Research Update: How Much and When to Irrigate

california
almonds
Almond Board of California

Session Speakers

Sebastian Saa, ABC

Tom Devol, ABC

Tom Buckley, UC Davis

Andrew McElrone, UC Davis

Brian Bailey, UC Davis

Ken Shackel, UC Davis

Research Update: How Much and When to Irrigate

Moderator, Sebastian Saa, Senior Manager, ABC


water
harvest dust
ALMOND
ORCHARD
2025 GOALS
zero waste
pest management
REDUCE THE AMOUNT OF WATER USED
TO GROW A POUND OF ALMONDS BY 20%

Research Update: How Much and When to Irrigate

- Tom Devol, Senior Manager, Almond Board of California
  - CASP Update
- Tom Buckley, Professor, UC Davis
  - Irrigation and photosynthesis
- Andrew McElrone, Professor, USDA-ARS; UC Davis
  - Validating ET estimates for almonds
- Brian Bailey, Professor, UC Davis
  - Thermal Imagery
- Ken Shackel, Professor, UC Davis
  - Tree water sensors

CASP Update

Tom Devol
Sr. Manager, Field Outreach
& Education

CASP Turns 10 - Participant & Orchard Statistics

CALIFORNIA ALMOND SUSTAINABILITY PROGRAM

2397 Participates

791 Organizations

240,639
22% Orchard Acres*

493.296
45% Organization Acres*

*Percentage Statewide Bearing Acreage
Updated November 25, 2019

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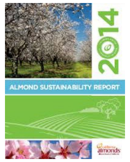
CASP Timeline & Evolution

2009
- 1st Best Practices Modules

2011
- 3 Additional Modules

2012
- 1st Statistical Analysis of Aggregate Data
- Launch of Online Assessment Platform

2014
- 1st Almond Sustainability Report



- N-Tool Debut

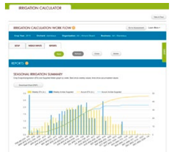
2015
- 3 Additional Modules

- Added NMP reporting and Mapping

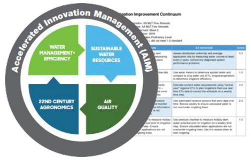
CASP ➔ Drought Communications

2016
- Updated & Streamlined Modules
- New Bee Health & Pollination Module
- Mobile Optimized

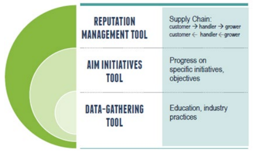
- Irrigation Tool Debut



2017
- Irrigation Continuum E-Module



- User Dashboard
- 2nd Statistical Analysis of Aggregate Data



2018
- Supply Chain Engagement / Pilot Program
- Administrative self-service reporting

2019
- Benchmarking to Global Platforms

FSA
FARM SUSTAINABILITY ASSESSMENT
BY SAI PLATFORM

- Streamlined Navigation

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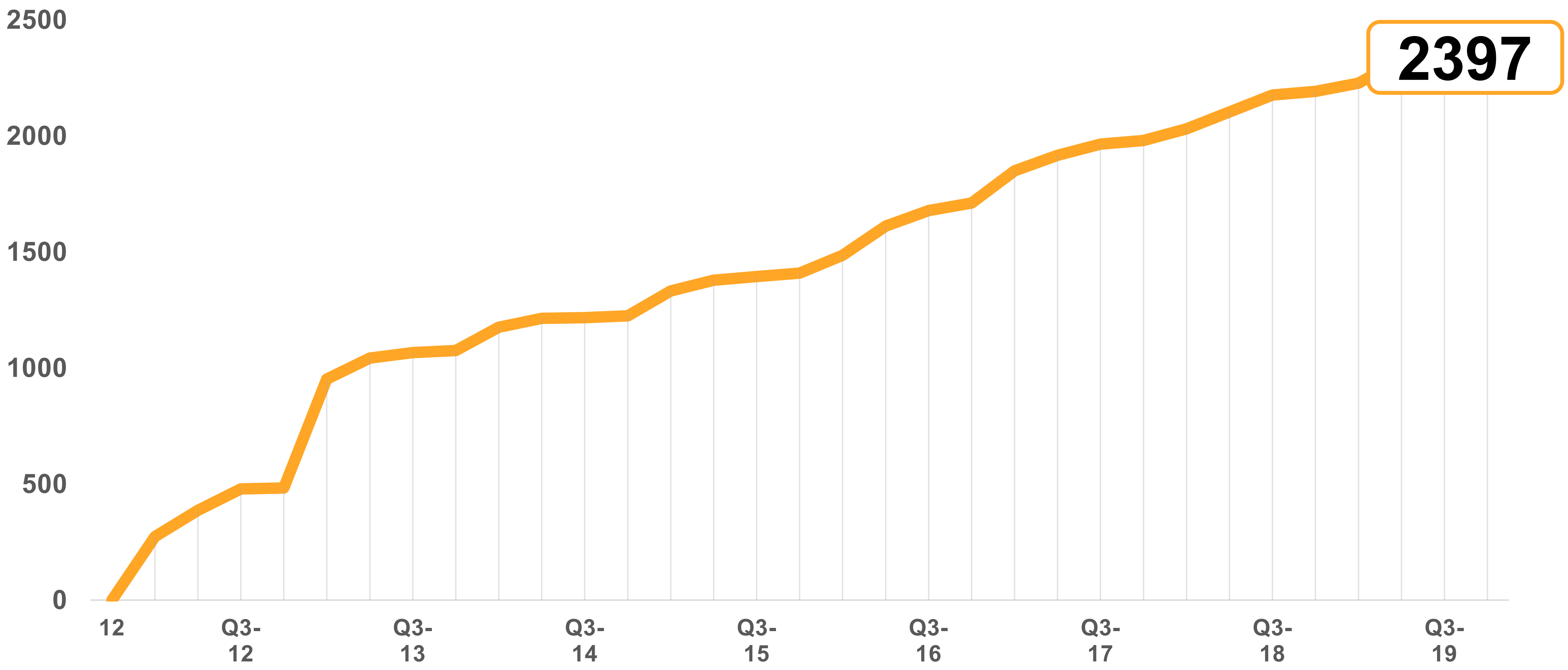
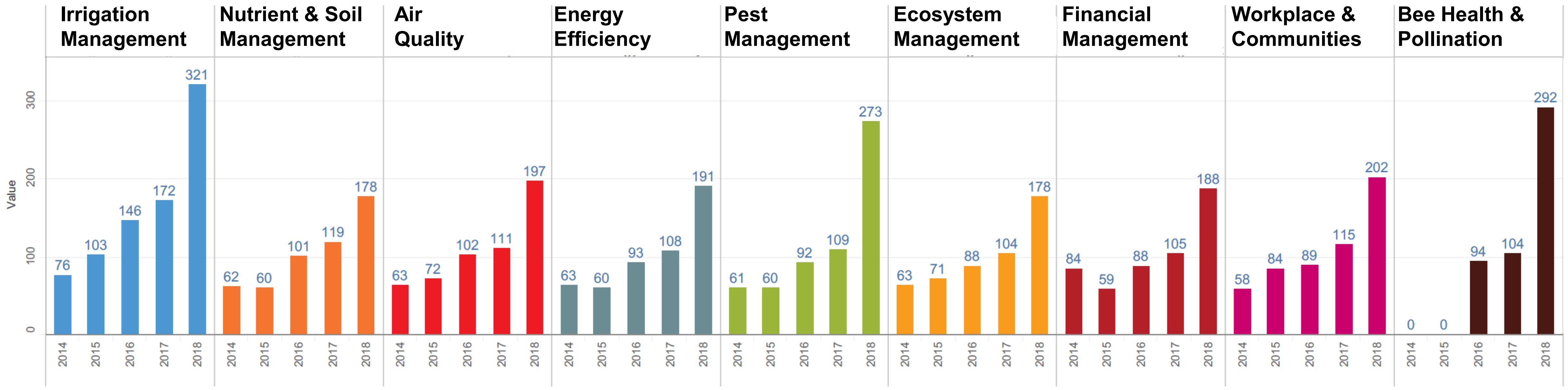
Participant Statistics



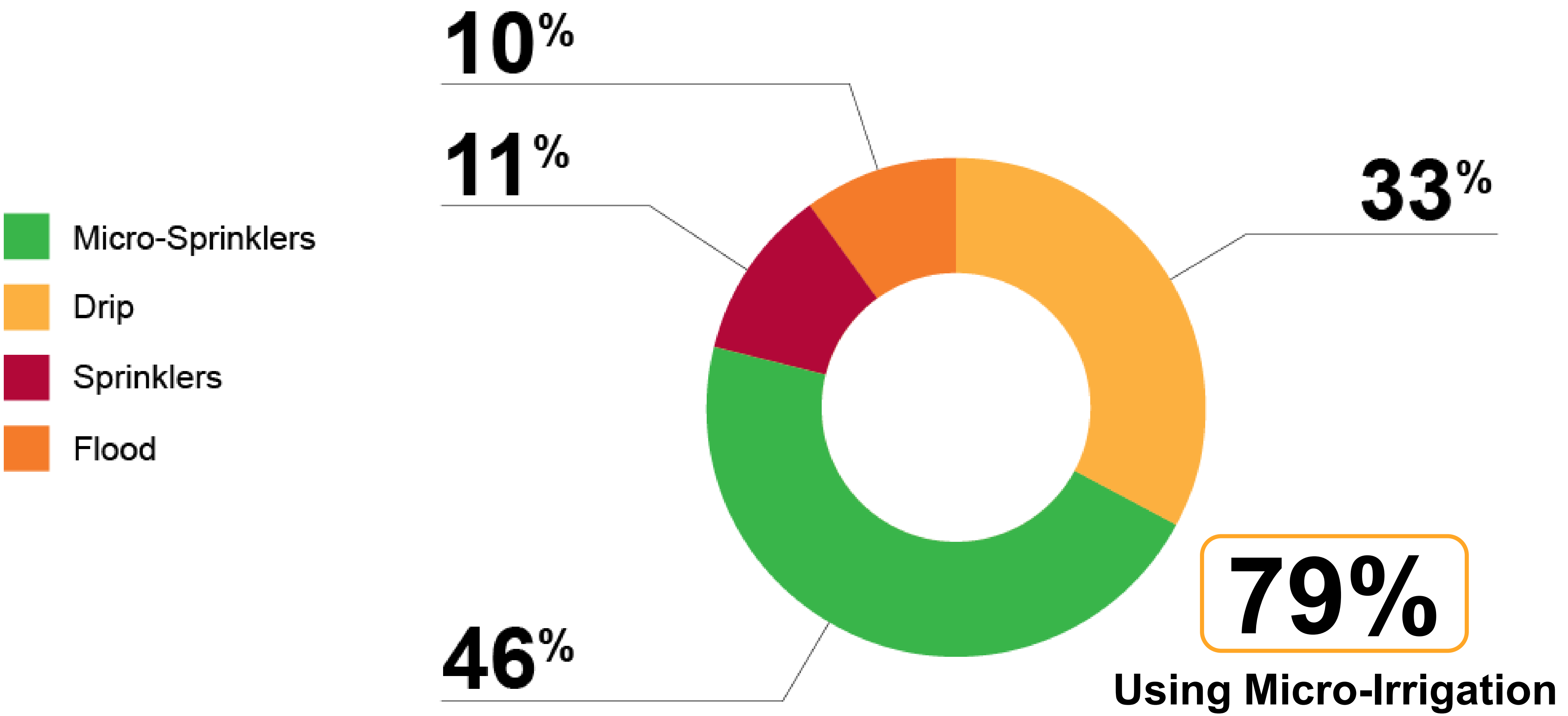
Total Orchard Module Responses



Update Nov 26, 2019

New Modules Added to Assess Orchard 2025 Goal Adoption

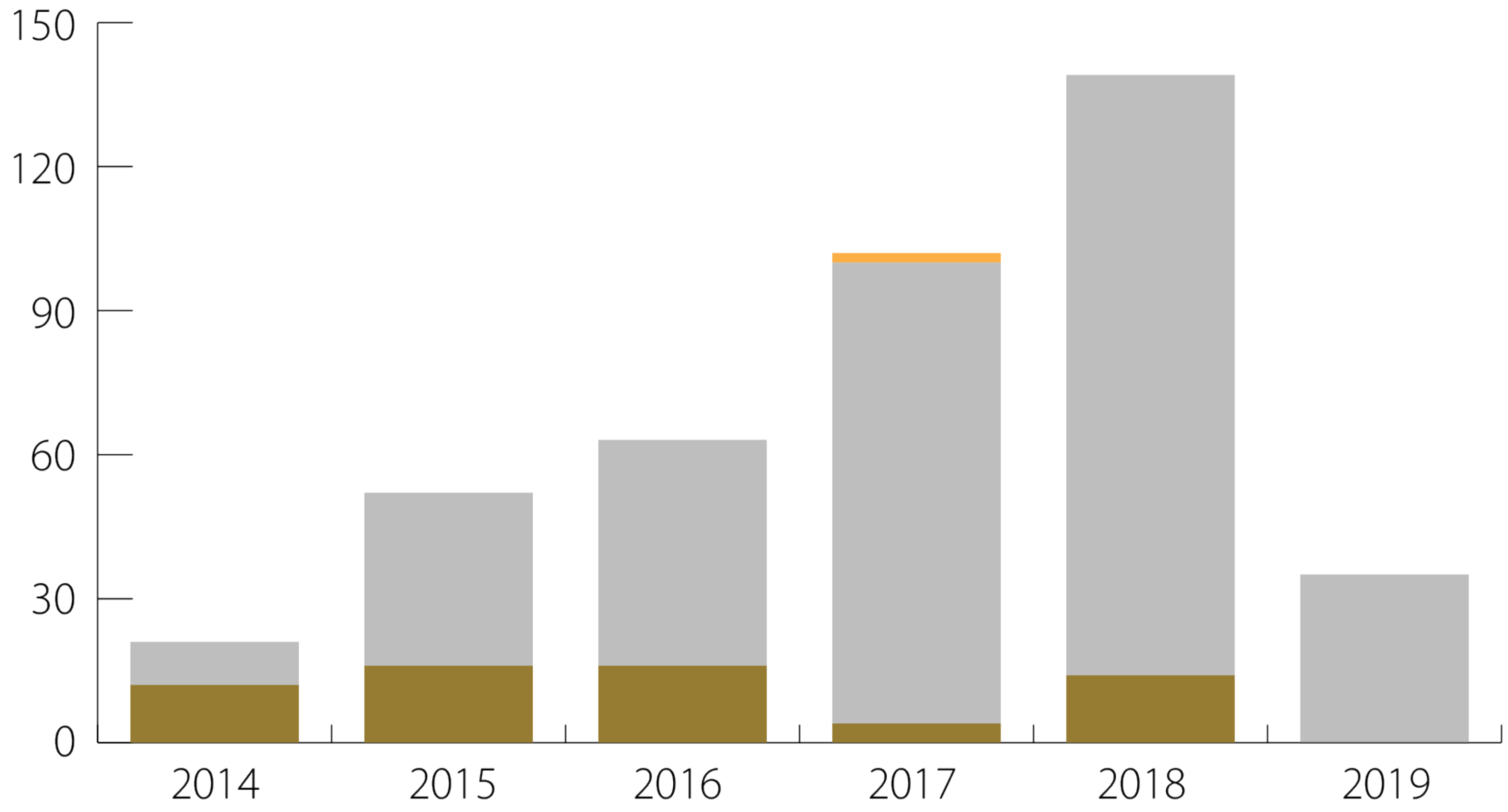
CASP Participation - Irrigation Type Used

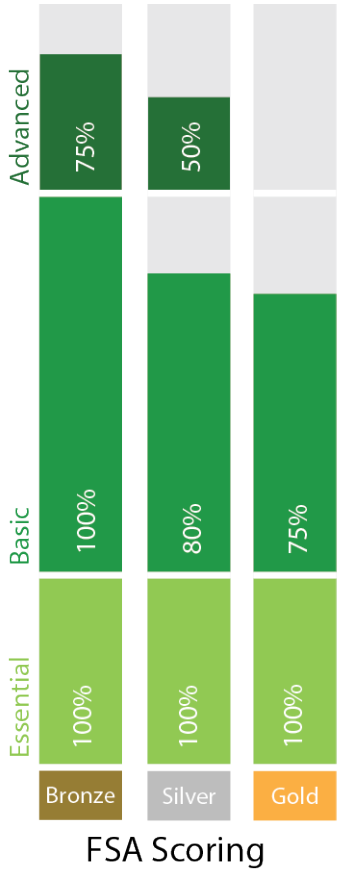


CASP Irrigation Information – How Irrigation Decisions are Made

Use Schedule Program	ETc Based Scheduling	Water District Influenced Schedule	Deficit Irrigation Used at Hull Split
85%	75%	23%	76%
Remotely Read Soil Moisture Sensors	Manually Read Soil Moisture Sensors	Pressure Chamber Used	Pressure Chamber to Determine First Irrigation
61%	59%	31%	20%
Use Flow Meters	Estimate Water Use	Hand Feel Method Used to Determine Moisture	Use Soil Auger to Check Moisture
43%	57%	89%	49%

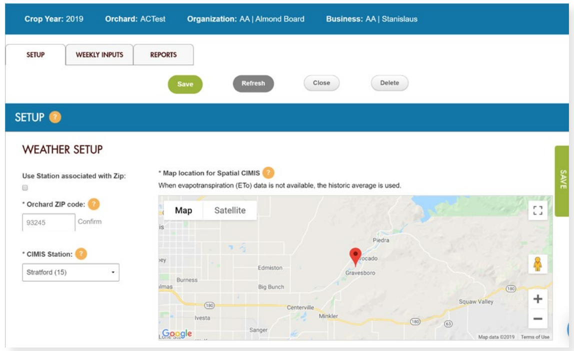
CASP & Farm Sustainability Assessment (FSA) Scoring





Developed by SAI Platform, the Farm Sustainability Assessment (FSA) is a set of tools for food and drink businesses that want to assess, improve and validate on-farm sustainability in their supply chains. The tools enable effective and efficient supply chain collaboration right down to the level of the farmer.

Irrigation Tool Adoption by Time



updated on July 31, 2019

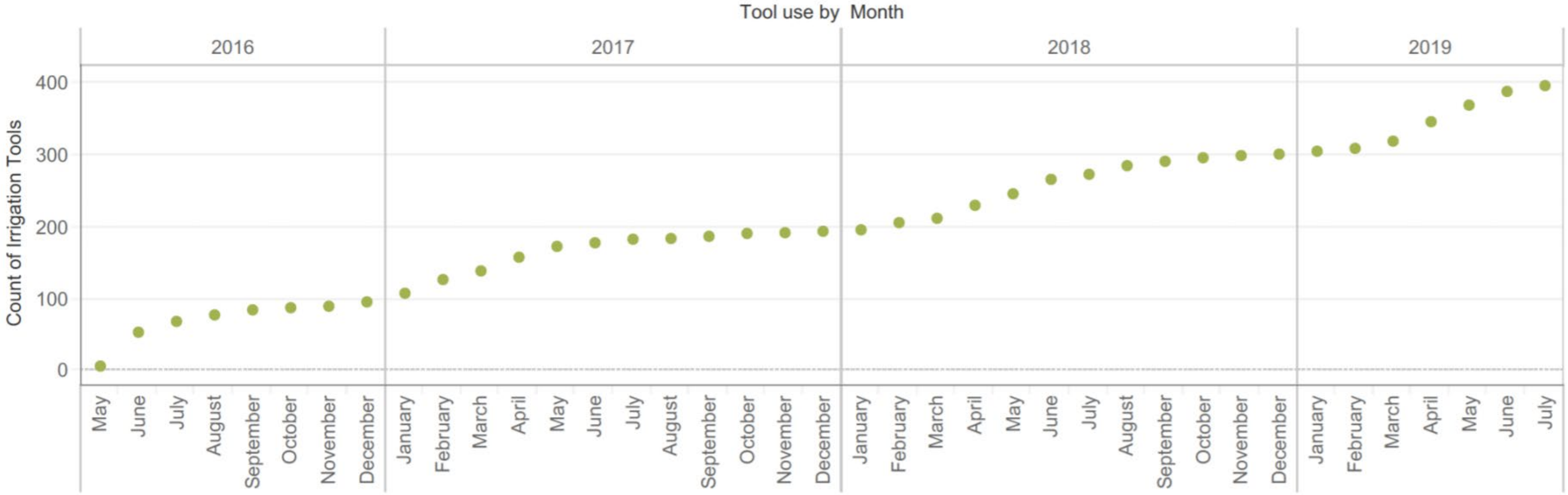


Figure 2: Irrigation Calculator Tool Adoption by Month up to July 31, 2019.

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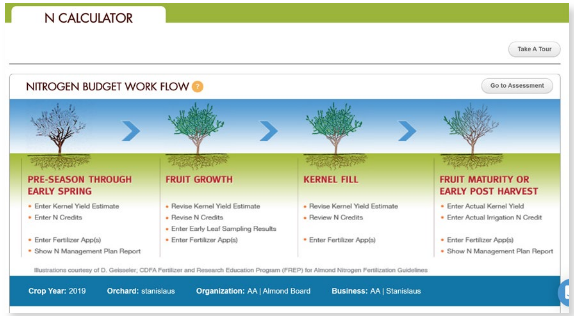
Nitrogen Tool Adoption by Time



updated on July 31, 2019

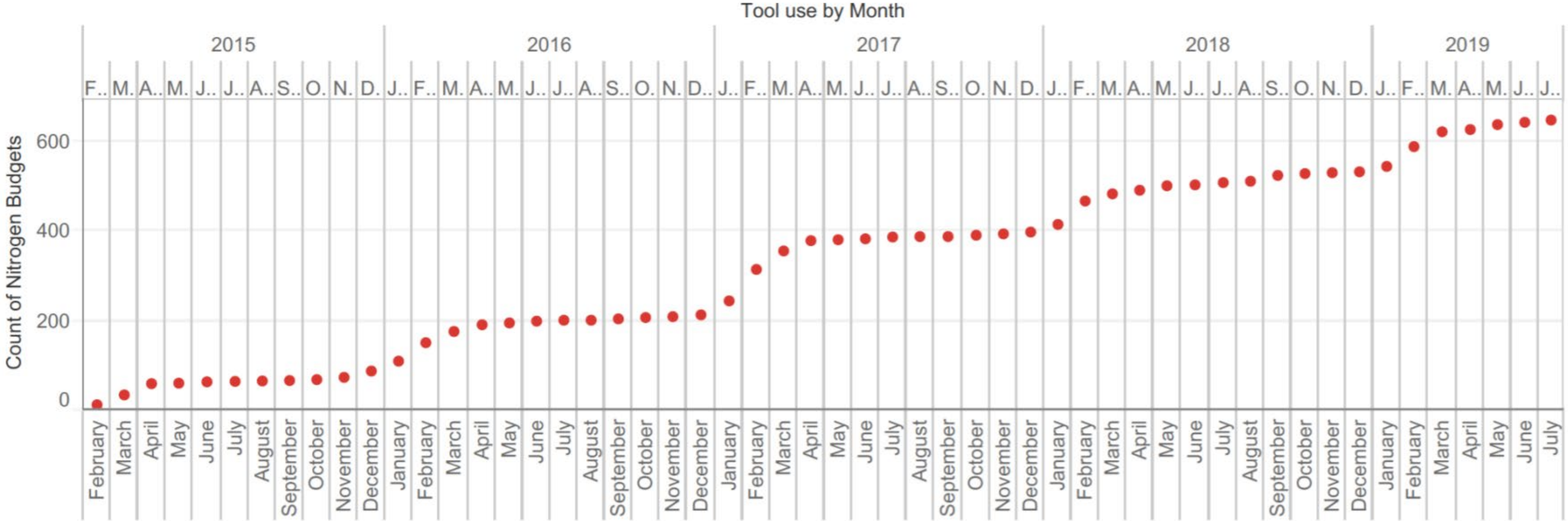


Figure 1: N-Calculator Tool Adoption by Month up to July 31, 2019.

Thank You

Tom Devol
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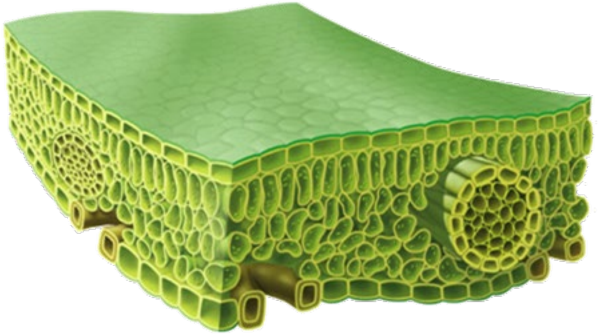
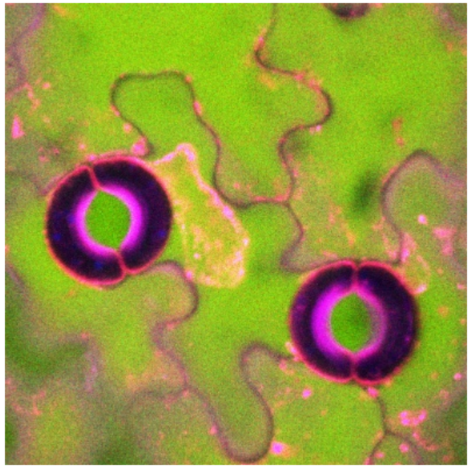
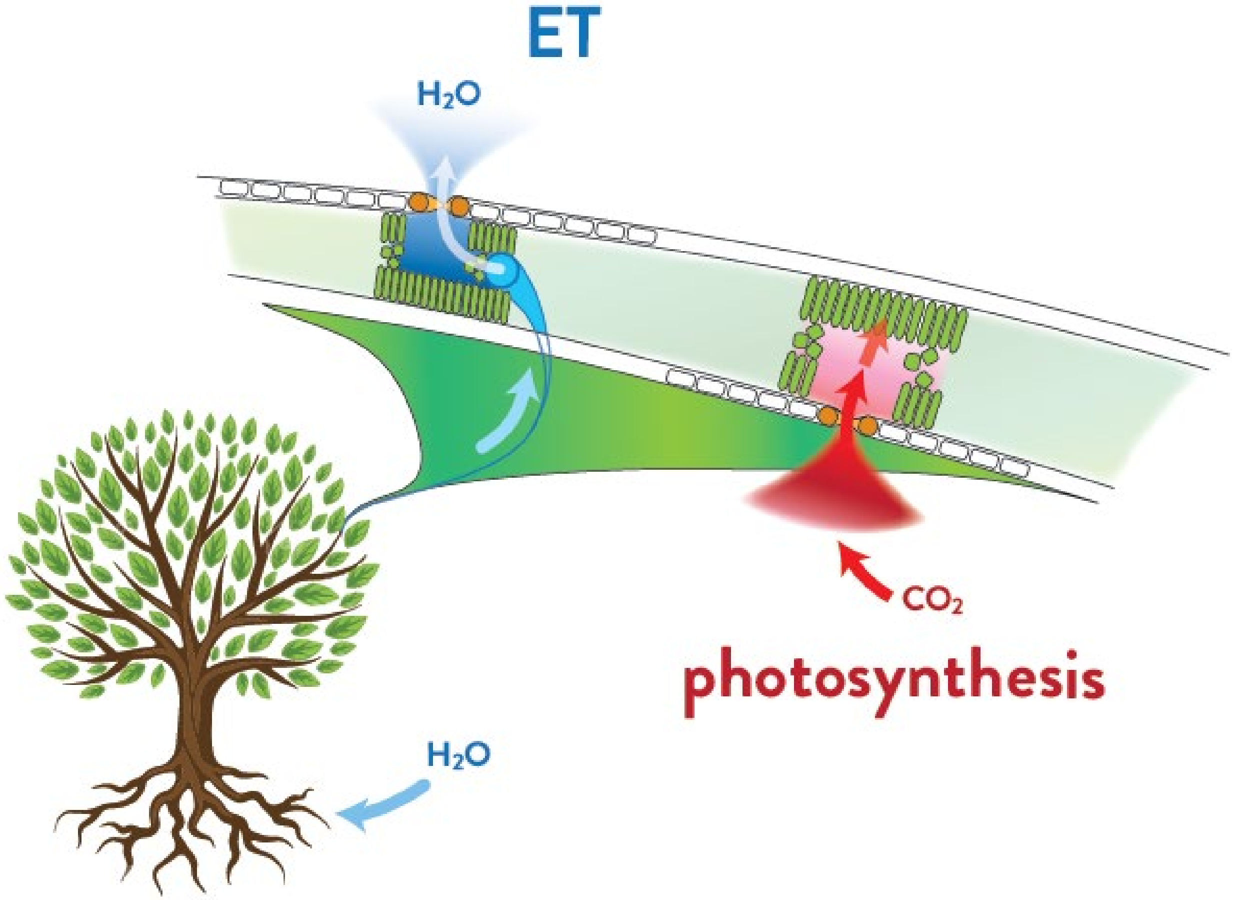
Diminishing returns? Irrigation and photosynthesis in almond

- Tom Buckley & Heather Vice
- UC Davis Department of Plant Sciences

How does regulation of tree water use via irrigation affect photosynthetic carbon gain in almond?







How does regulation of tree water use via irrigation affect photosynthetic carbon gain in almond?

