# Irrigation 101 + Precision Ag Research

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growing
ADVANTAGE
The Almond Conference

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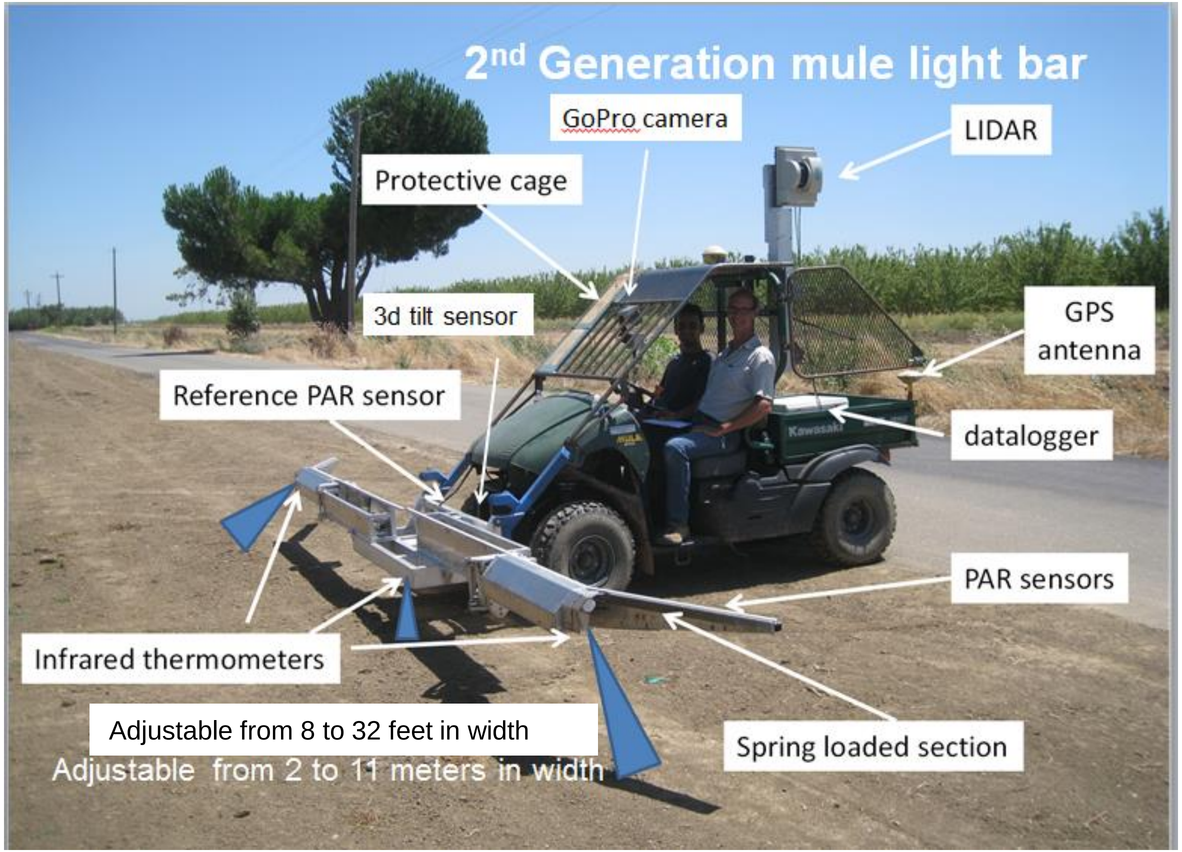
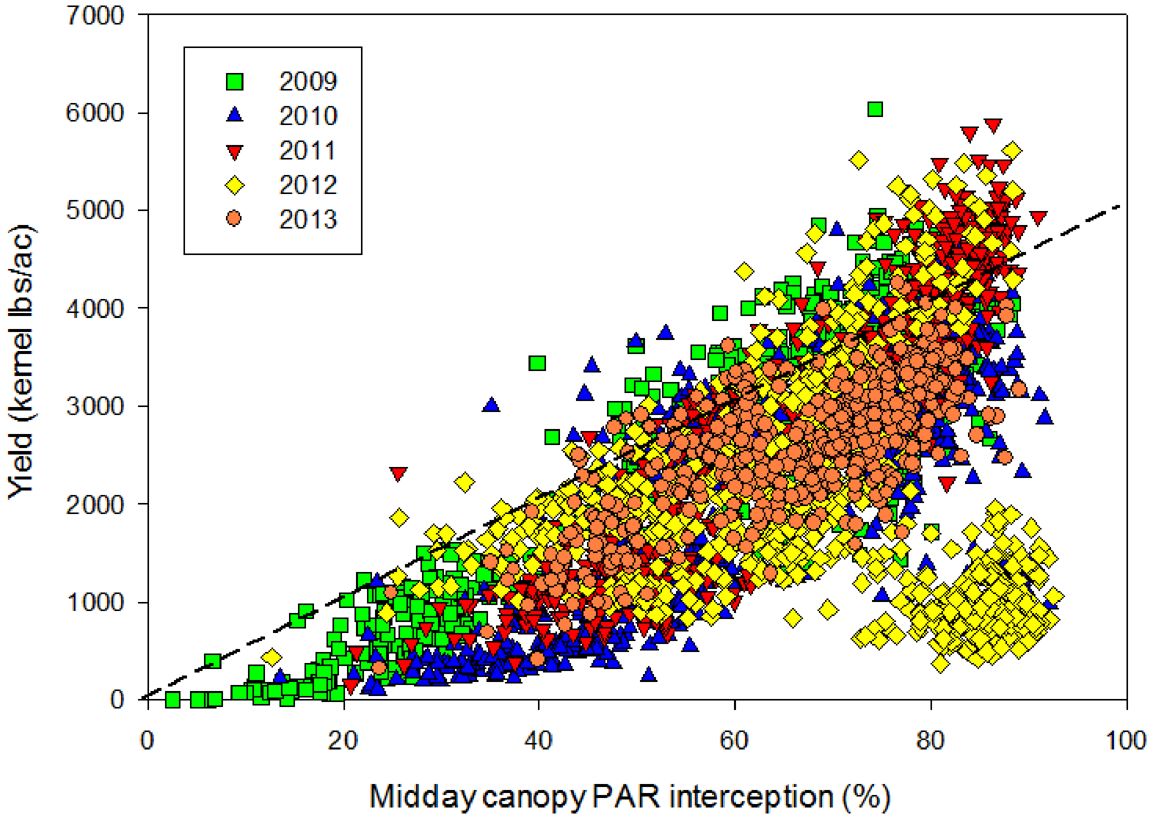
# We survived droughts in the past but have things changed?

Bruce Lampinen
UC Davis Plant Sciences

# Second generation mule light bar

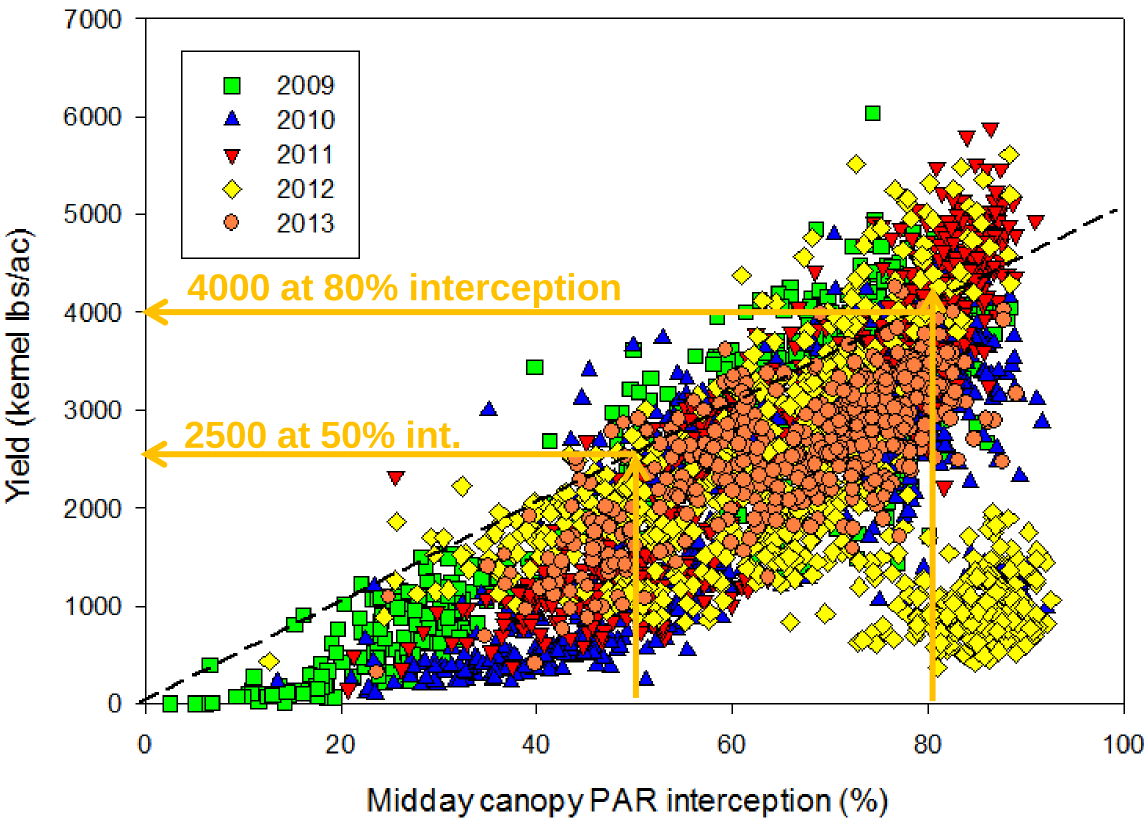


# Relationship between light interception and yield potential



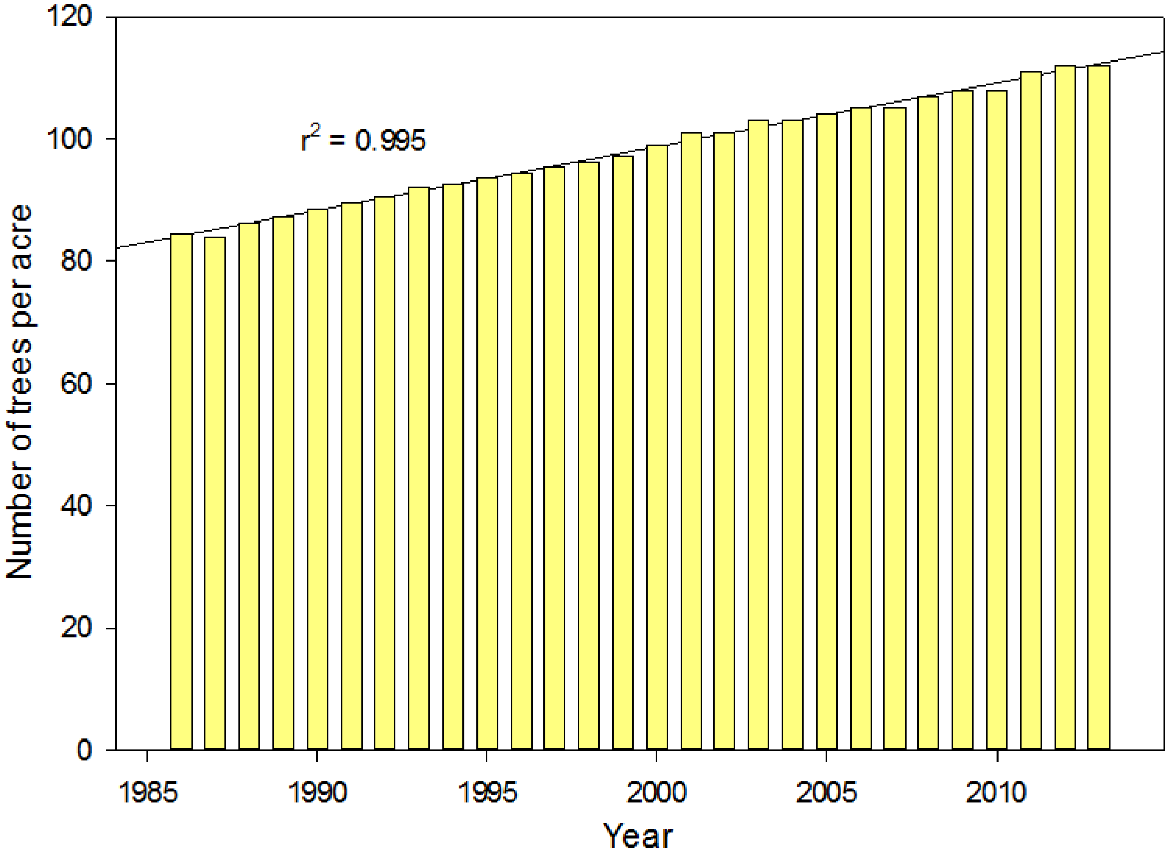

We have found that you can produce about 50 kernel pounds for each 1% of the total incoming light you can intercept

# Relationship between light interception and yield potential




Food safety risk increases above 80% interception due to difficulty in drying nuts and lack of sun to orchard floor

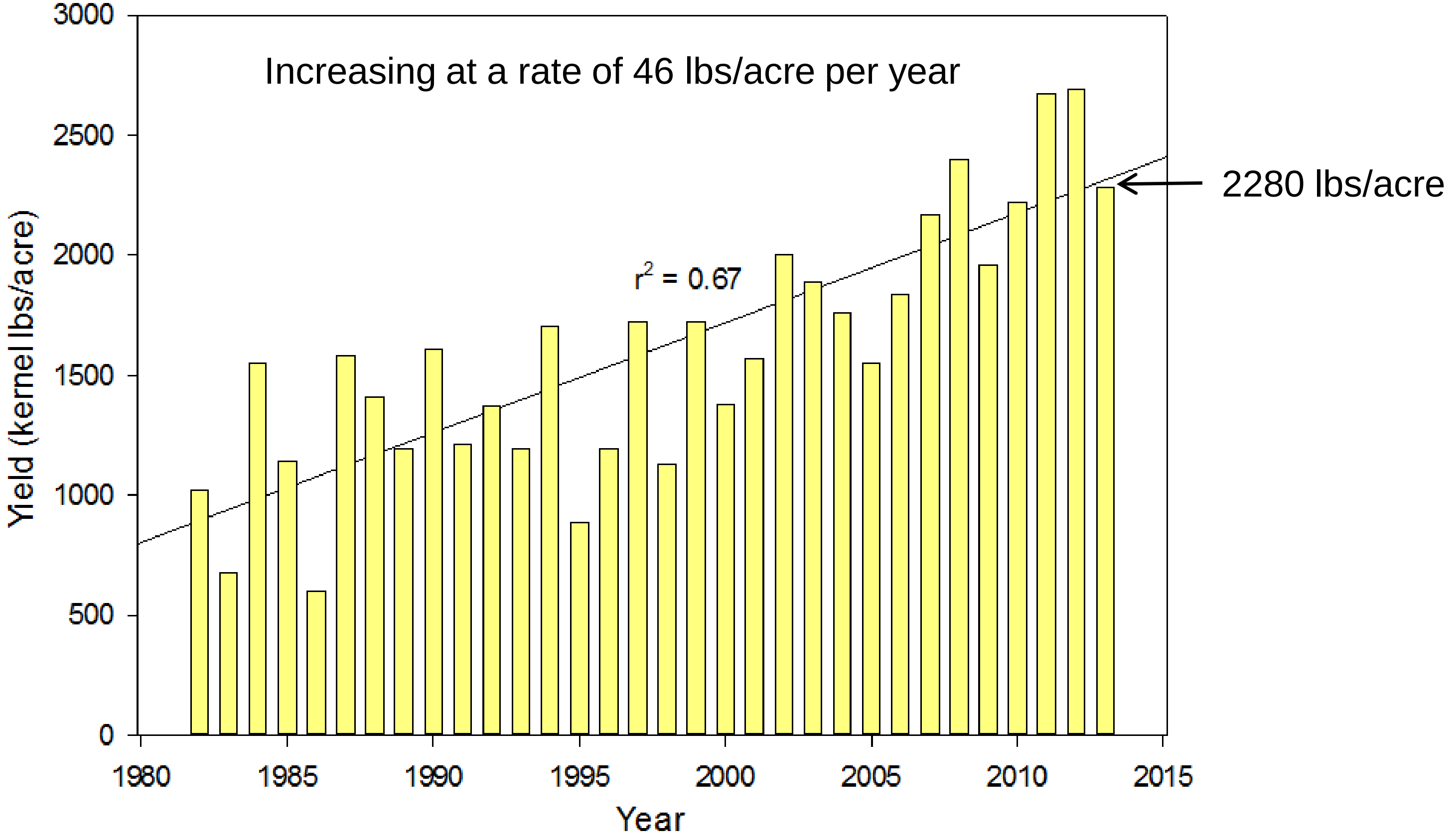
# Trees per acre from 1986 to 2013 in California




112 trees/ac in 2013

(~18.5' x 21')

# Per acre yield from 1982 to 2013 in California



# Midday PAR interception versus estimated water needs and yield potential

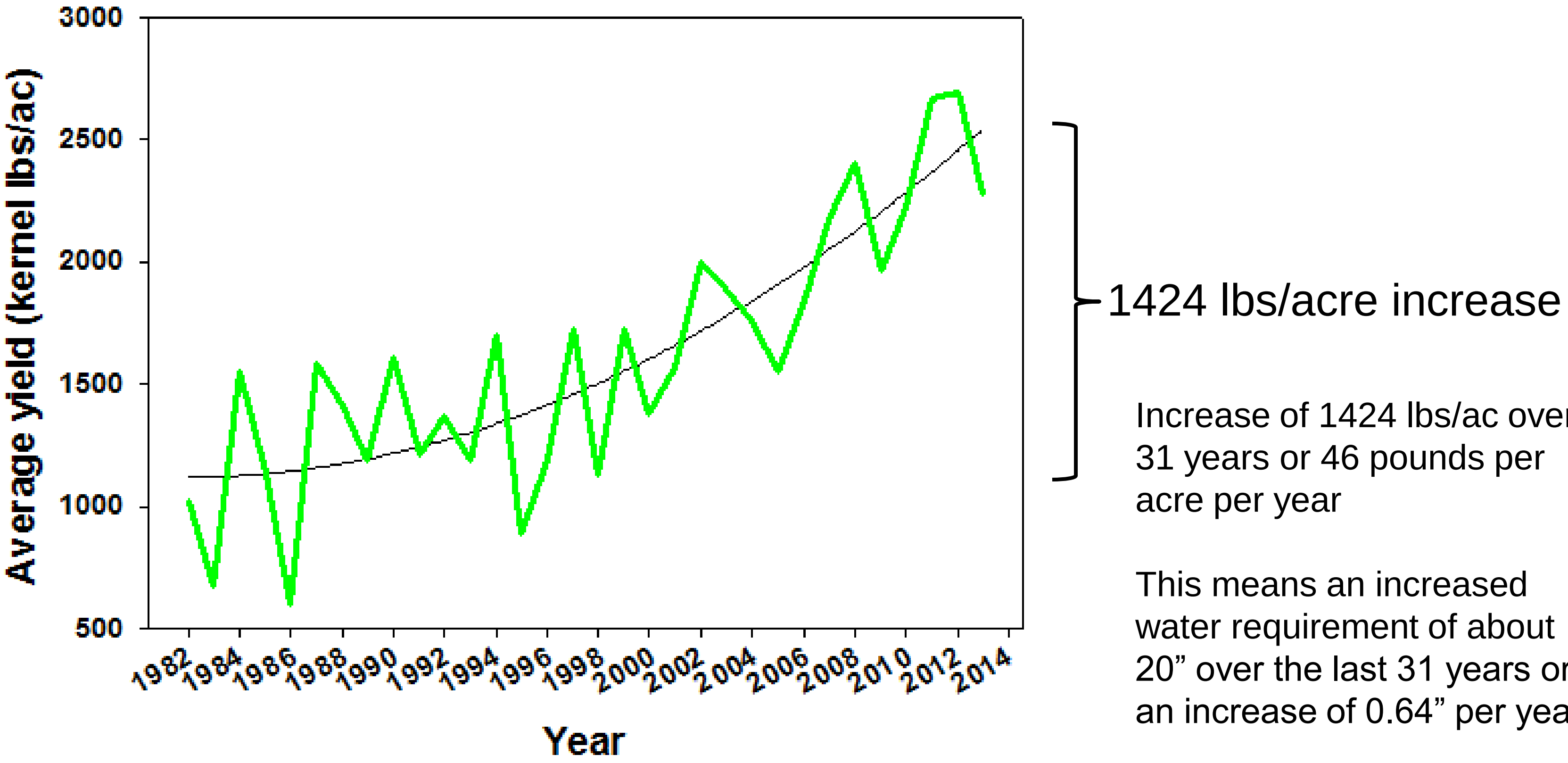
| Midday PAR interception | | Applied plus stored water (inches) | | Yield potential (kernel lbs/ac) |
|---|---|---|---|---|
| 10 | /1.43 = | 7 | x 71.43 = | 500 |
| 20 | | 14 | | 1000 |
| 30 | | 21 | | 1500 |
| 40 | | 28 | | 2000 |
| 50 | | 35 | | 2500 |
| 60 | | 42 | | 3000 |
| 70 | | 49 | | 3500 |
| 80 | | 56 | | 4000 |
| 90 | | 63 | | 4500 |

