoming Features: Field Level Summaries



Upcoming Features: Wireless Field Sensors



- Flow measurements – irrigation applications
- Soil water content or potential

Upcoming Features: Field-Level Reports

Past 3 days:								Next 3 days:			
Field	ETo	Kcb mean	Kcb max	Kcb min	ETcb	SWB	**Runtime 8/8/2010**	ETo	ETcb	SWB	**Runtime 8/11/2010**
F-01	0.83	1.05	1.09	0.95	0.87	+0.30	--	0.79	0.83	-0.53	**2.5**
F-02	0.83	0.97	1.04	0.91	0.81	-0.12	**1**	0.79	0.77	-0.77	**4**
F-03	0.83	1.09	1.12	1.02	0.90	+1.14	--	0.79	0.86	0.28	--
...											

- Considers weather, soil texture, crop type, root depth, precipitation, prior irrigation amounts, method of application, and application rate.
- Parameters to include measures of within-field variability.
- Summary reports planned for delivery via text messages / PDFs sent to mobile devices.

Water Management Research Unit

Fort Collins, CO

United States Department of Agriculture
Agricultural Research Service

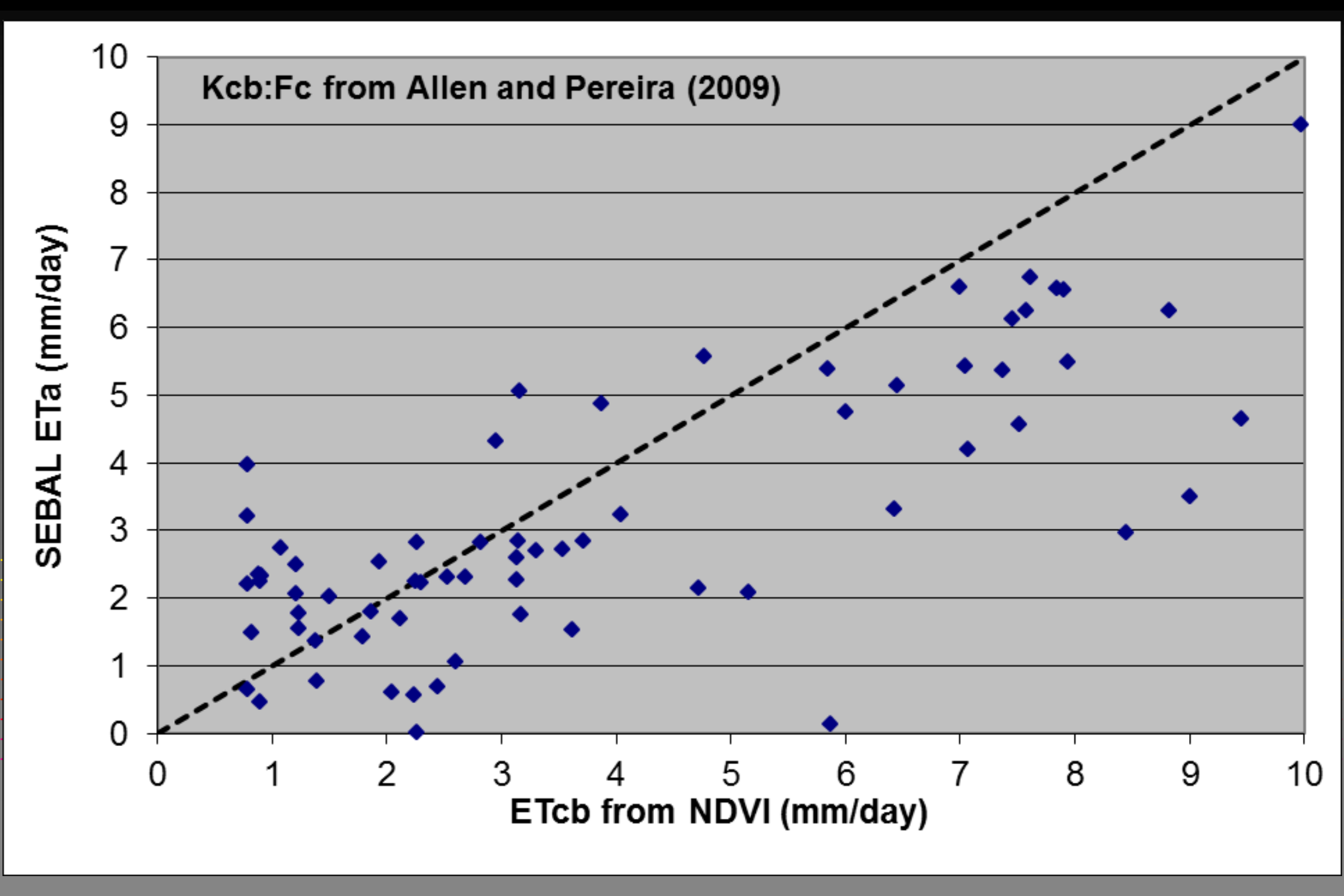
Funding: California Department of Water Resources