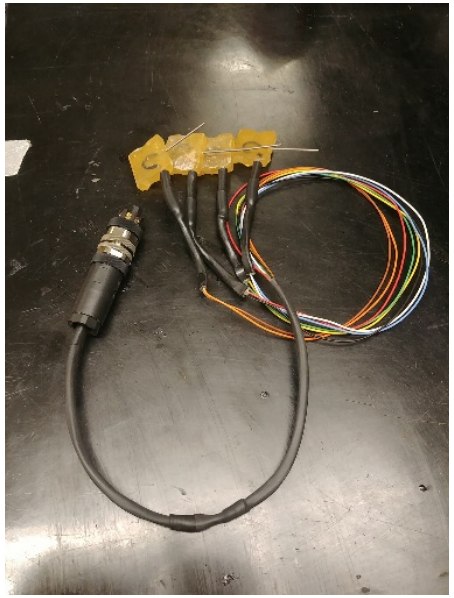
Hypotheses:

(1) Irrigating to ETc is not optimal with respect to photosynthesis, so redistributing water use over the season will increase total carbon gain

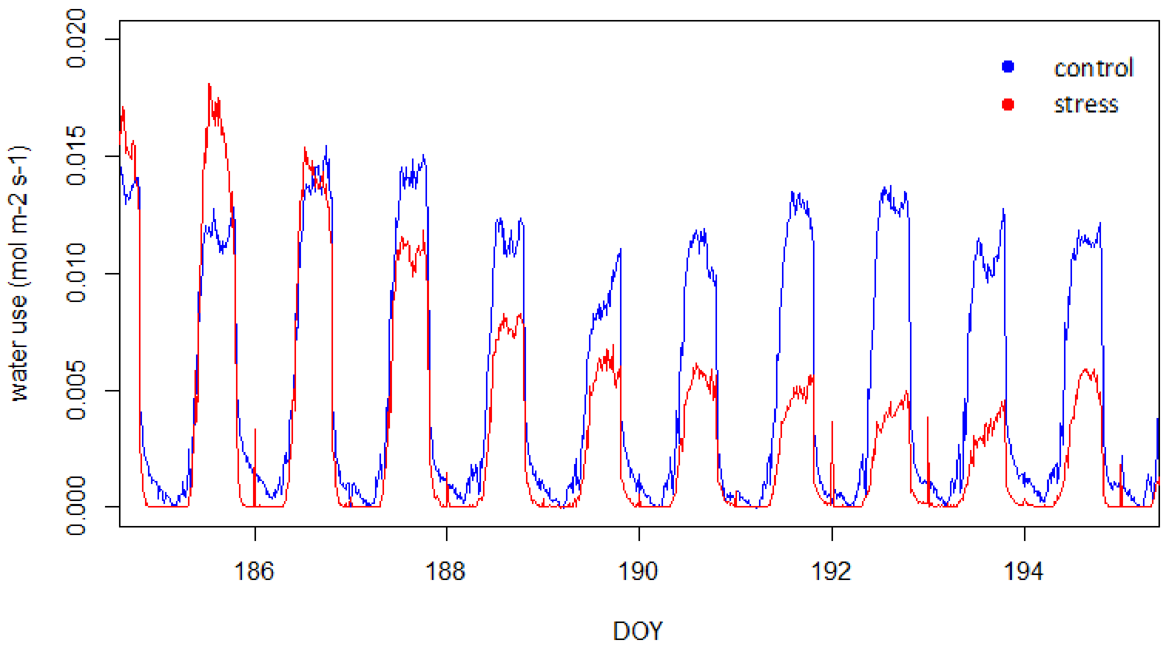
(2) In-season drought will irreversibly reduce photosynthesis, due to hydraulic failure and suppression of photosynthetic enzymes

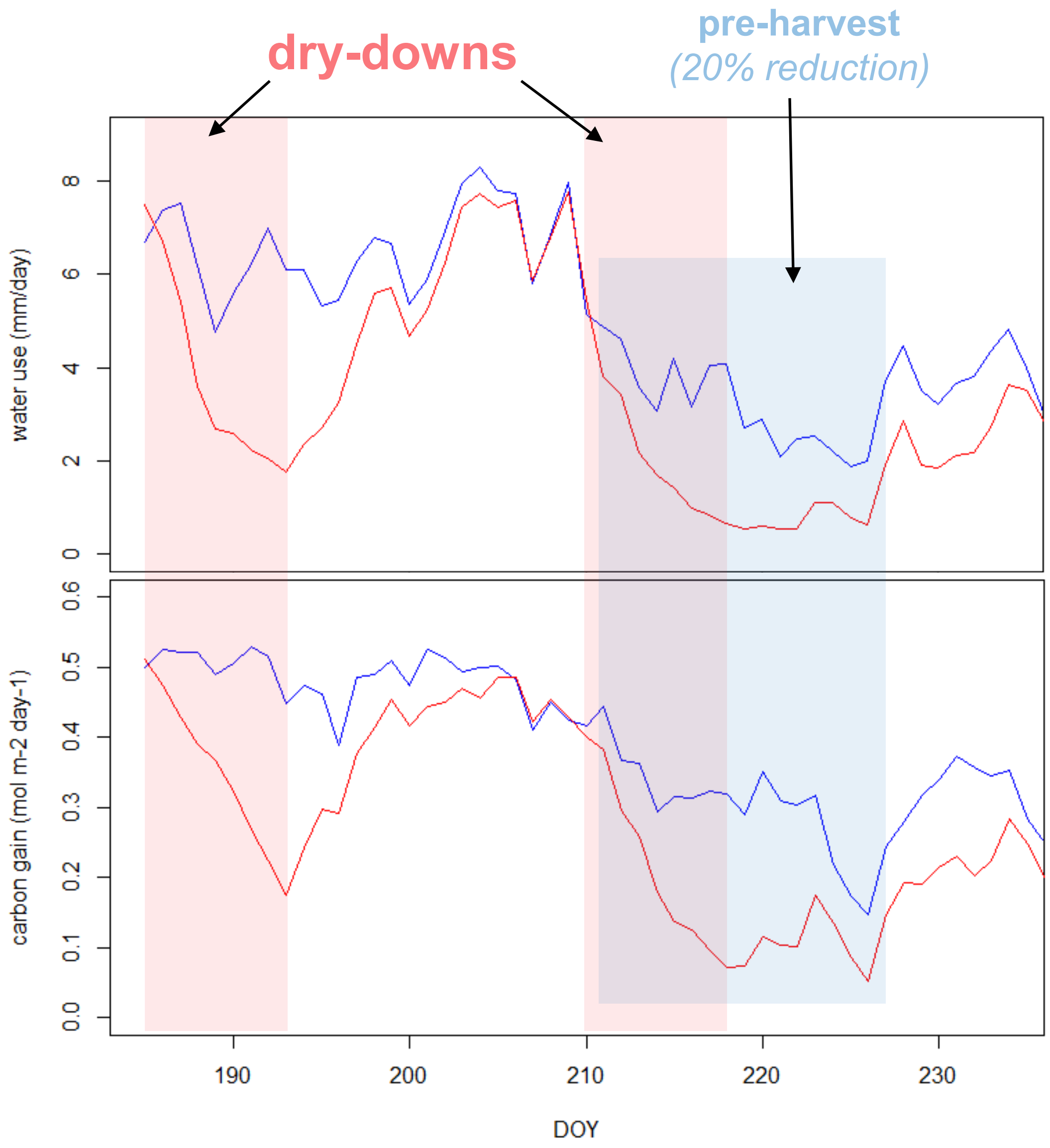
We modeled canopy photosynthesis from sap flow, leaf-level physiological measurements and meteorological data

- 20 trees (Nonpareil and Aldrich)
- Nickels research orchard (Arbuckle)
- Two 7-10 day transient droughts for half the trees

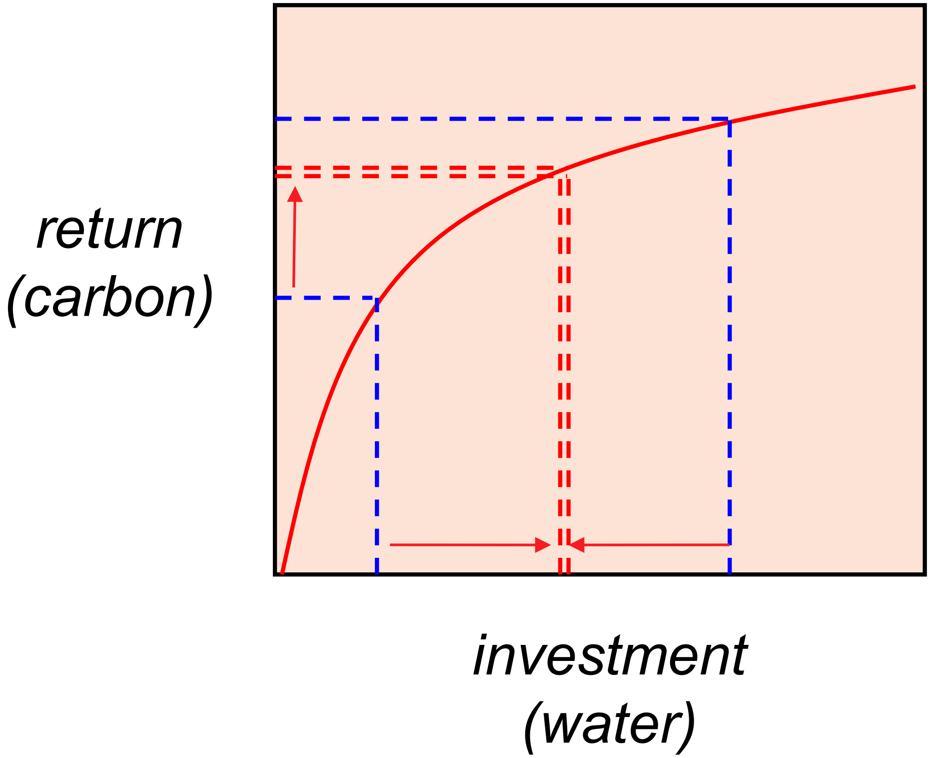


Sap flow, canopy conductance & canopy photosynthesis



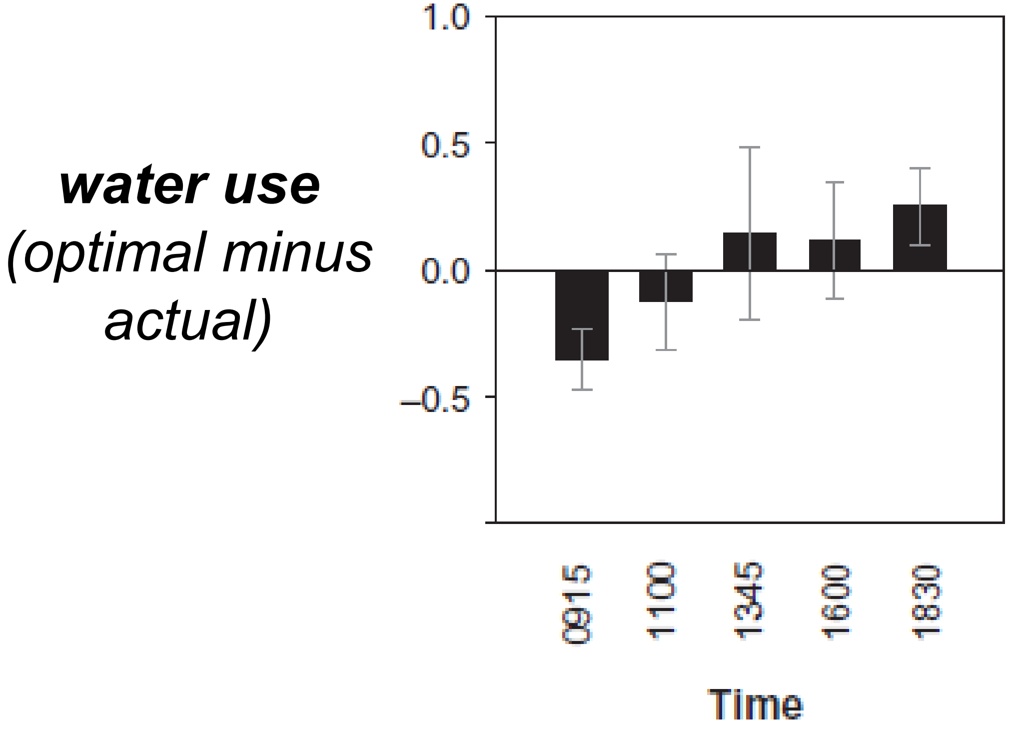


Hypothesis (1): Redistributing water across the season will increase total carbon gain



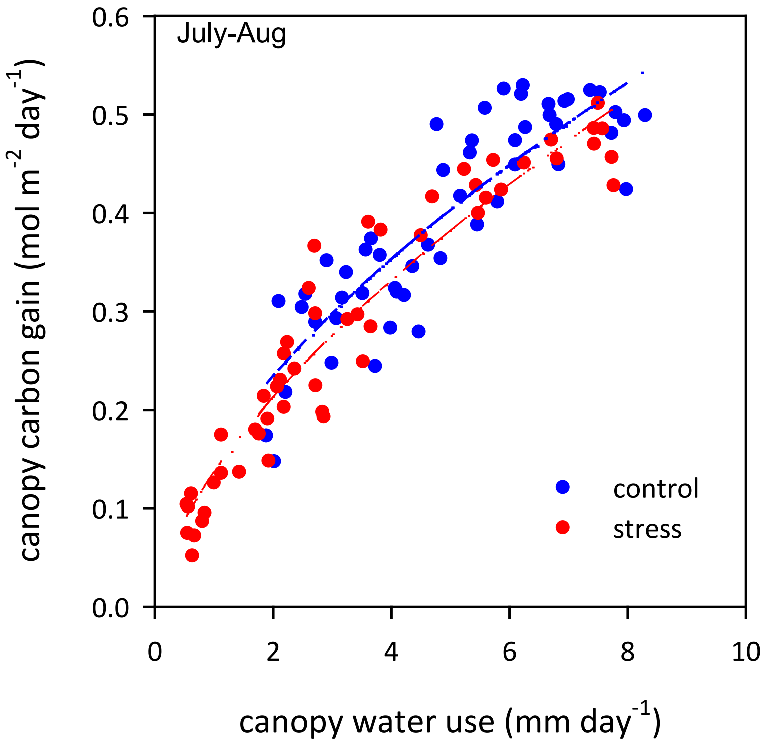
grapevine (Mallorca)

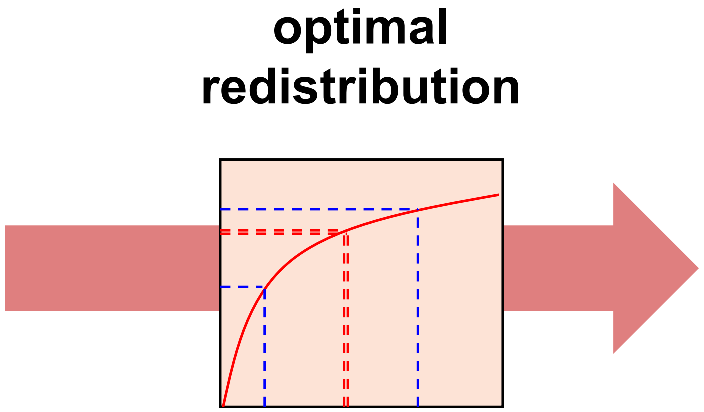
20% gain possible



Buckley et al. (2014)
Plant Cell Environ 37:2707

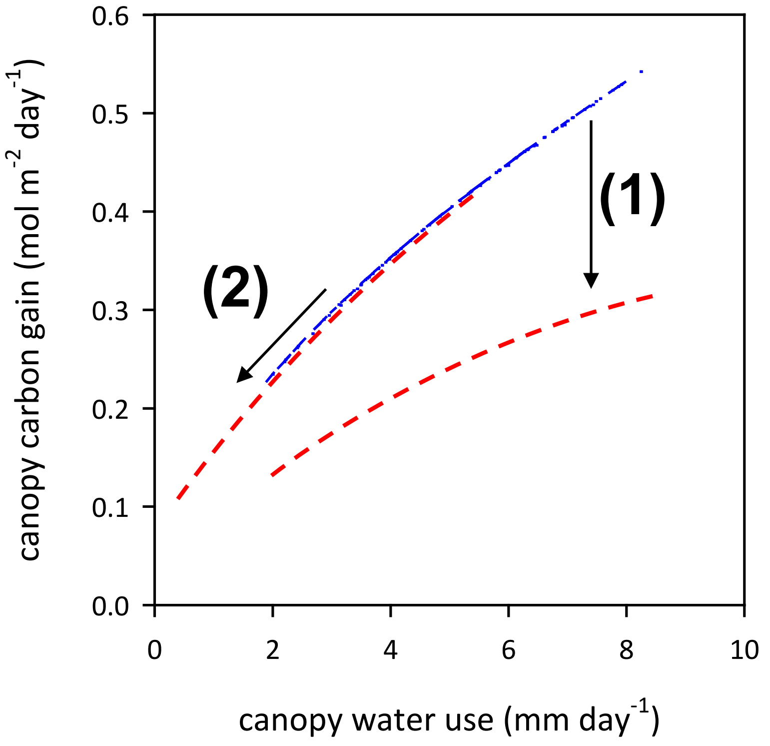
Hypothesis (1): Redistributing water across the season will increase total carbon gain





~no more than 5% increase in canopy photosynthesis

Hypothesis (2): In-season drought will irreversibly reduce canopy photosynthesis

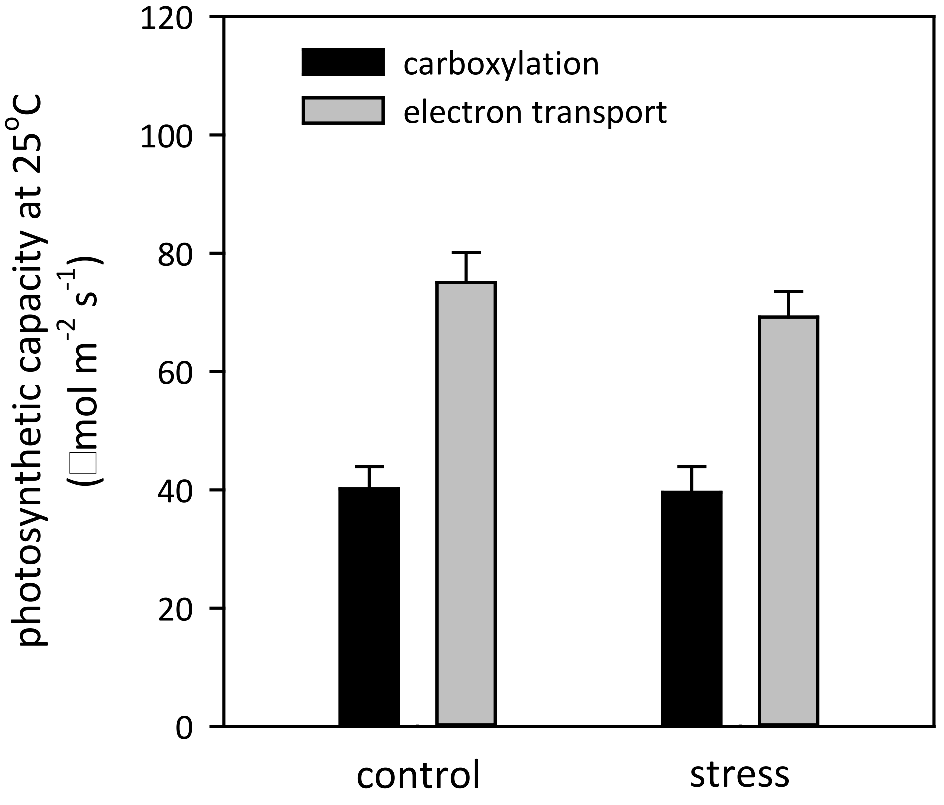


(1) reduced photosynthetic capacity

(2) reduced stomatal opening due to hydraulic failure

Hypothesis (2): In-season drought will irreversibly reduce canopy photosynthesis

(1) reduced photosynthetic capacity?



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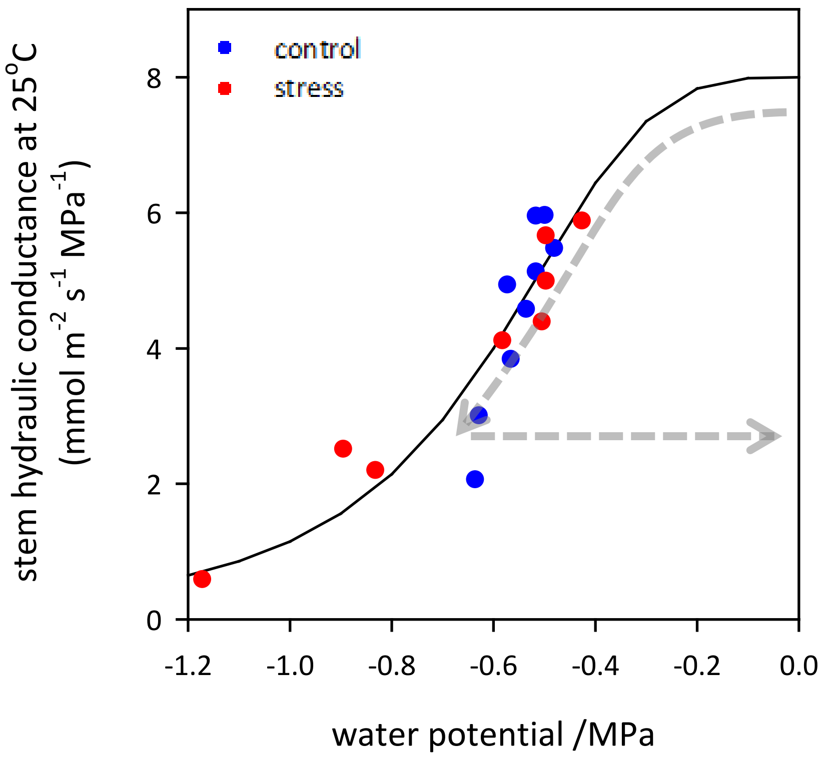
Hypothesis (2): In-season drought will irreversibly reduce canopy photosynthesis

~~(1) reduced photosynthetic capacity~~

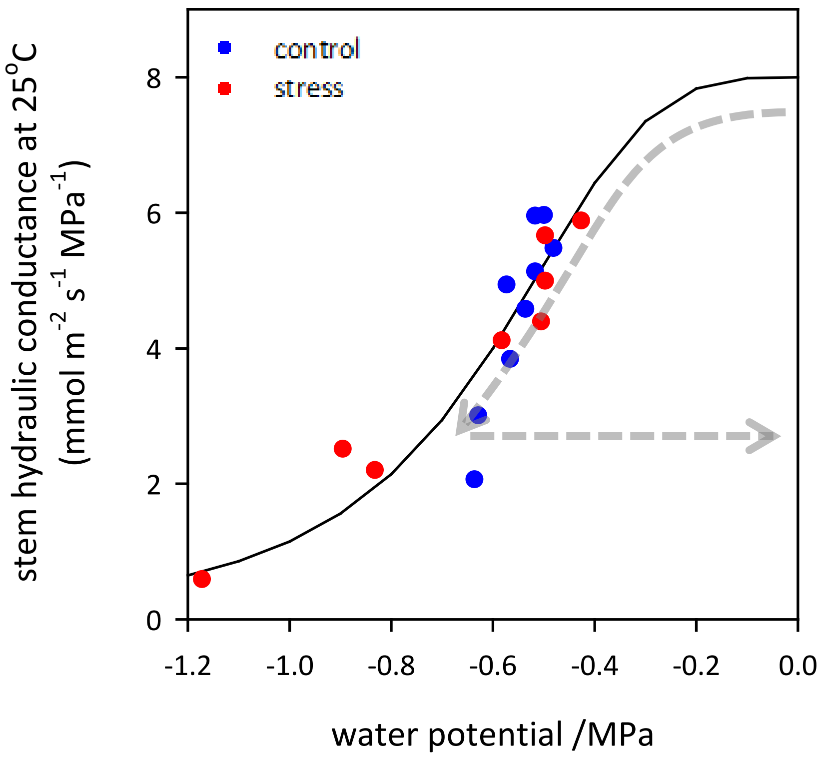
(2) hydraulic failure?

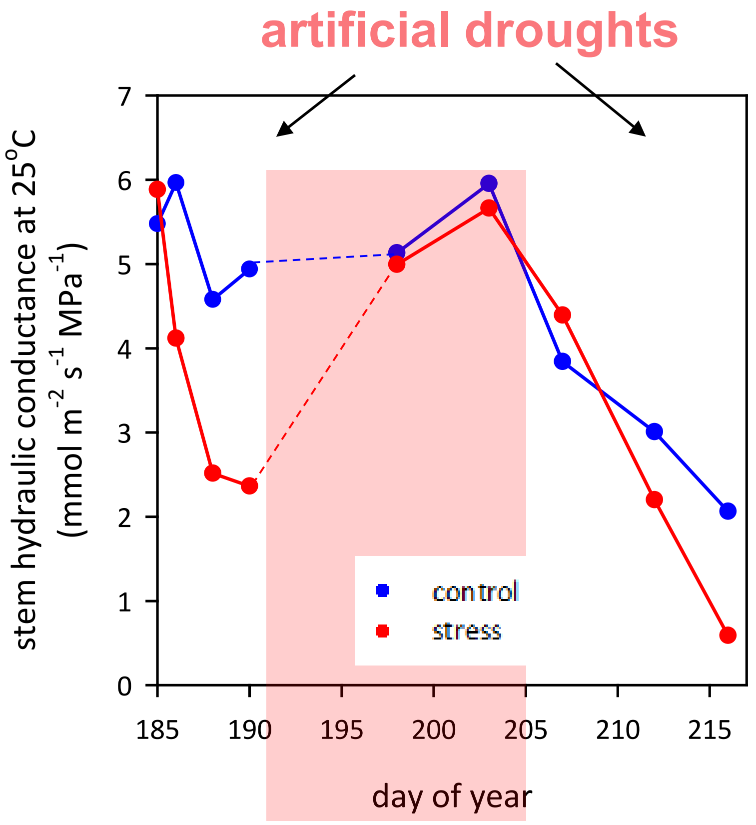


Hypothesis (2): In-season drought will irreversibly reduce canopy photosynthesis

~~(1) reduced photosynthetic capacity~~

(2) hydraulic failure?





Take-home messages

- **Photosynthesis is not "saturated" with respect to water use (in this orchard)**

- **Irrigating to ETc is surprisingly efficient with respect to photosynthesis**

- **Moderate in-season drought may (semi?)-permanently reduce photosynthesis**
    - due to reduction of **water transport capacity**

Questions moving forward:

- Examine photosynthesis and hydraulic failure in the context of harvest stress

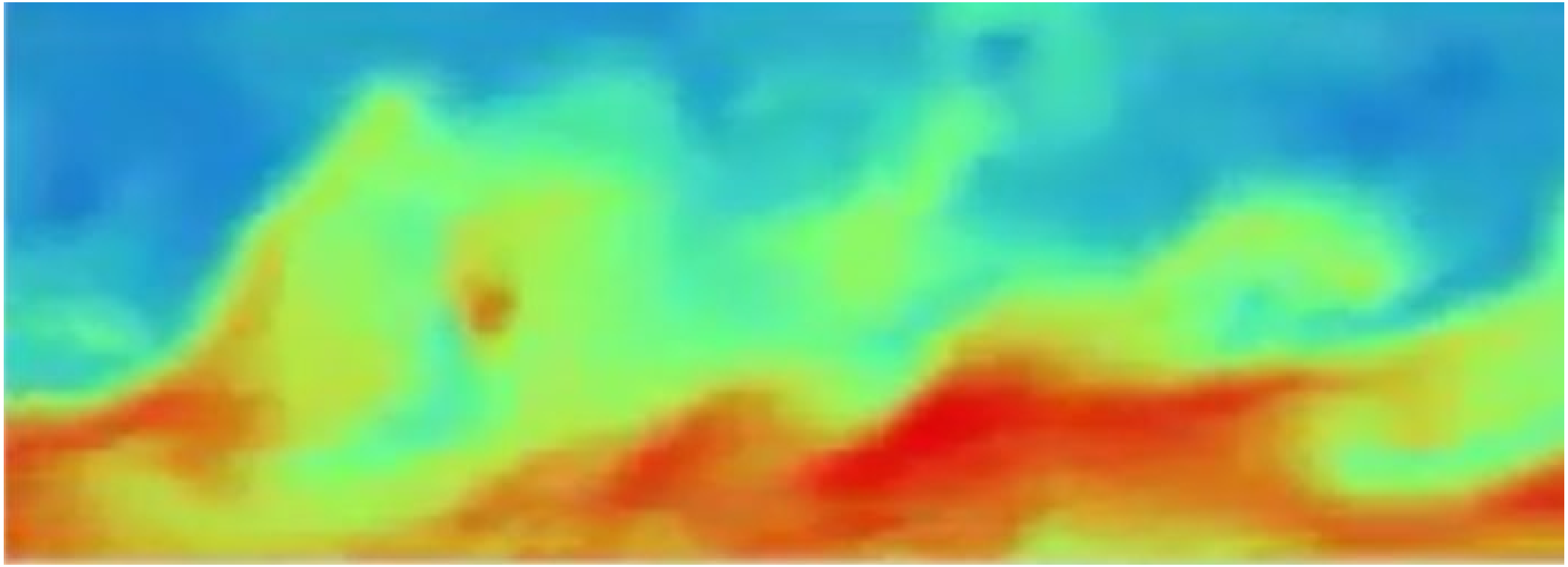
- Quantify effect of temperature on photosynthetic capacity beyond current climate envelope

Thanks to the Almond Board of California for generous support

Thanks also to:

Sam Metcalf
Franz Niederholzer
Stan Cutter
Marshall Pierce
Paula Guzman-Delgado
Ian Boyles
George Brahler
Nico Bambach
Andrew McElrone

Validating ET estimates for almonds



Andrew J. McElrone; ajmcelrone@ucdavis.edu

Evapotranspiration (ET): Evaporation + Transpiration

Integrates soil, plant and atmosphere

Irrigation management→ how much & when?