Midday PAR/1.43 = applied plus stored water

Applied plus stored water x 71.43 = yield potential

Note:
This analysis is based on microirrigation data only

# Increases in yield potential result in increased water needs




Increase of 1424 lbs/ac over 31 years or 46 pounds per acre per year

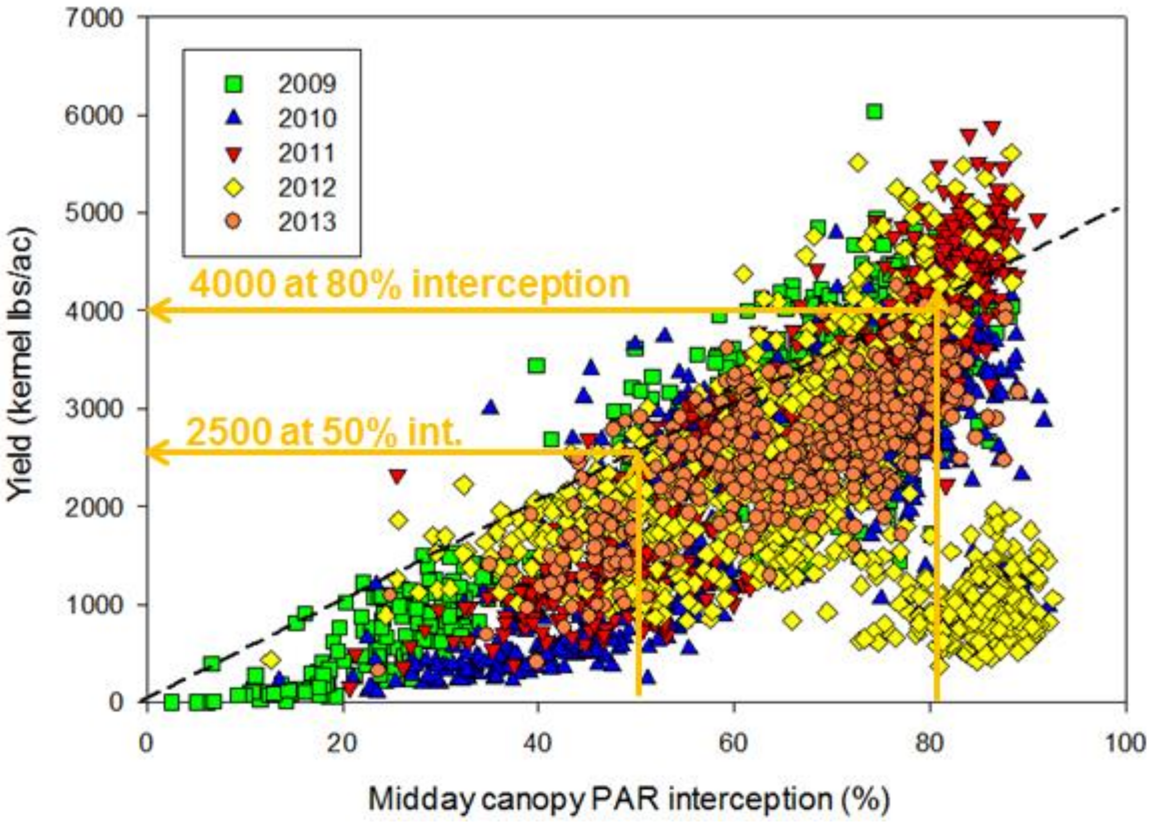
This means an increased water requirement of about 20” over the last 31 years or an increase of 0.64” per year

# While water demand has increased, changes in irrigation practices have increased efficiency as well.

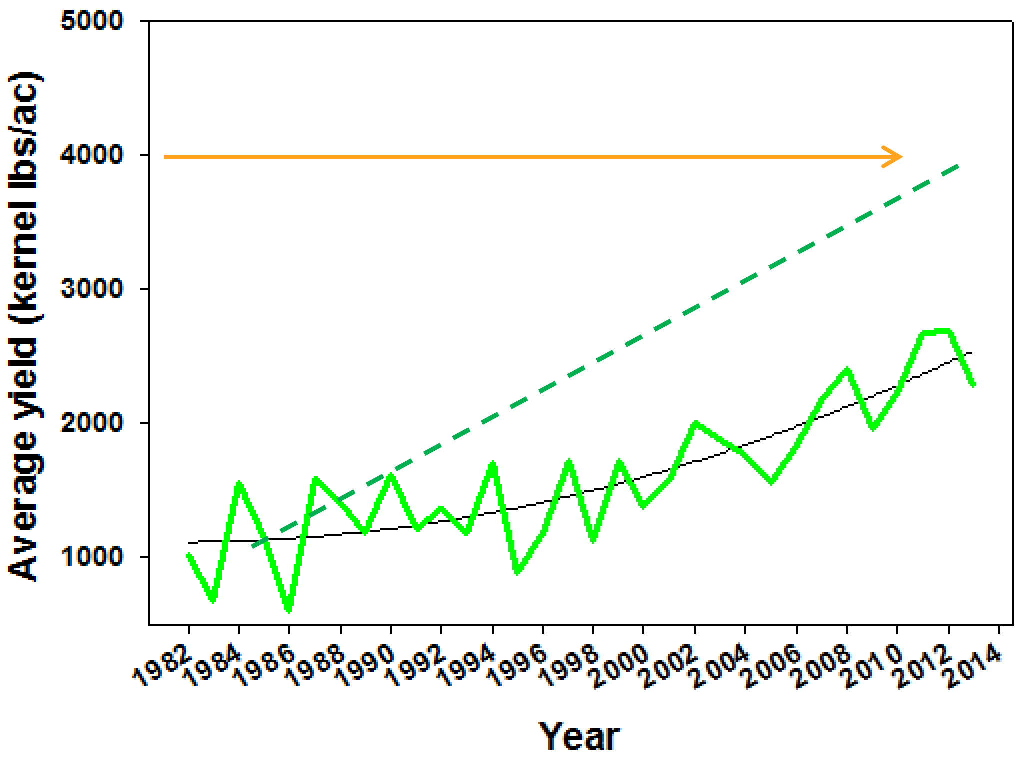
| | | **Source** |
|---|---|---|
| vg. '90 -'94 Almond water use inches (ET) | 40.24 | UC Drought Management - Historical Almond ET, see http://ucmanagedrought.ucdavis.edu/Agriculture/Irrigation_Scheduling/Evapotranspiration_Scheduling_ET/Historical_ET/Almonds_960/ |
| ‘90 –‘94 Avg. Pounds/acre | 1345 | Almond Board of California Almanac |
| ‘90 - '94 water inches/pound | 0.0299 | |
| | | |
| vg. '10 -'14 Almond water use inches (ET) | 47.57 | UC Drought Management - Historical Almond ET Updated to new almond crop coefficients, new coefficients in:<br>Goldhamer, David. 2012. Almond in Grop Yield Response to Water. FAO Irrigation and Drainage Paper No. 66, P. Steduto, T.C. Hsiao, E. Fereres, and D. Raes, eds. Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 246:296. |
| ‘10 -'14 Avg. Pounds/acre | 2390 | Almond Board of California Almanac |
| ‘10 - '14 water inches/pound | 0.0199 | |
| | | |
| **Reduction in water inches/pound** | **-33%** | |

Based on ET estimates from 1990 versus 2012, moving from flood to microirrigation, new varieties, better nutrition, etc. have increased the yield per amount of water applied.

# Best orchards are yielding in 4000 kernel pound per acre range at 80% PAR interception



# Water needs based on yield potential



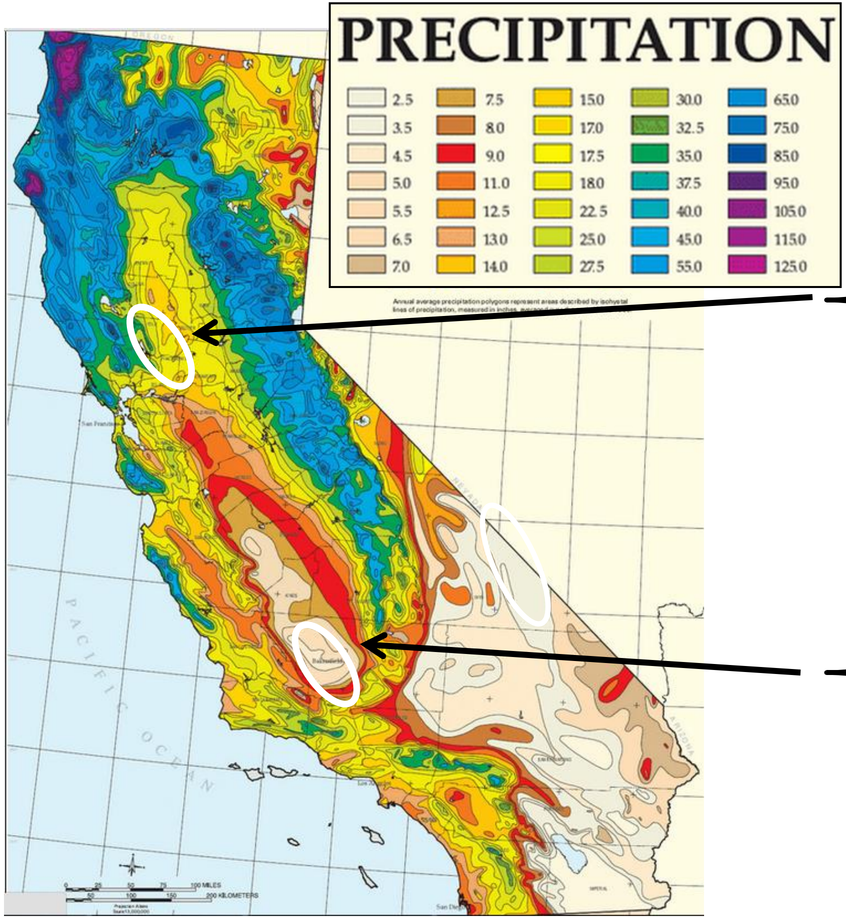

Best orchards need 56 inches (80% canopy cover)

Average orchard needed 36 inches

# It is difficult to put on 56” of water on most soils without causing tree health problems particularly during high evaporative demand periods in July and August

# Dryland orchard in Yolo County

# Dryland yield potential




Average rainfall ~20 inches in areas of Yolo County where dryland almonds still exist

20“ of rain = 1420 kernel lbs/ac yield potential at 30% PAR int.

Try this in western Kern County with 5” of rain

5” rain = 350 kernel lbs/ac yield potential at 7% PAR interception

# Ground cover also uses water

~35% PAR interception
needs ~25 inches of water

~40% PAR interception from trees plus 40% from grass = 80% total
needs ~56” of water

# Higher yields per acre means more efficient production

Growing 3800 pounds on 80 acres is much more efficient than growing 1950 and 1850 pounds on 160 acres

Less light for weeds and groundcover, less fuel for mowing, spraying, harvest, etc., less land cost

3800 lbs/ac

39% (1950 lbs/ac)

37% (1850 lbs/ac)

76% (3800 lbs/ac)

# Drought impacts

Drought will have much larger impacts in 2014 versus in 1991-1992

Impact on your orchards will depend on winter rainfall and canopy cover/productivity

1991-1992

State Water Project water deliveries were 50% of normal

Average almond orchard was producing 1200 kernel pounds per acre so would have required about 17 inches of water

2014

Average almond orchard producing in range of 2500+ kernel pounds per acre so would require about 35 inches of water

Best orchards producing about 4000 kernel pounds per acre so would require about 56 inches of water

If State Water project delivered 50% of normal (actually only delivered 40% in 2013)

| | |
|---|---|
| Average orchard deficit 1991-1992 | 17/2 = 8.5 inches |
| Average orchard deficit 2013 | 35/2 = 17.5 inches |
| Best orchard deficit 2013 | 56/2 = 28 inches |

# Blake Sanden, UCCE-Kern County

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# Optimal Water Management for Almonds: Irrigation 101

Blake Sanden - Irrigation & Agronomy Farm Advisor
Kern County

growing ADVANTAGE
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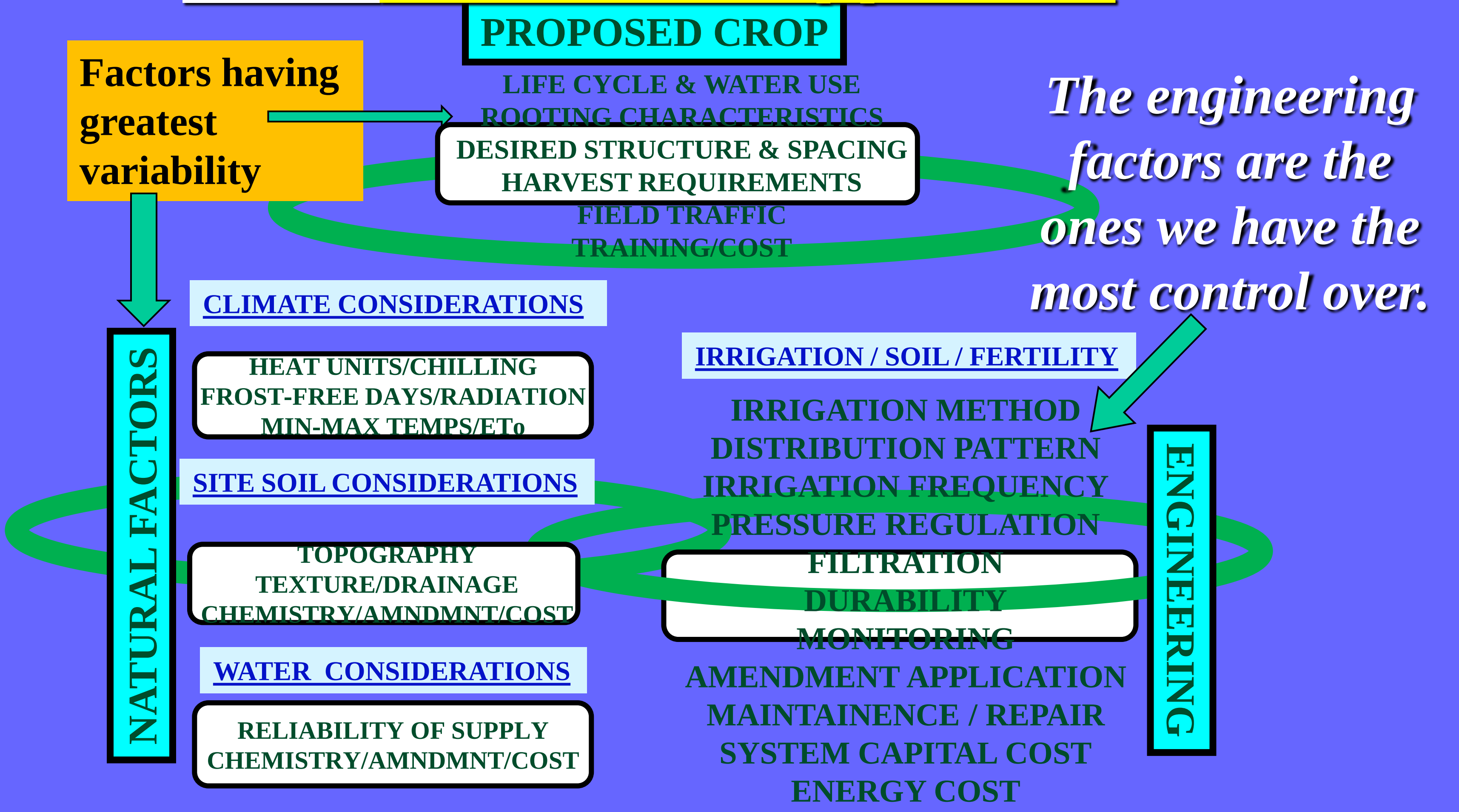
The Almond Conference
Sacramento, CA Dec 9-11, 2014

# Irrigation 101: 5-point sermon

- Canopy cover (PAR)/yield/ET, calculating almond ET, soil water holding capacity, –Lampinen, Sanden
- Irrigation uniformity, system mechanics, salt accumulation & leaching – Fulton
- Soil moisture & plant monitoring options – Dave Doll
- What do we know about plant stress, deficit irrigation impacts on plant growth and yield? – Shackel
- High tech plant/field monitoring – Upadhaya

# SO WHAT'S ESSENTIAL for EFFICIENT IRRIGATION, OPTIMAL WATER BALANCE & CROP PRODUCTIVITY?

# Irrigation & soil management are the essential foundations of crop production

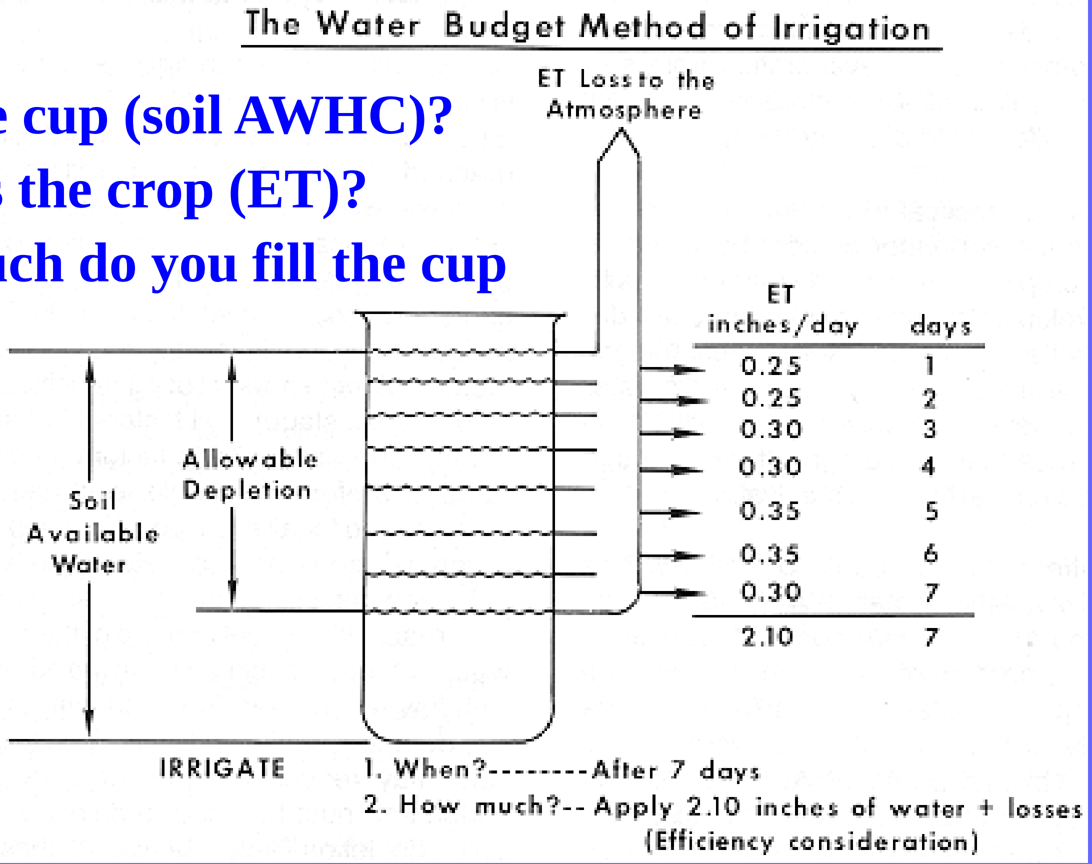


# Where do I start?

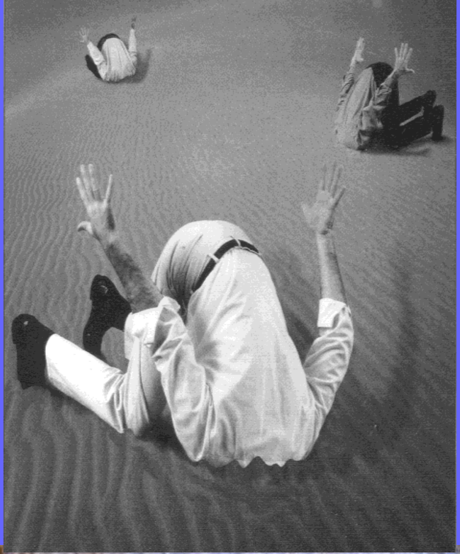
1. Pray for miracles.  We need all the help/rain we can get!
2. Get all the information you can! (That's why you're here.)
3. Get down on your knees (Similar to Step 1, but now this is work.) so you can check the soil profile, emitter flowrates, adjust pressure regulators and optimize uniformity!

# Creating the efficient field water balance – your soil moisture checking account!

- How big is the cup (soil AWHC)?
- How thirsty is the crop (ET)?
- How often/much do you fill the cup (Scheduling)?



Check your dirt! It has more secrets than the CIA.