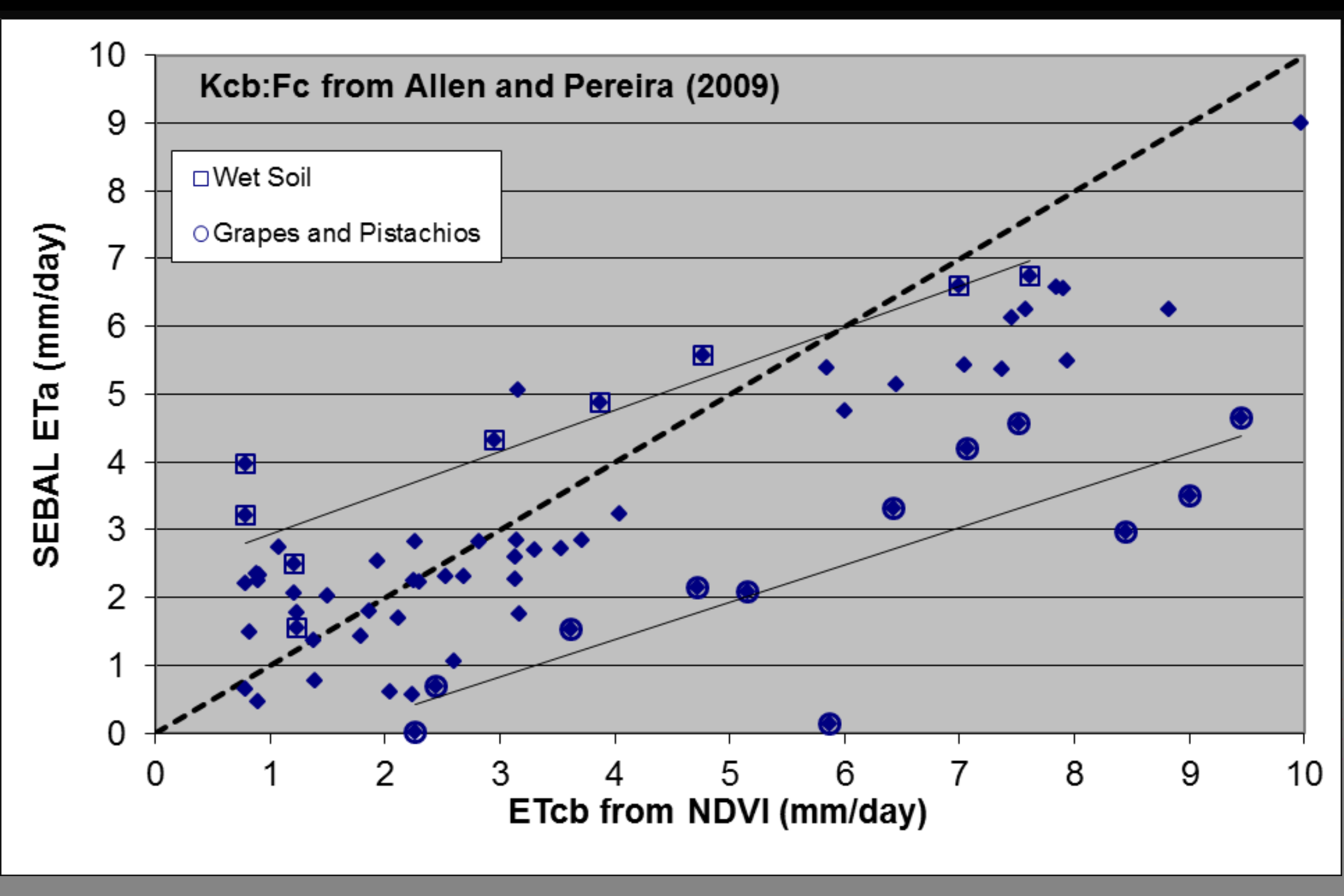
Obrigado

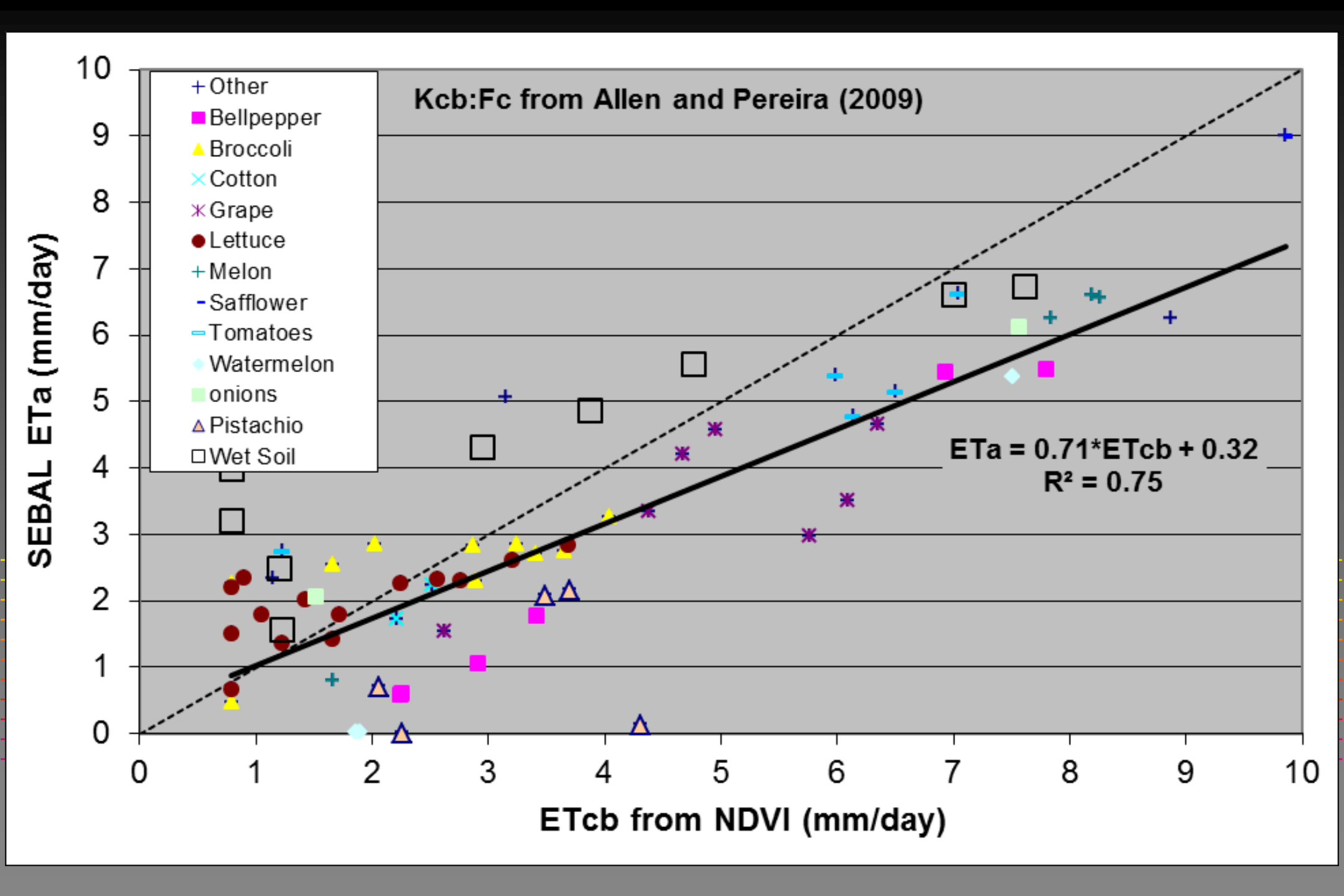
http://ecocast.org/dgw/sims

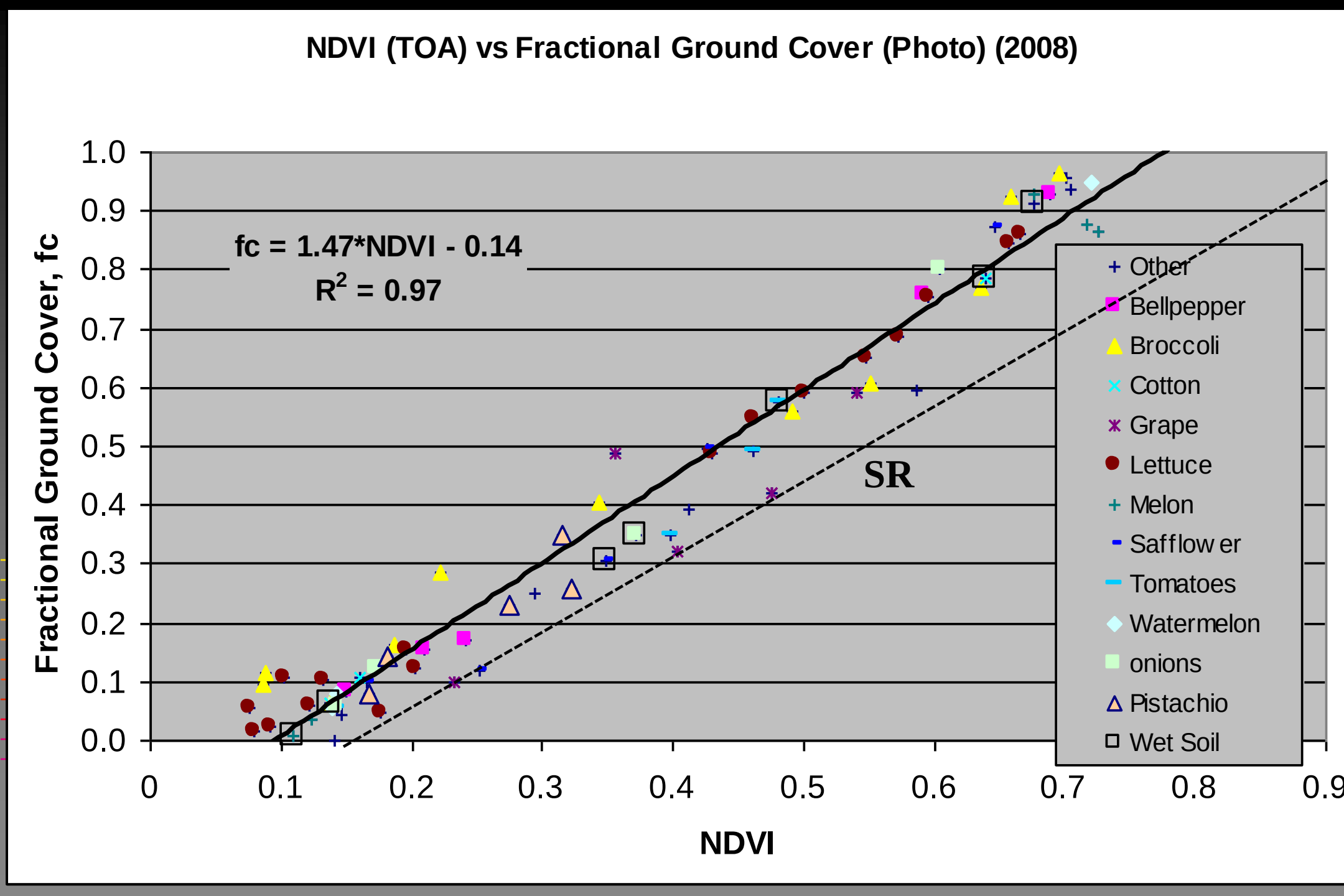
SEB or NDVI

- **Surface Energy Balance**
  - Direct estimate of ETc
  - Complex (expensive)
  - Few RS image options, low resolution
  - Difficult to interpolate/extrapolate from point-in-time
- **NDVI – fc – Kcb – ETc**
  - Indirect estimate of ETc
  - Relatively simple
  - Many RS image options, many resolutions