<u>Water lost</u>: replacement needs

<u>Detect crop stress</u>: push thresholds to achieve water savings and other outcomes

California Irrigation Management Information System (CIMIS)

$$ET_c = K_c * ET_o$$

Tree evapotranspiration

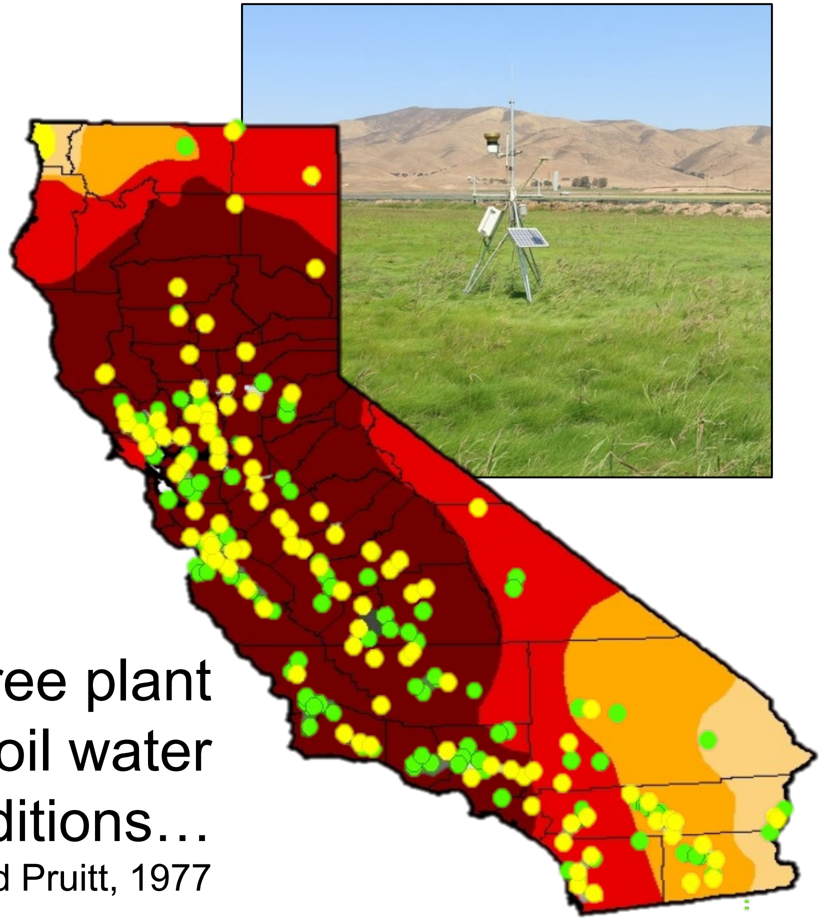
Crop coefficient

Reference ET (well-watered model grass)

Kearney Agricultural Center
Univ. of California- Parlier CA

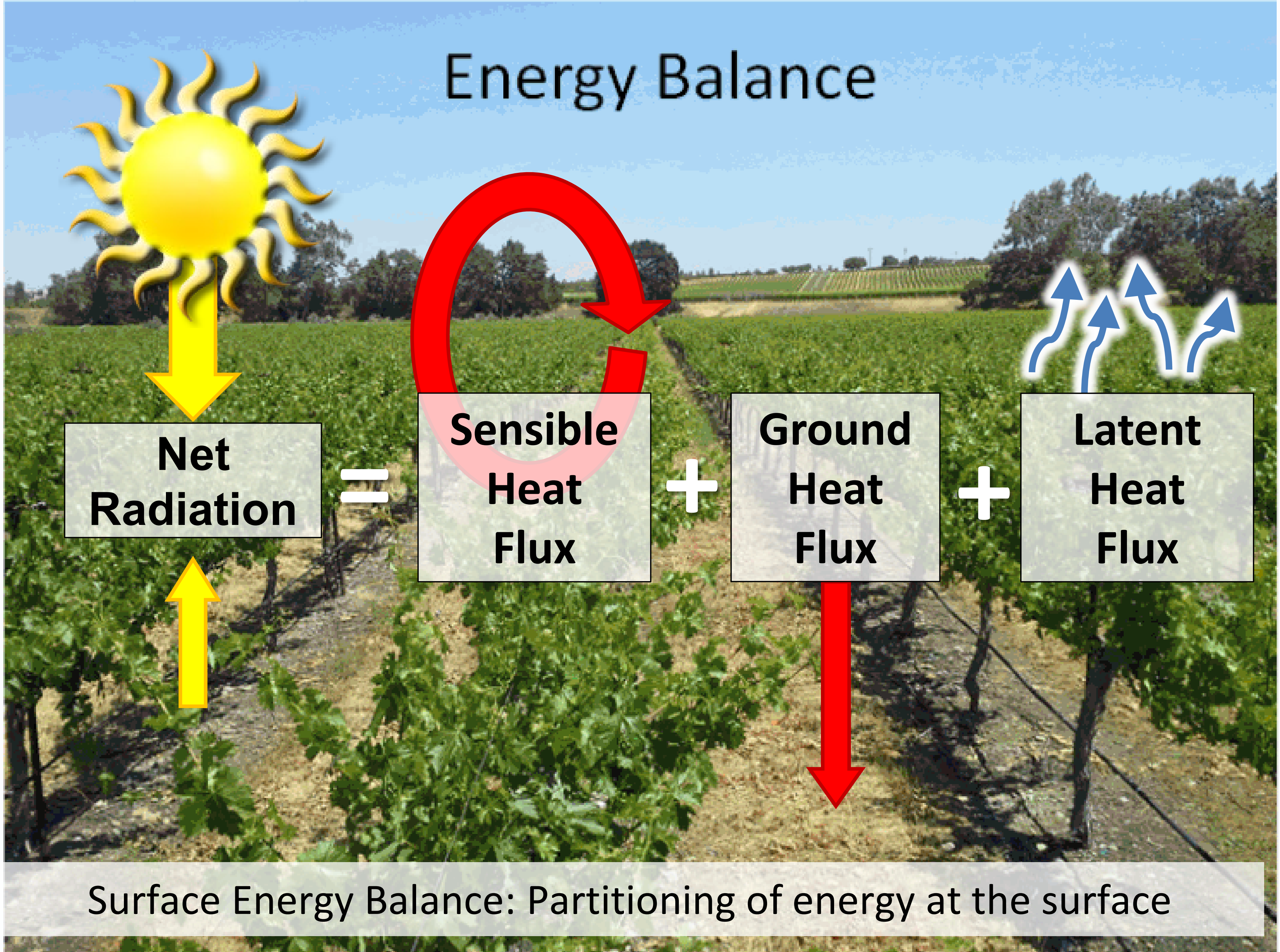
$$K_c = ET_c / ET_o$$

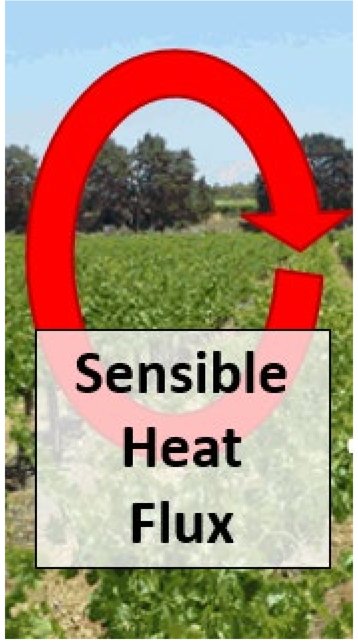
Obtained from plants in weighing lysimeter

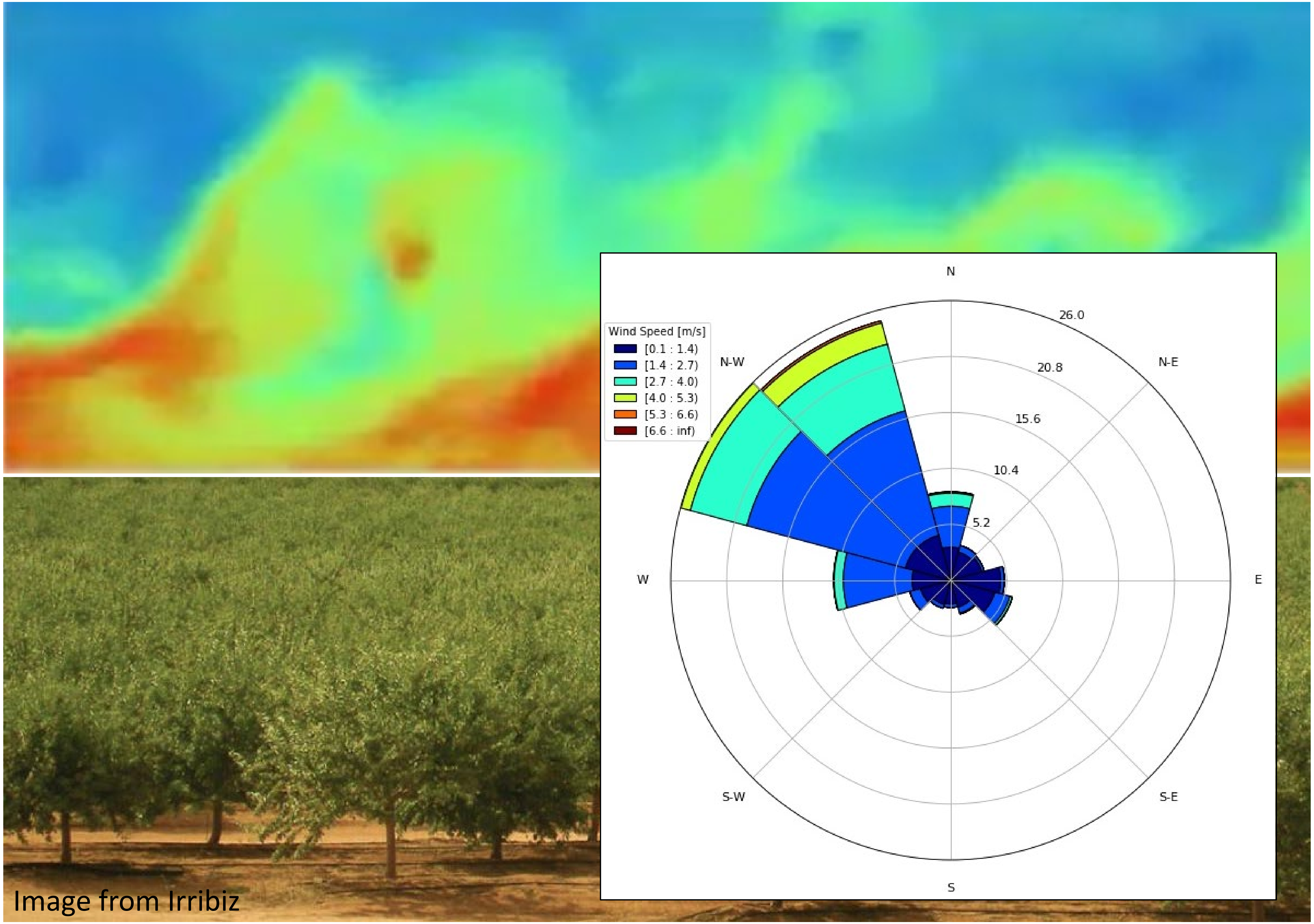


…assumes a disease-free plant grown under optimum soil water and nutrient conditions…

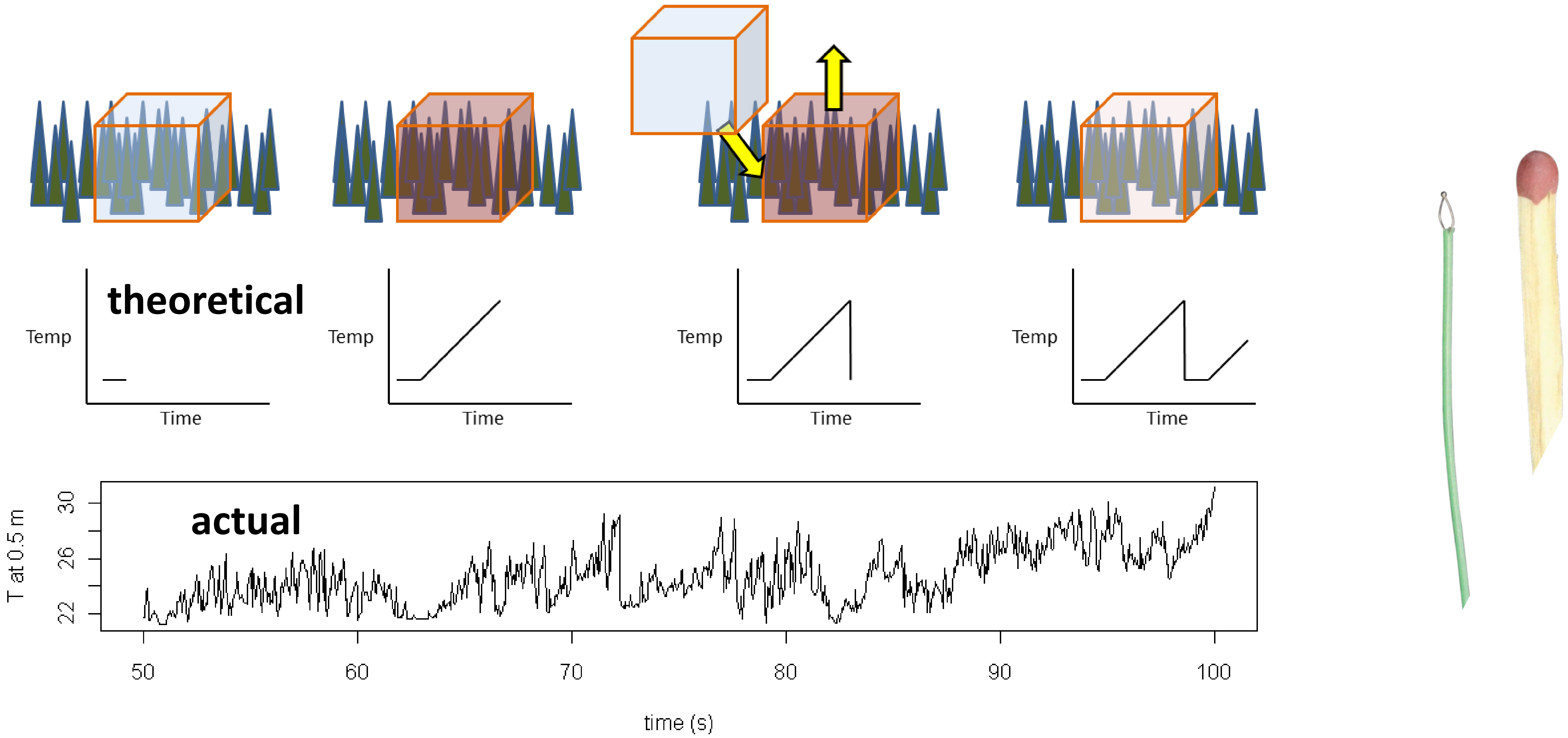
Doorenbos and Pruitt, 1977


Energy Balance
Net Radiation
=
Sensible Heat Flux
+
Ground Heat Flux
+
Latent Heat Flux
Surface Energy Balance: Partitioning of energy at the surface


Sensible
Heat
Flux


N
N-E
E
S-E
S
S-W
W
N-W
26.0
20.8
15.6
10.4
5.2
Wind Speed [m/s]
[0.1 : 1.4)
[1.4 : 2.7)
[2.7 : 4.0)
[4.0 : 5.3)
[5.3 : 6.6)
[6.6 : inf)
Image from Irribiz

Surface Renewal- Theory vs. Reality



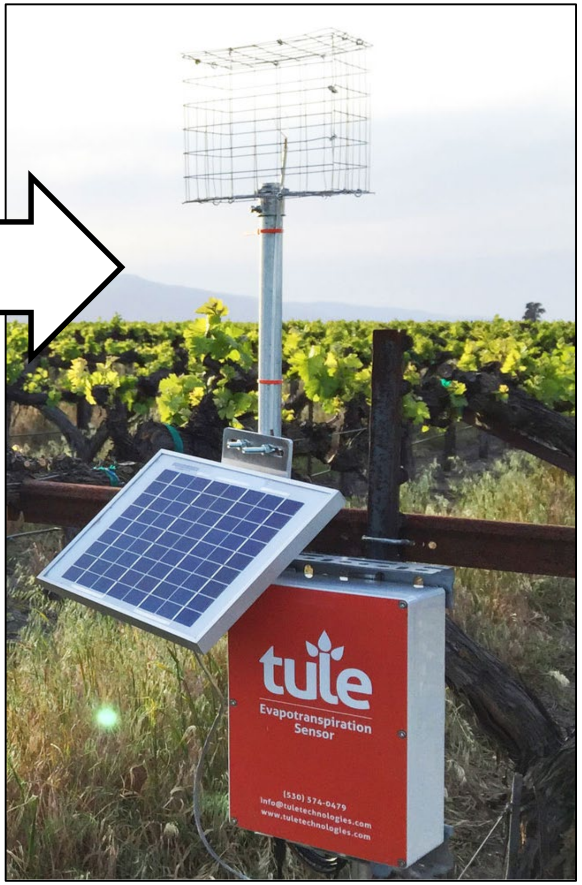
Successfully removed the need to calibrate against expensive research grade system (Shapland et al. 2012a,b, 2014)

Goal: inexpensive, site-specific measurement of actual crop water use

Surface Renewal

Research Grade System ~$10K

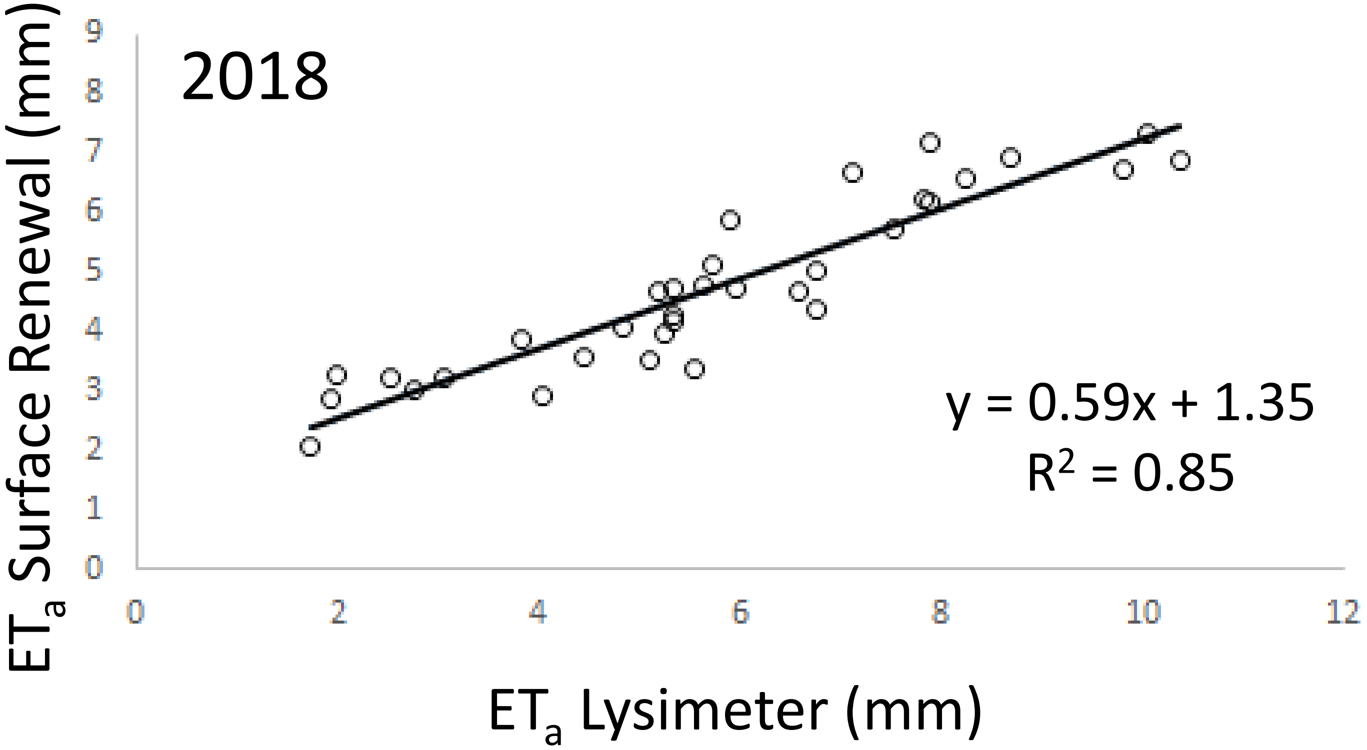
Paw U et al. (1989, 1991, 1995)



Commercial System

New Surface Renewal Method vs. Almond Weighing Lysimeter

Kearney Agricultural Center
Univ. of California- Parlier CA



New Surface Renewal Method vs. Almond Weighing Lysimeter

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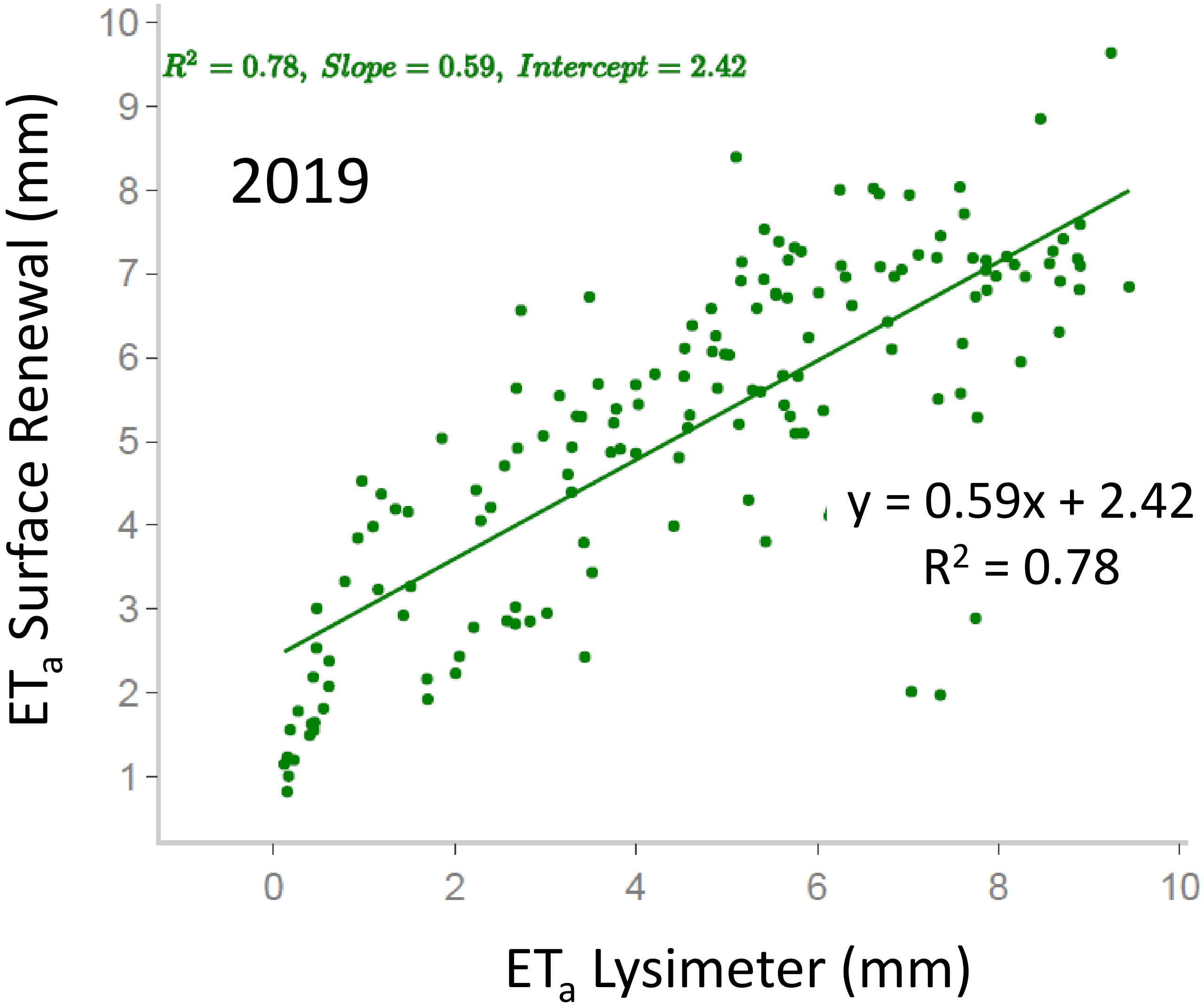
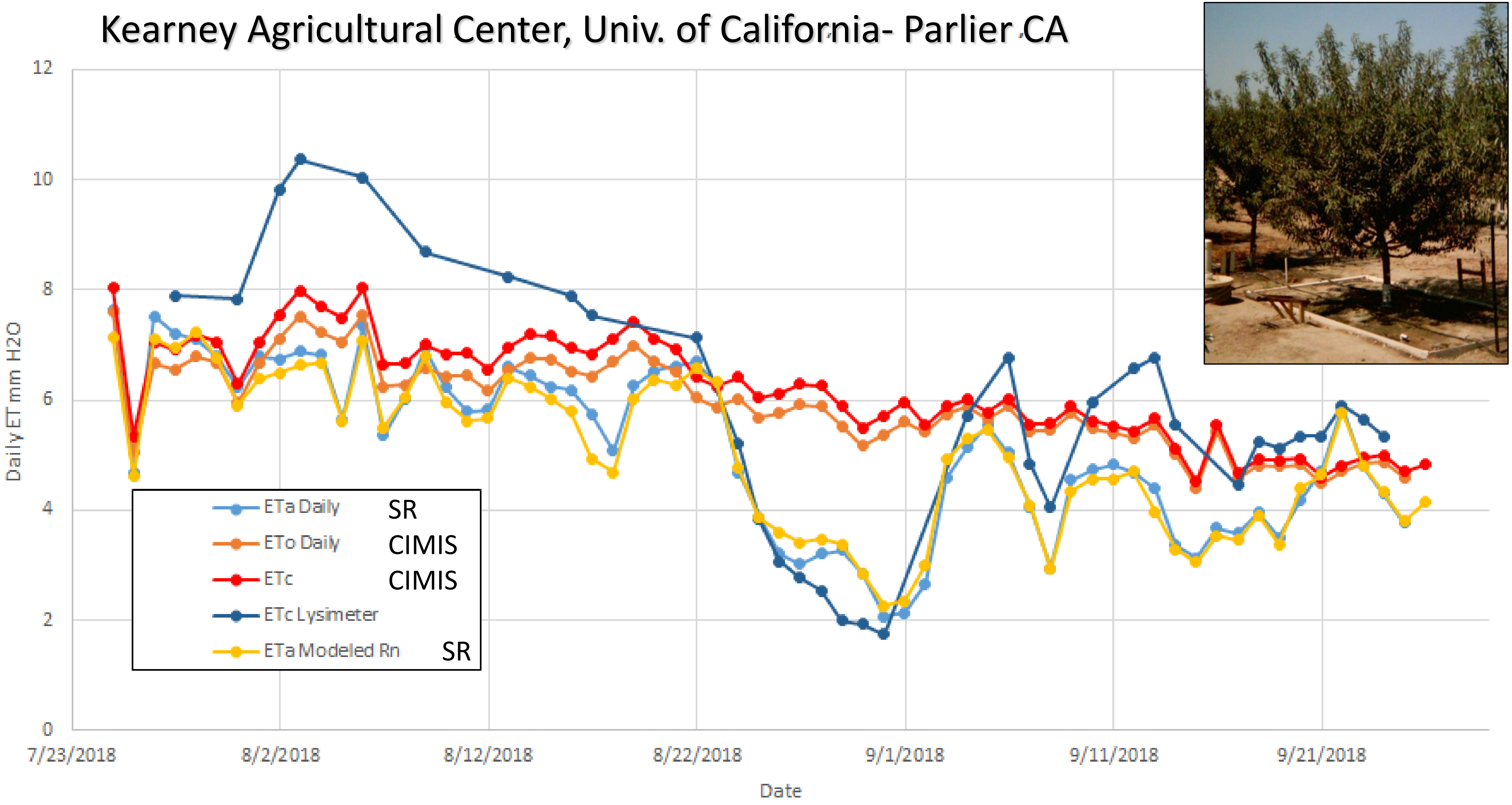
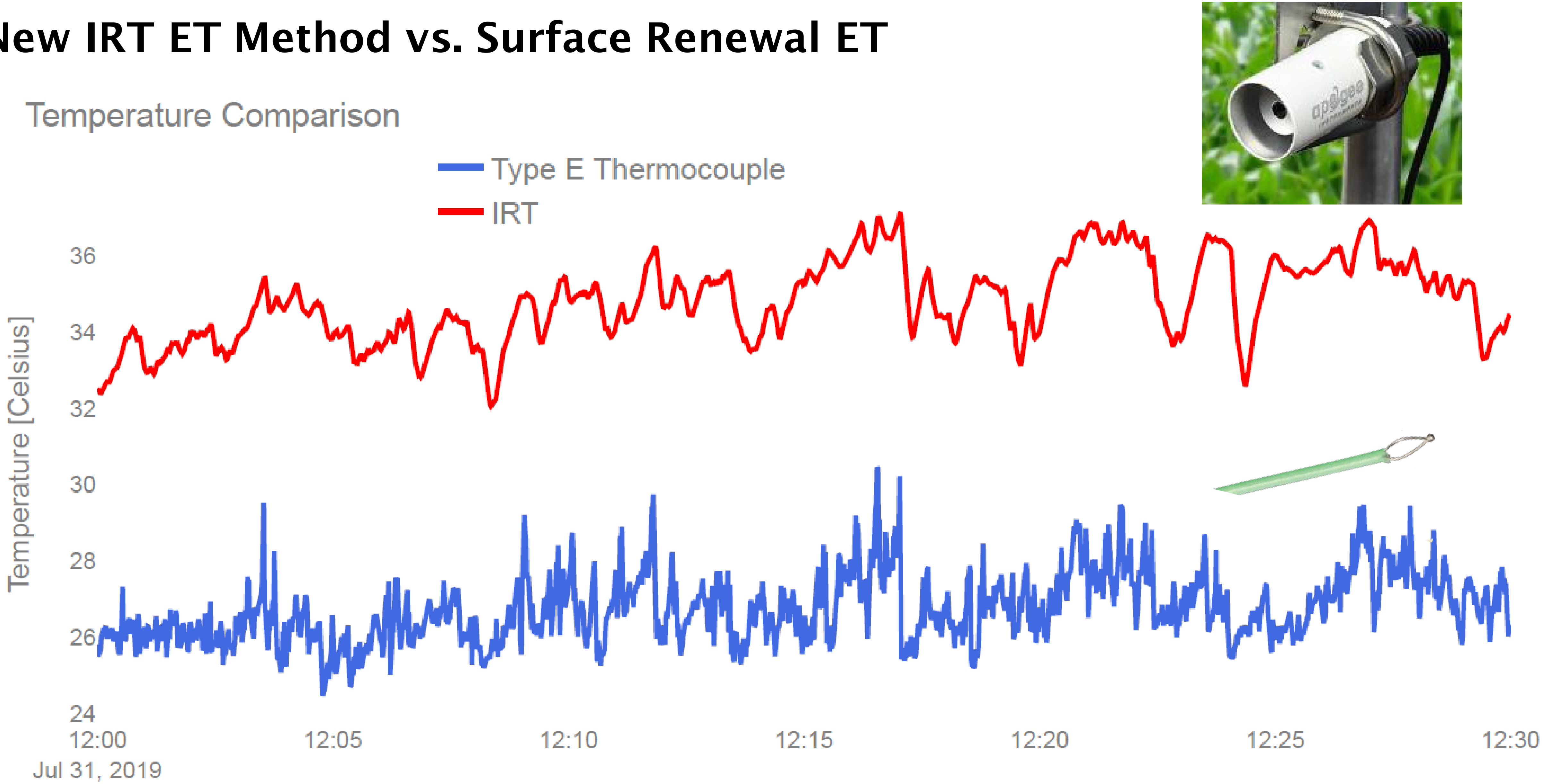