# *How to do it*

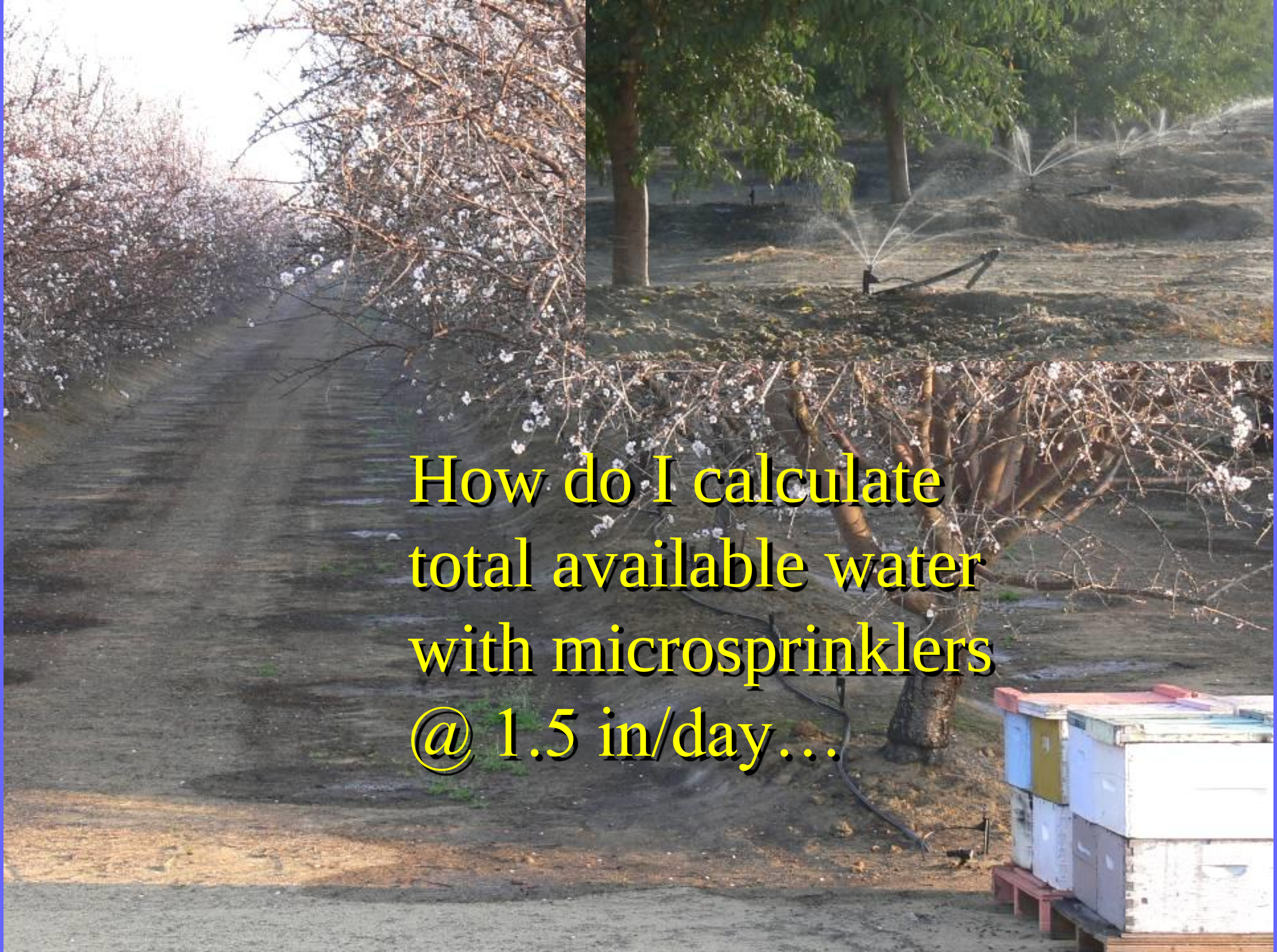
## SOIL TEXTURE

**Estimating soil texture by a "ribbon" test from a moistened ball. Sandy Clay Loam – Westside Kern County**

# Backhoe Pits – the Worm's Eye View!

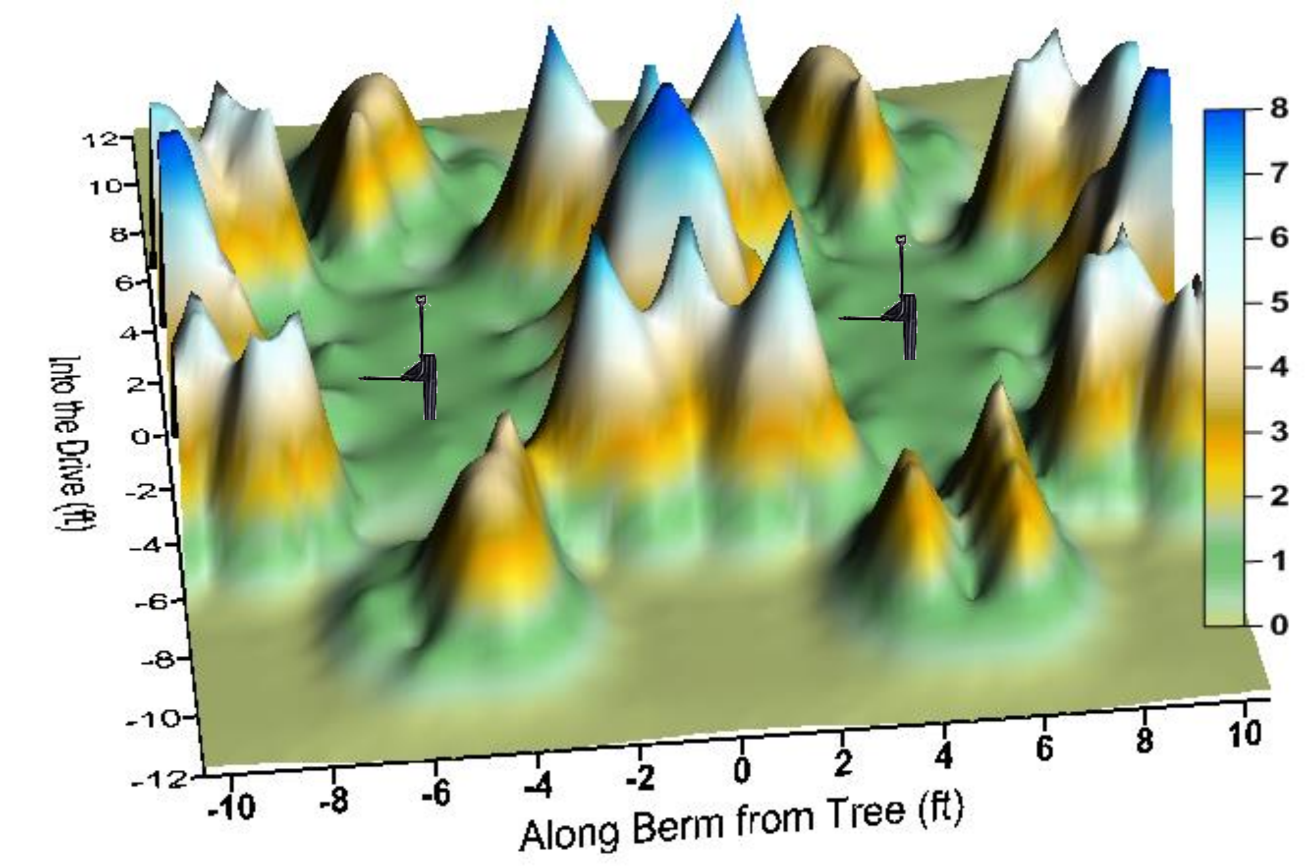

# Hand-powered twist augers
# ($150 - $300)

Micro-irrigation system capable of injecting fertilizer and applying 0.6 to 1.5 inches/day

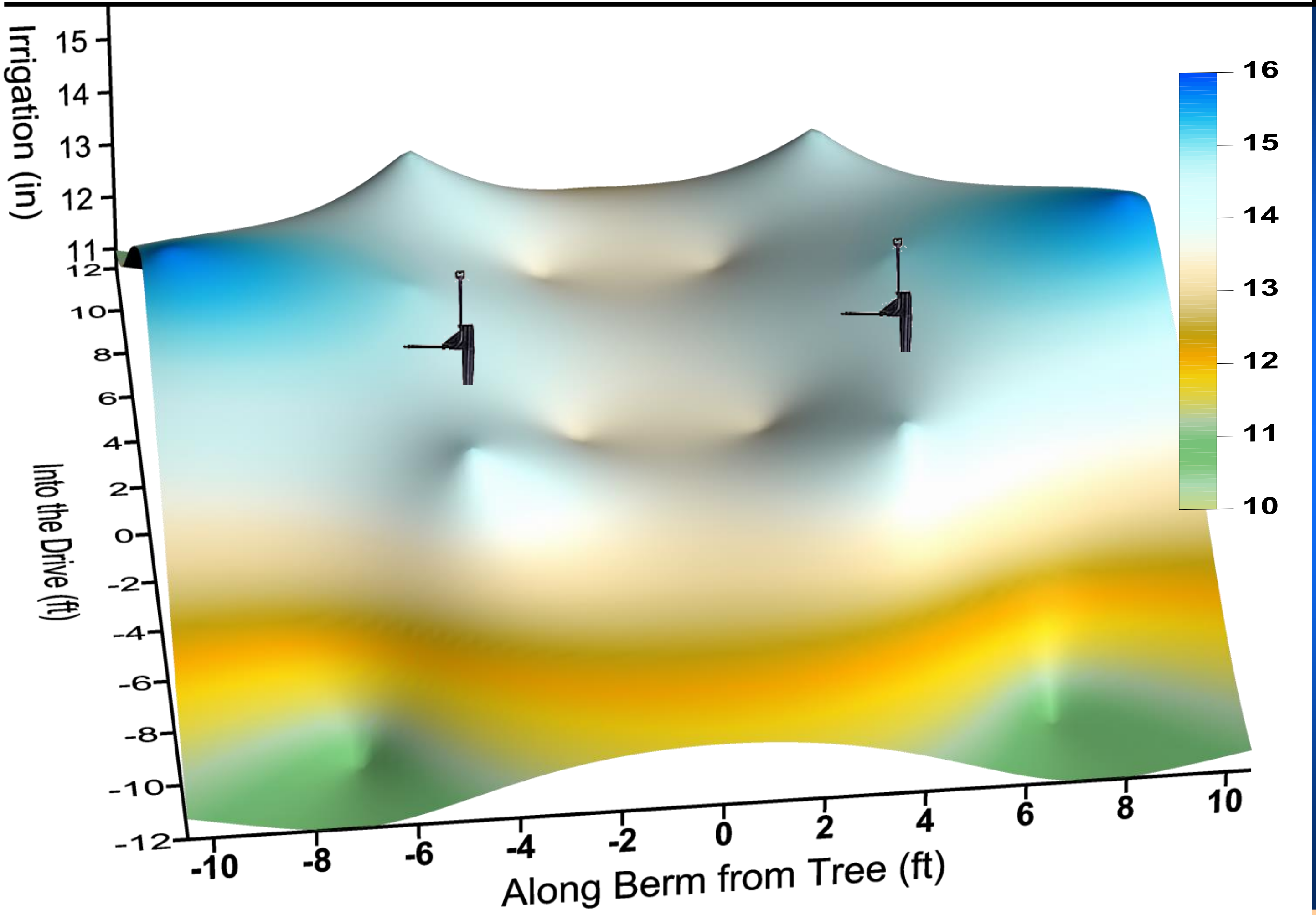

How do I calculate
total available water
with microsprinklers
@ 1.5 in/day…


Irrigation evaluation for
application patterns &
rootzone subbing 4/23/09
Bowsmith A-40
microsprinkler

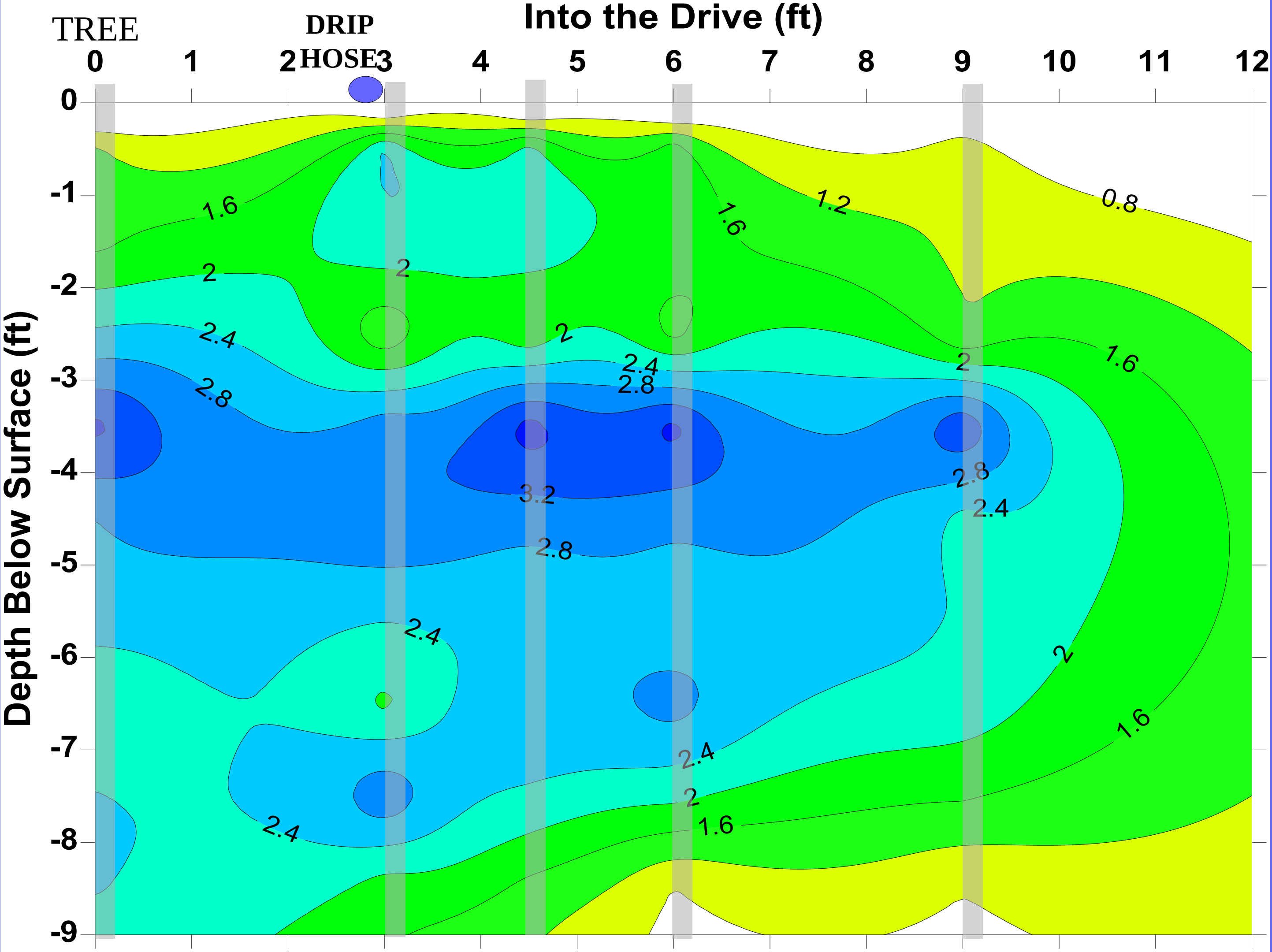
# Interpolated pattern of applied water from 2 Fanjets/tree



# Summed 0-6 ft water content 6/24/09 after 24 hour irrigation



… or account for "subbing" in a double-line drip?



TREE
DRIP HOSE
Into the Drive (ft)
0
1
2
3
4
5
6
7
8
9
10
11
12
Depth Below Surface (ft)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0.8
1.2
1.6
2
2.4
2.8
3.2

# Water Holding Capacity & Microirrigation Set Times for Orchards (Google: cekern soil moisture fill)

Refill Times for Different Soil Textures and Micro Systems

[1]Irrigation Time to Refill & Moisture Reserve of 4 Foot Wetted Rootzone @ 50% to 100% Available

ALMONDS 0.30 inch/day ET

| Soil Texture | Available Soil Moisture (in/ft) | Avg Drip Subbing Diameter from 1 to 4' Depth (ft) | Dble-Line Drip 1-gph, 10 per tree (irrig hrs) | Moisture Reserve @ 0.30"/day (days) | 10 gph Fanjet, 1 per tree (irrig hrs) | Moisture Reserve @ 0.30"/day (days) | 14 gph Fanjet, 1 per tree (irrig hrs) | Moisture Reserve @ 0.30"/day (days) |
|---|---|---|---|---|---|---|---|---|
| Sand | 0.7 | 2 | 2.2 | 0.3 | 11.6 | 1.4 | 12.5 | 2.1 |
| Loamy Sand | 1.1 | 3 | 7.8 | 0.9 | 19.6 | 2.4 | 20.9 | 3.6 |
| Sandy Loam | 1.4 | 4 | 17.5 | 2.1 | 26.9 | 3.3 | 28.3 | 4.8 |
| Loam | 1.8 | 5 | 35.9 | 4.4 | 37.1 | 4.5 | 38.6 | 6.6 |
| Silt Loam | 1.8 | 6 | 43.1 | 5.3 | 39.7 | 4.8 | 40.8 | 7.0 |
| Sandy Clay Loam | 1.3 | 6 | 31.1 | 3.8 | 28.6 | 3.5 | 29.5 | 5.0 |
| Sandy Clay | 1.6 | 7 | 44.7 | 5.4 | 37.6 | 4.6 | 38.3 | 6.5 |
| Clay Loam | 1.7 | 8 | 54.3 | 6.6 | 42.6 | 5.2 | 42.9 | 7.3 |
| Silty Clay Loam | 1.9 | 9 | 68.2 | 8.3 | 50.6 | 6.2 | 50.5 | 8.6 |
| Silty Clay | 2.4 | 9 | 86.2 | 10.5 | 64.0 | 7.8 | 63.8 | 10.9 |
| Clay | 2.2 | 10 | 87.8 | 10.7 | 62.3 | 7.6 | 61.5 | 10.5 |

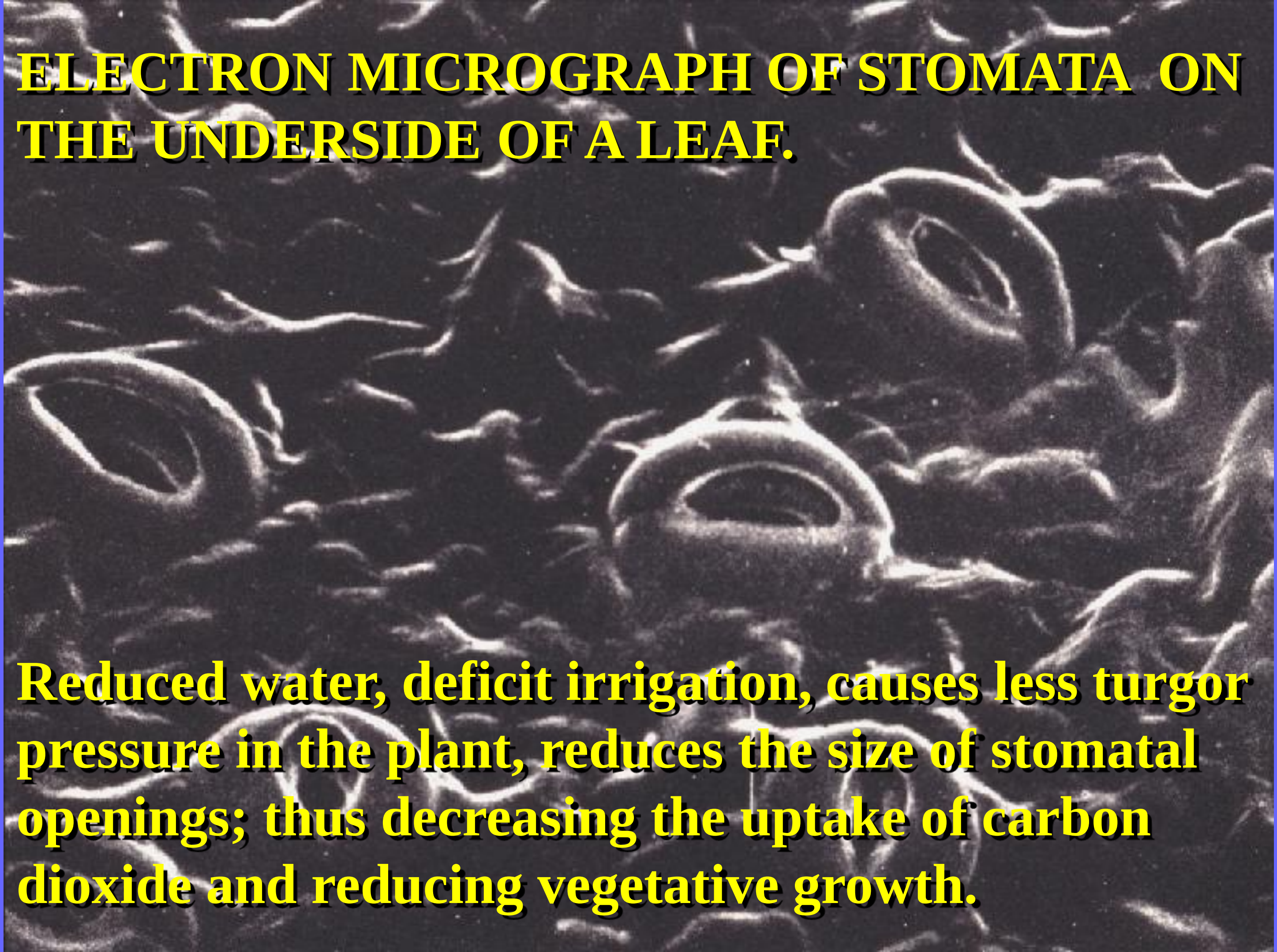
[1]Based on a tree spacing of 20 x 22'. Drip hoses 6' apart. 10 gph fanjet wets 12' diameter. 14 gph fanjet @ 15' diameter.

Note: Peak water use @ 0.30"/day and 20 x 22' spacing = 82 gallons/day/tree. 0.20"/day = 55 gallons/day/tree.

Table takes into account merging water patterns below soil surface for drip irrigation.

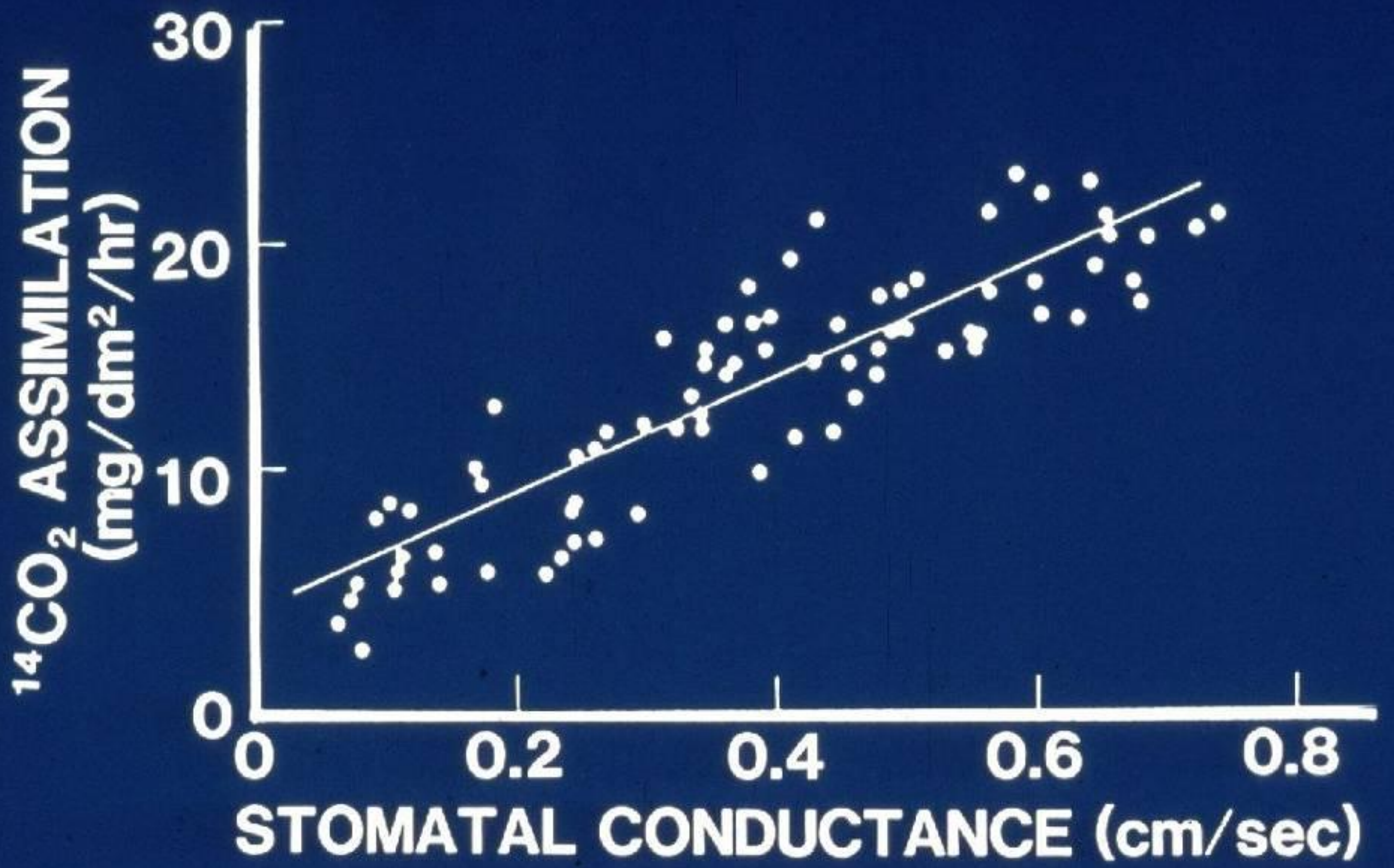
## What's the critical process that keeps the crop growing?