  - Fairly easy to interpolate/extrapolate – plant growth
  - Can't estimate ETc of stressed crops
  - Can't estimate stomatal control – maturity/senescence


Kcb:Fc from Allen and Pereira (2009)
SEBAL ETa (mm/day)
ETcb from NDVI (mm/day)
0
1
2
3
4
5
6
7
8
9
10


Kcb:Fc from Allen and Pereira (2009)
Wet Soil
Grapes and Pistachios
SEBAL ETa (mm/day)
ETcb from NDVI (mm/day)
0
1
2
3
4
5
6
7
8
9
10


Kcb:Fc from Allen and Pereira (2009)
Other
Bellpepper
Broccoli
Cotton
Grape
Lettuce
Melon
Safflower
Tomatoes
Watermelon
onions
Pistachio
Wet Soil
ETa = 0.71*ETcb + 0.32
R² = 0.75
SEBAL ETa (mm/day)
ETcb from NDVI (mm/day)
0
1
2
3
4
5
6
7
8
9
10


NDVI (TOA) vs Fractional Ground Cover (Photo) (2008)
fc = 1.47*NDVI - 0.14
R2 = 0.97
SR
Fractional Ground Cover, fc
NDVI
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Other
Bellpepper
Broccoli
Cotton
Grape
Lettuce
Melon
Safflower
Tomatoes
Watermelon
onions
Pistachio
Wet Soil