New Surface Renewal Method vs. Almond Weighing Lysimeter

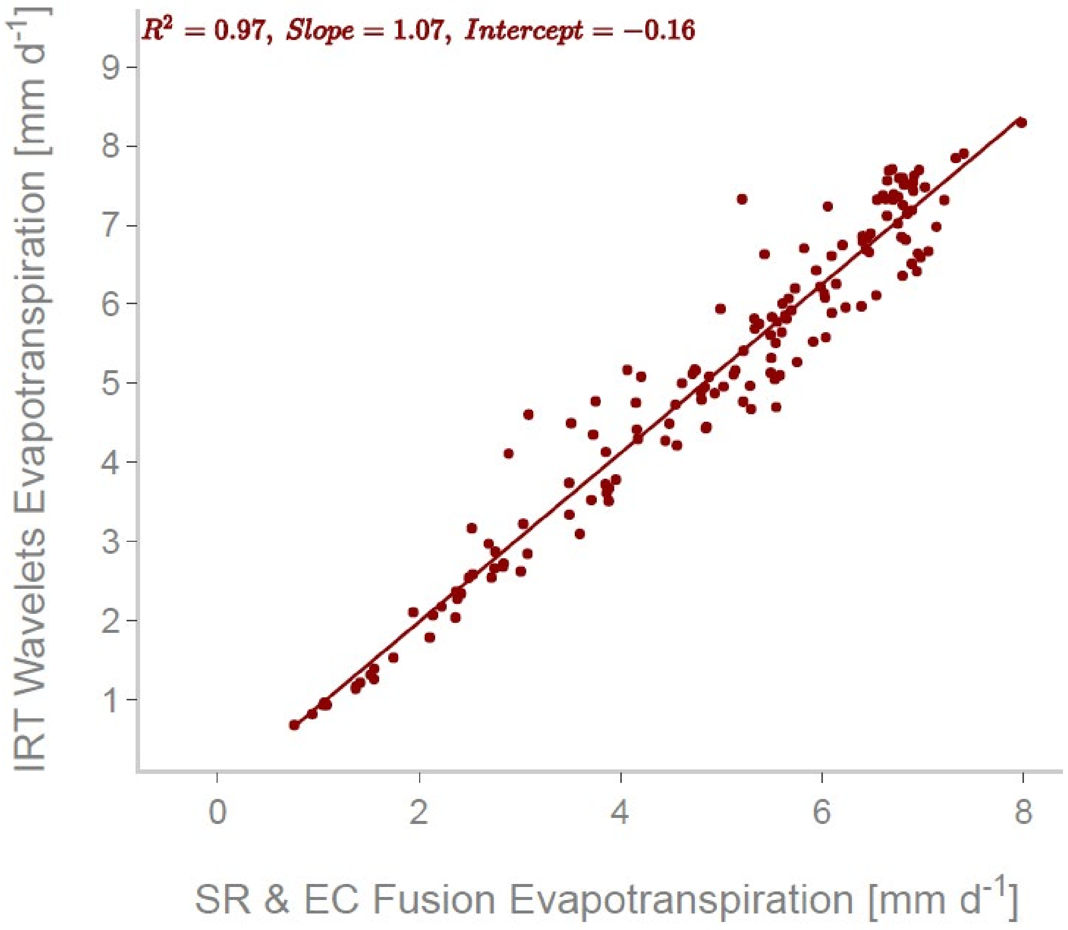
Kearney Agricultural Center, Univ. of California- Parlier CA

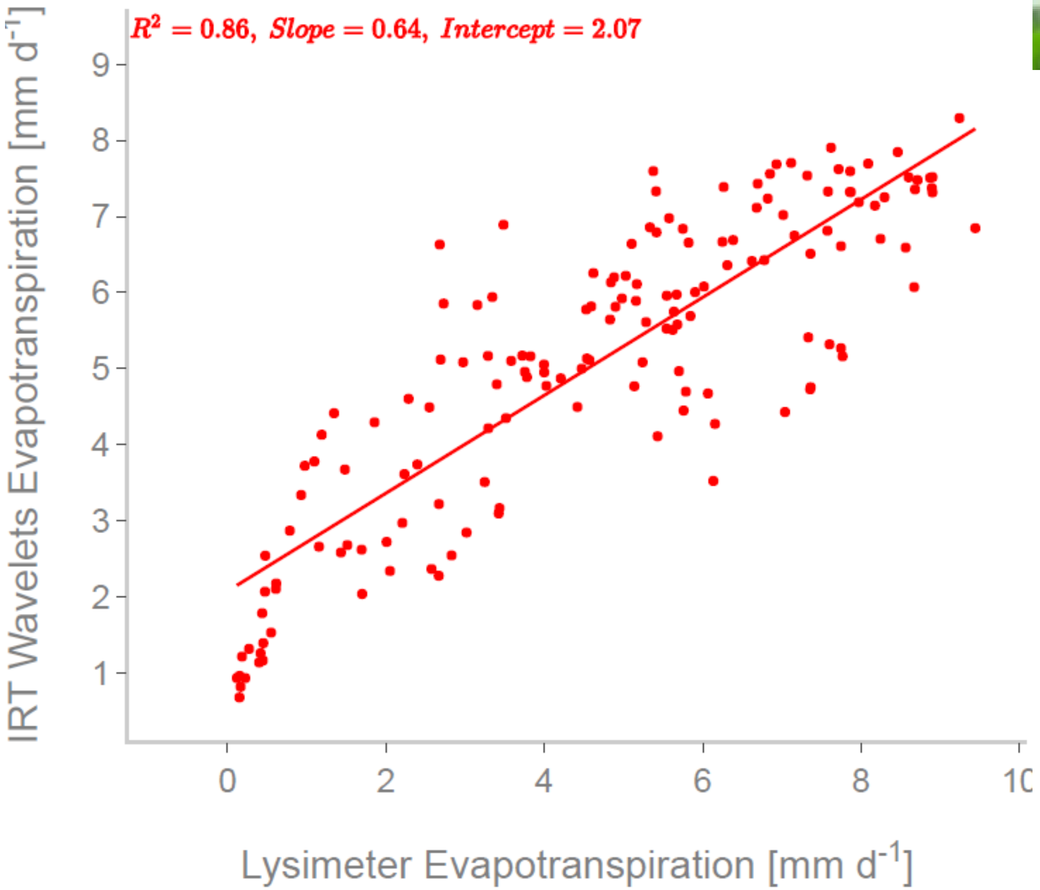


New IRT ET Method vs. Surface Renewal ET



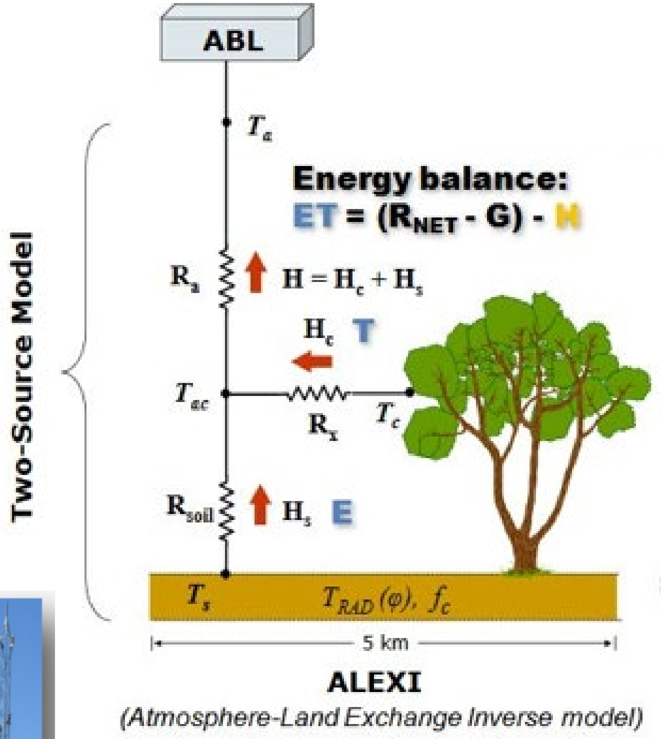
New IRT ET Method vs. Almond Eddy Covariance ET



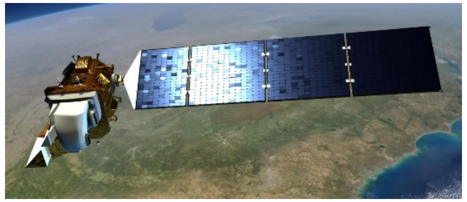


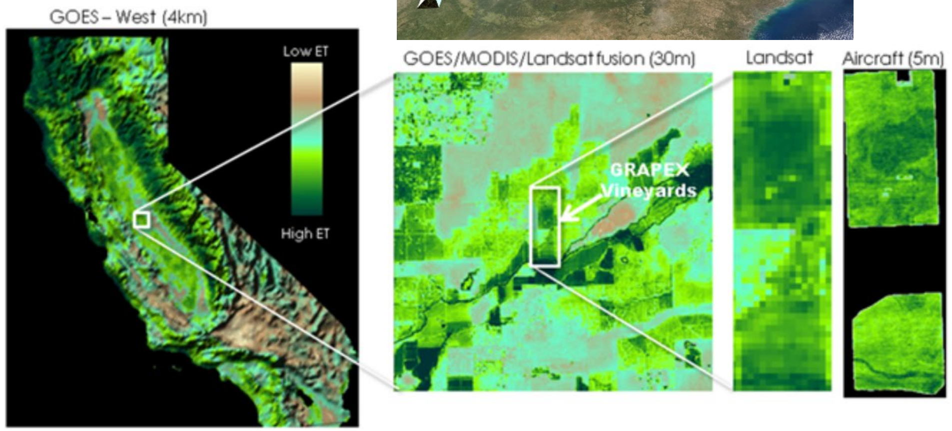
Grape Remote sensing Atmospheric Profile & Evapotranspiration eXperiment

Two Source Energy Balance



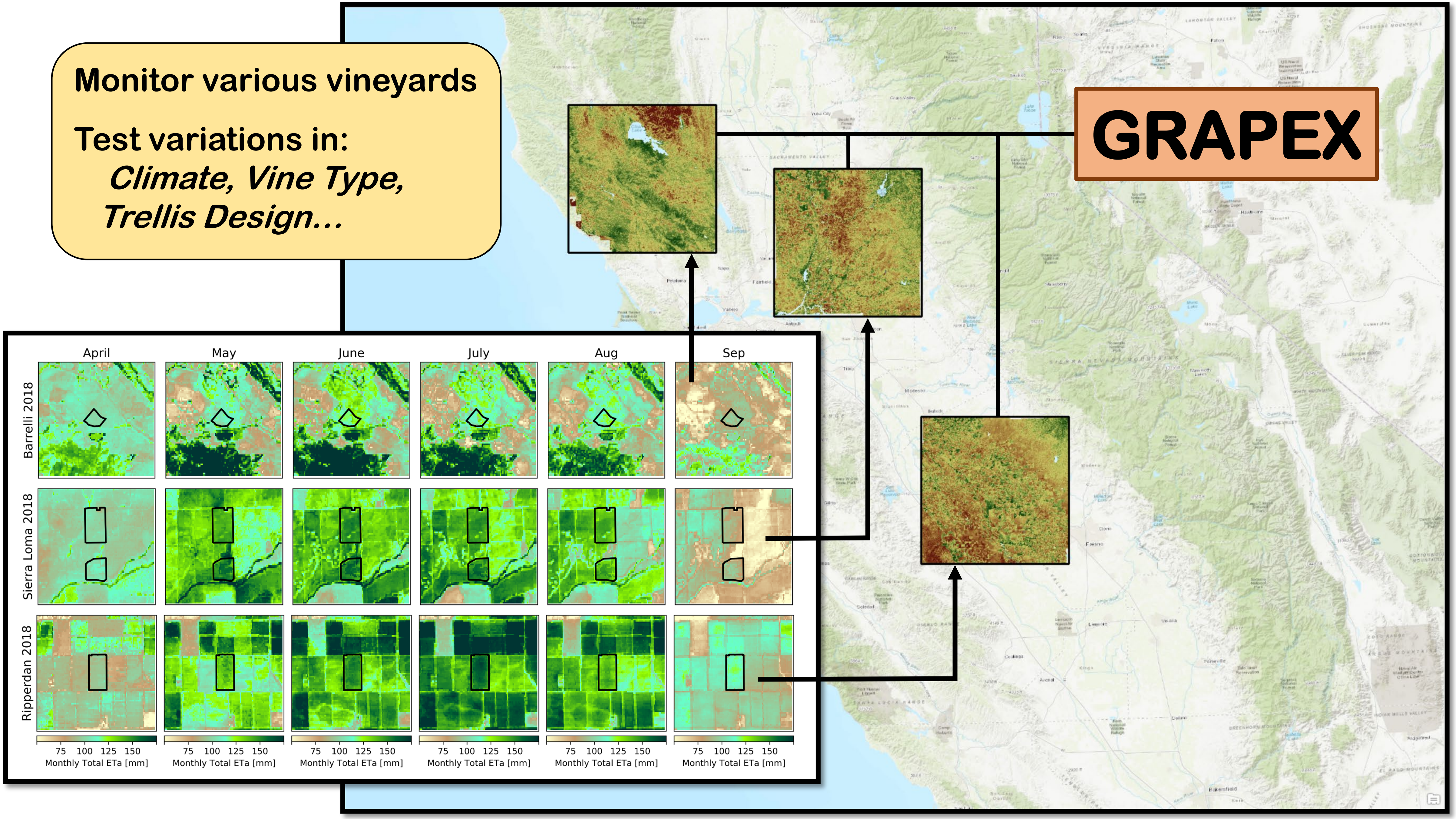
Refine and apply a multi-scale remote sensing ET toolkit for mapping crop water use and stress for improved irrigation management in CA

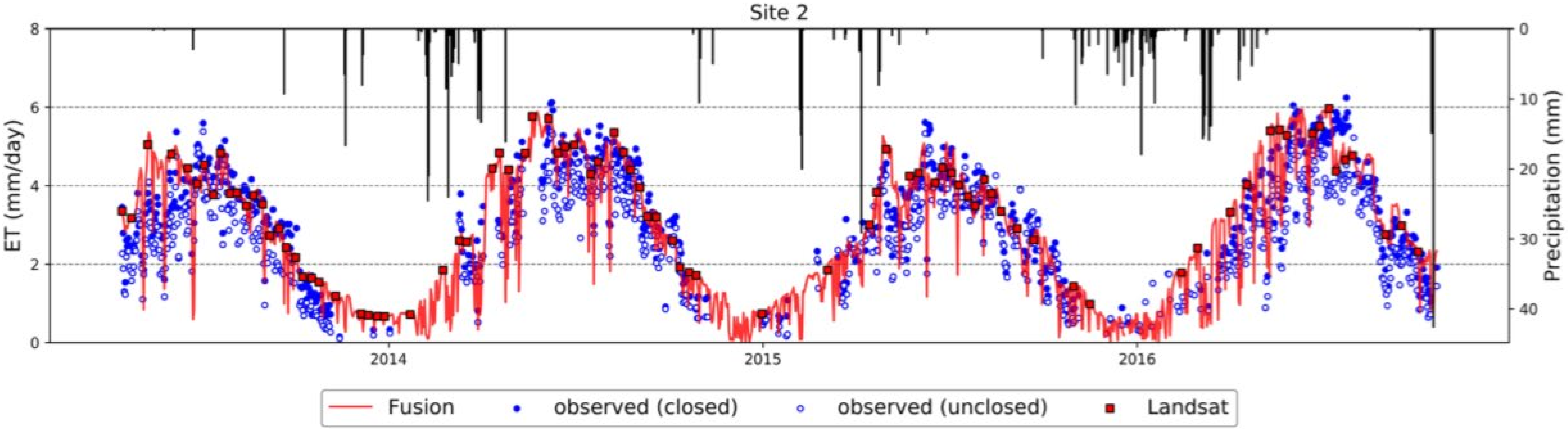




Monitor various vineyards

Test variations in:
Climate, Vine Type,
Trellis Design...



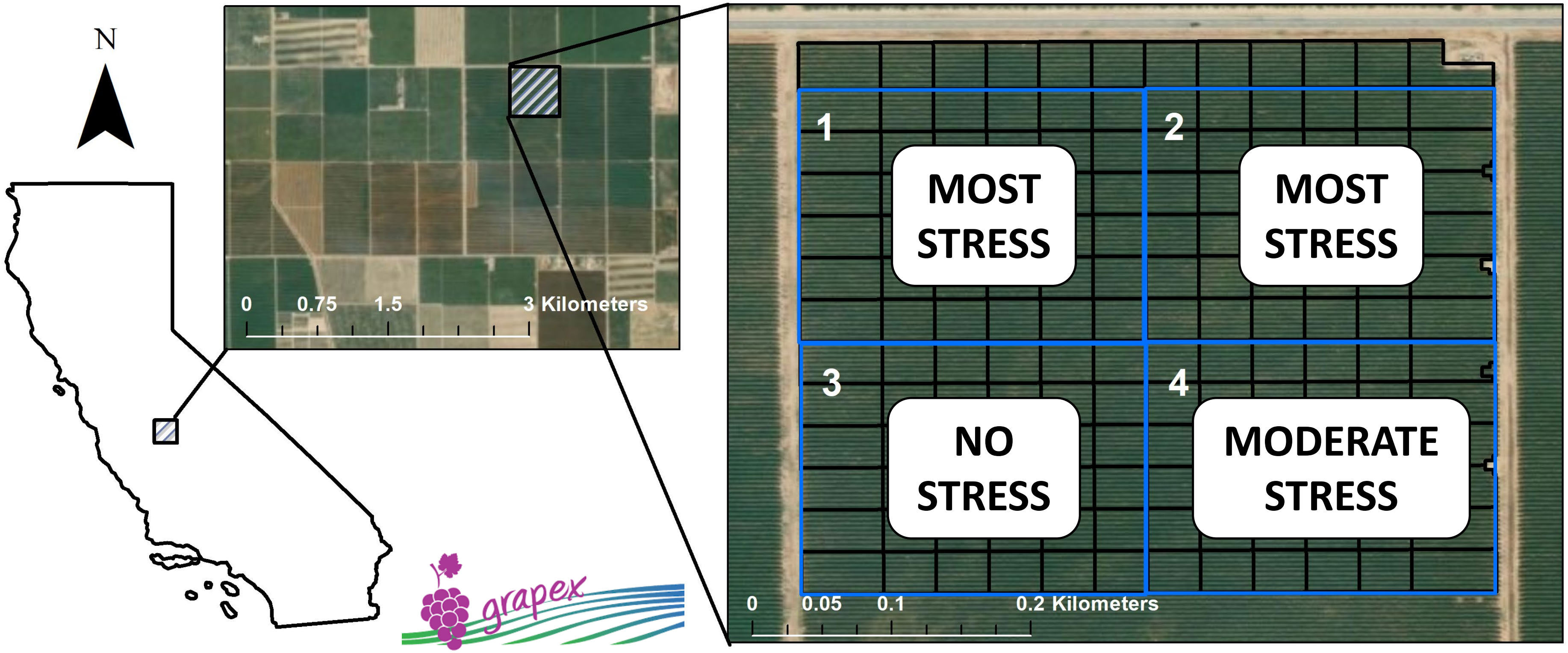


Knipper et al. 2019

Partnered with E & J Gallo Wineries

→

Provide weekly total ET for irrigation decision support



March 2018							
Nº	S	M	T	W	T	F	S
9					1	2	3
10	4	5	6	7	8	9	10
11	11	12	13	14	15	16	17
12	18	19	20	21	22	23	24
13	25	26	27	28	29	30	31

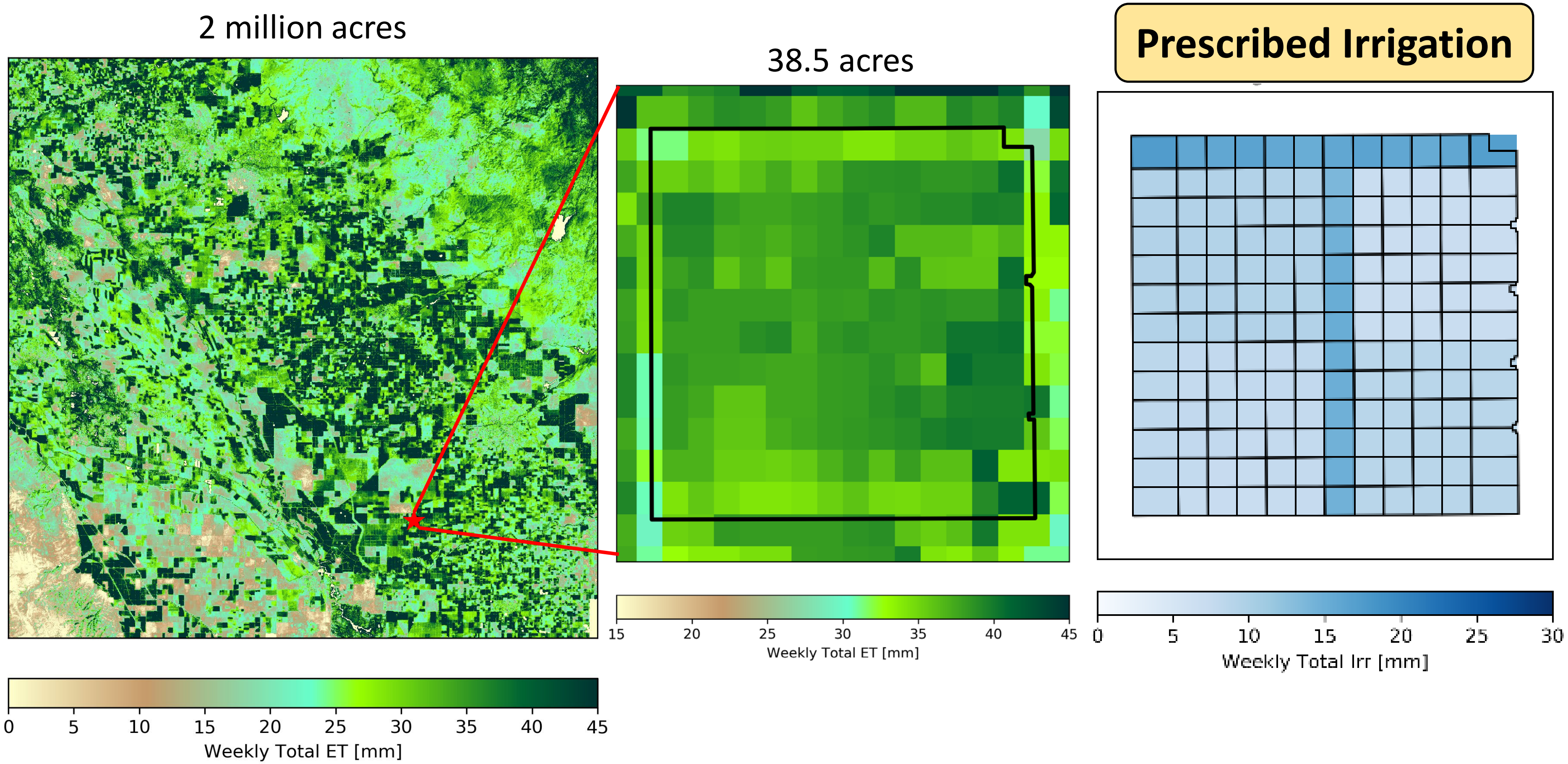
April 2018							
Nº	S	M	T	W	T	F	S
14	1	2	3	4	5	6	7
15	8	9	10	11	12	13	14
16	15	16	17	18	19	20	21
17	22	23	24	25	26	27	28
18	29	30					

May 2018							
Nº	S	M	T	W	T	F	S
18			1	2	3	4	5
19	6	7	8	9	10	11	12
20	13	14	15	16	17	18	19
21	20	21	22	23	24	25	26
22	27	28	29	30	31		

June 2018							
Nº	S	M	T	W	T	F	S
22						1	2
23	3	4	5	6	7	8	9
24	10	11	12	13	14	15	16
25	17	18	19	20	21	22	23
26	24	25	26	27	28	29	30

July 2018							
Nº	S	M	T	W	T	F	S
27	1	2	3	4	5	6	7
28	8	9	10	11	12	13	14
29	15	16	17	18	19	20	21
30	22	23	24	25	26	27	28
31	29	30	31				

August 2018							
Nº	S	M	T	W	T	F	S
31				1	2	3	4
32	5	6	7	8	9	10	11
33	12	13	14	15	16	17	18
34	19	20	21	22	23	24	25
35	26	27	28	29	30	31	



March 2018							
Nº	S	M	T	W	T	F	S
9					1	2	3
10	4	5	6	7	8	9	10
11	11	12	13	14	15	16	17
12	18	19	20	21	22	23	24
13	25	26	27	28	29	30	31

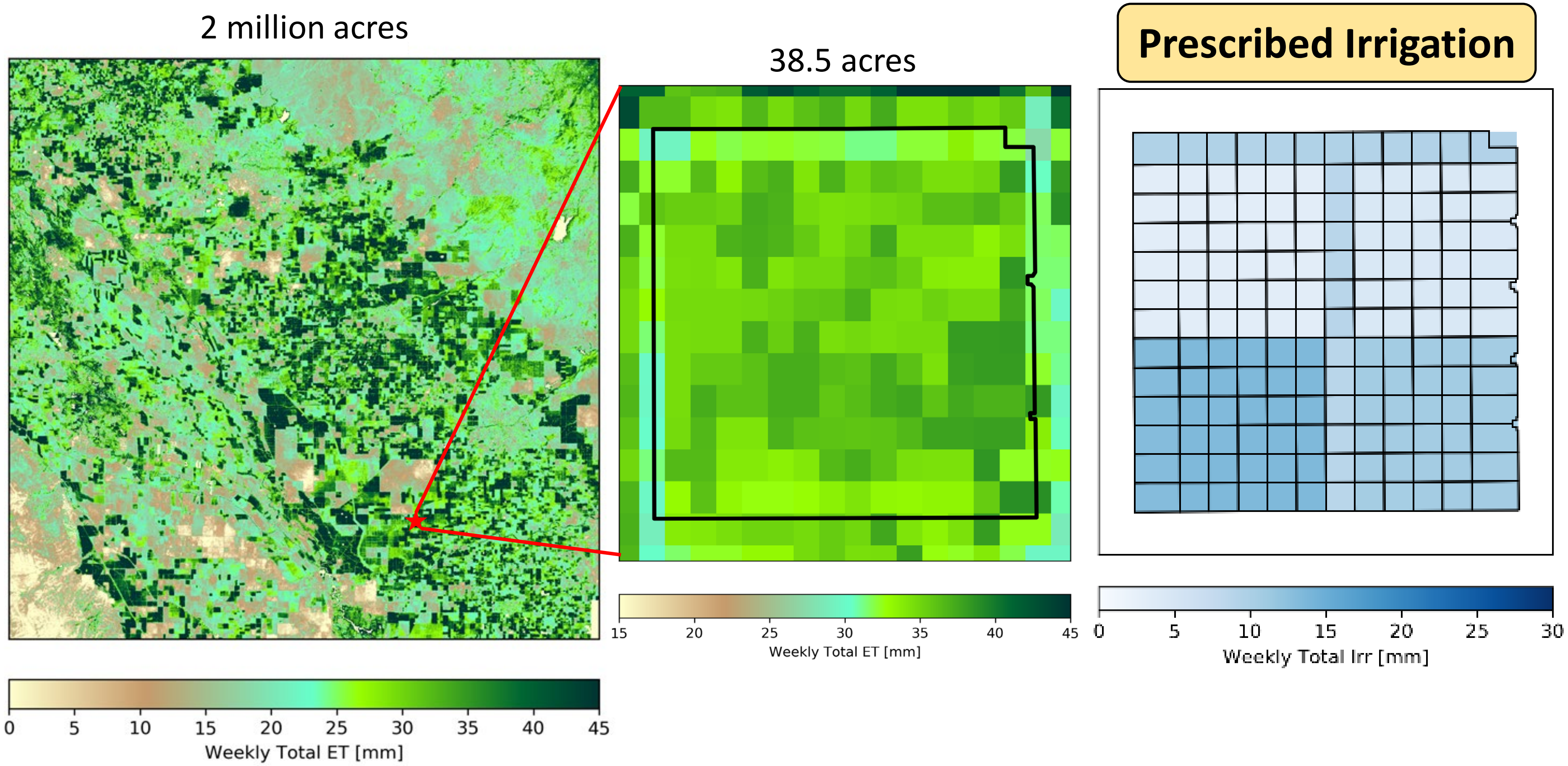
April 2018							
Nº	S	M	T	W	T	F	S
14	1	2	3	4	5	6	7
15	8	9	10	11	12	13	14
16	15	16	17	18	19	20	21
17	22	23	24	25	26	27	28
18	29	30					