- Optimal photosynthesis
- Maximum carbon dioxide uptake



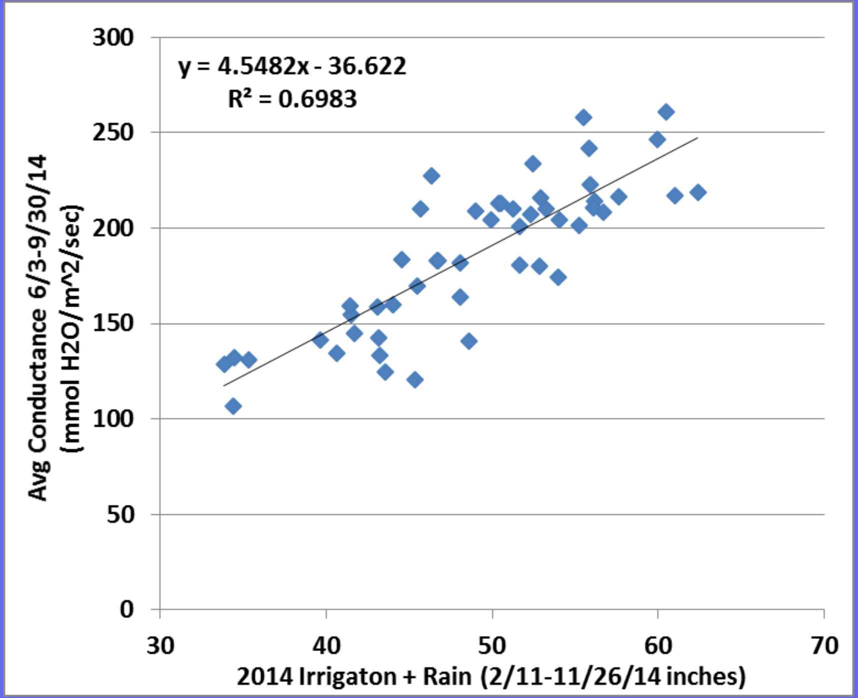
# ELECTRON MICROGRAPH OF STOMATA ON THE UNDERSIDE OF A LEAF.

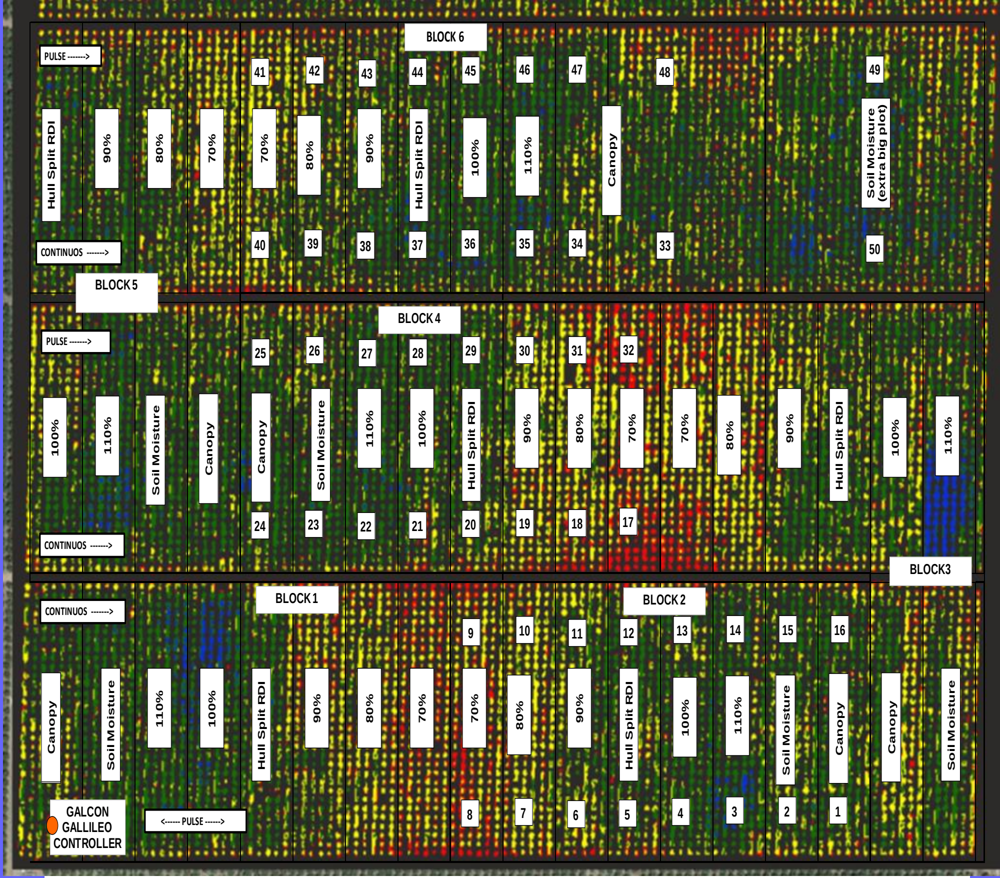
**Reduced water, deficit irrigation, causes less turgor pressure in the plant, reduces the size of stomatal openings; thus decreasing the uptake of carbon dioxide and reducing vegetative growth.**



30
20
10
0
0
0.2
0.4
0.6
0.8
14CO2 ASSIMILATION
(mg/dm2/hr)
STOMATAL CONDUCTANCE (cm/sec)

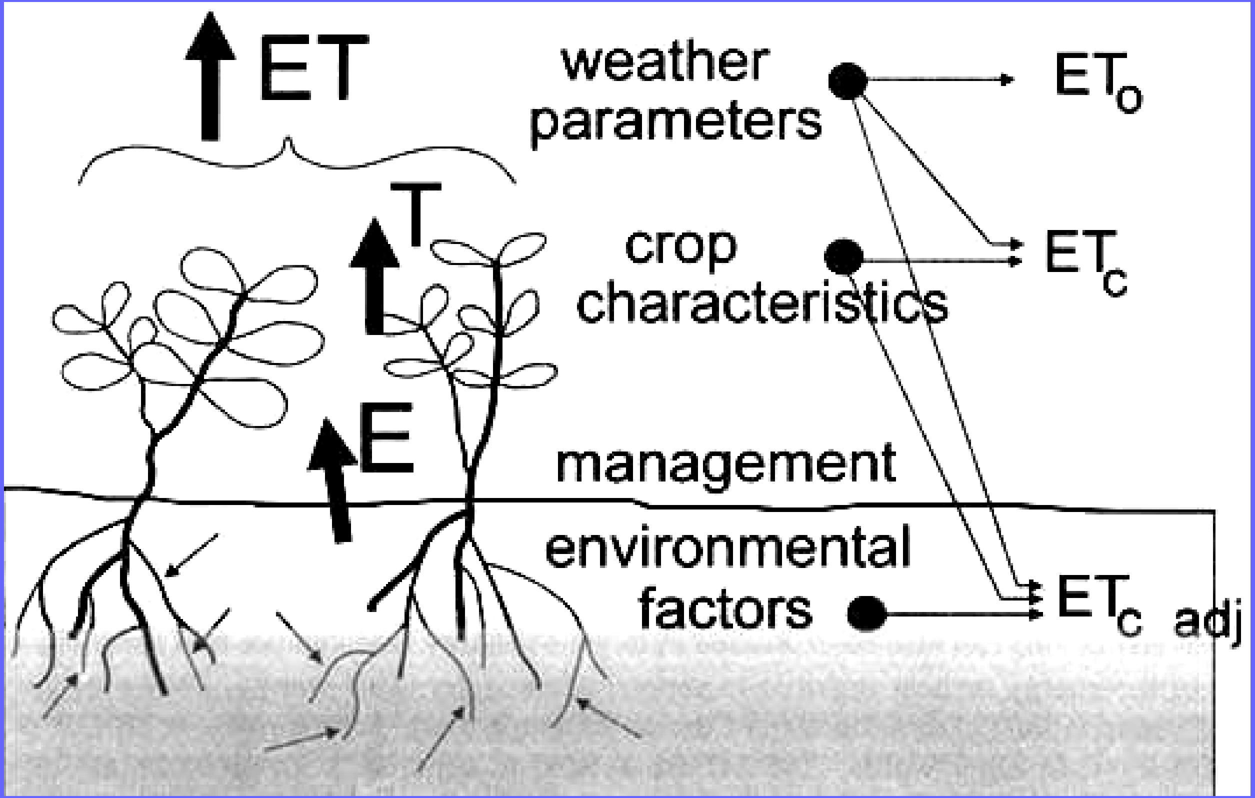
# 6/3-9/30/14 average almond plot water conductance by 2014 applied irrigation

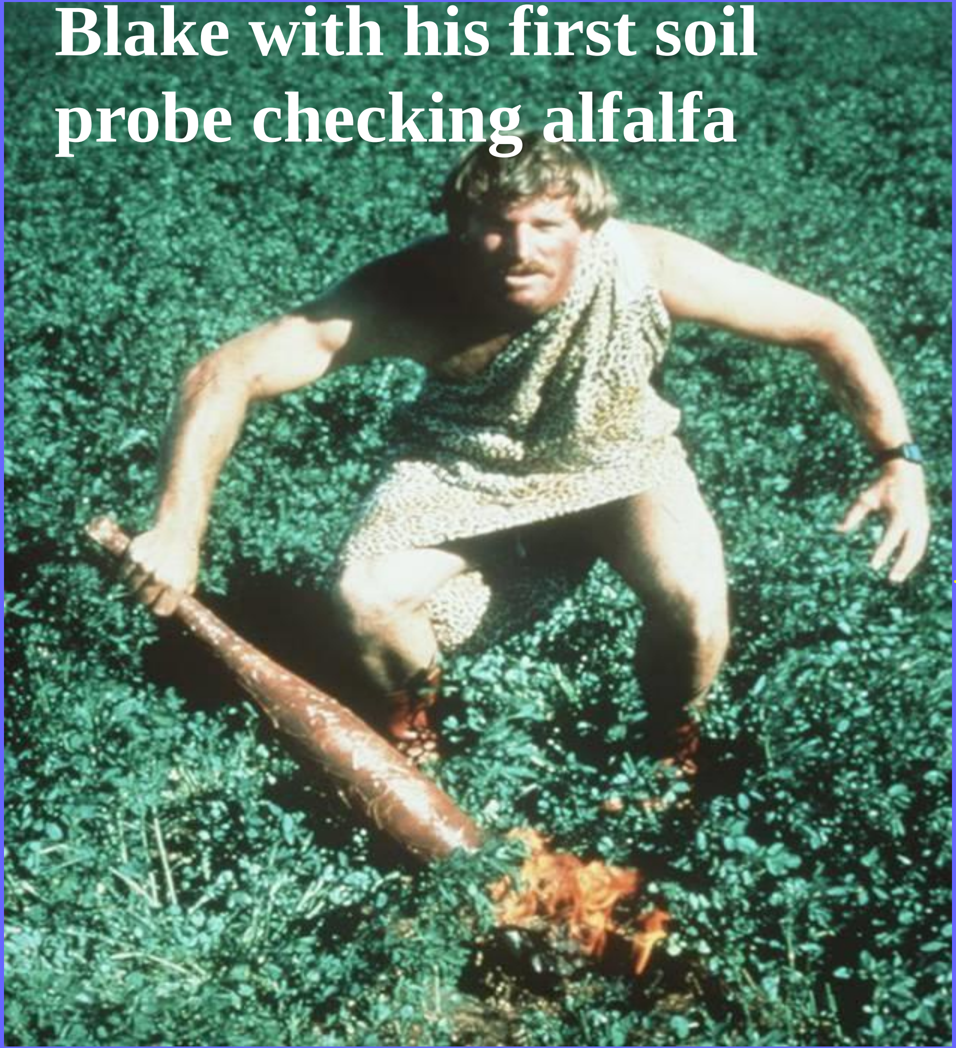



**Canopy Temp/Water Stress by Irrigation Treatment (CERES Spectral Imaging 6-3-14, Shackel, et al. Yield Production Function Trial)**

# Crop water use is made up of EVAPORATION (E) from the soil, and TRANSPIRATION (T), water moving through plant to evaporate from the leaves, hence ET






**We haven't been out of the cave that long regarding a scientific understanding of crop water use and "Normal Year" ET**

**From 1968 to 1993 detailed records of Class A pan evaporation were recorded in dozens of locations around the SJV by the Dept of Water Resources**

**Using ETo = 0.85 Evaporation**

**a 20 year average ETo of 49.3 inches was published by CA Dept of Water Resources**

# CIMIS

## CALIFORNIA IRRIGATION MANAGEMENT INFORMATION SERVICE

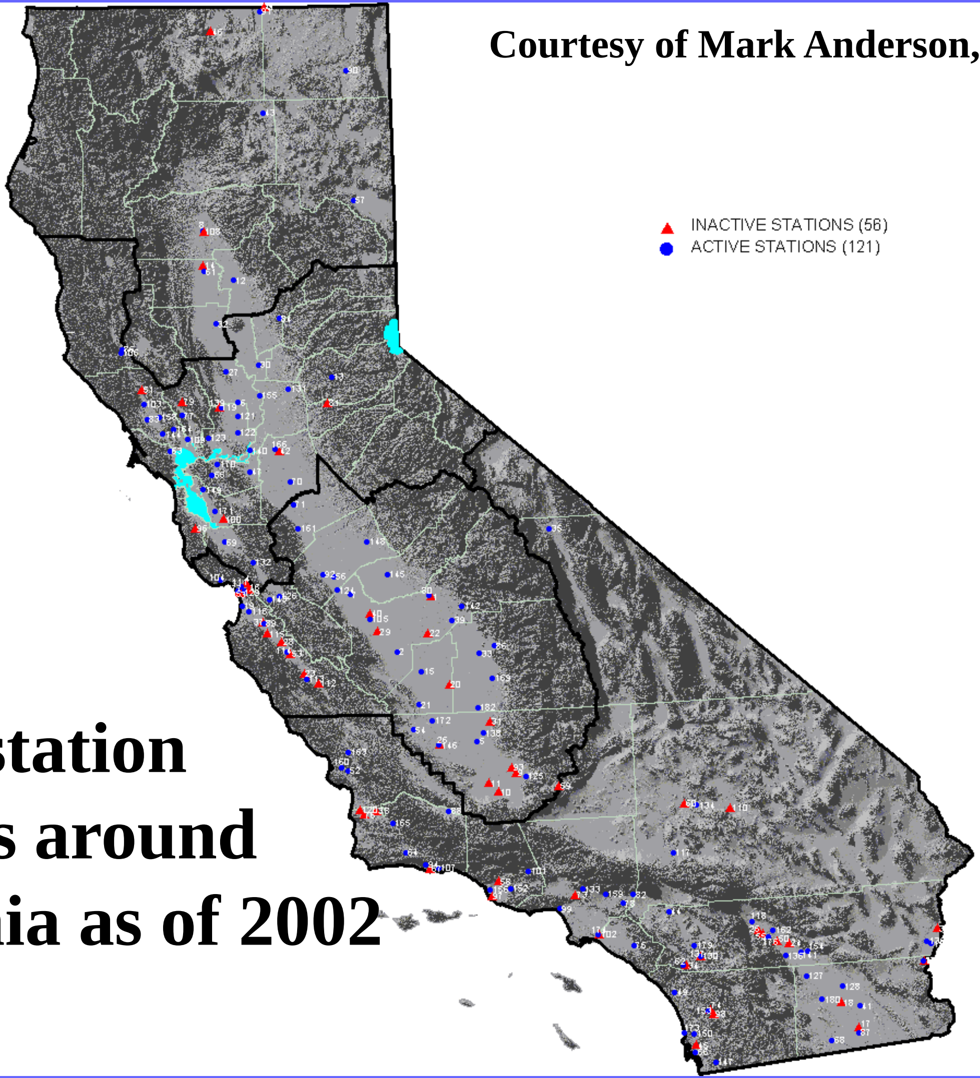
**Courtesy of Mark Anderson, DWR**

# CIMIS Weather Station

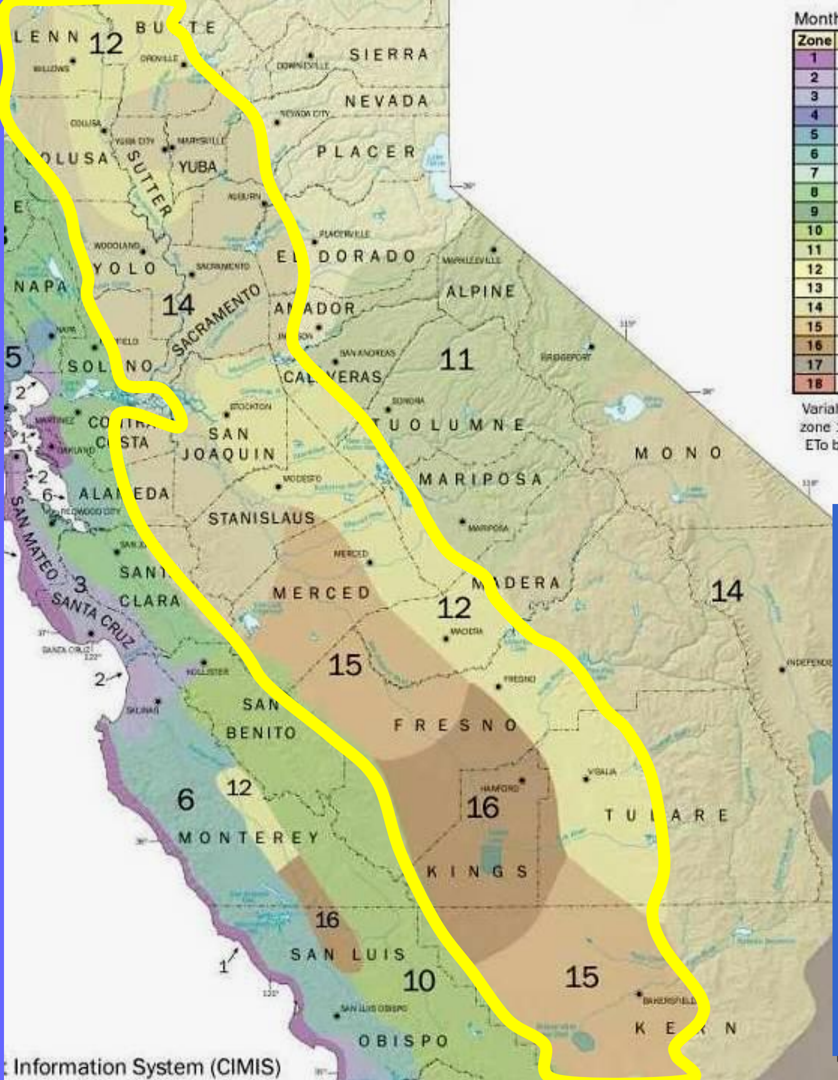
The ET number from CIMIS is "potential" ET (ETo) which equals the water use of a non-stressed cool season grass.

Courtesy of Mark Anderson, DWR

Courtesy of Mark Anderson, DWR




# CIMIS station locations around California as of 2002




Monthly Average Reference Evapotranspiration by ETo Zone (inches/month)

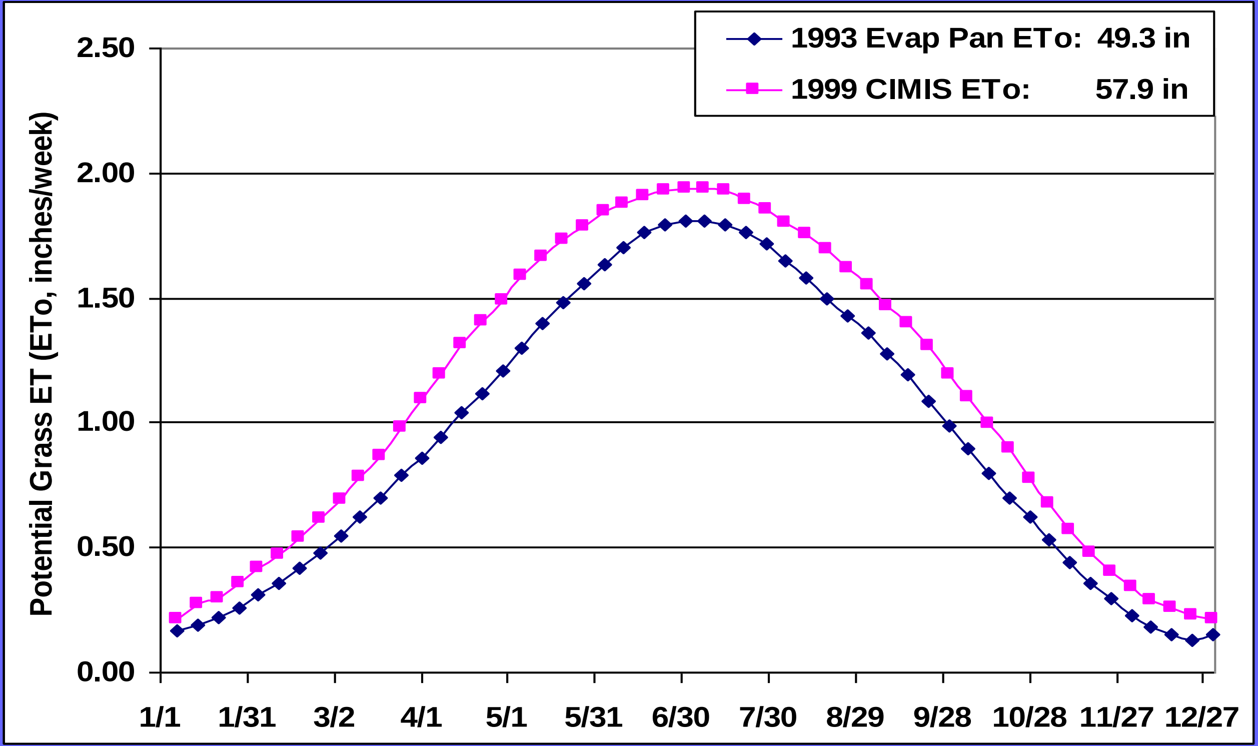
| Zone | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.93 | 1.40 | 2.48 | 3.30 | 4.03 | 4.50 | 4.65 | 4.03 | 3.30 | 2.48 | 1.20 | 0.62 | 33.0 |
| 2 | 1.24 | 1.68 | 3.10 | 3.90 | 4.65 | 5.10 | 4.96 | 4.65 | 3.90 | 2.79 | 1.80 | 1.24 | 39.0 |
| 3 | 1.86 | 2.24 | 3.72 | 4.80 | 5.27 | 5.70 | 5.58 | 5.27 | 4.20 | 3.41 | 2.40 | 1.86 | 46.3 |
| 4 | 1.86 | 2.24 | 3.41 | 4.50 | 5.27 | 5.70 | 5.89 | 5.58 | 4.50 | 3.41 | 2.40 | 1.86 | 46.6 |
| 5 | 0.93 | 1.68 | 2.79 | 4.20 | 5.58 | 6.30 | 6.51 | 5.89 | 4.50 | 3.10 | 1.50 | 0.93 | 43.9 |
| 6 | 1.86 | 2.24 | 3.41 | 4.80 | 5.58 | 6.30 | 6.51 | 6.20 | 4.80 | 3.72 | 2.40 | 1.86 | 49.7 |
| 7 | 0.62 | 1.40 | 2.48 | 3.90 | 5.27 | 6.30 | 7.44 | 6.51 | 4.80 | 2.79 | 1.20 | 0.62 | 43.4 |
| 8 | 1.24 | 1.68 | 3.41 | 4.80 | 6.20 | 6.90 | 7.44 | 6.51 | 5.10 | 3.41 | 1.80 | 0.93 | 49.4 |
| 9 | 2.17 | 2.80 | 4.03 | 5.10 | 5.89 | 6.60 | 7.44 | 6.82 | 5.70 | 4.03 | 2.70 | 1.86 | 55.1 |
| 10 | 0.93 | 1.68 | 3.10 | 4.50 | 5.89 | 7.20 | 8.06 | 7.13 | 5.10 | 3.10 | 1.50 | 0.93 | 49.1 |
| 11 | 1.55 | 2.24 | 3.10 | 4.50 | 5.89 | 7.20 | 8.06 | 7.44 | 5.70 | 3.72 | 2.10 | 1.55 | 53.0 |
| 12 | 1.24 | 1.96 | 3.41 | 5.10 | 6.82 | 7.80 | 8.06 | 7.13 | 5.40 | 3.72 | 1.80 | 0.93 | 53.3 |
| 13 | 1.24 | 1.96 | 3.10 | 4.80 | 6.51 | 7.80 | 8.99 | 7.75 | 5.70 | 3.72 | 1.80 | 0.93 | 54.3 |
| 14 | 1.55 | 2.24 | 3.72 | 5.10 | 6.82 | 7.80 | 8.68 | 7.75 | 5.70 | 4.03 | 2.10 | 1.55 | 57.0 |
| 15 | 1.24 | 2.24 | 3.72 | 5.70 | 7.44 | 8.10 | 8.68 | 7.75 | 5.70 | 4.03 | 2.10 | 1.24 | 57.9 |
| 16 | 1.55 | 2.52 | 4.03 | 5.70 | 7.75 | 8.70 | 9.30 | 8.37 | 6.30 | 4.34 | 2.40 | 1.55 | 62.5 |
| 17 | 1.86 | 2.80 | 4.65 | 6.00 | 8.06 | 9.00 | 9.92 | 8.68 | 6.60 | 4.34 | 2.70 | 1.86 | 66.5 |
| 18 | 2.48 | 3.36 | 5.27 | 6.90 | 8.68 | 9.60 | 9.61 | 8.68 | 6.90 | 4.96 | 3.00 | 2.17 | 71.6 |

Variablity between stations within single zones is as high as 0.02 inches per day for zone 1 and during winter months in zone 13. The average standard deviation of the ETo between estimation sites within a zone for all months is about 0.01 inches per day for all 200 sites.

**The whole Central Valley covers Zones 12 to 16: for an "normal year" ETo of 53.3 to 62.5 in/yr, with most land @ 53 to 58 inches.**

# Comparing 1993 and 1999 estimates of Potential Evapotranspiration (ETo) for SJV

(Potential ETo, reference crop ET, is water use by a tall cool-season non-stressed pasture grass)



# Calculating ET for crops:

$$\mathbf{ET_{crop} = ET_o * K_c * E_f}$$

$ET_o$ = **reference crop** (tall grass) ET

$K_c$ = **crop coefficient** for a given stage of growth as a ratio of grass water use. May be 0 to 1.3, standard values are good starting point.

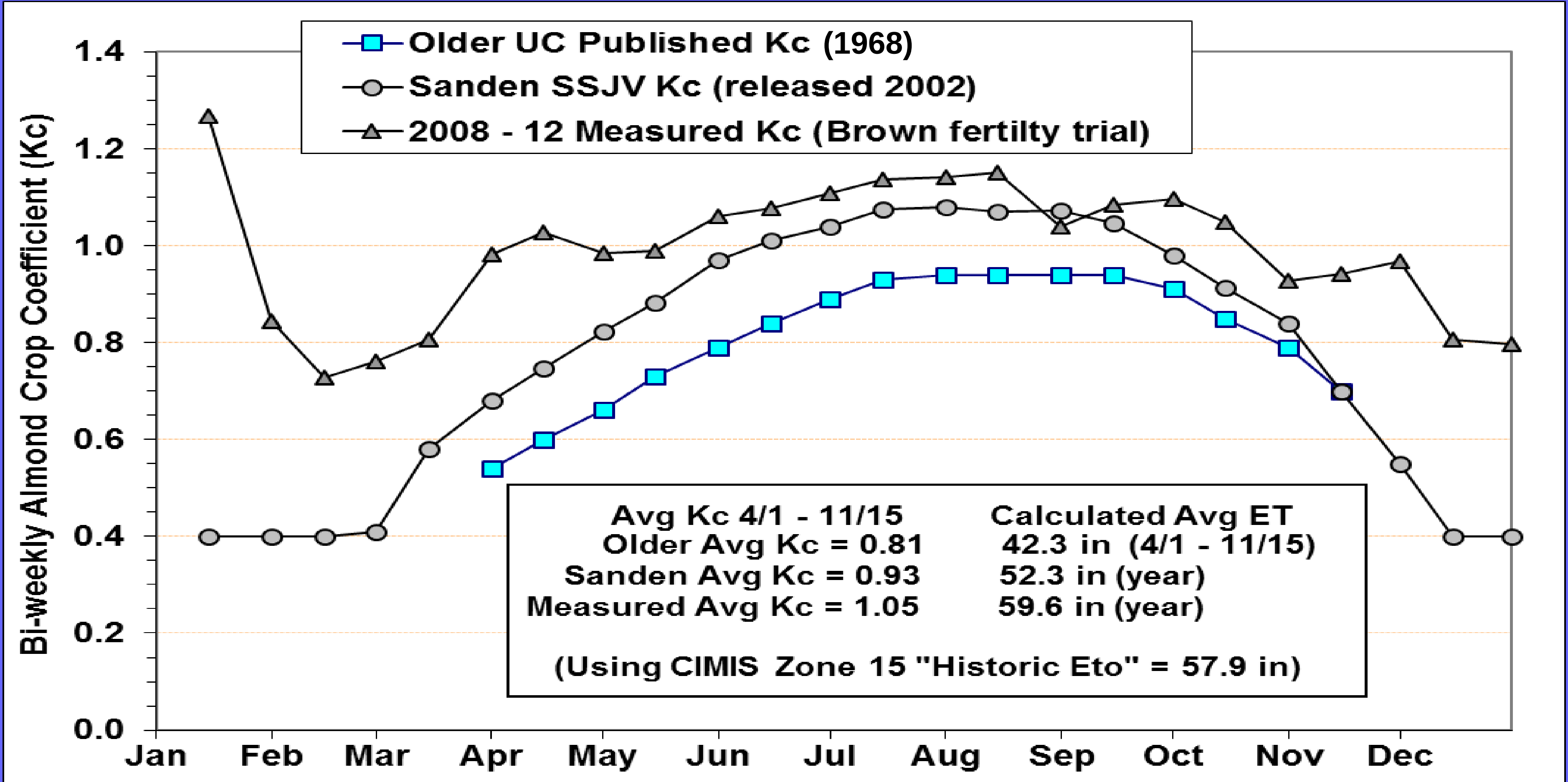
$E_f$ = an "**environmental factor**" that can account for immature permanent crops and/or impact of salinity. May be 0.1 to 1.1, determined by site.

**Google: cekern almond drip ET**

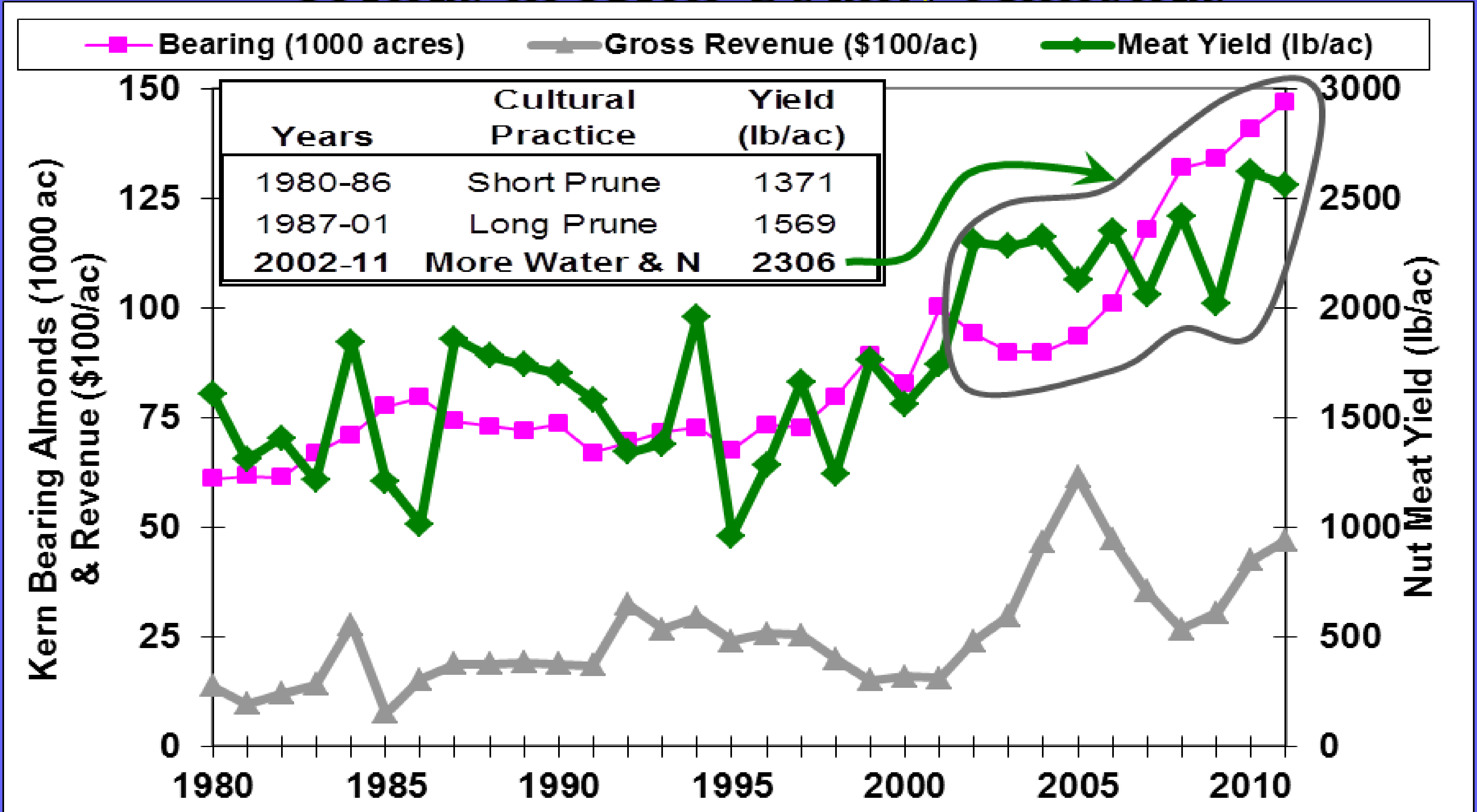
ET Estimates Using CIMIS Zone 15 Southern SJV "Historic" ETo (1st published 2002)

| Week | Normal Year Grass ETo (in) | Mature Crop Coef-ficient (Kc) | Almond ET -- Minimal Cover Crop, MIcrosprinkler (inches, S. San Joaquin Valley) 1st Leaf @ 40% | 2nd Leaf @ 55% | 3rd Leaf @ 75% | 4th Leaf @ 90% | Mature | Monthly Total | | Daily Avg | 20X22 Spacing Gallon / day / tree |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/6 | 0.21 | 0.40 | 0.03 | 0.05 | 0.06 | 0.08 | **0.09** | | | 0.01 | **3** |
| 1/13 | 0.28 | 0.40 | 0.04 | 0.06 | 0.08 | 0.10 | **0.11** | | | 0.02 | **4** |
| 1/20 | 0.30 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | 0.02 | **5** |
| 1/27 | 0.36 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | JAN | 0.46 | 0.02 | **6** |
| 2/3 | 0.42 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | 0.02 | **7** |
| 2/10 | 0.47 | 0.40 | 0.08 | 0.10 | 0.14 | 0.17 | **0.19** | | | 0.03 | **7** |
| 2/17 | 0.54 | 0.40 | 0.09 | 0.12 | 0.16 | 0.19 | **0.22** | | | 0.03 | **8** |
| 2/24 | 0.61 | 0.40 | 0.10 | 0.13 | 0.18 | 0.22 | **0.24** | | | 0.03 | **10** |
| 3/3 | 0.69 | 0.42 | 0.12 | 0.16 | 0.22 | 0.26 | **0.29** | FEB | 1.02 | 0.04 | **11** |
| 5/5 | 1.59 | 0.86 | 0.55 | 0.75 | 1.03 | 1.23 | **1.37** | | | 0.20 | **54** |
| 5/12 | 1.66 | 0.90 | 0.60 | 0.83 | 1.13 | 1.35 | **1.50** | | | 0.21 | **59** |
| 5/19 | 1.73 | 0.94 | 0.65 | 0.89 | 1.22 | 1.46 | **1.63** | | | 0.23 | **64** |
| 5/26 | 1.78 | 0.96 | 0.69 | 0.94 | 1.29 | 1.54 | **1.72** | | | 0.25 | **67** |
| 6/2 | 1.85 | 0.98 | 0.72 | 0.99 | 1.35 | 1.62 | **1.80** | MAY | 7.15 | 0.26 | **71** |
| 6/9 | 1.86 | 0.99 | 0.73 | 1.01 | 1.38 | 1.65 | **1.83** | | | 0.26 | **72** |
| 6/16 | 1.90 | 1.02 | 0.77 | 1.06 | 1.45 | 1.74 | **1.93** | | | 0.28 | **76** |
| 6/23 | 1.93 | 1.05 | 0.81 | 1.11 | 1.52 | 1.82 | **2.03** | | | 0.29 | **79** |
| 6/30 | 1.93 | 1.06 | 0.82 | 1.13 | 1.54 | 1.85 | **2.05** | JUN | 8.36 | 0.29 | **80** |
| 10/27 | 0.77 | 0.83 | 0.26 | 0.35 | 0.48 | 0.58 | **0.64** | OCT | 3.49 | 0.09 | **25** |
| 11/3 | 0.67 | 0.78 | 0.21 | 0.29 | 0.39 | 0.47 | **0.53** | | | 0.08 | **21** |
| 11/10 | 0.57 | 0.71 | 0.16 | 0.22 | 0.31 | 0.37 | **0.41** | | | 0.06 | **16** |
| 11/17 | 0.48 | 0.68 | 0.13 | 0.18 | 0.25 | 0.30 | **0.33** | | | 0.05 | **13** |
| 11/24 | 0.42 | 0.60 | 0.10 | 0.14 | 0.19 | 0.22 | **0.25** | | | 0.04 | **10** |
| 12/1 | 0.36 | 0.50 | 0.07 | 0.10 | 0.13 | 0.16 | **0.18** | NOV | 1.32 | 0.03 | **7** |
| 12/8 | 0.31 | 0.40 | 0.05 | 0.07 | 0.09 | 0.11 | **0.12** | | | 0.02 | **5** |
| 12/15 | 0.29 | 0.40 | 0.05 | 0.06 | 0.09 | 0.10 | **0.11** | | | 0.02 | **4** |
| 12/22 | 0.25 | 0.40 | 0.04 | 0.06 | 0.08 | 0.09 | **0.10** | | | 0.01 | **4** |
| 12/29 | 0.21 | 0.40 | 0.03 | 0.05 | 0.06 | 0.08 | **0.09** | DEC | 0.47 | 0.01 | **3** |
| **Total** | **57.90** | | **20.91** | **28.75** | **39.20** | **47.05** | **52.27** | | **52.27** | | |

# Measured Brown Fertility Trial ET compared to 2002 Sanden & 1968 UC Almond ET

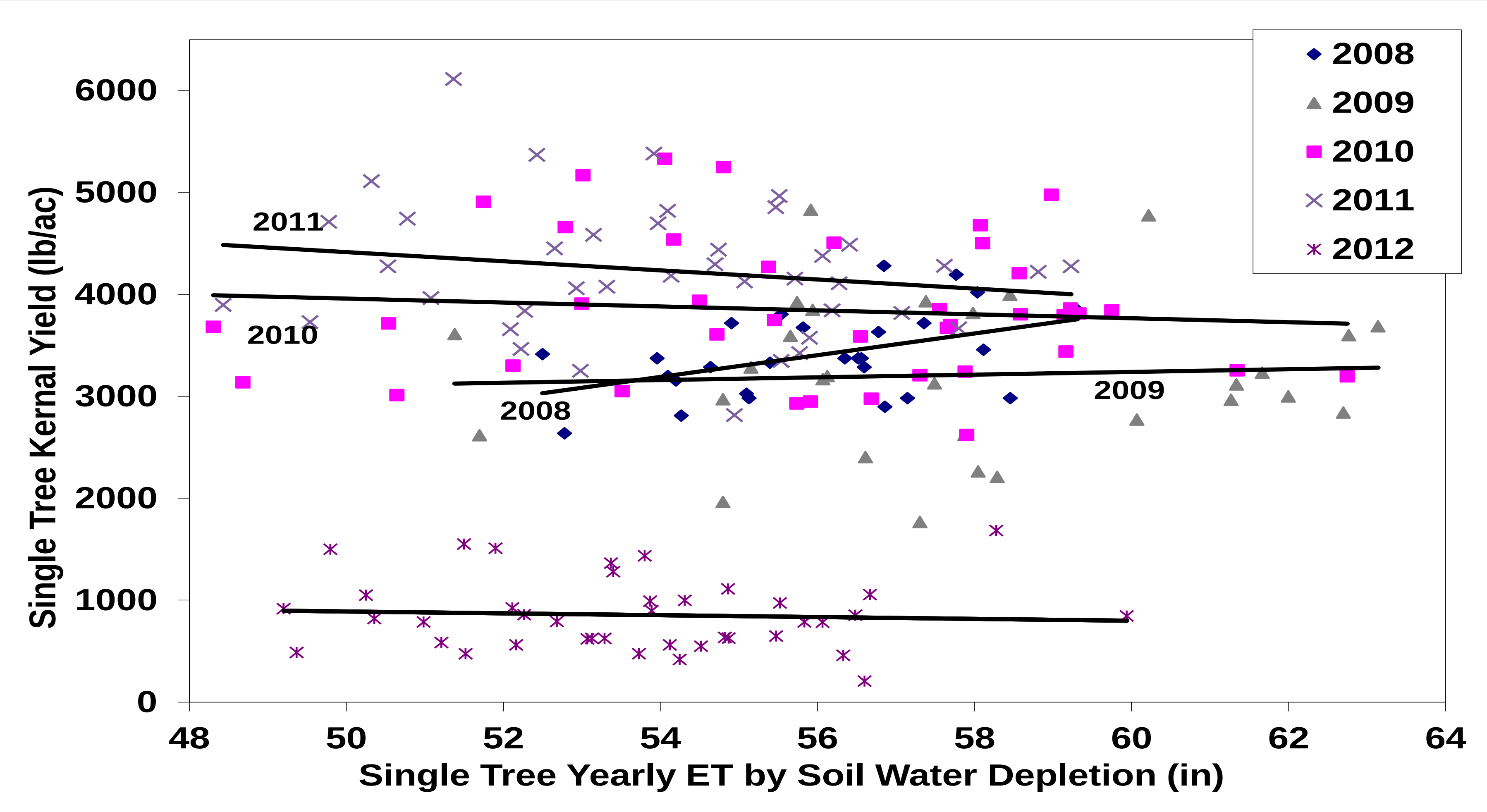


# Trends in Kern County Almonds



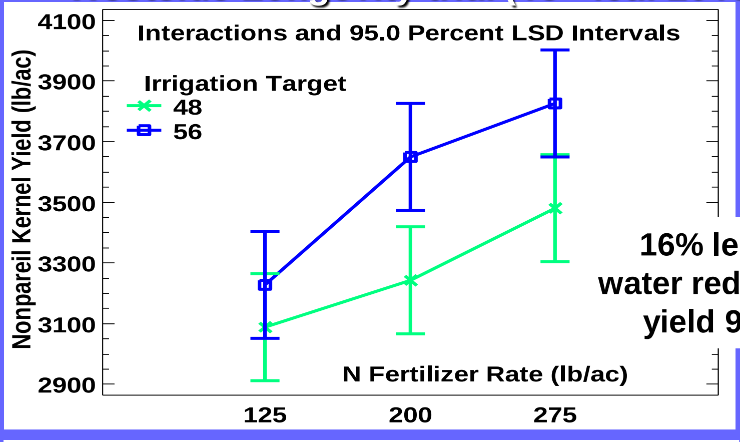

| Years | Cultural Practice | Yield (lb/ac) |
|---|---|---|
| 1980-86 | Short Prune | 1371 |
| 1987-01 | Long Prune | 1569 |
| **2002-11** | **More Water & N** | **2306** |