May 2018							
Nº	S	M	T	W	T	F	S
18			1	2	3	4	5
19	6	7	8	9	10	11	12
20	13	14	15	16	17	18	19
21	20	21	22	23	24	25	26
22	27	28	29	30	31		

June 2018							
Nº	S	M	T	W	T	F	S
22						1	2
23	3	4	5	6	7	8	9
24	10	11	12	13	14	15	16
25	17	18	19	20	21	22	23
26	24	25	26	27	28	29	30

July 2018							
Nº	S	M	T	W	T	F	S
27	1	2	3	4	5	6	7
28	8	9	10	11	12	13	14
29	15	16	17	18	19	20	21
30	22	23	24	25	26	27	28
31	29	30	31				

August 2018							
Nº	S	M	T	W	T	F	S
31				1	2	3	4
32	5	6	7	8	9	10	11
33	12	13	14	15	16	17	18
34	19	20	21	22	23	24	25
35	26	27	28	29	30	31	



March 2018

Nº	S	M	T	W	T	F	S
9					1	2	3
10	4	5	6	7	8	9	10
11	11	12	13	14	15	16	17
12	18	19	20	21	22	23	24
13	25	26	27	28	29	30	31

April 2018

Nº	S	M	T	W	T	F	S
14	1	2	3	4	5	6	7
15	8	9	10	11	12	13	14
16	15	16	17	18	19	20	21
17	22	23	24	25	26	27	28
18	29	30					

May 2018

Nº	S	M	T	W	T	F	S
18			1	2	3	4	5
19	6	7	8	9	10	11	12
20	13	14	15	16	17	18	19
21	20	21	22	23	24	25	26
22	27	28	29	30	31		

June 2018

Nº	S	M	T	W	T	F	S
22						1	2
23	3	4	5	6	7	8	9
24	10	11	12	13	14	15	16
25	17	18	19	20	21	22	23
26	24	25	26	27	28	29	30

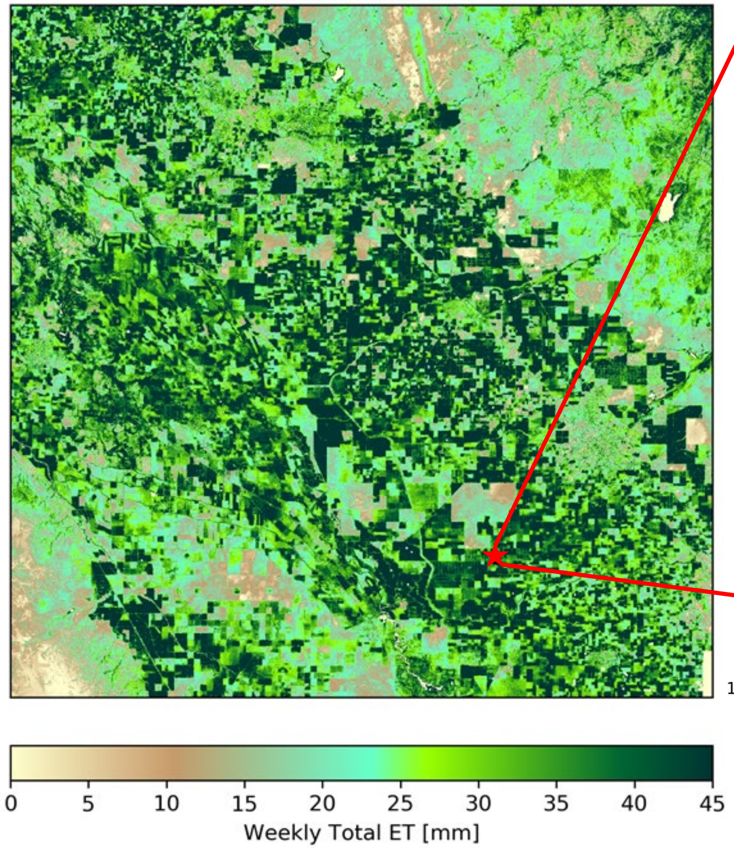
July 2018

Nº	S	M	T	W	T	F	S
27	1	2	3	4	5	6	7
28	8	9	10	11	12	13	14
29	15	16	17	18	19	20	21
30	22	23	24	25	26	27	28
31	29	30	31				

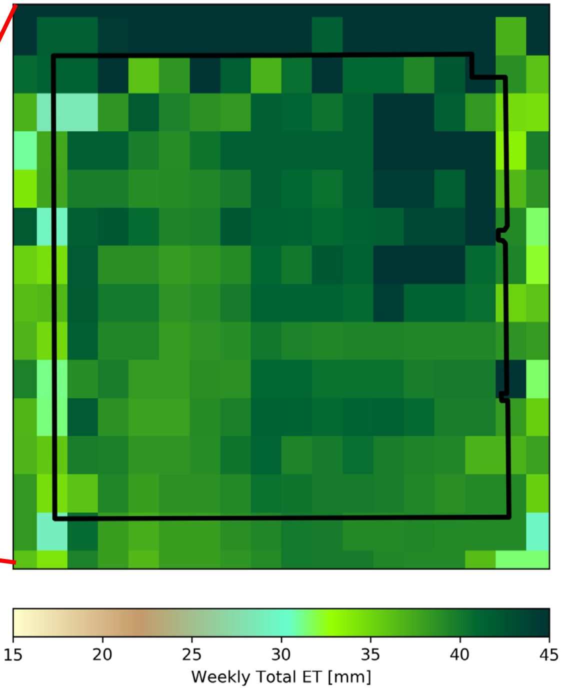
August 2018

Nº	S	M	T	W	T	F	S
31				1	2	3	4
32	5	6	7	8	9	10	11
33	12	13	14	15	16	17	18
34	19	20	21	22	23	24	25
35	26	27	28	29	30	31	

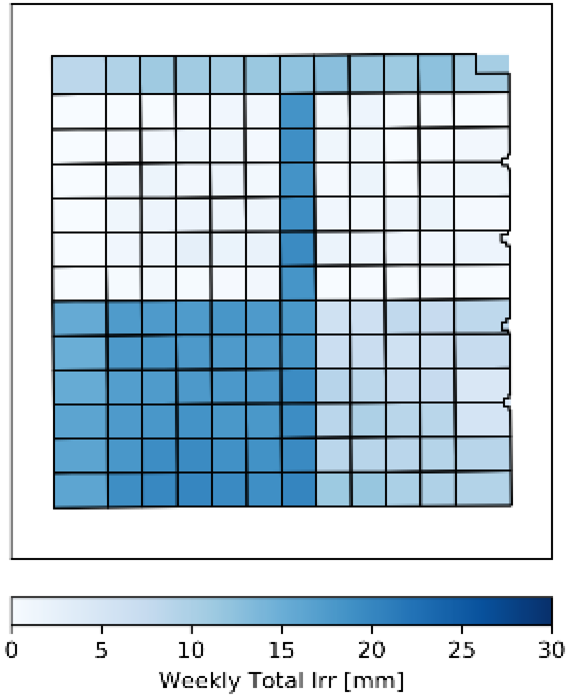
2 million acres



38.5 acres



Prescribed Irrigation



March 2018							
Nº	S	M	T	W	T	F	S
9					1	2	3
10	4	5	6	7	8	9	10
11	11	12	13	14	15	16	17
12	18	19	20	21	22	23	24
13	25	26	27	28	29	30	31

April 2018							
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16	15	16	17	18	19	20	21
17	22	23	24	25	26	27	28
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May 2018							
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20	13	14	15	16	17	18	19
21	20	21	22	23	24	25	26
22	27	28	29	30	31		

June 2018							
Nº	S	M	T	W	T	F	S
22						1	2
23	3	4	5	6	7	8	9
24	10	11	12	13	14	15	16
25	17	18	19	20	21	22	23
26	24	25	26	27	28	29	30

July 2018							
Nº	S	M	T	W	T	F	S
27	1	2	3	4	5	6	7
28	8	9	10	11	12	13	14
29	15	16	17	18	19	20	21
30	22	23	24	25	26	27	28
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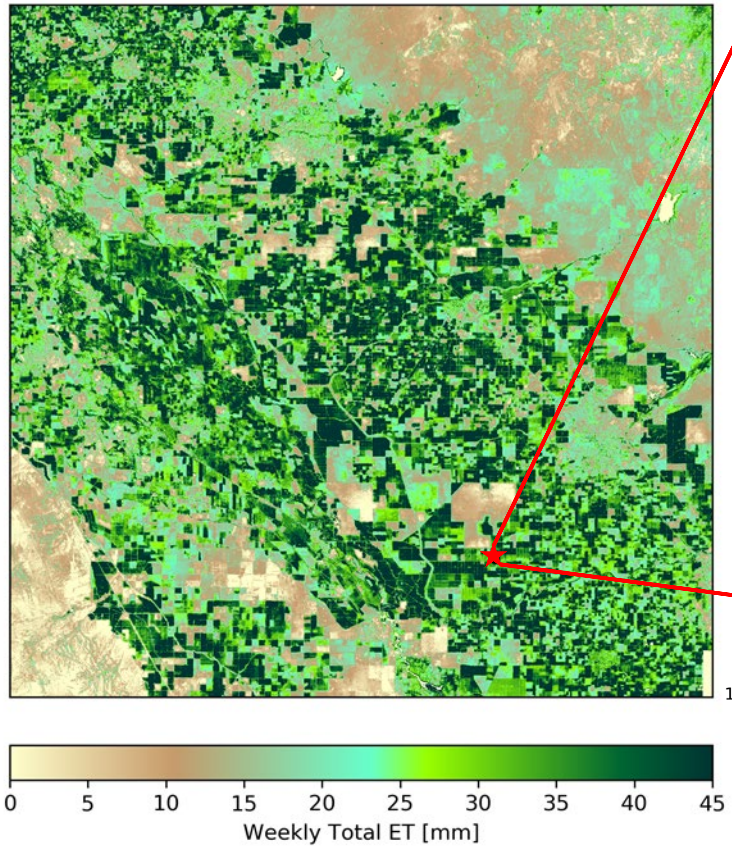
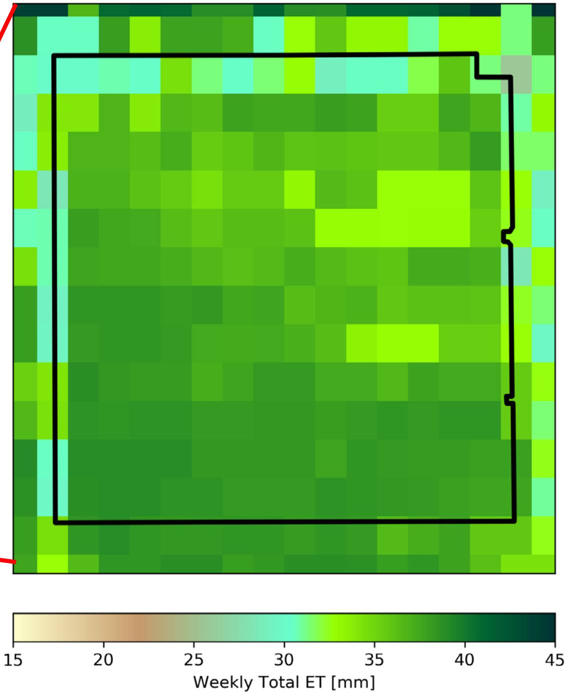
August 2018							
Nº	S	M	T	W	T	F	S
31				1	2	3	4
32	5	6	7	8	9	10	11
33	12	13	14	15	16	17	18
34	19	20	21	22	23	24	25
35	26	27	28	29	30	31	

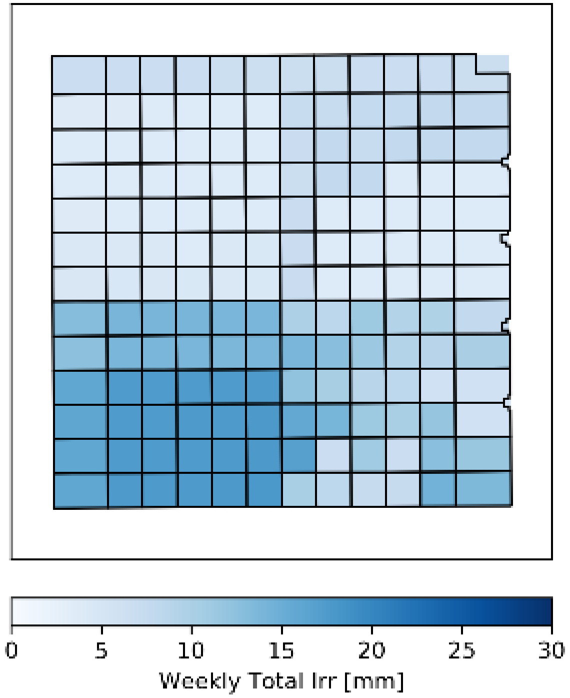
2 million acres



38.5 acres



Prescribed Irrigation



March 2018							
Nº	S	M	T	W	T	F	S
9					1	2	3
10	4	5	6	7	8	9	10
11	11	12	13	14	15	16	17
12	18	19	20	21	22	23	24
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April 2018							
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16	15	16	17	18	19	20	21
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21	20	21	22	23	24	25	26
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25	17	18	19	20	21	22	23
26	24	25	26	27	28	29	30

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29	15	16	17	18	19	20	21
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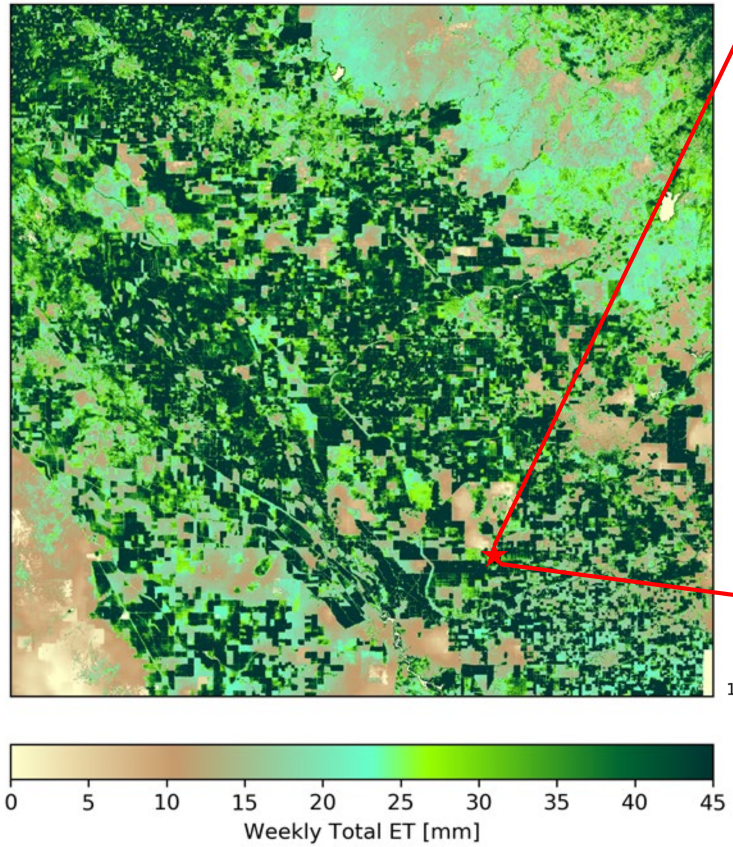
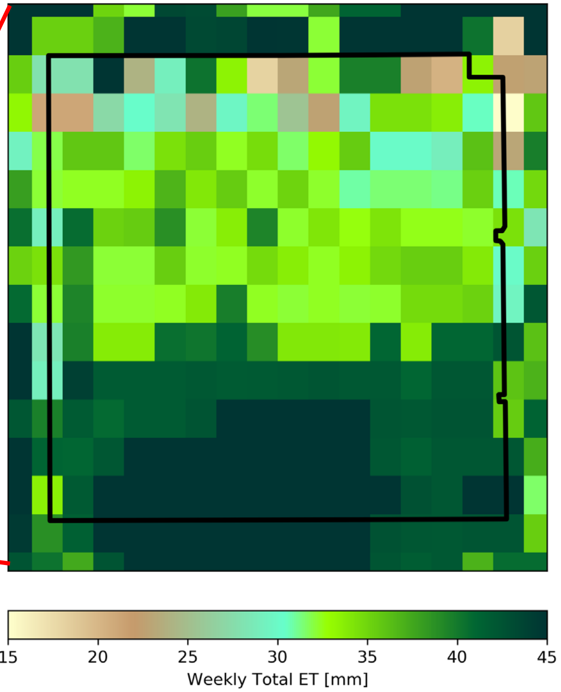
33	12	13	14	15	16	17	18
34	19	20	21	22	23	24	25
35	26	27	28	29	30	31	

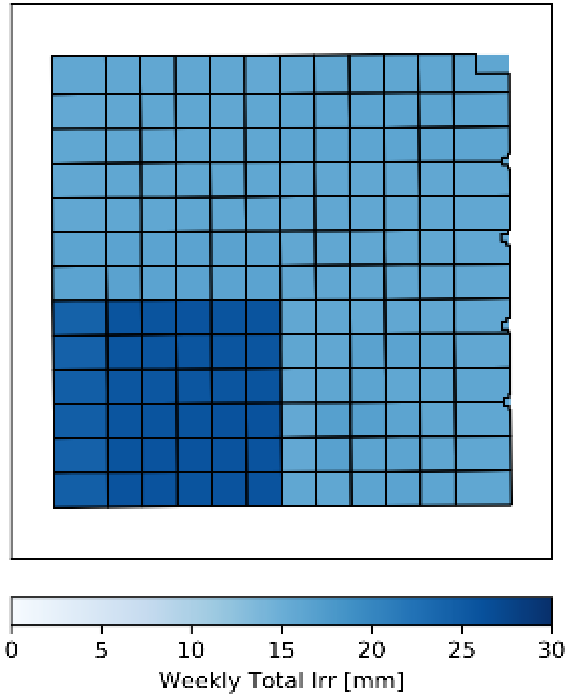
2 million acres

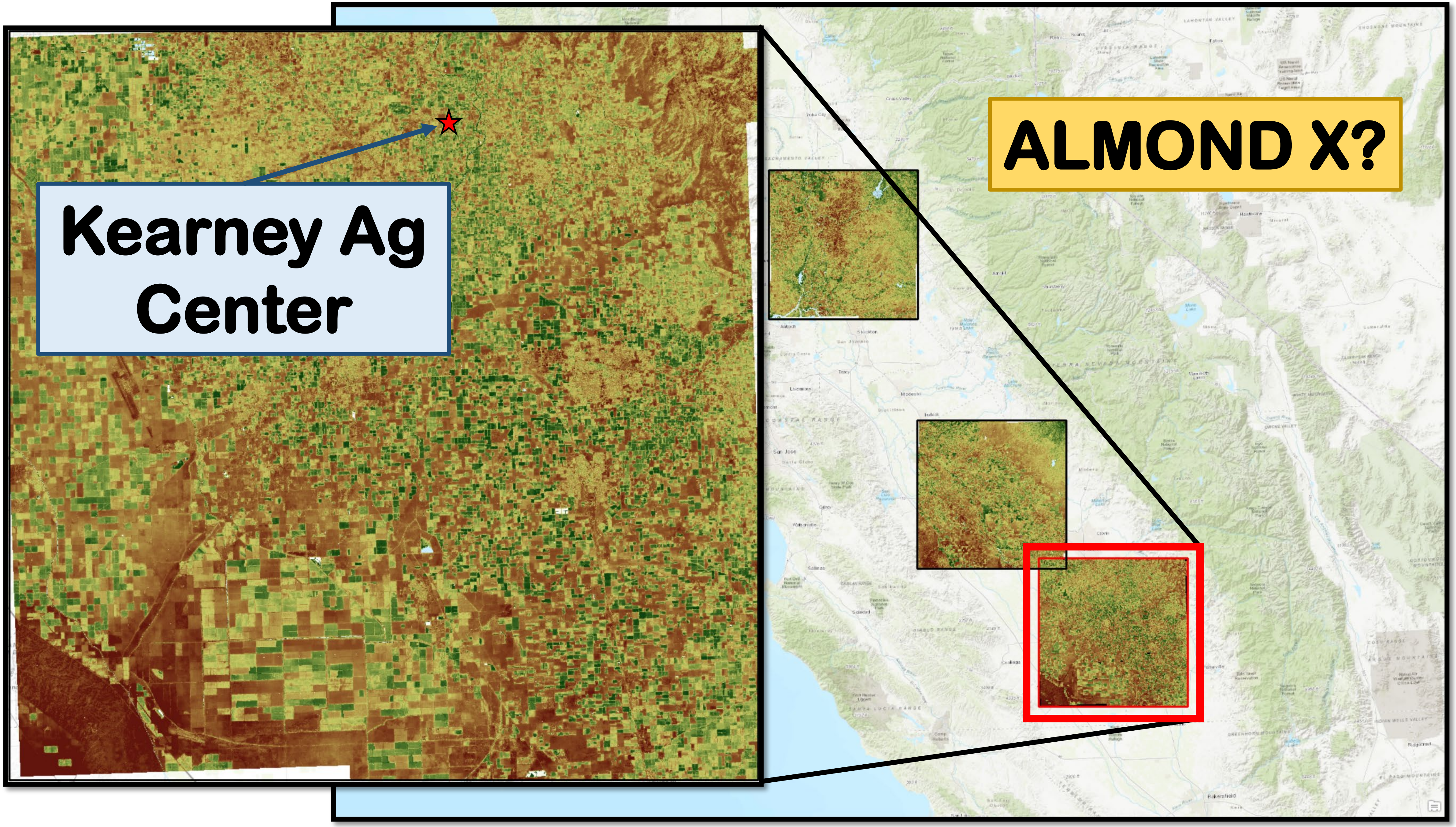


38.5 acres

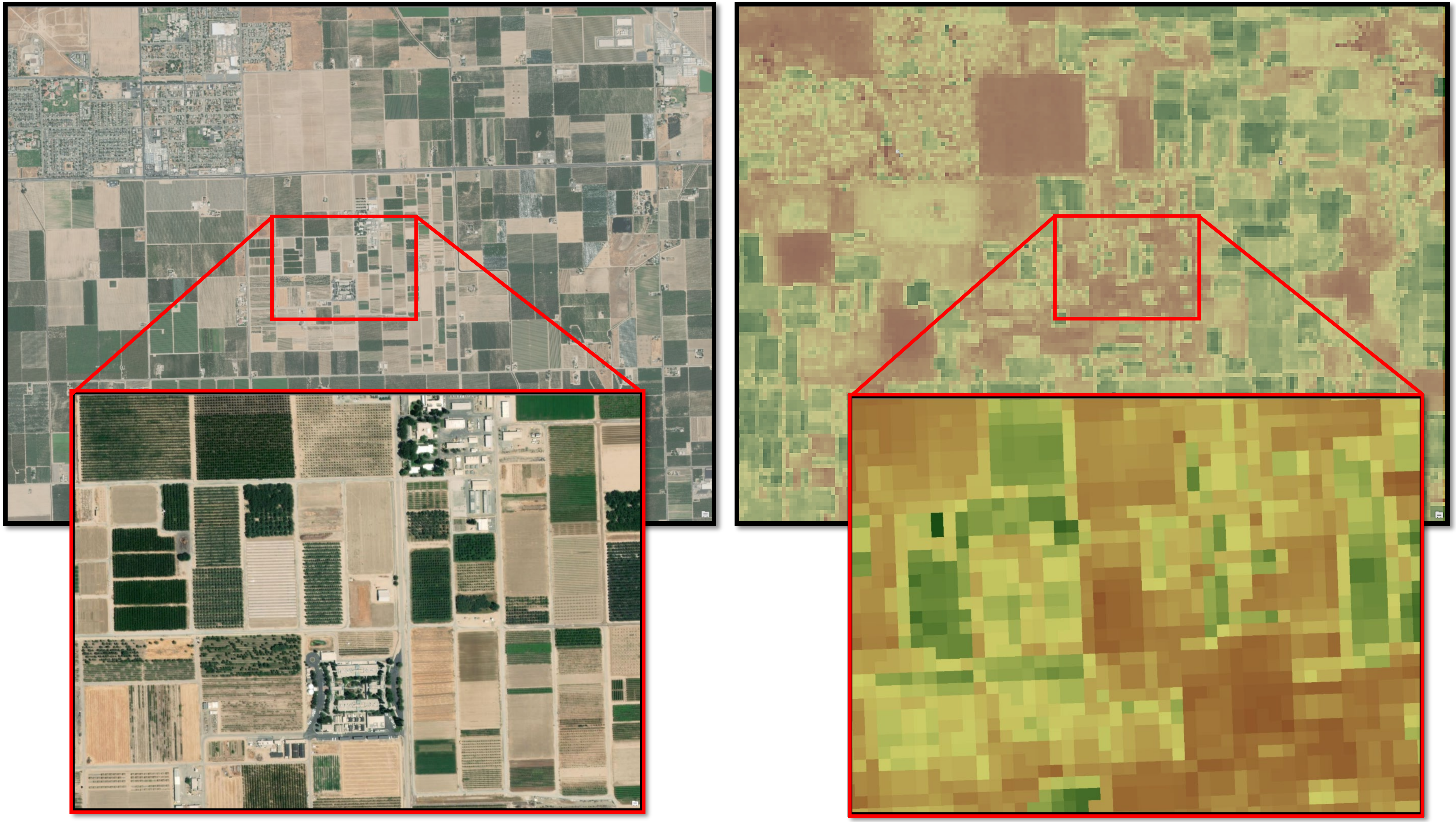


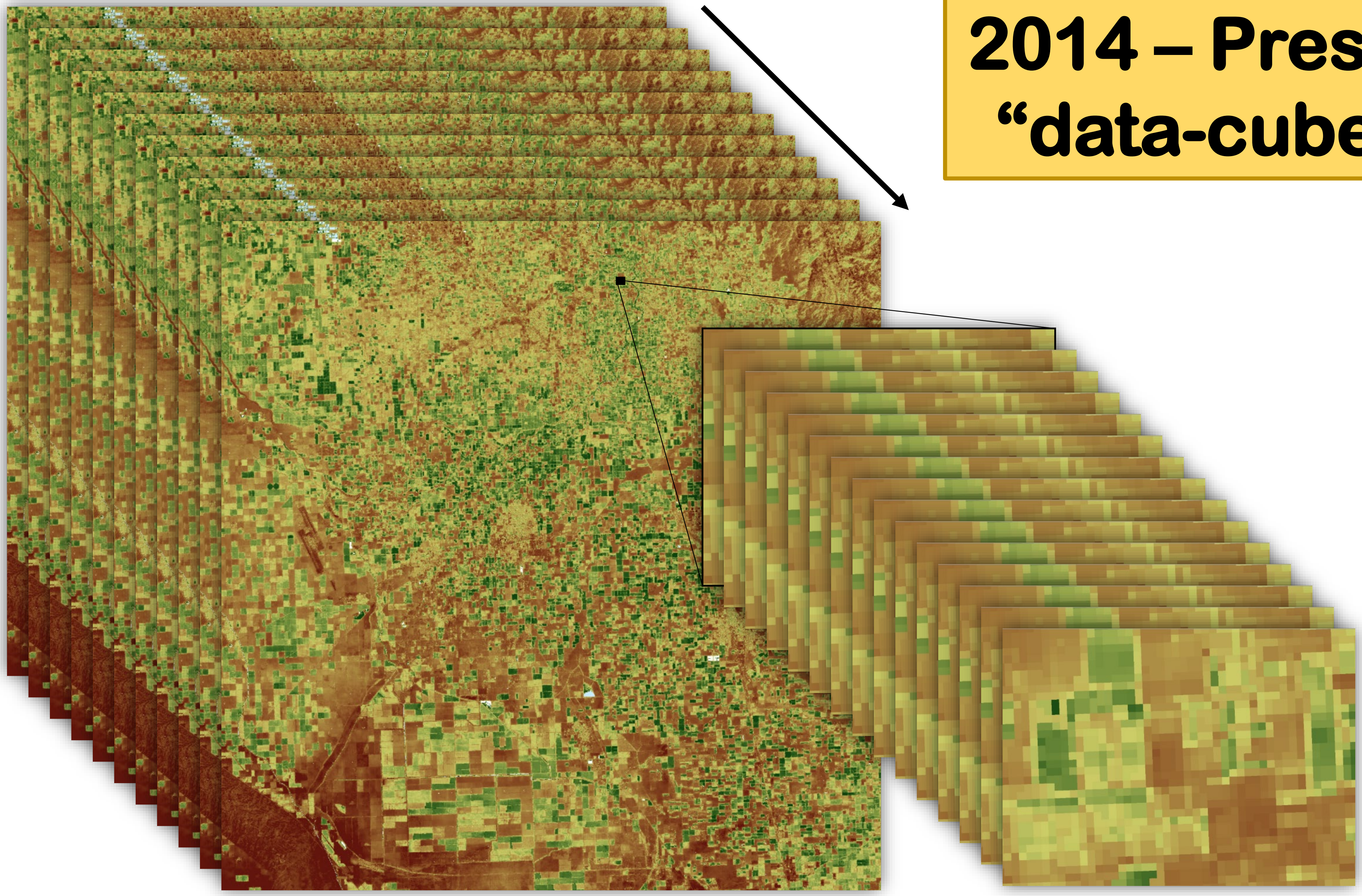
Prescribed Irrigation





Kearney Ag Center
ALMOND X?