# Do you get 6,000 lb/ac with 60" ET?

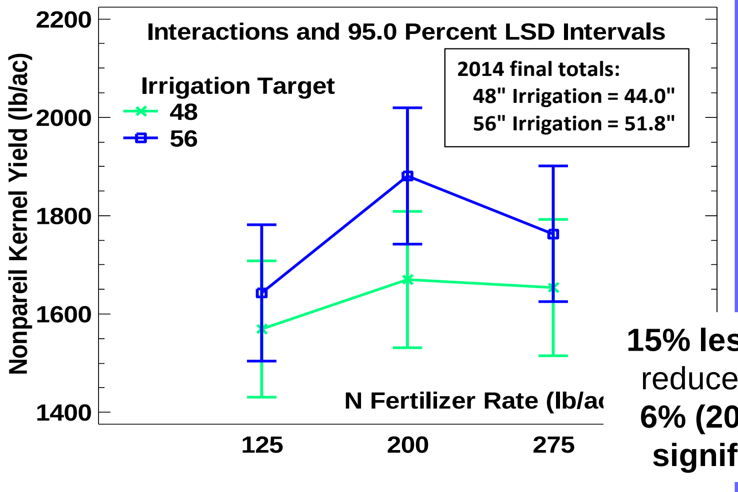


# Current findings on almond ET and yield impacts in Kern County

## Westside Longevity trial (15th leaf 2013)

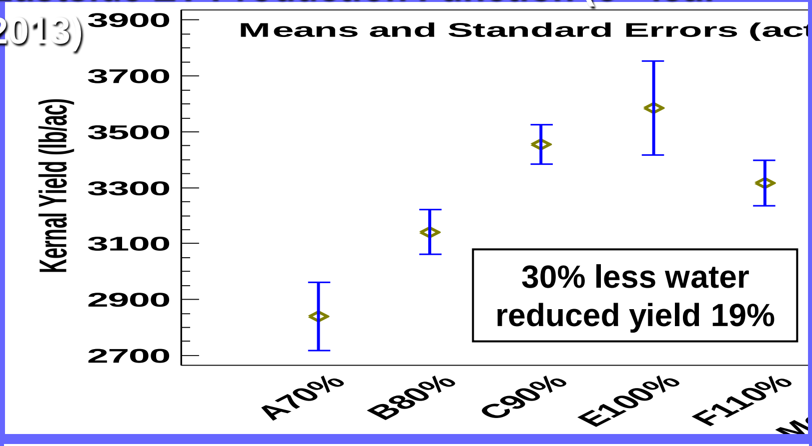



16% less water reduced yield 9%

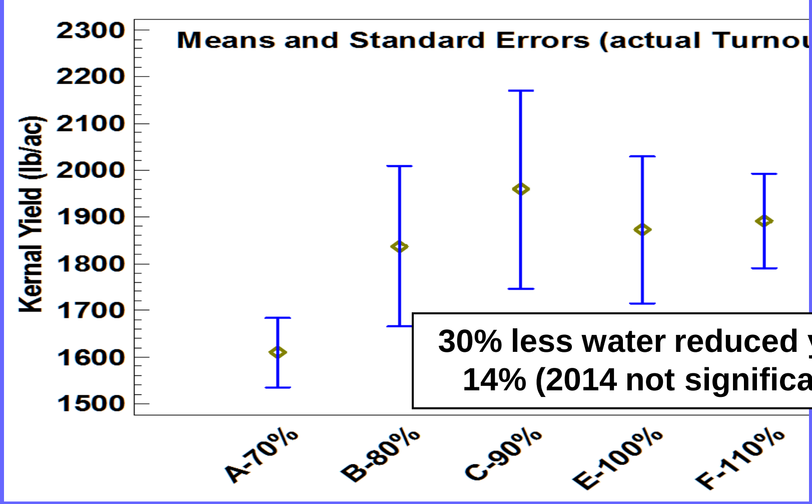



15% less water reduced yield 6% (2014 not significant)

## Eastside ET Production Function (8th leaf 2013)

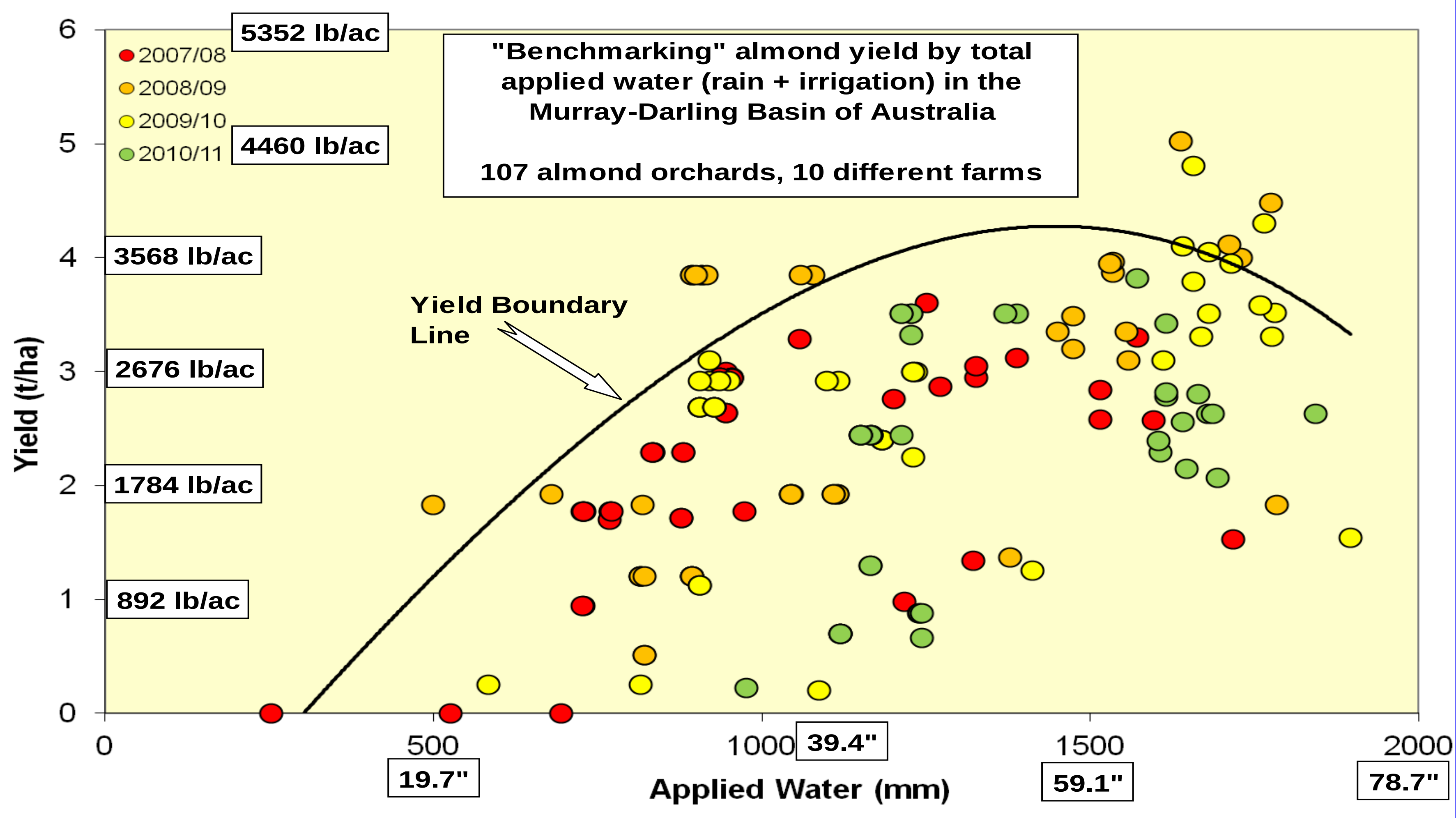



30% less water reduced yield 19%




30% less water reduced yield 14% (2014 not significant)

# Yield by applied water, Murray-Darling River Valley Australia



- QUESTIONS:

1. A fanjet system wetting 40% of the orchard floor has more “E” than any double-line drip system? True/False
2. Rootzone moisture storage for a fanjet system is always greater than for a double-line drip? True/False
3. For a 1”/day microsprinkler system wetting 50% of the floor, which irrigation duration/orchard age combination has the lowest “E”?

   a)8 hrs – 6th leaf b) 24 hrs – 2nd leaf c) 24 hrs - 6th leaf

   d) 12 hrs – 10th leaf e) 48 hrs – 5th leaf
4. 56” of water generates an 80-90% canopy cover and guarantees 4,000 lb/ac? True/False

# Allen Fulton, UCCE-Tehama County

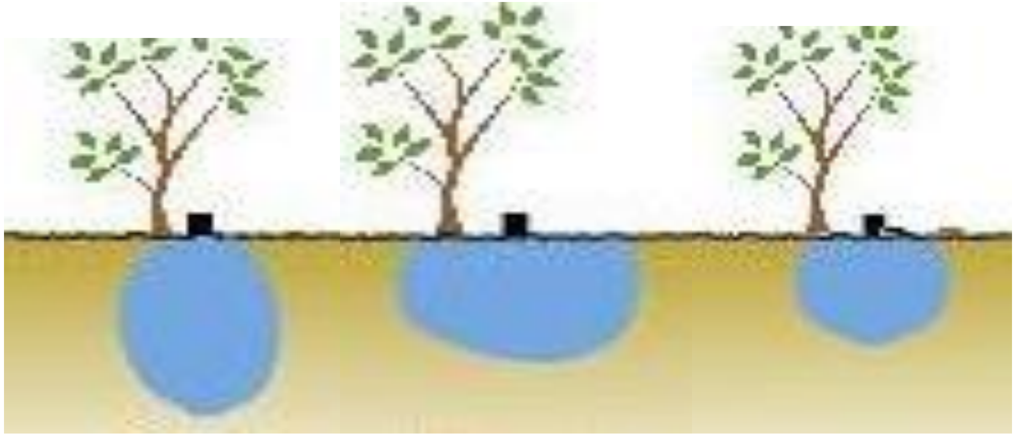
# Irrigation Scheduling 101

Allan Fulton
UC Cooperative Extension
Tehama, Glenn, Colusa, and Shasta Counties

## Topics:

- Irrigation Distribution Uniformity
- Salinity Management

# Irrigation Distribution Uniformity (DU) - Simple Concept



## Important to the bottom line:

- water demand
- energy demand
- orchard production and tree health
- production per unit water and land

# DU is not as simple to technically quantify

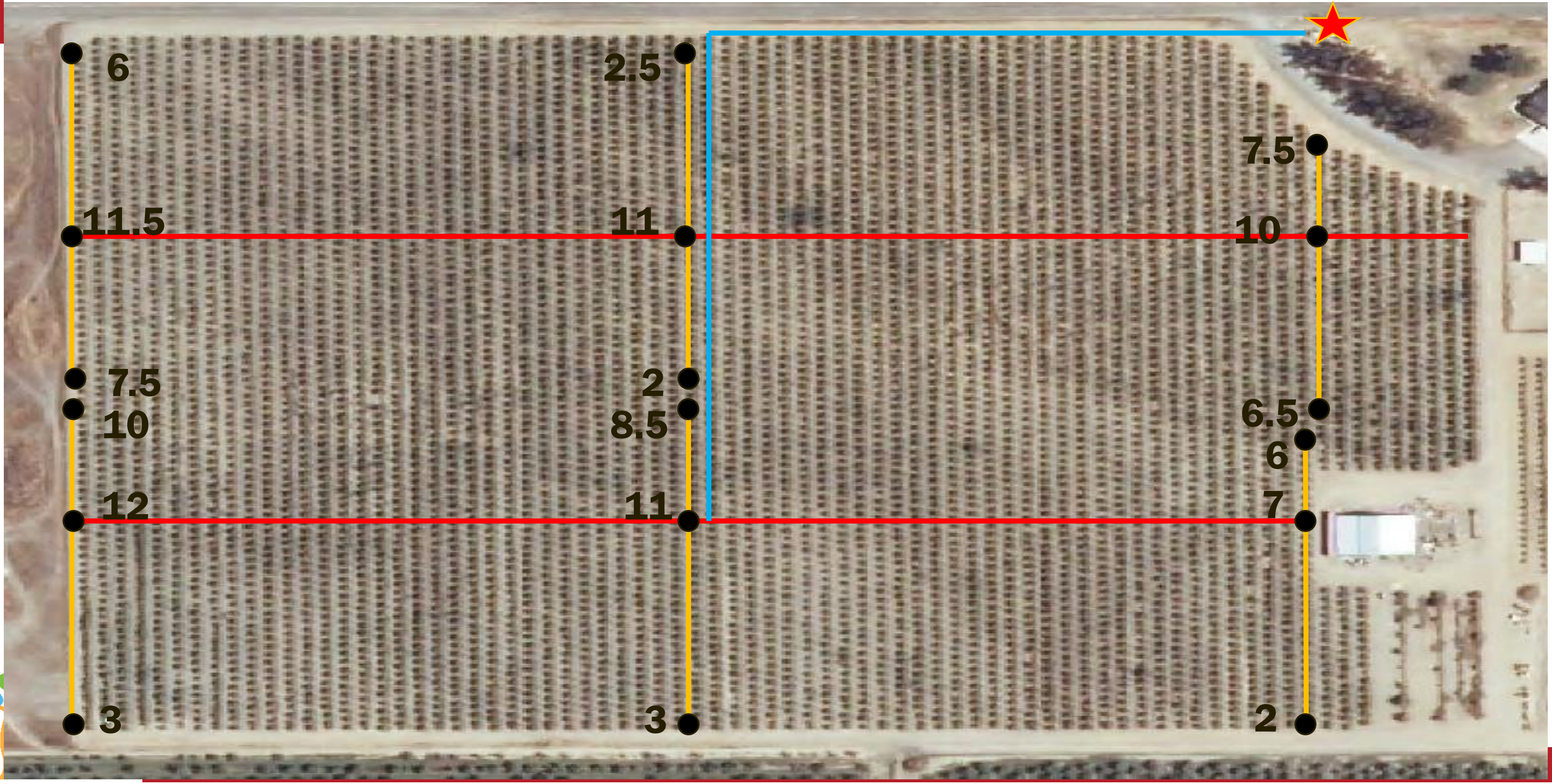
$$\text{Distribution Uniformity (DU)} = \frac{\text{Average infiltrated water of low quartile of measurements in orchard}}{\text{Average infiltrated water whole field}}$$

- Amount of infiltrated water is difficult to measure

Instead:

- With drip and micro irrigation: pressure and emission flow rates are measured
- With flood: inflow, border check dimensions, water advance rates and distances are measured along with tailwater and time for water to recede

# Measuring DU is much simpler with drip and micro sprinkler



# How to check pressures and flows

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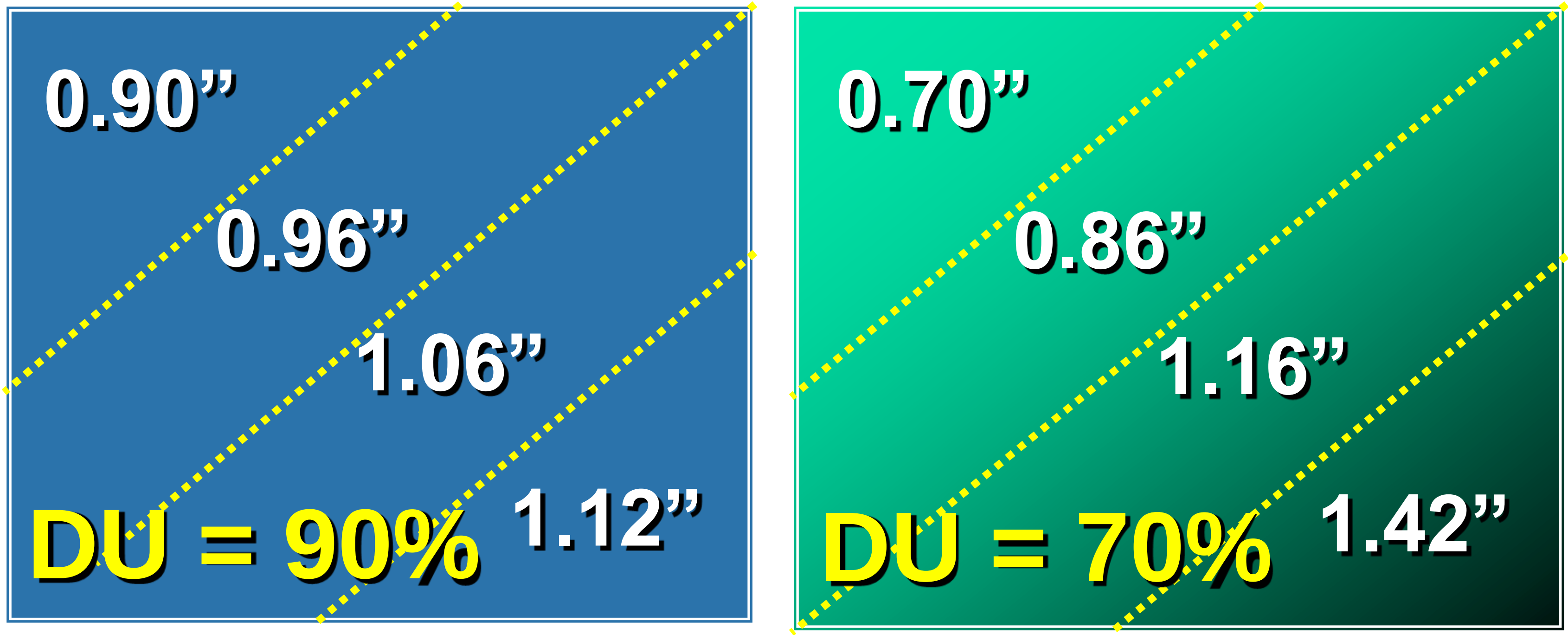
# Putting the Value of Irrigation Distribution Uniformity into Perspective

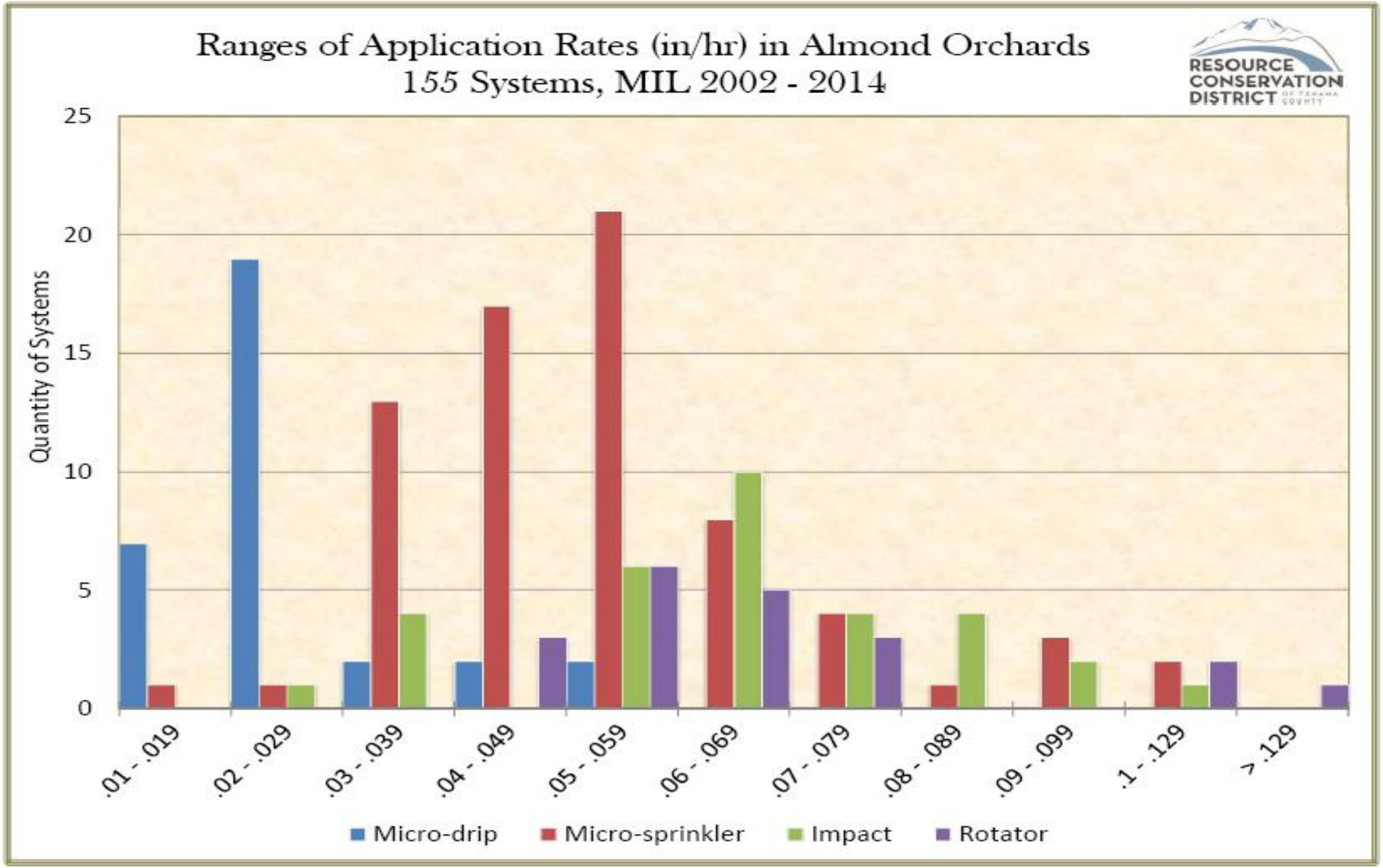
## Example:  Target application 1.0 inch water



# Putting the Value of Irrigation Distribution Uniformity into Perspective

## Example:  Target application 1.0 inch water

| DU | Water Applied High ¼ of orchard | Water Applied Low ¼ of orchard | Difference across orchard one irrigation | Difference thirty irrigation cycles |
|---|---|---|---|---|
| | ---------------------- | Inches applied | ------------------------- | |
| 90 | 1.12 | 0.90 | 0.22 | 6.6 |
| 80 | 1.27 | 0.80 | 0.47 | 14.1 |
| 70 | 1.42 | 0.70 | 0.72 | 21.6 |

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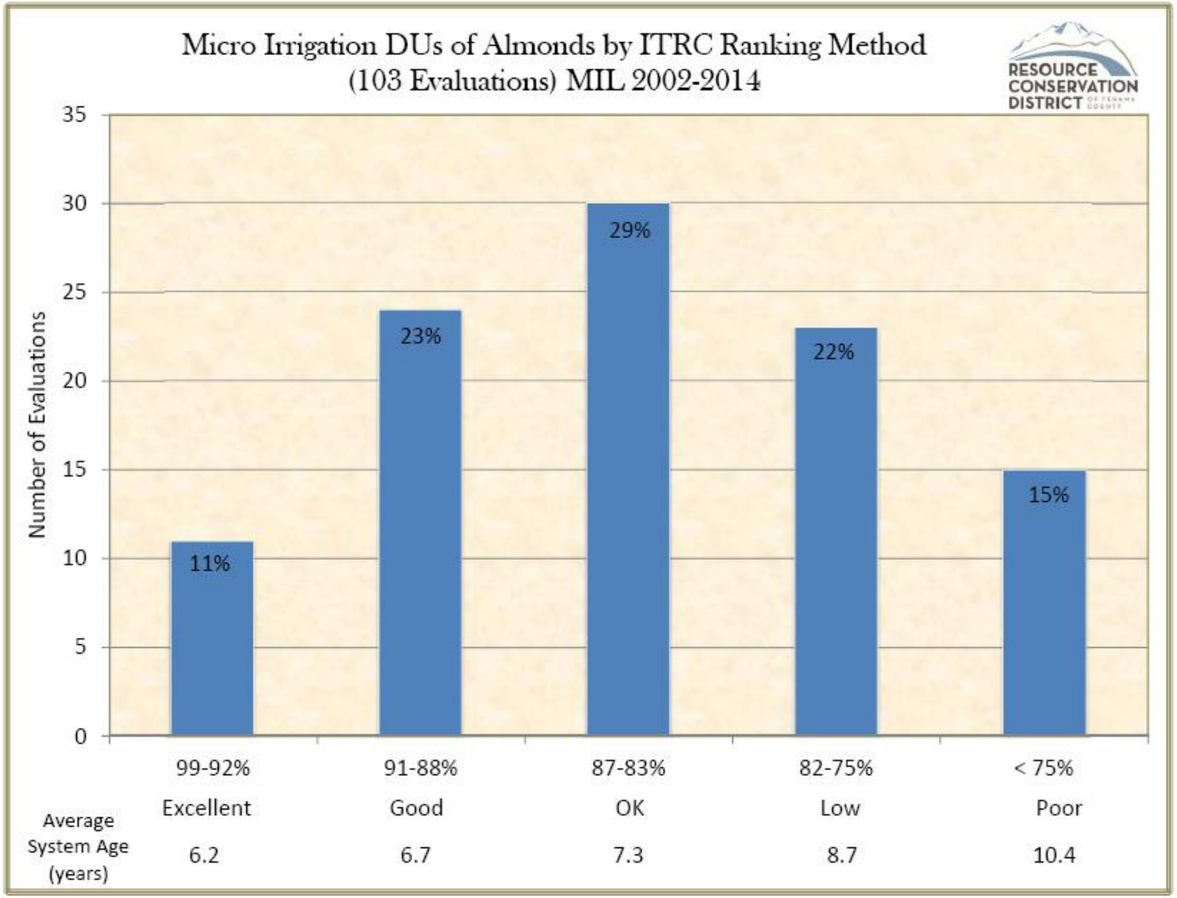
# Putting the Value of Irrigation Distribution Uniformity into Perspective

## Example: Target 1.0 inch of water in low ¼ of orchard using a micro sprinkler system with 0.05 inch/hr application rate

| DU | Hours to apply 1" low ¼ of orchard | Total hours thirty irrigation cycles | Hours irrigation (pump) time increased between DU's | Relative Increase % |
|---|---|---|---|---|
| 100 | 20 | 600 | Reference Point | ---- |
| 90 | 22 | 660 | 60 | 10 |
| 80 | 24 | 720 | 120 | 20 |
| 70 | 26 | 780 | 180 | 30 |

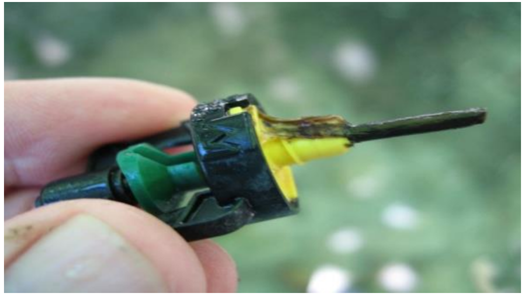
# Is there opportunity among the almond industry to improve DU?

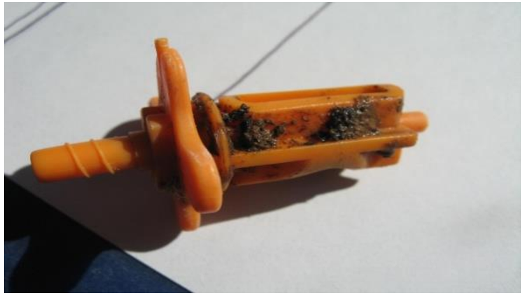


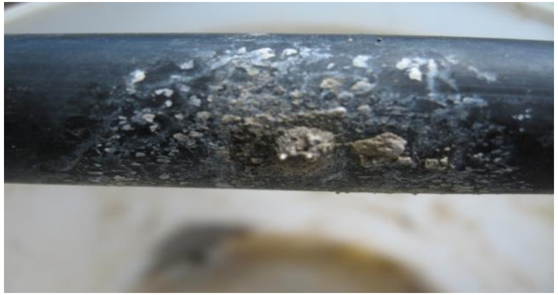
# Keys to Achieving or Maintaining high DUs (what works well)

- Balanced pressures
- Sprinkler types – must match
- Nozzle sizes – must match
- Maintenance – filtering & flushing
- Maintenance – breaks and leaks
- Maintenance - chemigation

# Plugs, leaks, and breaks







# Salinity Management in Almonds

# About Almond Salt Tolerance:

- Evidence of greater sodium and chloride tolerance in peach-almond hybrid rootstocks than peach rootstock
- Support that some almond varieties will express sodium leaf toxicity before others (i.e. Fritz will express toxicity before Nonpareil)
- Data suggests almond may tolerate higher root zone salinity than past research indicated (old threshold 1.5 ds/m versus newer suggesting a threshold of 2.5 to 3.0 ds/m)

# On Reclaiming Salt Impacted Orchards

- Leaching is the primary step to manage salts but it is not necessary every irrigation or perhaps even every season, only when crop tolerances are approached
- Periodic soil testing in the root zone will help determine when and how much leaching is needed
- The soil water content must exceed field capacity in the root zone for leaching to occur
- Leaching is most efficient in the winter when crops are dormant and  ET is low. Also this timing does not coincide with critical periods of nitrogen fertilization and uptake
- Intermittent periods of irrigation and rainfall will more efficiently leach salts and boron than continuous

# On Reclaiming Salt Impacted Orchards

- If an orchard has been impacted by salinity and boron, when the water supply improves, research based estimates can be made as to how much leaching may be needed to reclaim an orchard back to tolerable levels

| Leaching Requirement | Proportion that orchard root zone salinity exceeds threshold salinity | | | | |
|---|---|---|---|---|---|
| | 1.3X | 2X | 2.6X | 3.3X | 4X |
| Depth of water (inches) per foot of rootzone | 0.6 | 1.8 | 3.0 | 4.2 | 5.4 |

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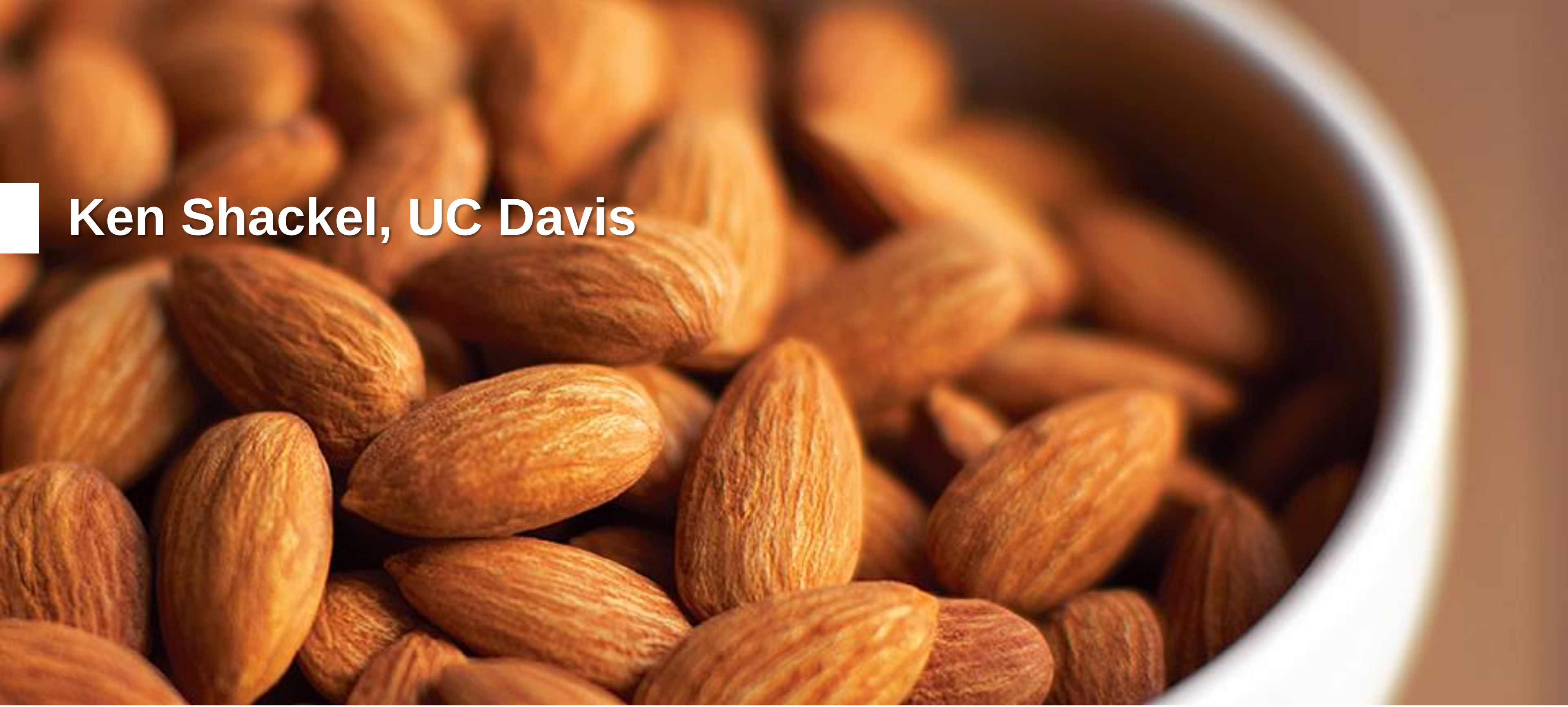
Thank You!



# Ken Shackel, UC Davis

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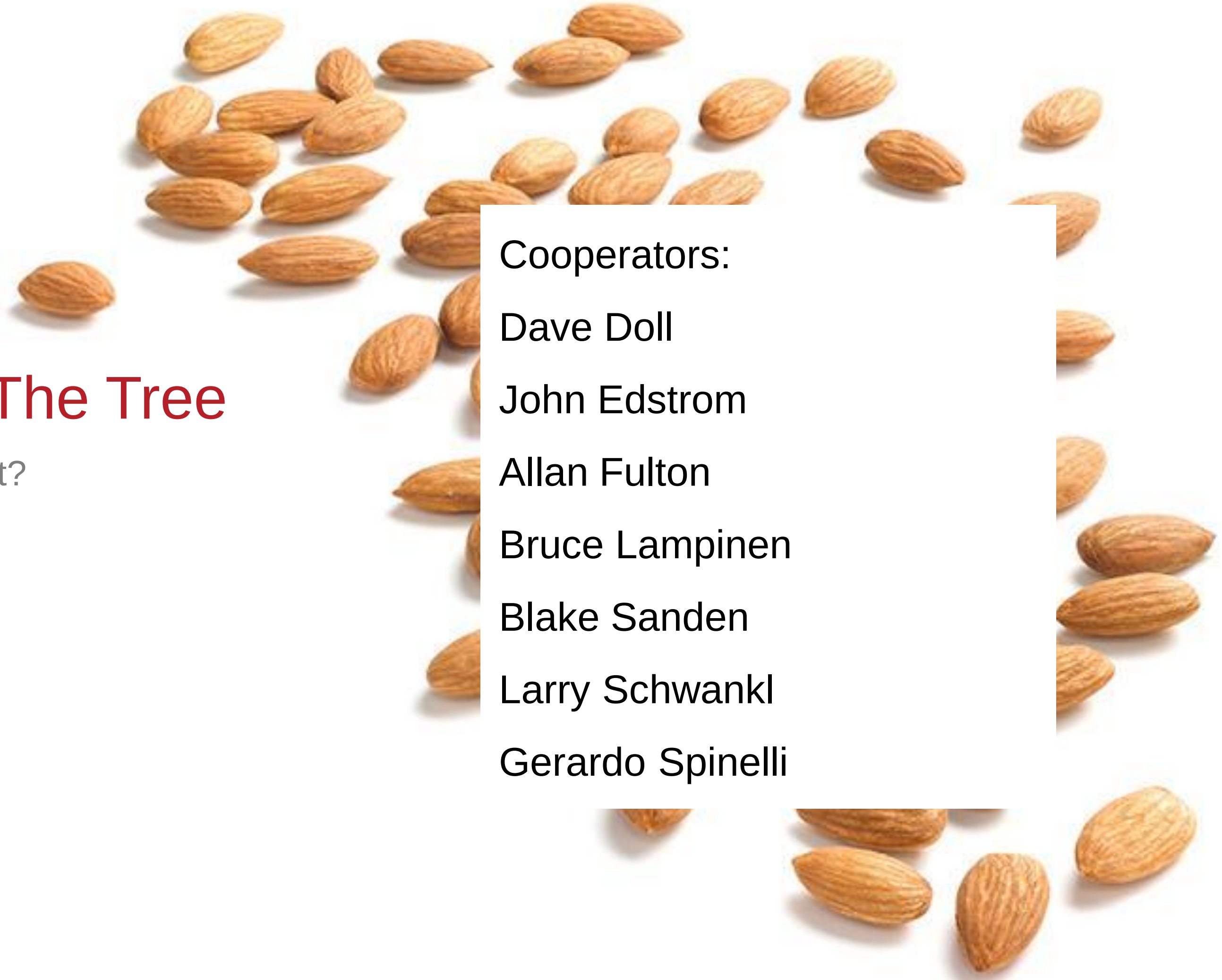
# Irrigation 101: The Tree

How does it feel and react?



Cooperators:

Dave Doll

John Edstrom

Allan Fulton

Bruce Lampinen

Blake Sanden

Larry Schwankl

Gerardo Spinelli

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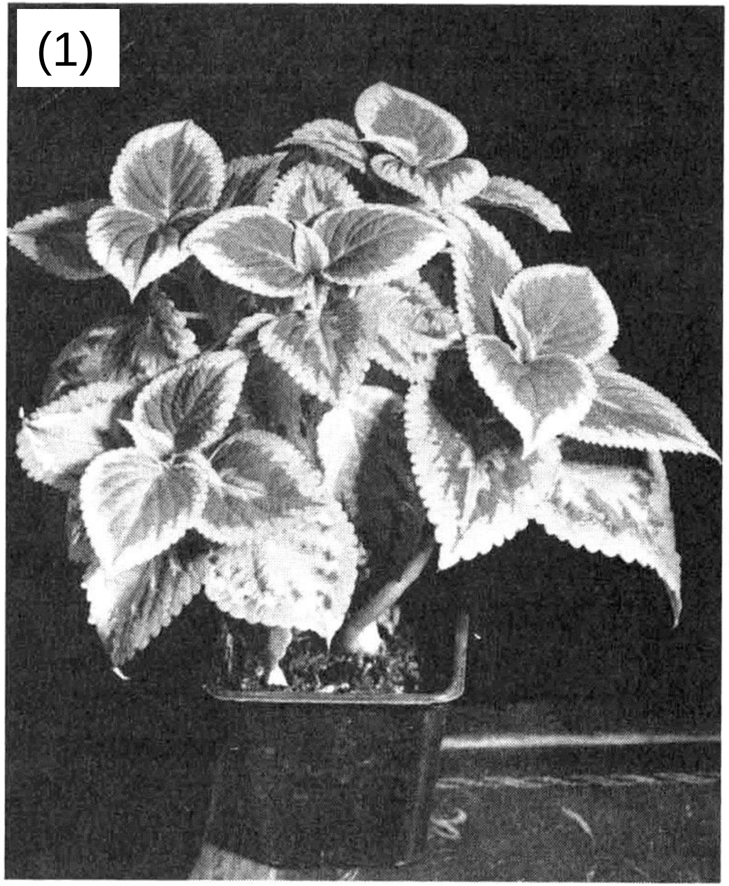
# Practice Question: Which plant needs irrigation?



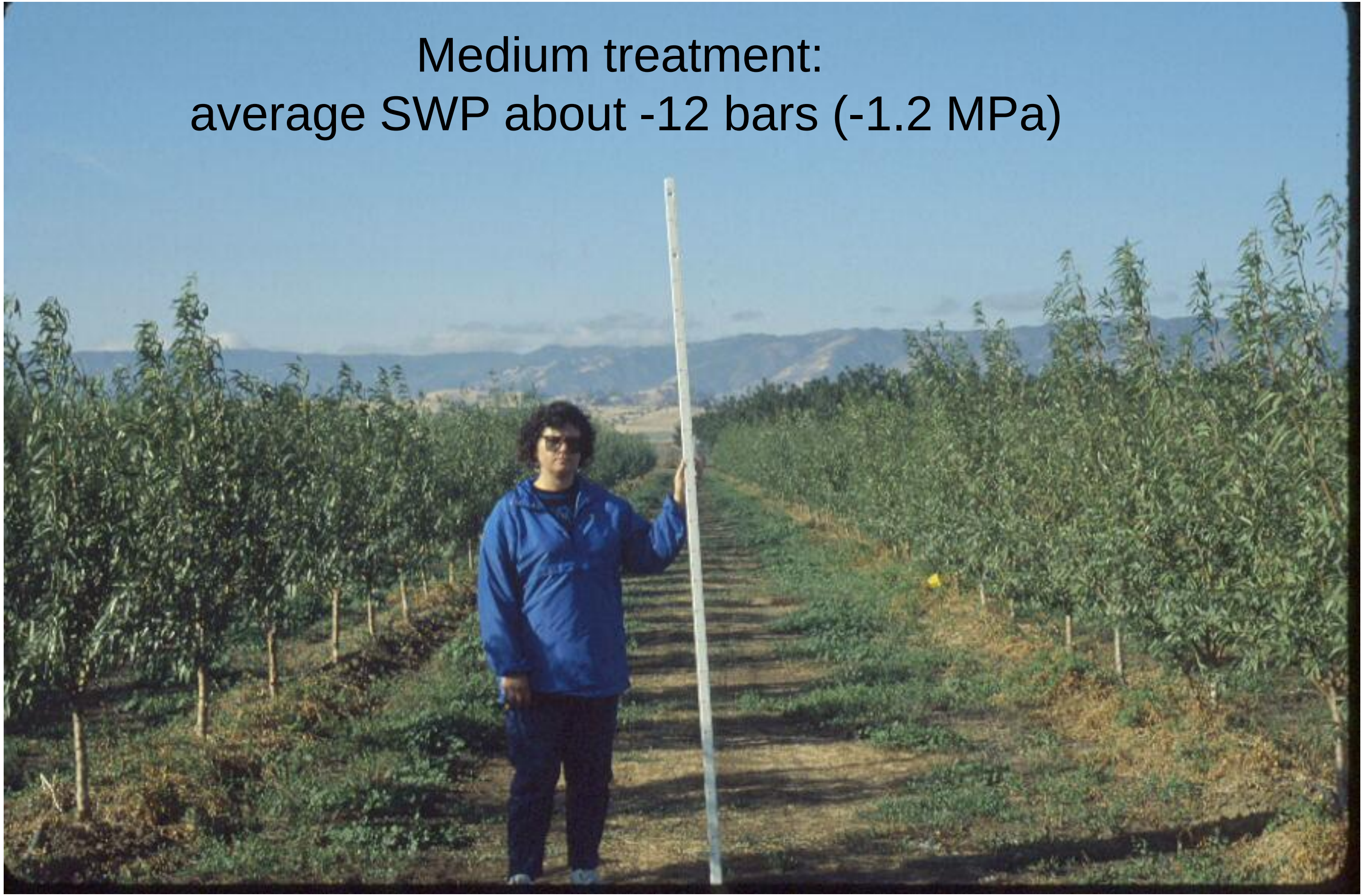


Salisbury & Ross, Plant Physiology (1992)

# First leaf almond orchard, Winters, CA, at the end of the first season of growth.

Question: how would you rate the level of water stress that you think might have been experienced during the growing season by this orchard?

1) Luxury water, no stress whatsoever.
2) Adequate water, no significant stress.
3) Mild water stress.
4) Moderate water stress.
5) Severe water stress.

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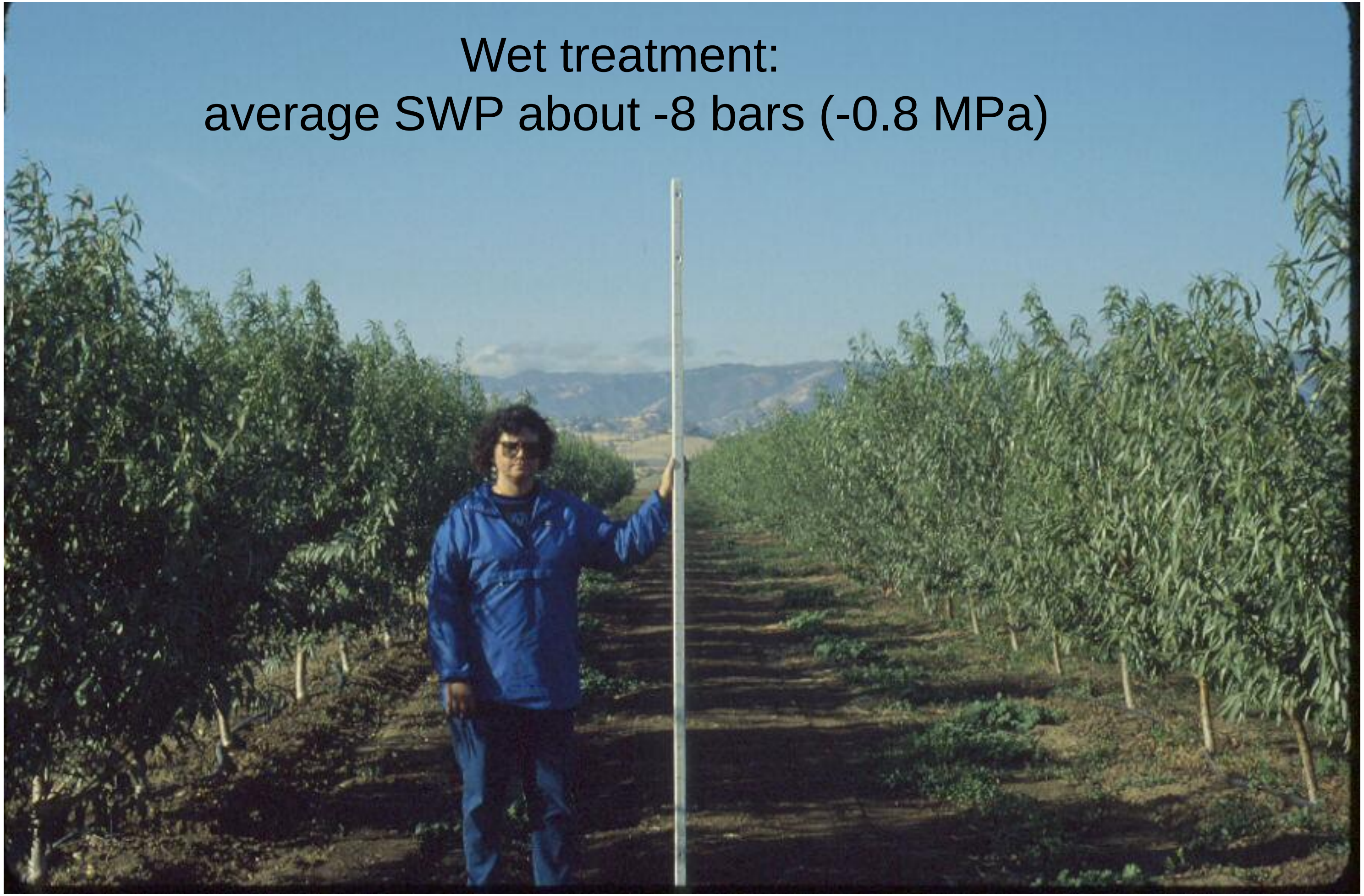
## Dry treatment:
## average SWP about -15 bars (-1.5 MPa)


Wet treatment:
average SWP about -8 bars (-0.8 MPa)

Forest Gump principle: Stress is as stress does.