2014 – Present
"data-cubes"

Conclusions

- How much?
  - SR accurately measures vineyard water loss
  - New IRT and remote sensing methods are promising
- When?
  - More work to resolve stress
  - Continuing work on infrared sensors

Assessment of Almond Water Status Using Inexpensive Thermal Imagery

Brian Bailey – U.C. Davis Dept. Plant Sciences

Project Personnel: Magalie Poirier-Pocovi – U.C. Davis Dept. Plant Sciences
Project Cooperators: Bruce Lampinen, Astrid Volder – U.C. Davis Dept. Plant Sciences

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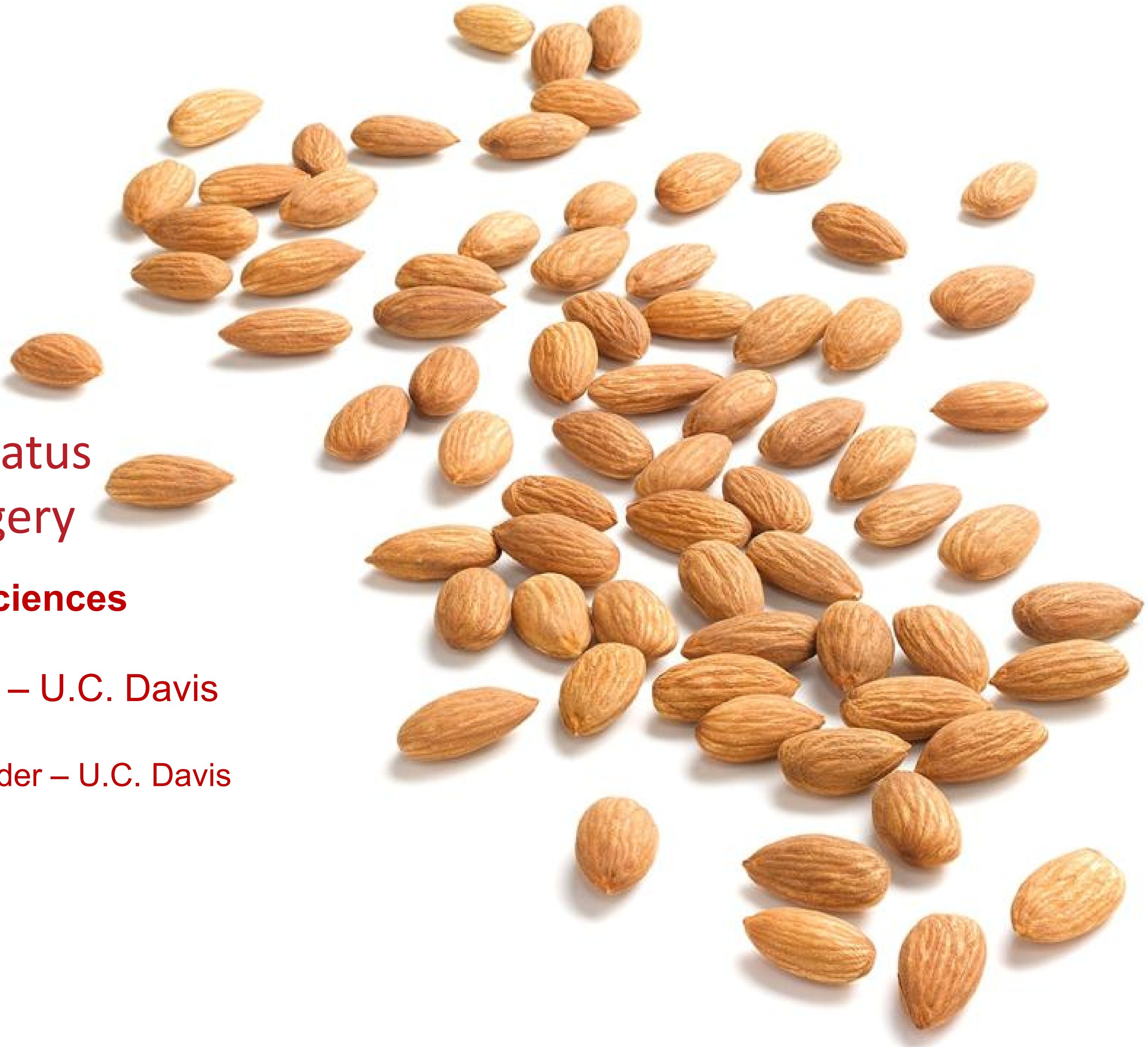
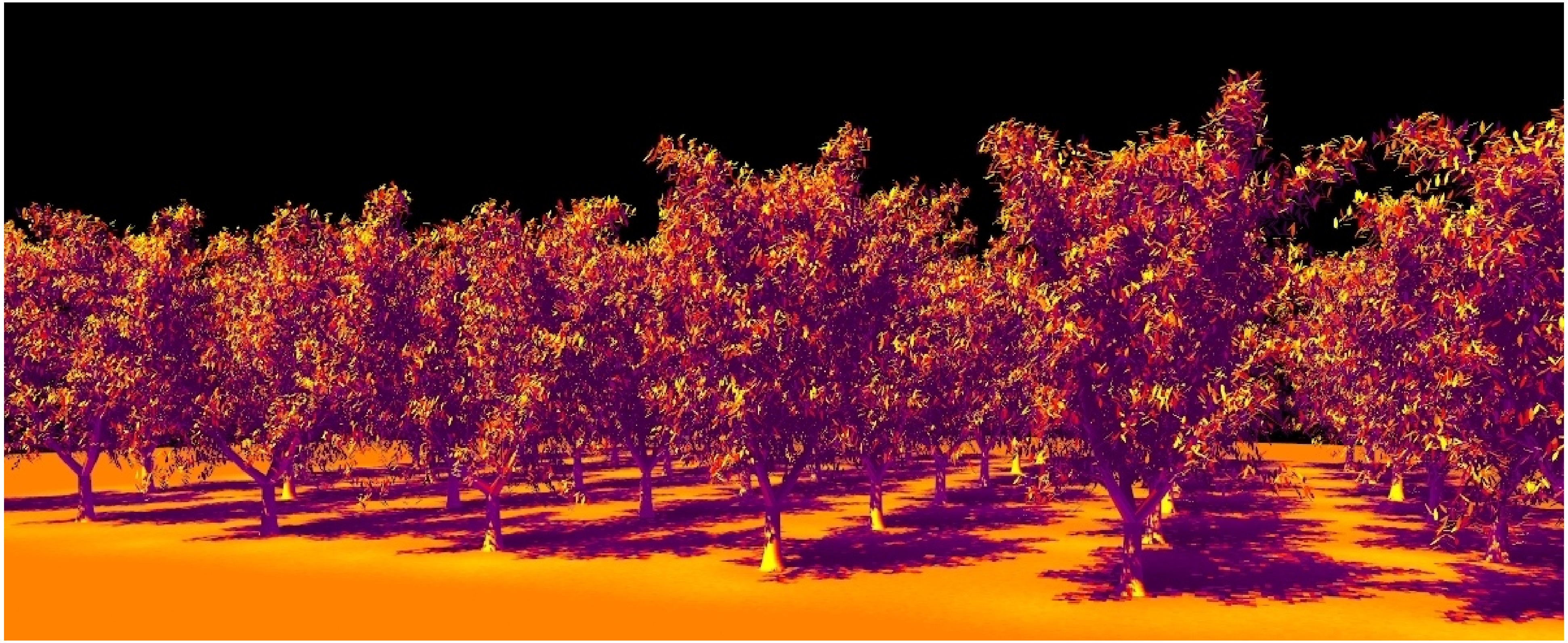
Almond Board of California

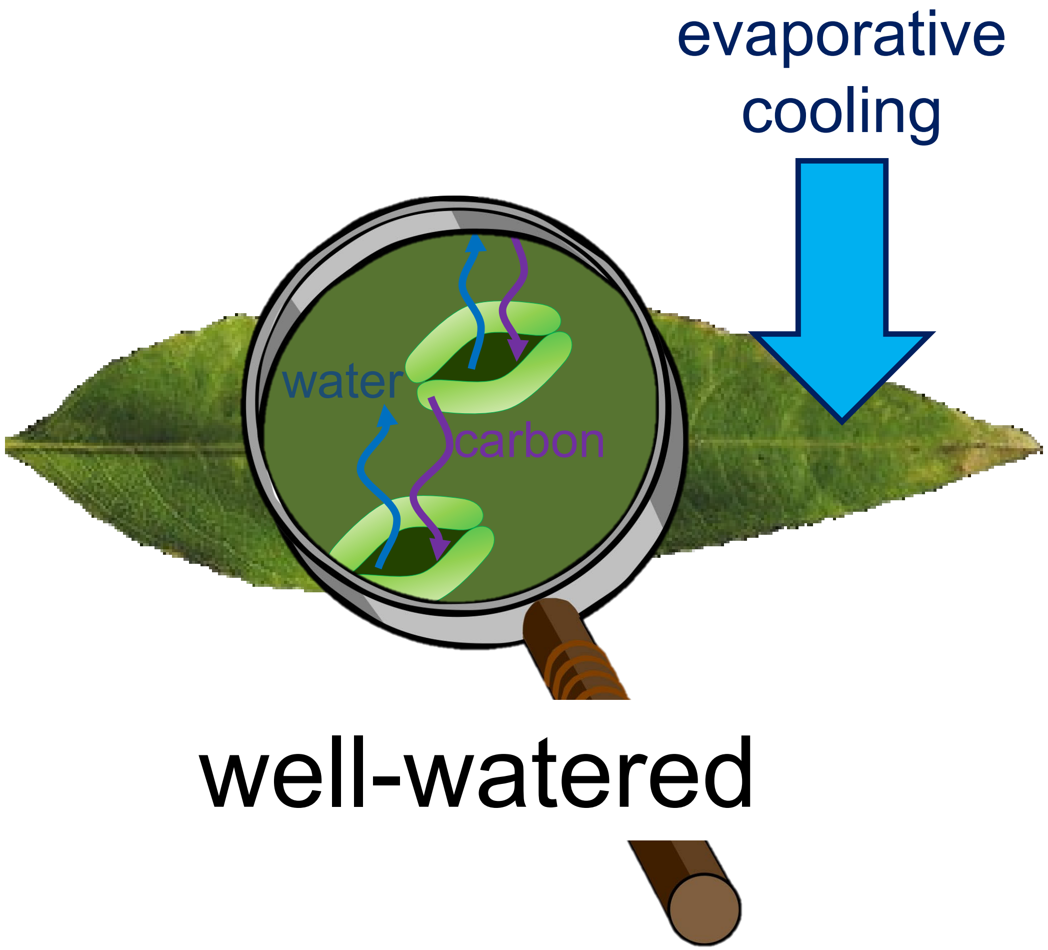


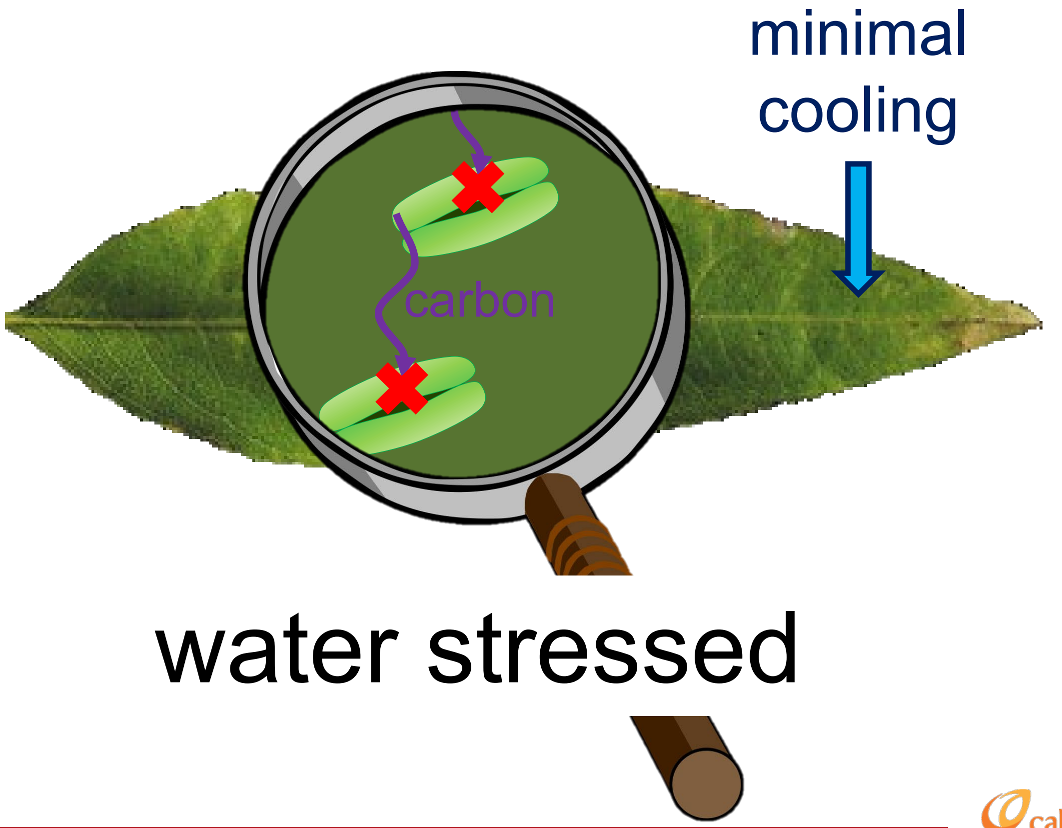
Project Goals

- Evaluate infrared thermography as a potential tool for measurement of plant water needs.
  - Can low-cost thermal cameras be used to infer water status?
  - Is thermography appropriate for scheduling irrigation?



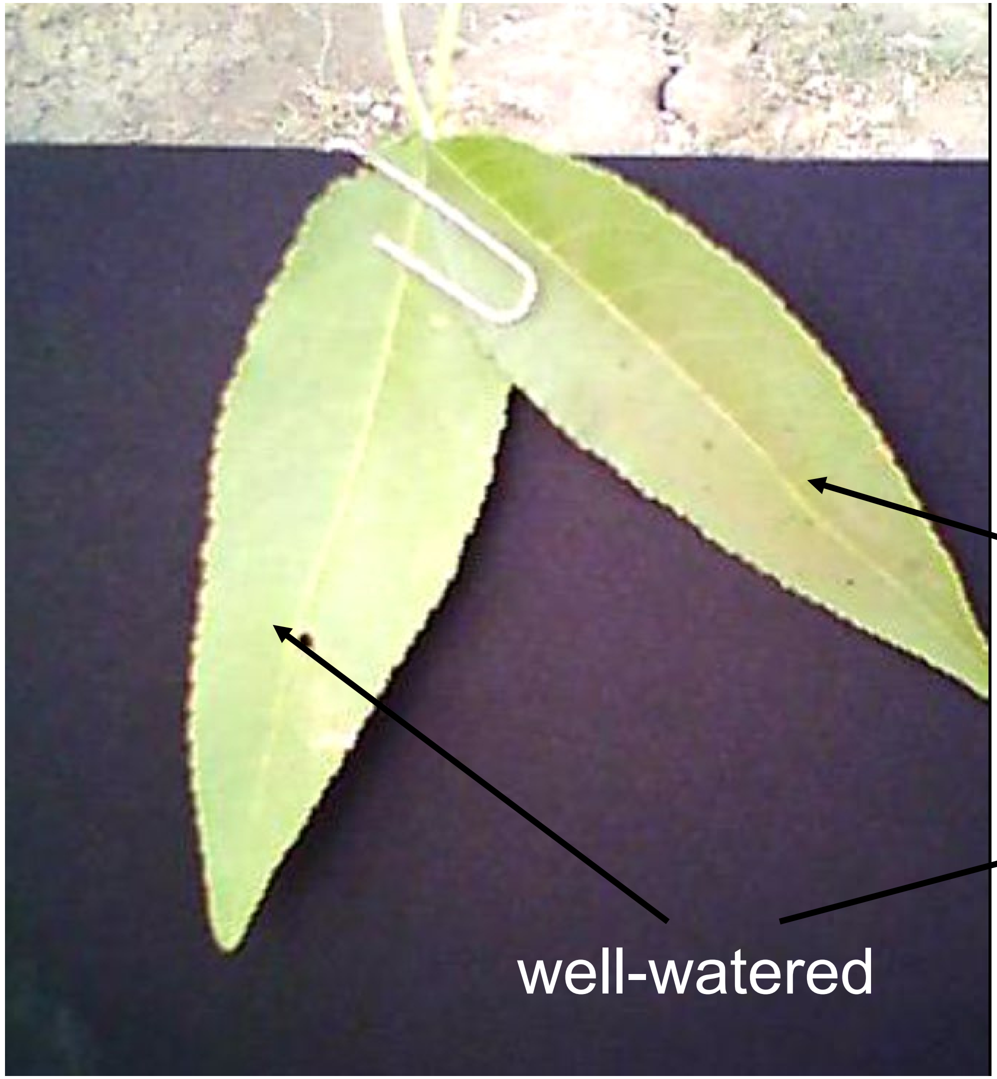
Basic Theoretical Premise



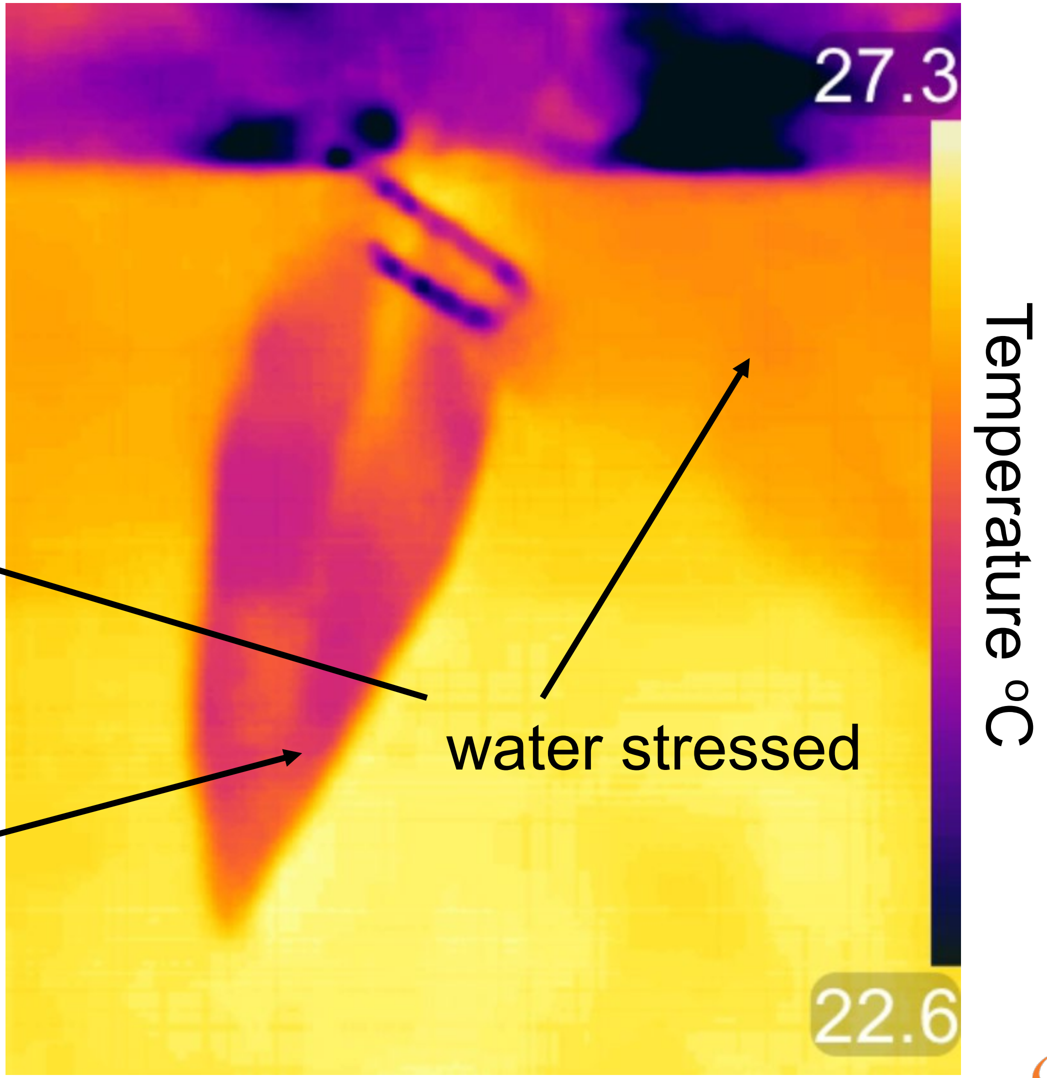


Inferring Water Status from Infrared Thermography

Color Image



Thermal Image

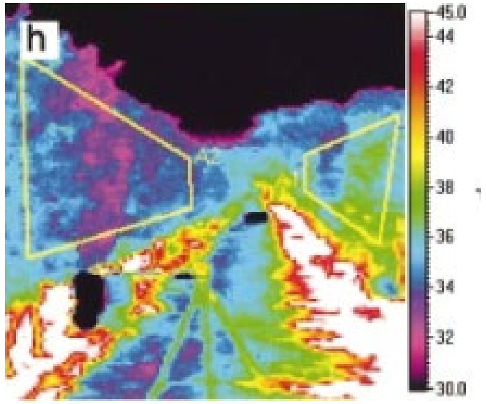


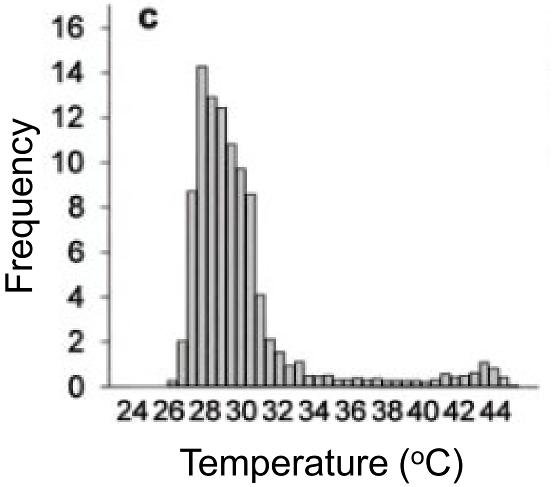
In general, this is not a new technique.

- Pioneered by Idso eta al. (1981). Normalizing the stress-degree-day parameter for environmental variability. *Agric Meteorol.* 24:44-55

- Dozens of papers illustrating that the technique can detect crop water “stress”

Inferring Water Status from Infrared Thermography

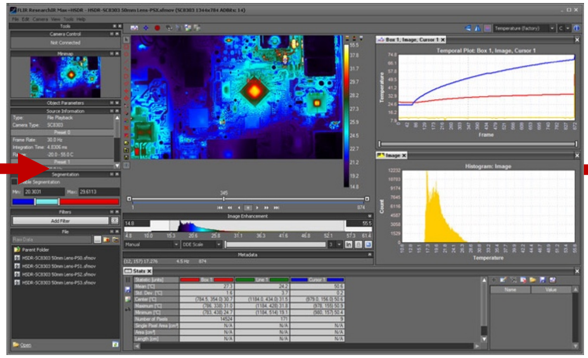




Inherent Limitations:

- Cost: starts at around $20,000
- Speed: We really want to do the data processing in real time to give an indication of water status.

$24,999



Export

3rd Party Software

Reducing the Cost

	Flir One Pro
Cost	$399
Resolution	160x120
Spectral Range	8-14 µm
Operating System	iOS or Android

Drone-Based Thermal Sensing

- ~$2,000
- Microbolometer
- Basically the same as the smartphone FlirOne smartphone camera, but with higher resolution and on-board processing.

Accuracy and Precision of Low-Cost Thermal Cameras

low accuracy, high precision

high accuracy, low precision

- Inexpensive thermal cameras (microbolometers) have relatively good precision, but poor accuracy (±8^{o}F error)
- Good for looking at relative differences in temperature within an image, but not good for measuring the actual value of temperature
- **Bottom line: need a calibration or reference surface/temperature within each image**

Challenges in Applying Thermal Methods:

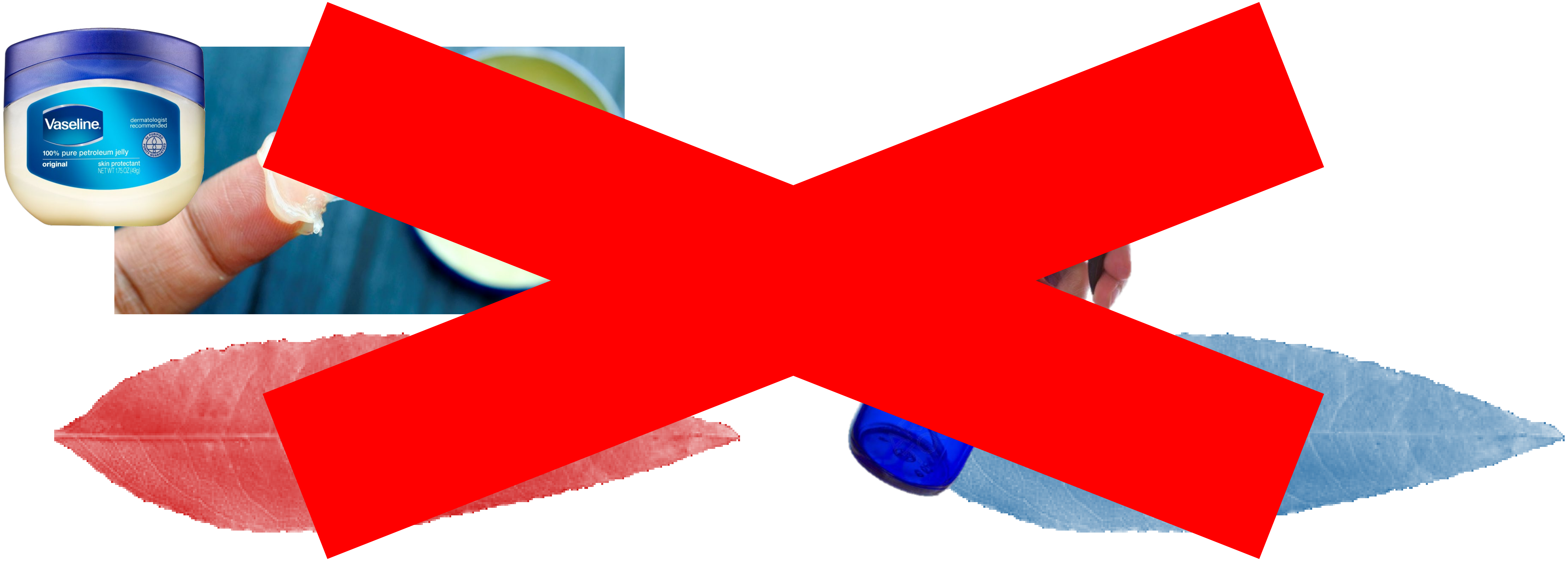
The temperature of a leaf is influenced by many other factors besides how much we water the tree:

- Weather: sunlight, air temperature, humidity, etc.

This means we need to correct or "normalize" our temperature for weather

$$\text{crop water stress index} = \text{CWSI} = \frac{T_{dry} - T}{T_{dry} - T_{wet}}$$

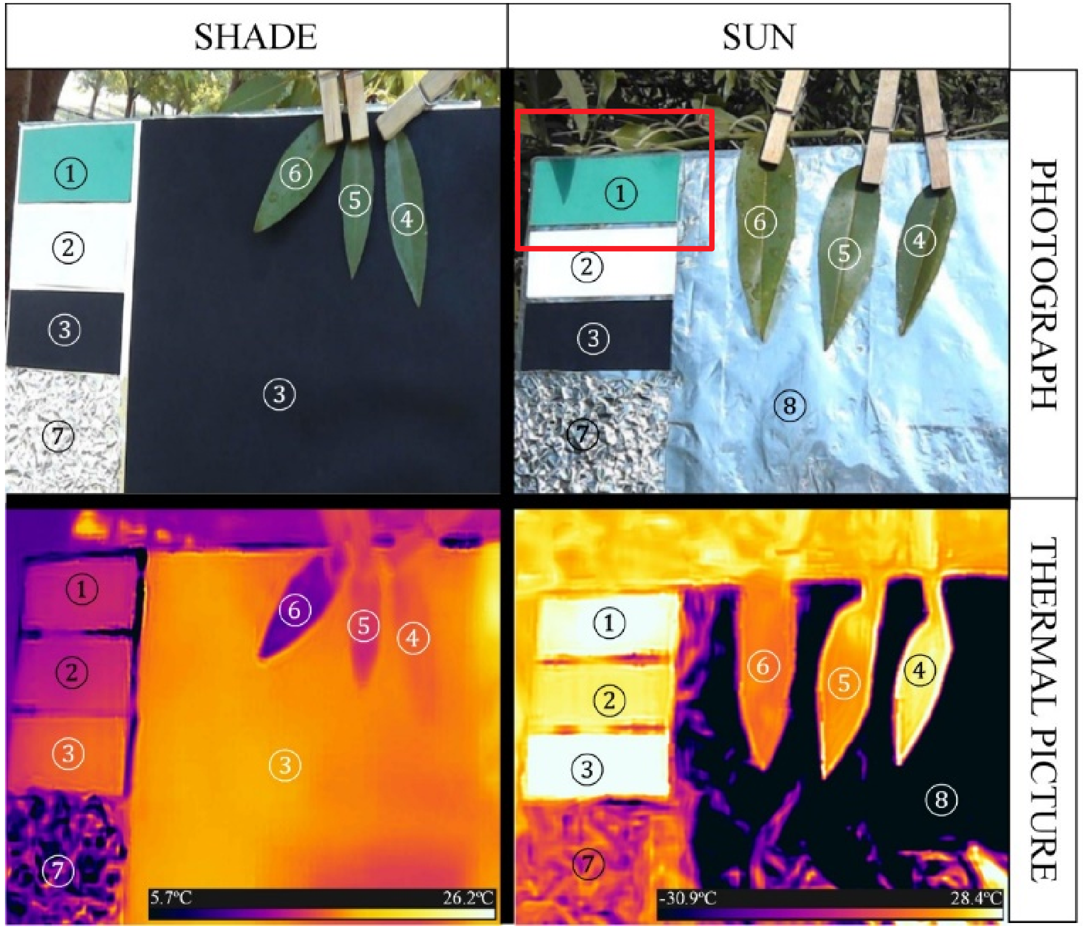
Calibrating for Weather Effects:



“dry” temperature (maximum)

“wet” temperature (minimum)

Easier Method for Collecting Reference Temperatures



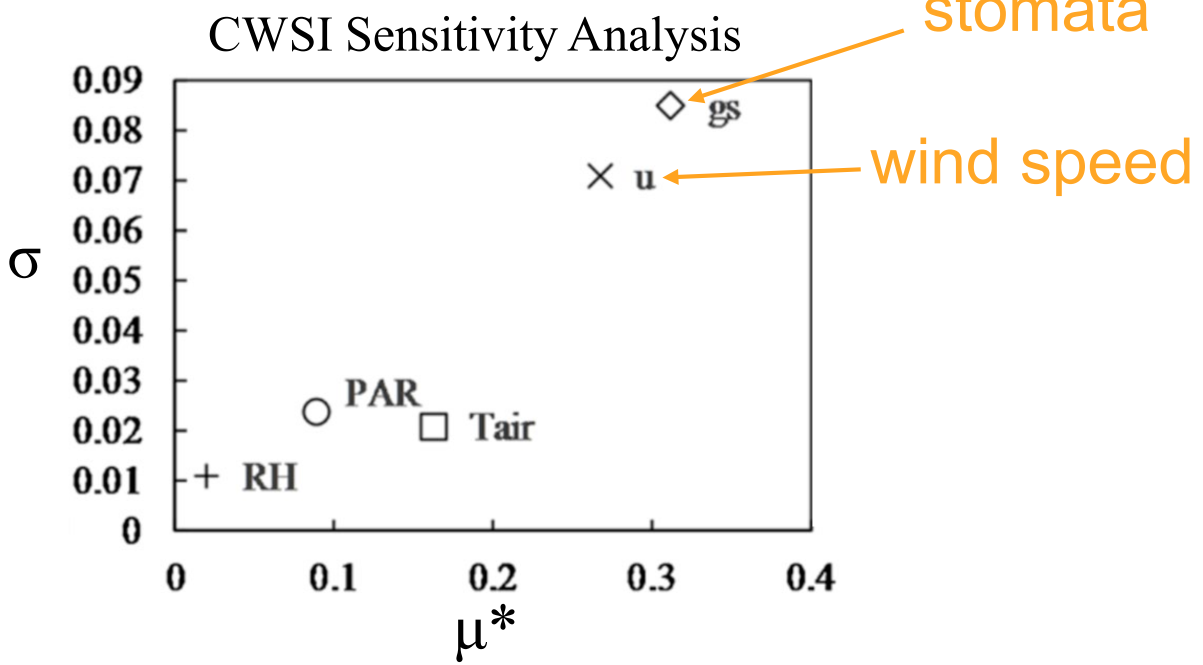
In the sun, we could accurately estimate the wet and dry reference temperatures based on the temperature of green paper.

$$CWSI = \frac{T_{dry} - T}{T_{dry} - T_{wet}}$$

Q: Does the CWSI really remove the effects of weather?

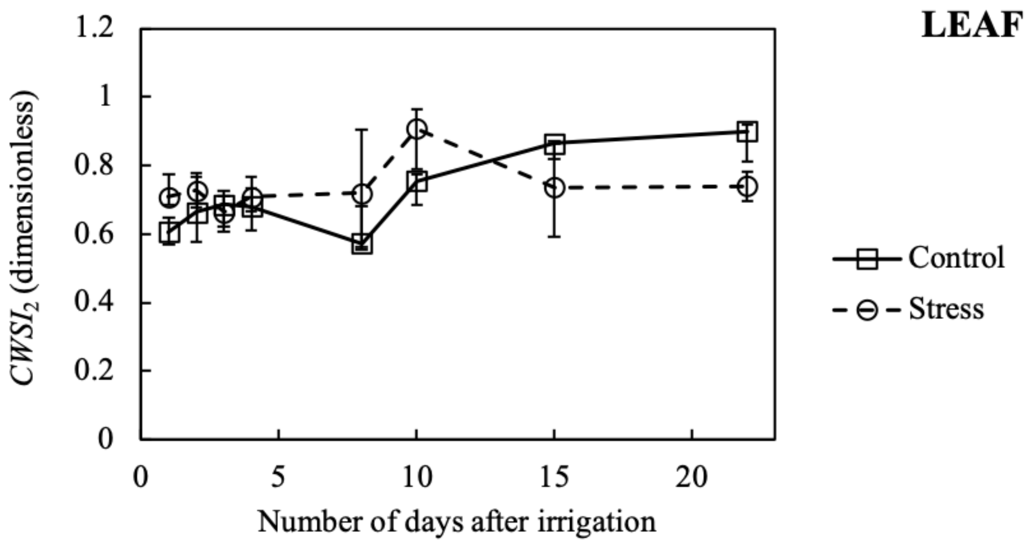
A: Almost…

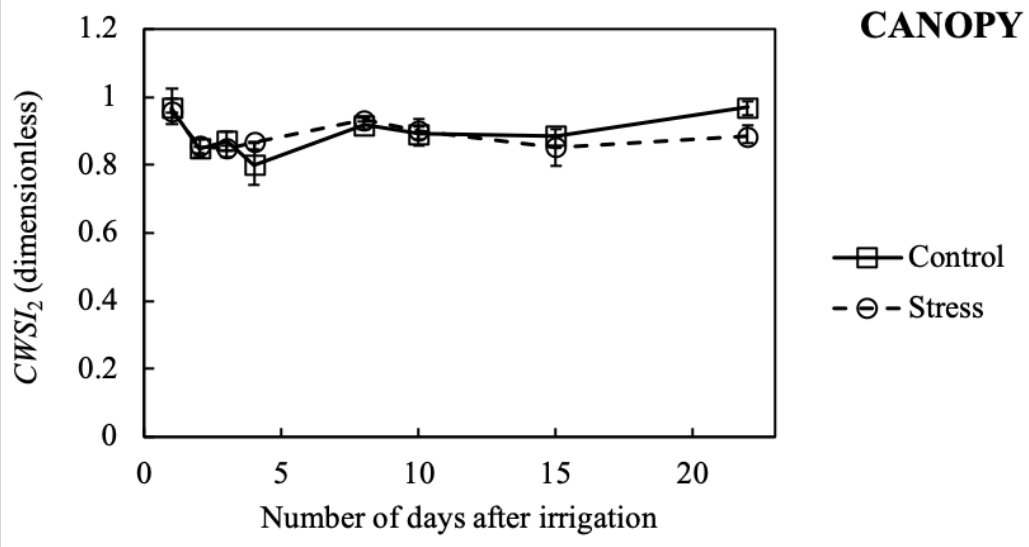
$$\text{CWSI} = \frac{T_{dry} - T}{T_{dry} - T_{wet}}$$

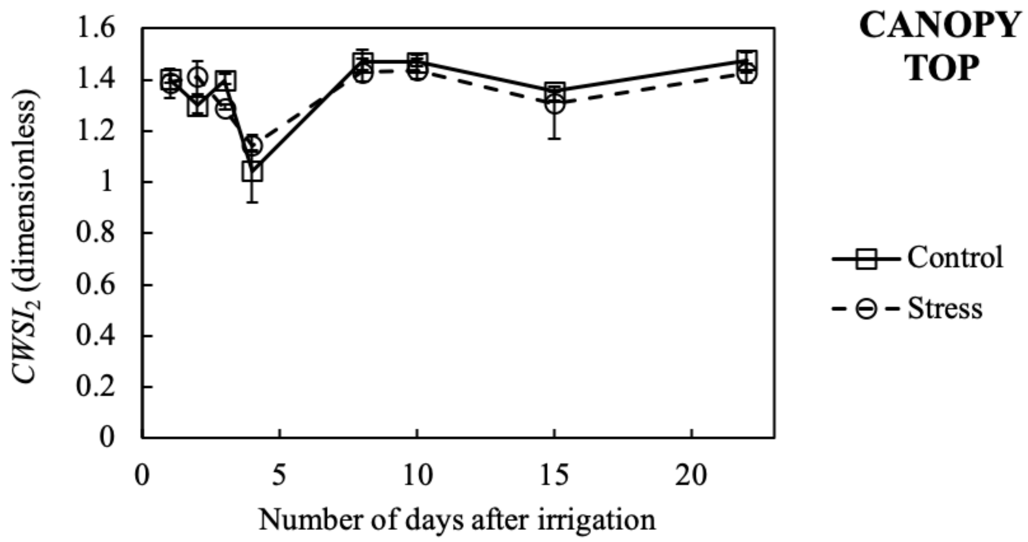


The CWSI is as sensitive to the wind as it is to stomata (i.e., water status) – this is a problem.

How Does It Perform?



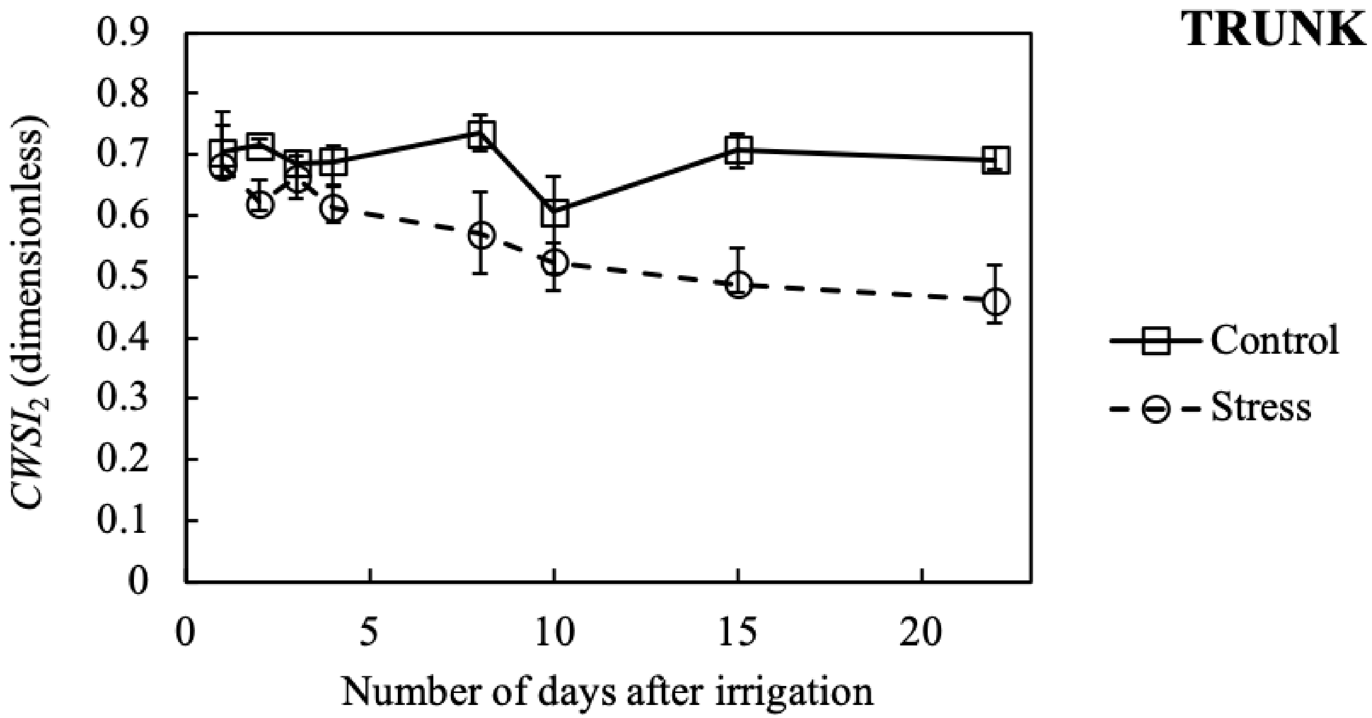




How Does It Perform?

$$CWSI = \frac{T_{trunk} - T_{soil}}{T_{air} - T_{soil}}$$

CWSI based on trunk temperature



Summary

- Is leaf/canopy infrared thermography capable of measuring almond water "stress"?
  - Yes, if the trees are very stressed. But when they are very stressed, you can probably see the symptoms visually.
- Is leaf/canopy infrared thermography capable of capturing spatial variation in water status across the orchard? (e.g., broken irrigation line, significant changes in soil texture)
  - Yes, provided the variation is "significant".
- Is leaf/canopy infrared thermography useful for determining *when* to irrigate?
  - Unless you are running deficit irrigation, not really.
- Is leaf/canopy infrared thermography useful for determining *how much* to irrigate?
  - Not really, because it is not very sensitive when trees are fully hydrated.

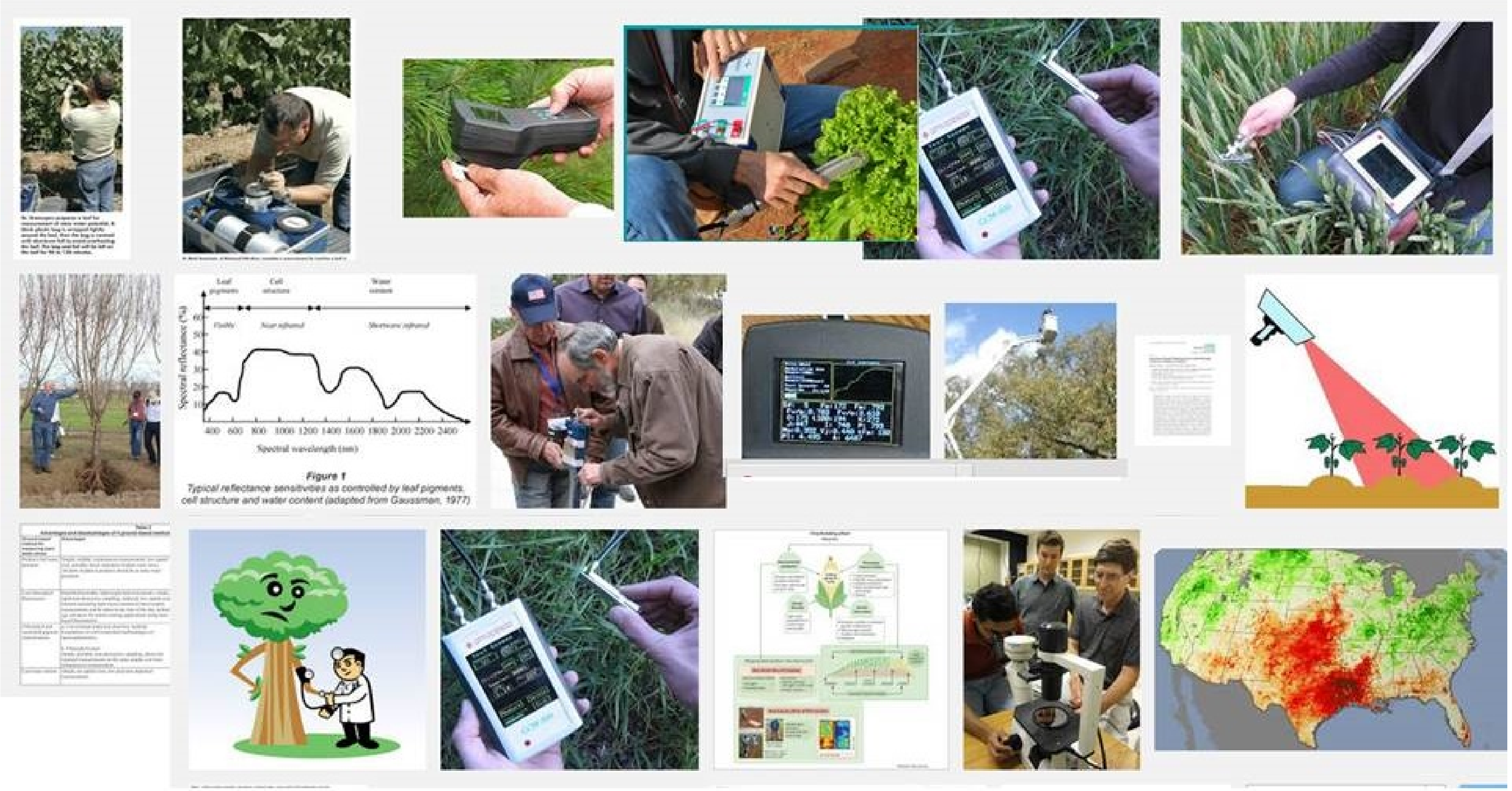
Work for Next Season

- Further explore the idea of trunk temperature based method
- Verify results on different soil types

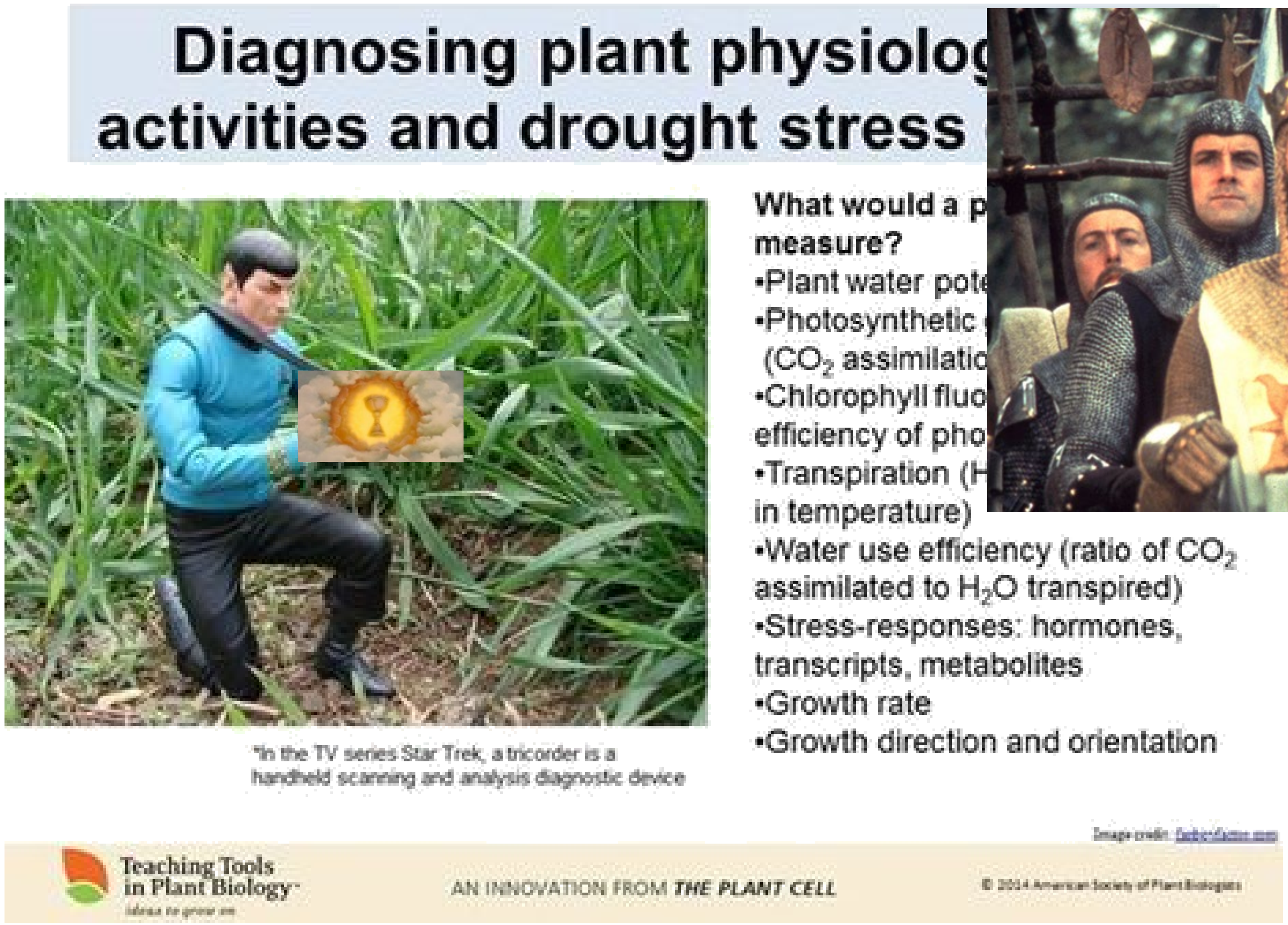
Thank You

This research was supported by the Almond Board of California project #17-HORT31-Bailey/ 18-HORT31-Bailey / 19-HORT31-Bailey

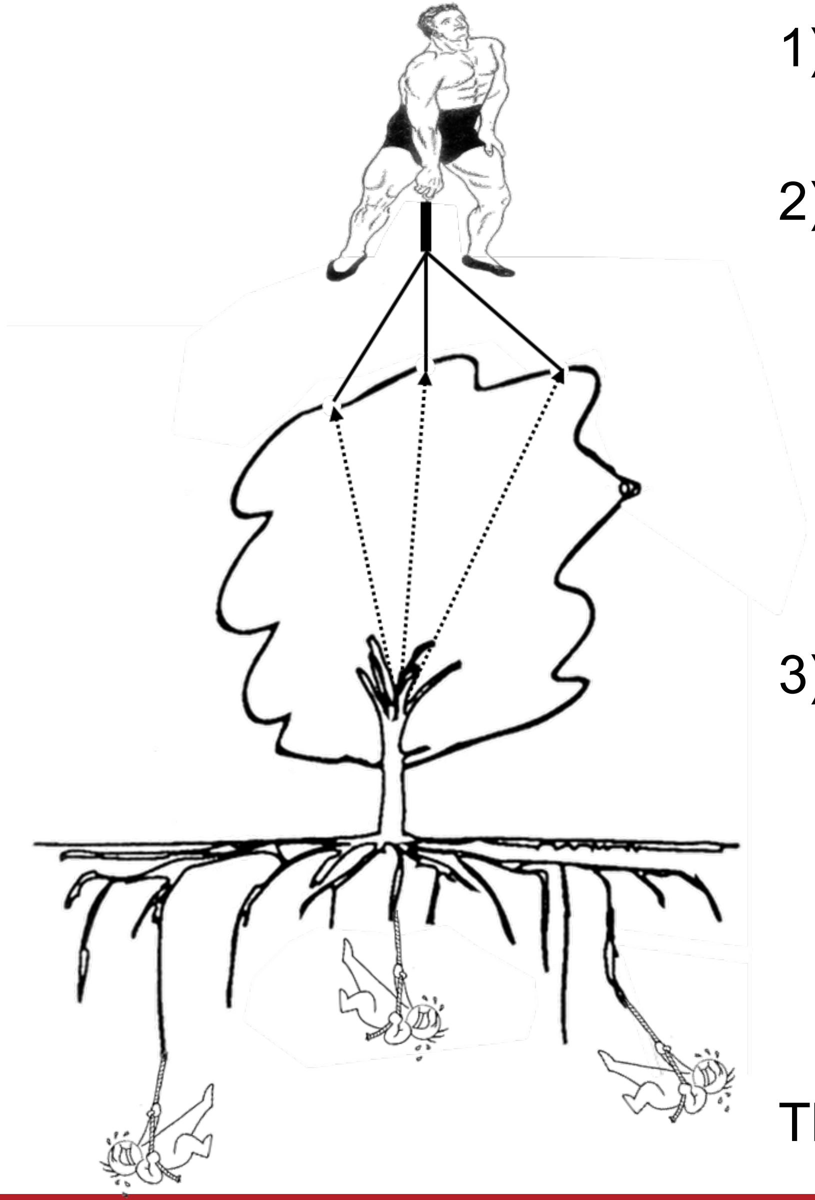
Tree water sensors that are currently on the market



Tree water sensors that are currently on the market
(futuristic vision of the multi-purpose sensor, 1966)



Direct and **Indirect** measures of water stress in almonds:



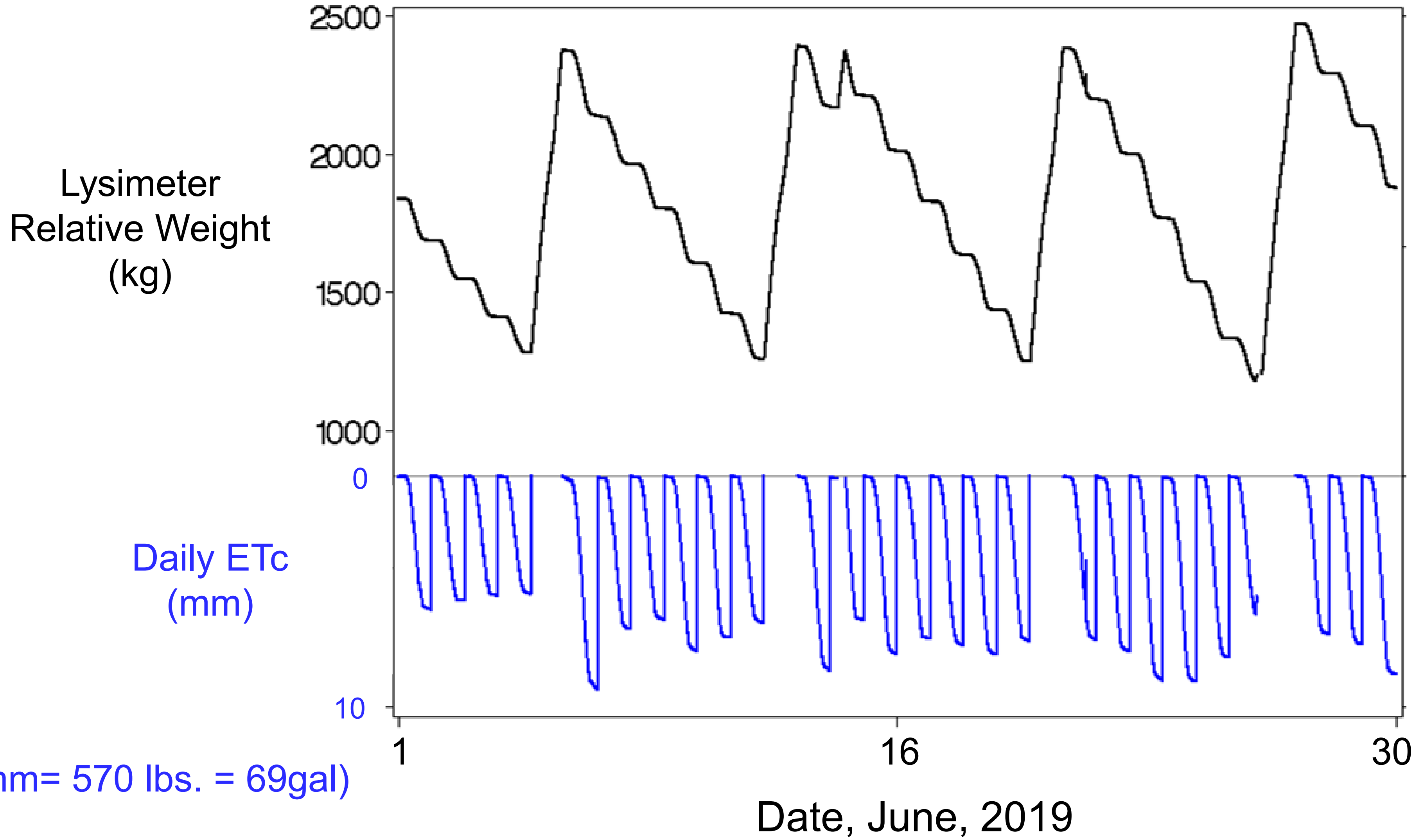
1) Plant water is under tension, especially when soil dries.
2) Assuming that the level of tension itself is the cause of almond water stress responses, the methods that measure this tension **directly** are:
   a) Pressure chamber/'bomb'
   b) Micro-tensiometer
   c) Psychrometer/Hygrometer
3) Some processes that can be used as **indirect** indicators of water stress are:
   a) Growth patterns of various parts (e.g., the trunk)
   b) Leaf or canopy temperature
   c) (Many others)

The perfect water sensor? ⬇$⬆

Almond lysimeter, Kearney Ag Center, Parlier, CA.

1) Directly measure ET
2) Use as a tool to study water stress

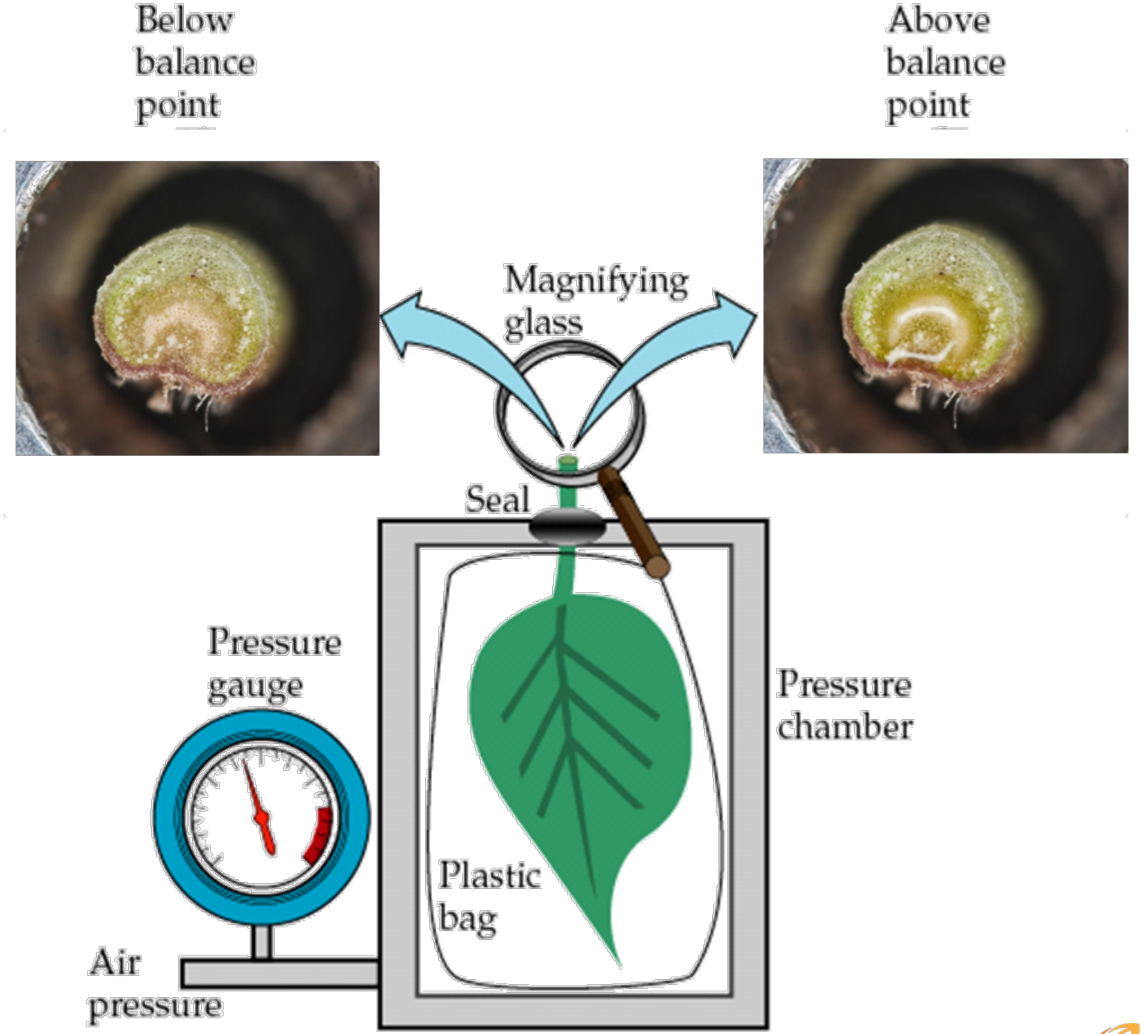
ETc: "Evapo-Transpiraiton" of the Crop.
Can be accurately measured as the daily loss of water weight.



(10 mm= 570 lbs. = 69gal)

Sensors: Direct (SWP)

1) Pressure chamber (many types)



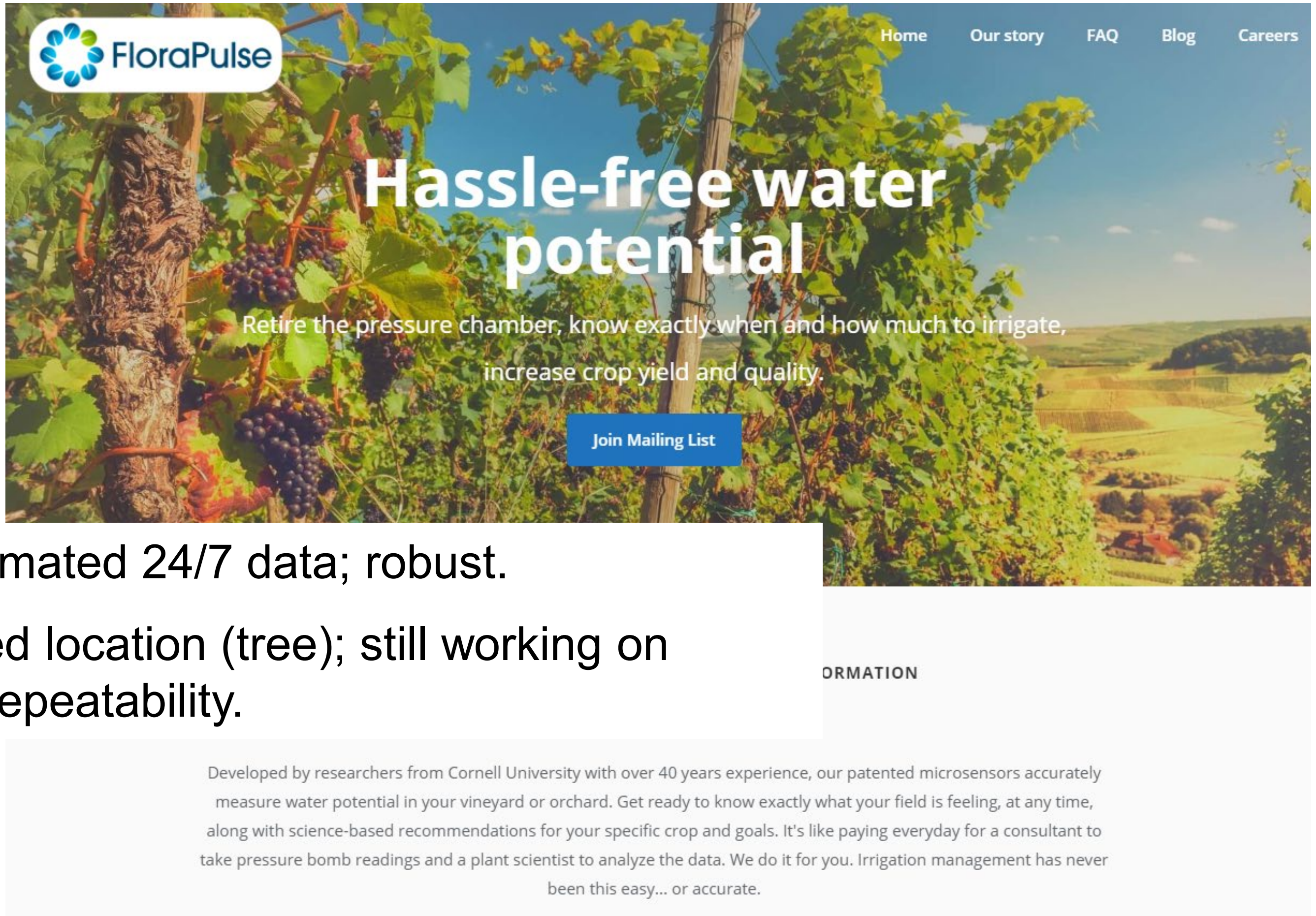
Pros: Established accuracy/repeatability; mobile (test multiple trees/sites).

Cons: Not automated, typically used for daily (midday) snapshot.

california almonds
Almond Board of California

Sensors: Direct (SWP)

1) Pressure chamber (many types)
2) Microtensiometer (FloraPulse)



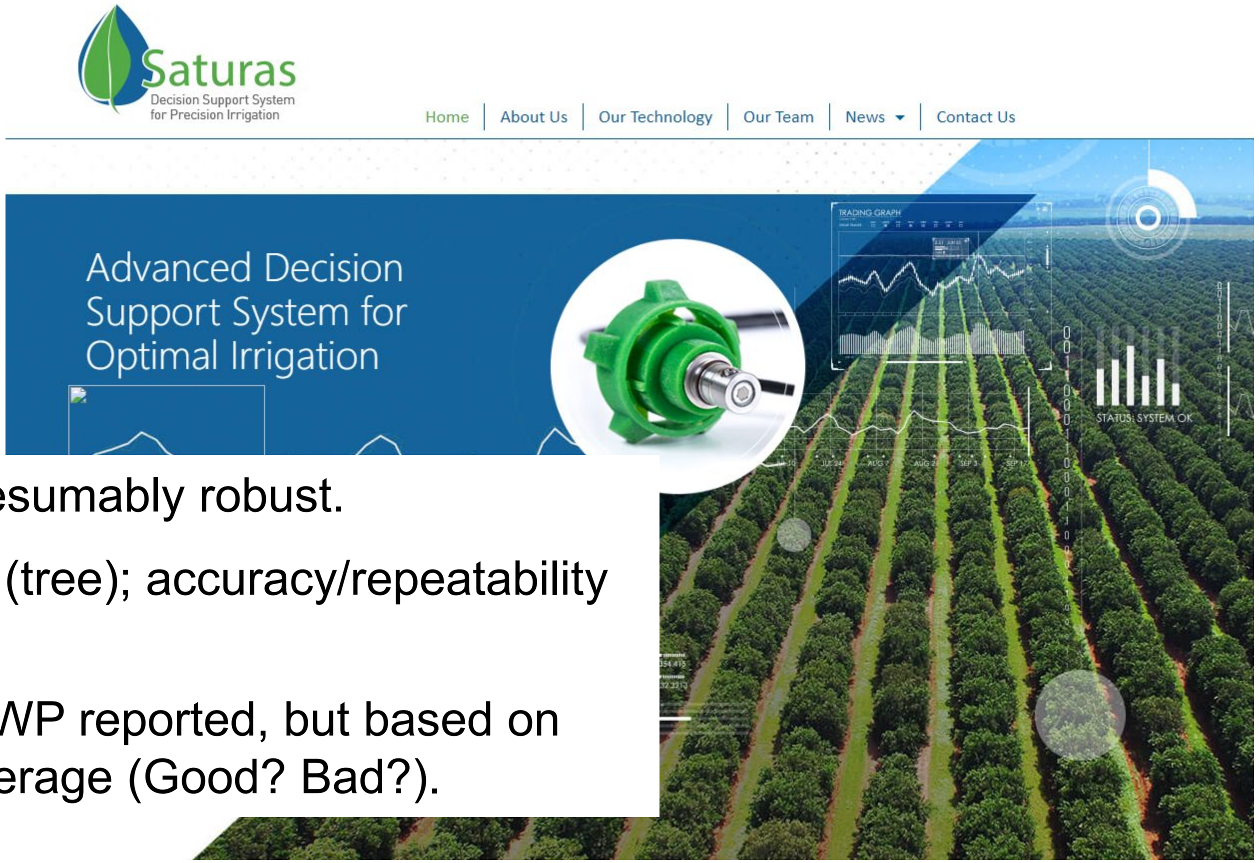
Pros: Automated 24/7 data; robust.

Cons: Fixed location (tree); still working on accuracy/repeatability.

california almonds
Almond Board of California

Sensors: Direct (SWP)

1) Pressure chamber (many types)
2) Microtensiometer (FloraPulse)
3) Miniature SWP sensor (Saturas – not tested)



Pros: Automated; presumably robust.

Cons: Fixed location (tree); accuracy/repeatability not yet clear.

Uncertain: Midday SWP reported, but based on correlation to 24h average (Good? Bad?).

Sensors: Direct (SWP)

1) Pressure chamber (many types)
2) Microtensiometer (FloraPulse)
3) Miniature SWP sensor (Saturas)
4) Stem Psychrometer/Hygrometer (ICT)

Pros: Automated 24/7 data.

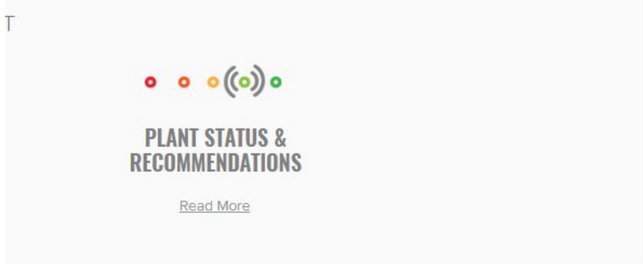
Cons: Fixed location (tree); difficult to know if data is correct without pressure chamber check; very temperature/handling sensitive; not robust.

Temperature compensated *in-situ* stem psychrometer (direct)

First publication: Dixon and Tyree, 1984

Sensors: Indirect (growth/swell/shrink)

1) Trunk dendrometers (Phytech)

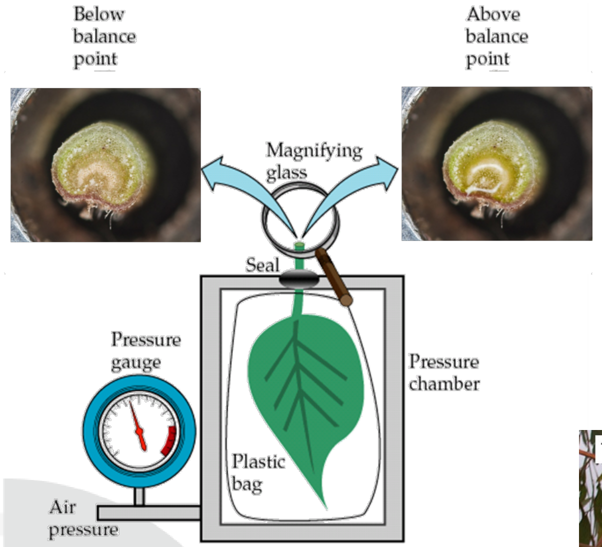


Pros: Automated, 24/7 data; robust.

Cons: Indirect; limited (5) levels of ‘plant status’ (saturated, no, low, mild, or high stress); typically based on a minimum of 3 trees.

Q: What should we expect from any tree water sensor?

A: Should be able to detect stress as it develops, in time for irrigation decisions.



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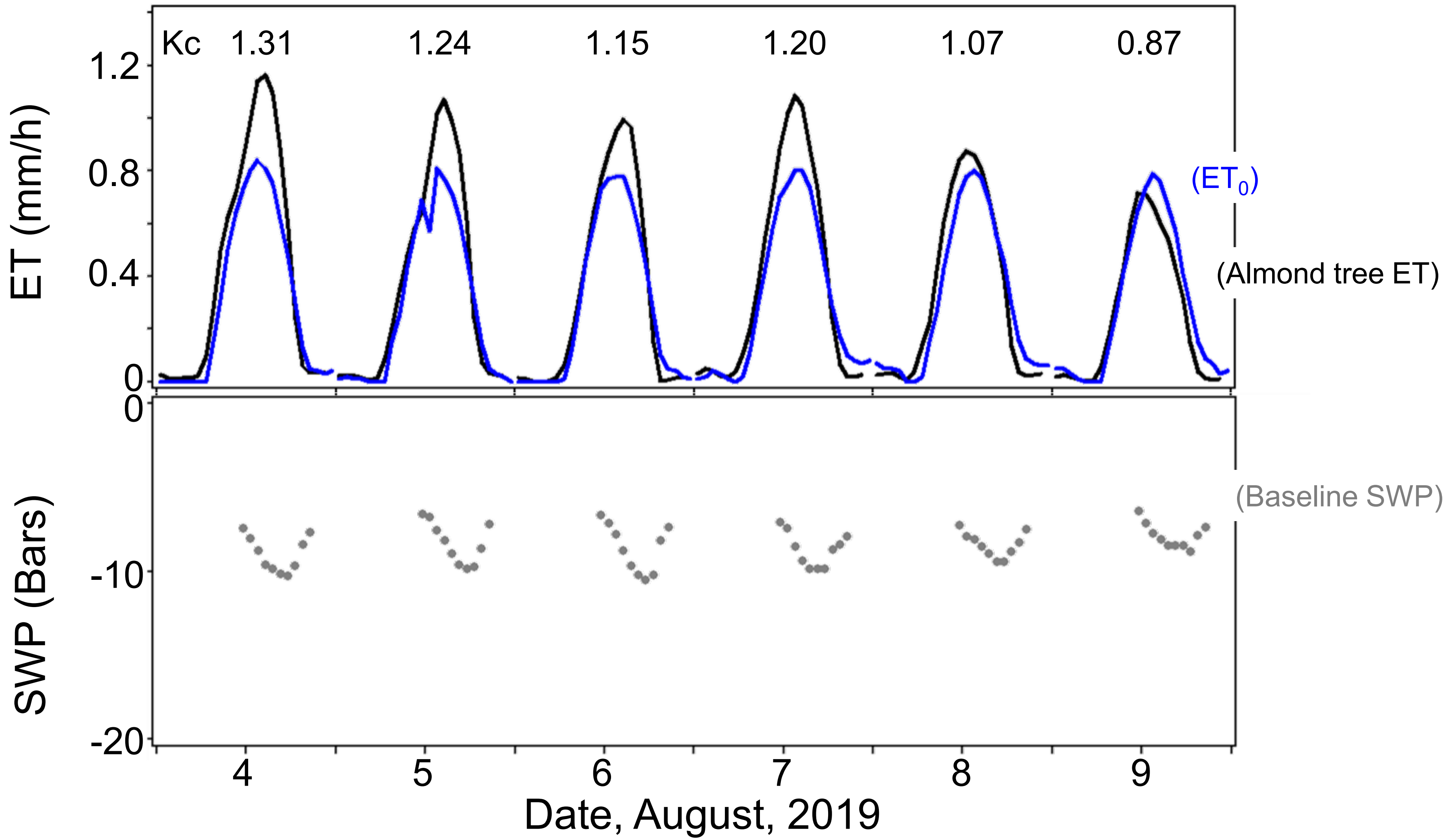
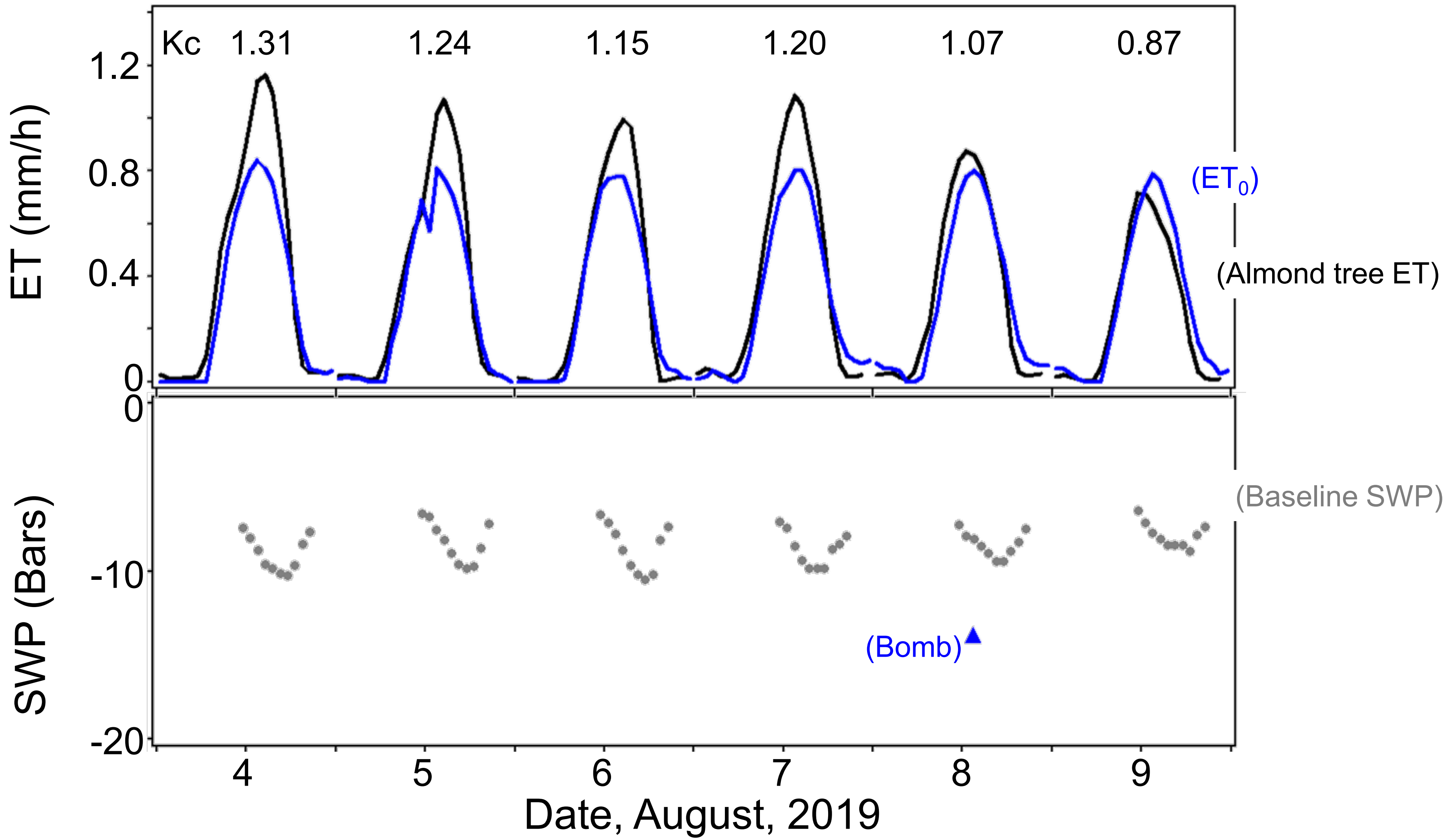
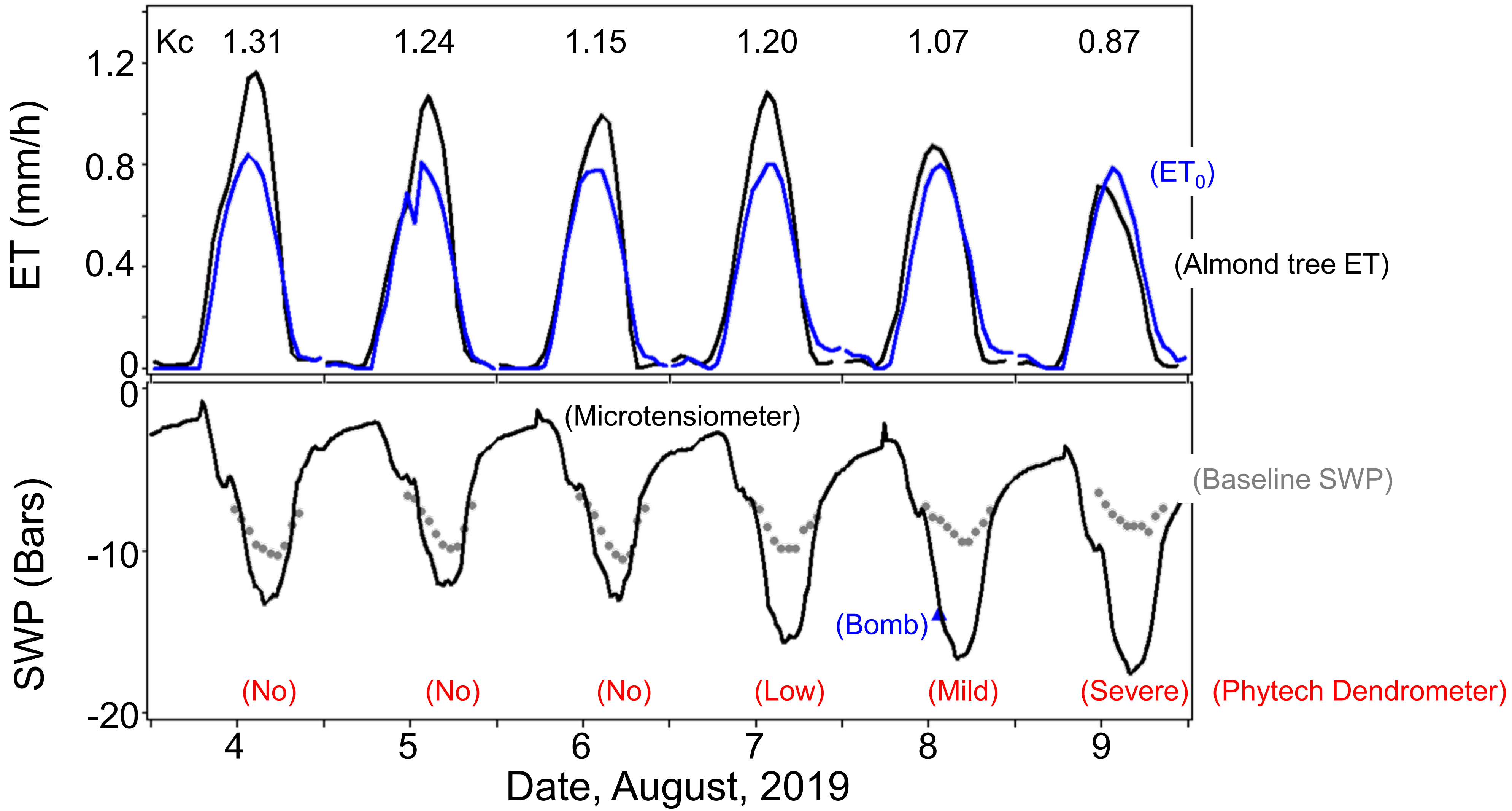
Example 7 day irrigation cycle in August



Example 7 day irrigation cycle in August



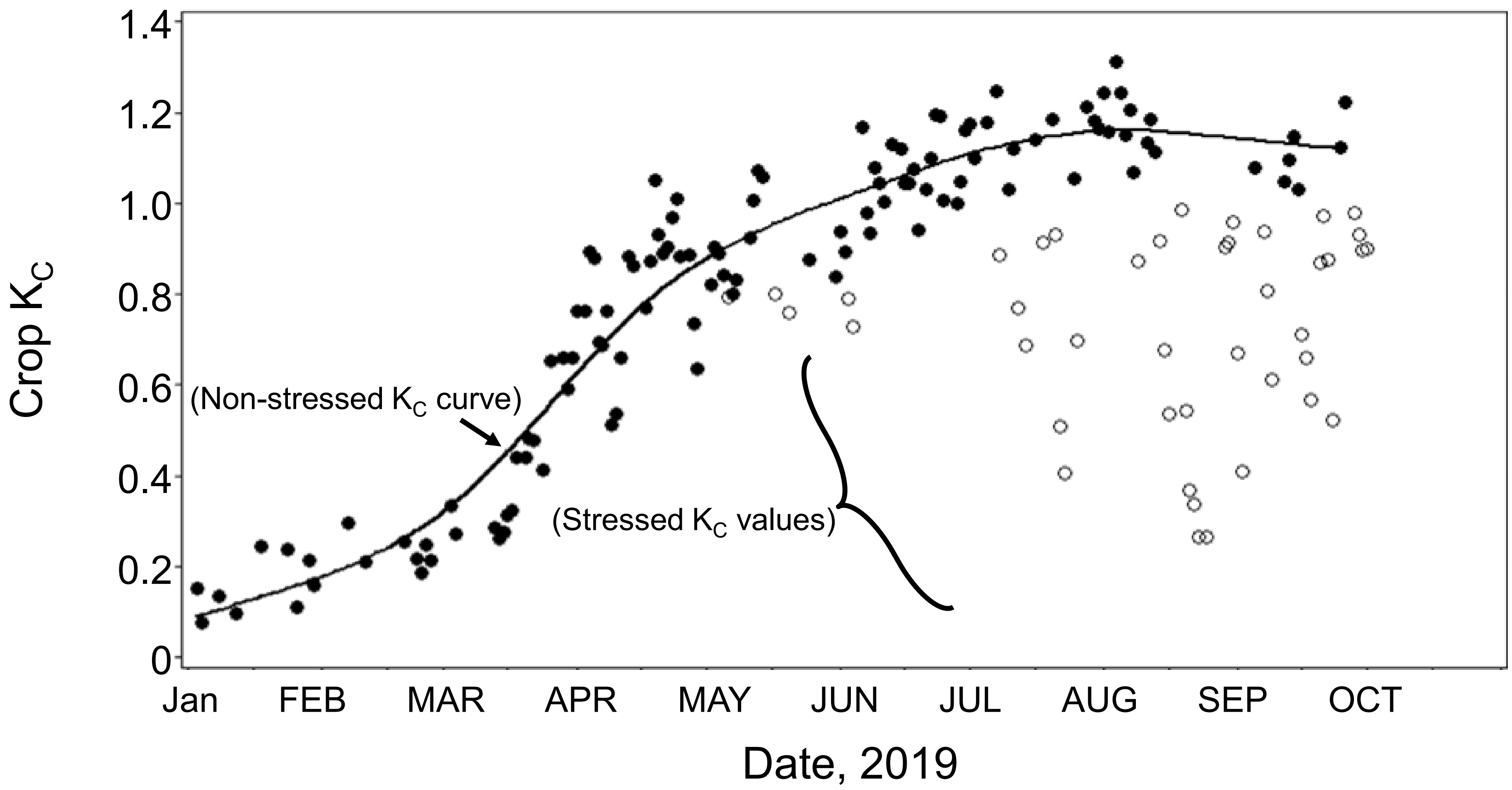
Example 7 day irrigation cycle in August



2019: There were many periods of stress, some intentional (hull split, harvest), some not.

1) The sensor best correlated to ET stress over the season was the 24h average SWP measured with the microtensiometer (installed 6/20/19).

2) However, all methods tested were able to detect stress, and all indicated a relatively rapid development of stress at the end of the irrigation cycle (important troubleshooting information).



Overall conclusions:

1) Sensor readings (or just more frequent pressure chamber readings) are very effective tools for trouble-shooting irrigation practices (e.g., we probably should have increased irrigation frequency in August in the lysimeter plot).

2) We also obtained preliminary evidence that daily trunk growth (dendrometer measurements) may be helpful in deciding when trees are ready to shake. It appears that just a few days of no net growth (due to water stress) may be associated with an increased resistance to shaker injury. This should be confirmed with further research.

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Research Update: How Much and When to Irrigate

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Thank you!