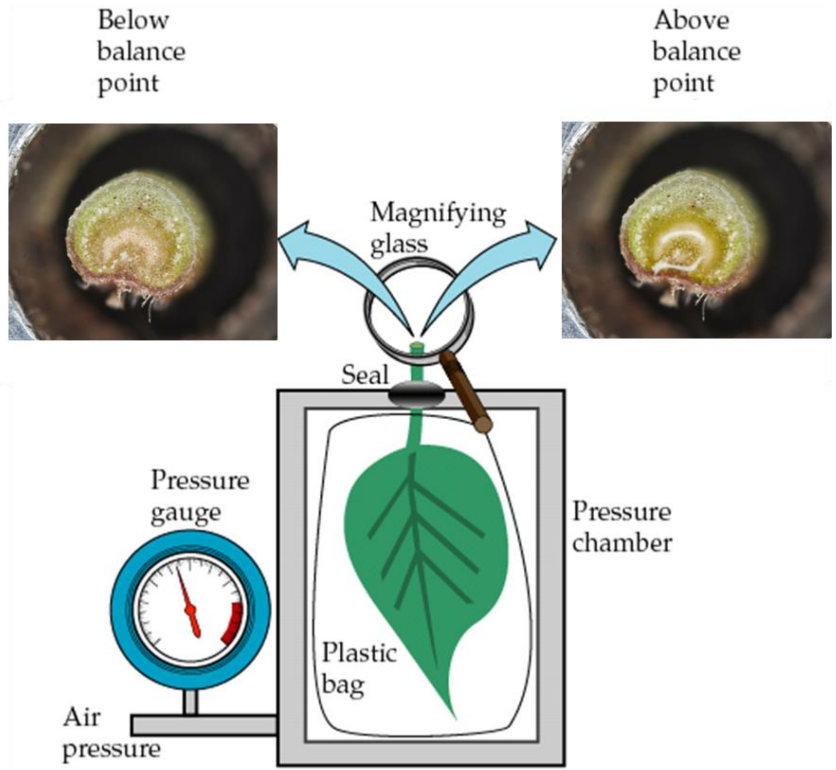
If you want to know whether a tree is under stress, then irrigate it.  If it gives a beneficial response, then it was under stress.  If not, it wasn't.  Either that, or it was, but there was nothing you could do about it.

For young orchards: filling the space quickly has great economic benefits, so growth is a beneficial response.

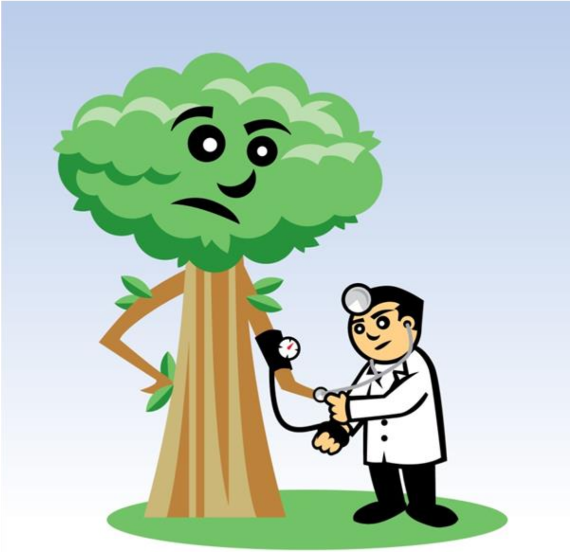
For mature orchards: the space is already filled, so excessive growth is not a beneficial response.

So, we need to understand how plants respond to water availability and water stress.

# Pressure chamber method for measuring water stress




Like measuring the "blood pressure" of the plant



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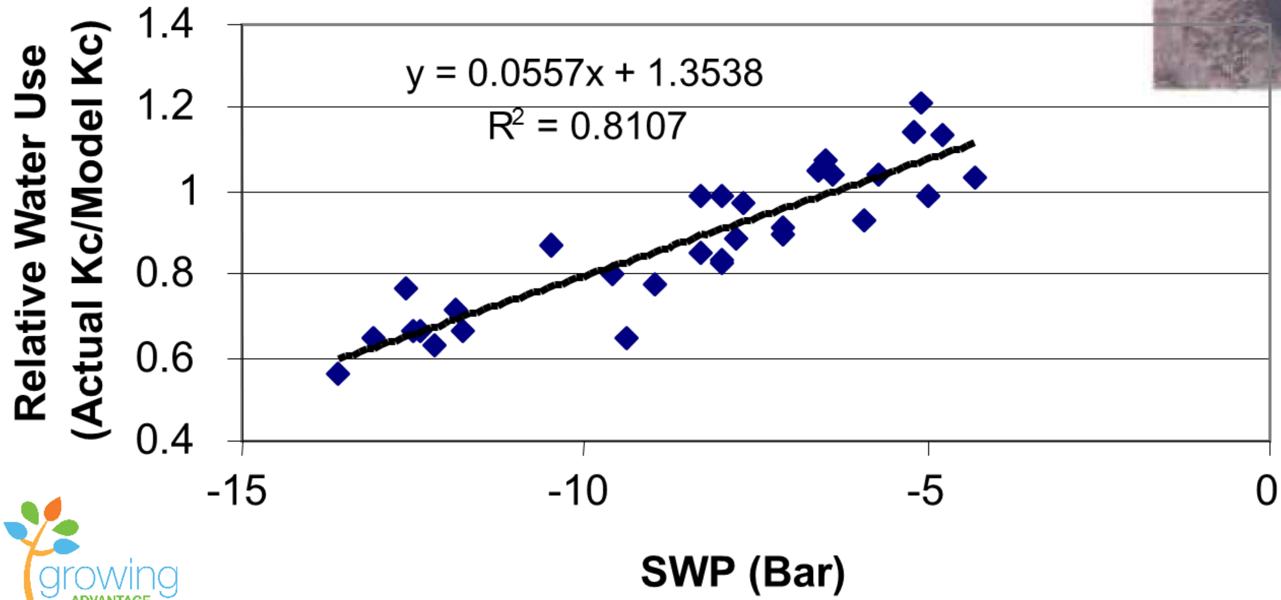
Johnson et al. 2005.

Peach ET response to SWP in a lysimeter




-11 bars difference gave about a **50%** reduction in ET

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For almonds we also see a similar reduction in stomatal conductance at the leaf level, but not at the canopy level using meterological methods. We are now planting almonds in the lysimeter to test this.

# Almond hull split

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## Proposed benefits of RDI for almonds during hull split:

1) Speed up Hull Split
2) Reduce Hull rot
3) Reduce Sticktights (Improve Harvestability)
4) Save Water

SWP recommendation: -14 to -18 bars during hull split

# Corning RDI study (2002-4)

# Corning: Prior to RDI

## % Hull Split in Carmel (East/West difference similar in all varieties)

| | Date, 2000 | | | | | |
|---|---|---|---|---|---|---|
| | 10 Aug | 16 Aug | 22 Aug | 31 Aug | 6 Sep | 14 Sep |
| East (Average SWP = -8.4 bars) | 0% | 0% | 5% | 13% | 32% | 40% |
| West (Average SWP = -14.1 bars) | 4% | 23% | 60% | 83% | 85% | 91% |

Problems with uneven hull split timing:

- Uncertain timing for hull split spray
- Irrigation management problems
- Uneven/delayed harvest

# Starting in 2001, under RDI (East soil), Nonpareil hull split was the same for East and West soils

| | | | | | | |
|---|---|---|---|---|---|---|
| 2001 | Date | Jul 13 | Jul 20 | Jul 27 | Aug 1 | Aug 13 |
| | East (silt) | 2% | 20% | 45% | 70% | 100% |
| | West (gravel) | 2% | 25% | 55% | 75% | 100% |
| | | | | | | |
| 2003 | Date | | Jul 29 | Aug 7 | Aug 15 | Aug 22 |
| | East (silt) | | 29% | 95% | 100% | 100% |
| | West (gravel) | | 29% | 88% | 100% | 100% |

# Corning Location – Irrigation Summary (RDI)

| Soil | 2002 | | 2003 | | 2004 | |
|---|---|---|---|---|---|---|
| | Water applied | Cutoff date | Water applied | Cutoff date | Water applied | Cutback date |
| East (silt) | 24” | 10-Jul | 14” | 1-Jul | 18” | 7-Jun |
| West (gravel) | 40” | 25-Aug | 41” | 4-Sep | 36” | 16-Sep |
| ETc | 43” | | 40” | | 42” | |

Very long cutoff/cutback OK on East (silt) soil

“West Side story”
Some unfortunate west side trees
growing the east side

# Drought Study in Almonds, 2009

## Main questions:

1) How much water does it take for an almond tree to survive?

2) Will application of small amounts of water (5”, 10”) over the season help?

3) Is there a critical level of tree water stress that will cause tree death or dieback?

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June 29, 2009

Control tree

- 9.8 bars SWP

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June 29, 2009

10” tree

- 25 bars SWP

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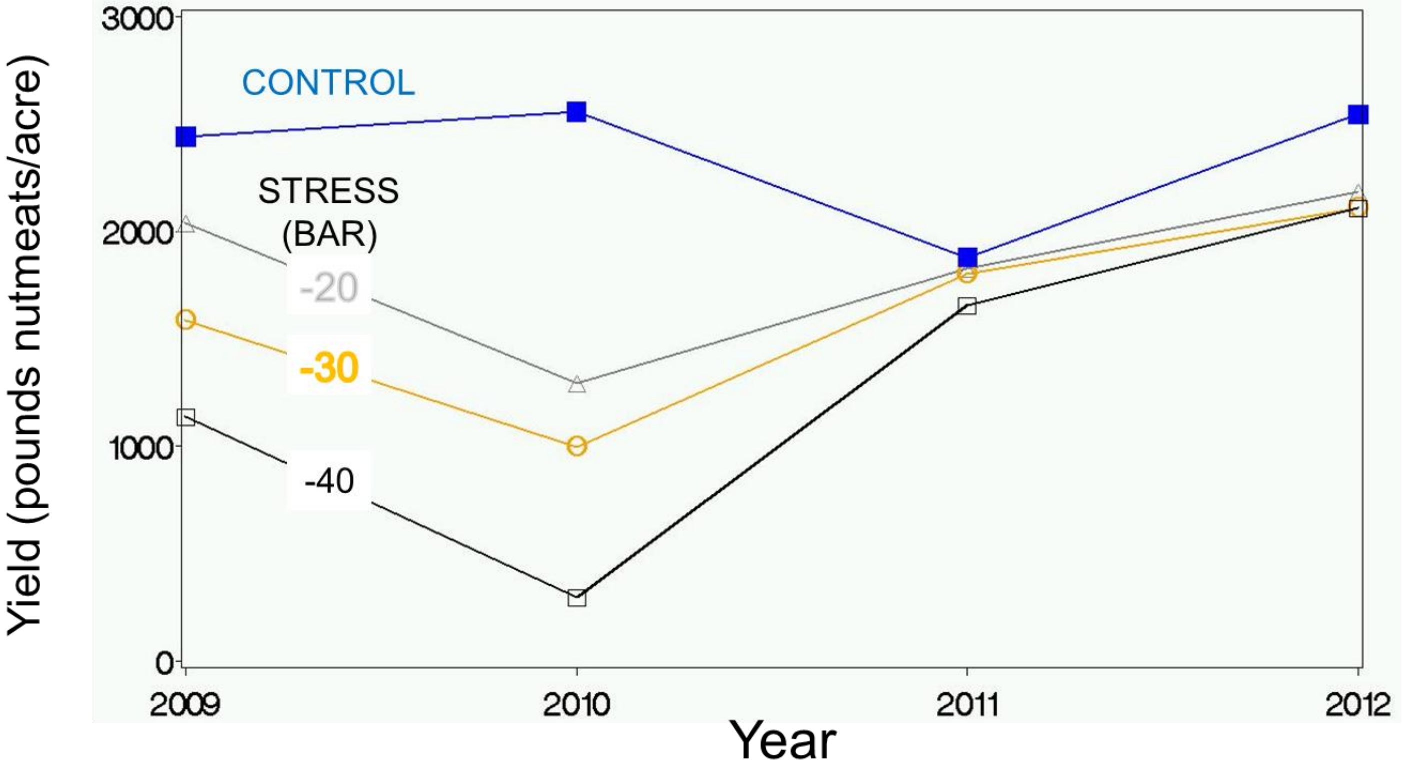
June 29, 2009

0” tree

- 40 bars SWP

**This tree had reached -63 bars on July 14, 2009, and by July 28 was completely defoliated. But notably, did not die!**

# Yield: The biggest reduction occurred in the year following the stress (i.e. carryover effect)

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# Water Production Function Yields and SWP's: Year 2

At most locations, irrigation treatments are causing the expected and statistically significant (but not large), differences in SWP.
The story is not so clear yet in yield.

| Kern | | | | Merced | | | | Tehama | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Yield (#/ac) | | SWP June-August | | Yield (#/ac) | | SWP June-August | | Yield (#/ac) | | SWP June-August | |
| %ET | Mean | %ET | Mean | %ET | Mean | %ET | Mean | %ET | Mean | %ET | Mean |
| 90 | 1960 | 110 | -16a | 110 | 2910 | 110 | -14a | 74 | 2340 | 116 | -12a |
| 110 | 1890 | 100 | -17a | 100 | 2900 | 100 | -15ab | 100 | 2315 | 100 | -15 b |
| 100 | 1870 | 80 | -19ab | 80 | 2640 | 90 | -16ab | 116 | 2260 | 86 | -16 b |
| 80 | 1840 | 90 | -19ab | 90 | 2540 | 80 | -18 bc | 86 | 2260 | 74 | -17 b |
| 70 | 1610 | 70 | -21 b | 70 | 2420 | 70 | -19 c | | | | |

Take home points:

1) Biology is complex - almonds have many responses to water stress.
2) Most responses are expected to reduce yield, but some may have beneficial side effects (i.e., hull split RDI), and there may be a ‘sweet spot’ for sustainable water management.
3) The severity of the response will depend on the level of stress (SWP).
4) Early symptoms are reduced growth and defoliation of lower leaves.
5) Almonds can survive very high levels of stress, but severe stress will reduce yield this year and especially next.
6) We are scratching the surface – many practical questions remain!

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Thanks for your attention and support

# David Doll, UCCE-Merced County

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# Plant and Soil Monitoring for Efficient Irrigation Management

David Doll UCCE Merced
-or- Allan Fulton, UCCE Tehama

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# Why Should I Monitor the Soil and Plant?

Increases Efficiency of Water Applications by:

- Determining proper timing of irrigation in a variable environment,
- Making sure water stays within the root-zone (and reducing application amounts if it doesn’t),
- Applying stress at specific periods to reduce water use (and provide disease control benefits)

# Monitoring Applications

## Soil Based Monitoring

- Provides an idea on movement and depth of water within soil
- Able to identify duration of irrigations based on movement of water within the soil
- Hard to interpret when salt or disease comes into the picture

## Plant Based Monitoring

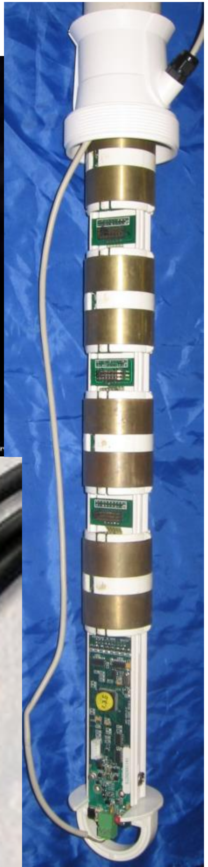
- Indicates plant stress levels, regardless of soil conditions;
- Useful in troubleshooting irrigation schedules, managing RDI;
- With exception of pressure chamber, not much work done in other systems;

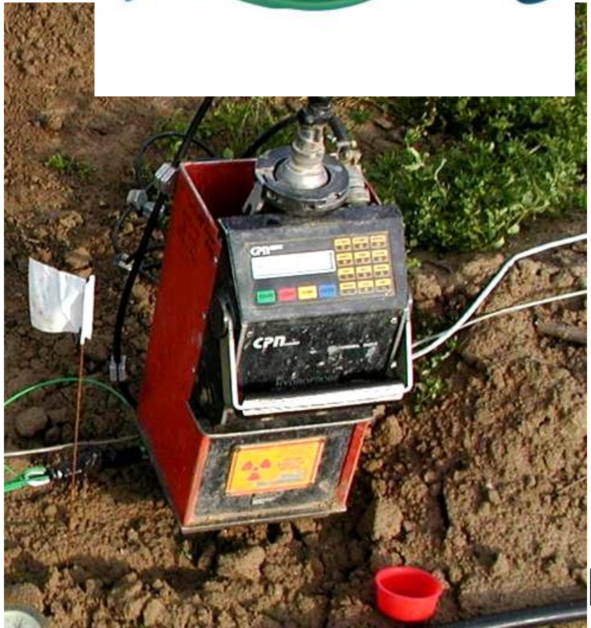
# Soil Moisture Monitoring Tools

Feel Method

Electrical Resistance

Capacitance/TDR




Neutron probe

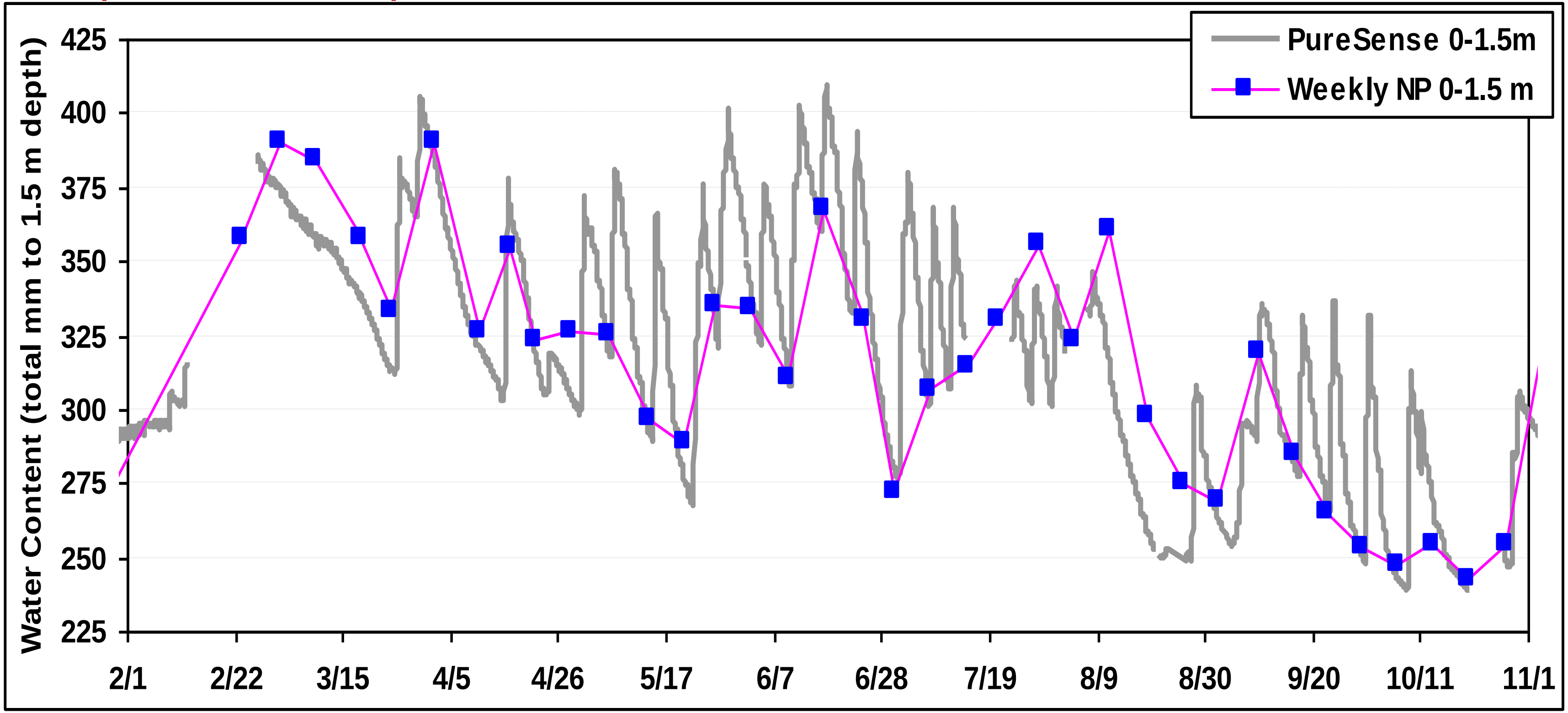

Tensiometer

# Soil Moisture Monitoring

| | "Feel" | Tensiometers | Dielectric Sensors | Electrical Resistance | Neutron Probes |
|---|---|---|---|---|---|
| **Basic Operation** | Soil between fingers | Measures the suction | Measures dielectric constant | Measures resistance | Measures neutrons slowed by water |
| **Requirement for Calibration** | Experience | Minimal | Yes, soil dependent | Moderate | Yes, soil dependent |
| **Monitoring Frequency** | Manual, Once | Manual or Automatic | Automatic | Automatic | Manual, once |
| **Zone of Measurement** | Size of Auger bucket | 2" off of sensor | About 1" from outside edge | 1" off of sensor, less in heavy, wet soils | 10" diameter |
| **Replacement, Maintenance** | None | Annual (check of vacuum and gauges), some require removal | Annual Maintenance | Annual, replacement every 3-7 years | Replace batteries, transport rules, annual radiation safety check |
| **Affected by Salinity, Alkalinity** | None | No | Yes , but depends on sensor type | Yes | No |
| **Soil Type Most Suitable** | All | All | Sand – Sandy Clay Loam (Non-cracking Soils) | Sandy Loam – Clay | All |
| **Common Companies** | | Hortau, Irrometers | Decagon, Aquacheck, EnviroSCAN | Watermarks | Contracted Services |

More information: http://ucmanagedrought.ucdavis.edu/

# Comparison of Capacitance to Neutron Probe

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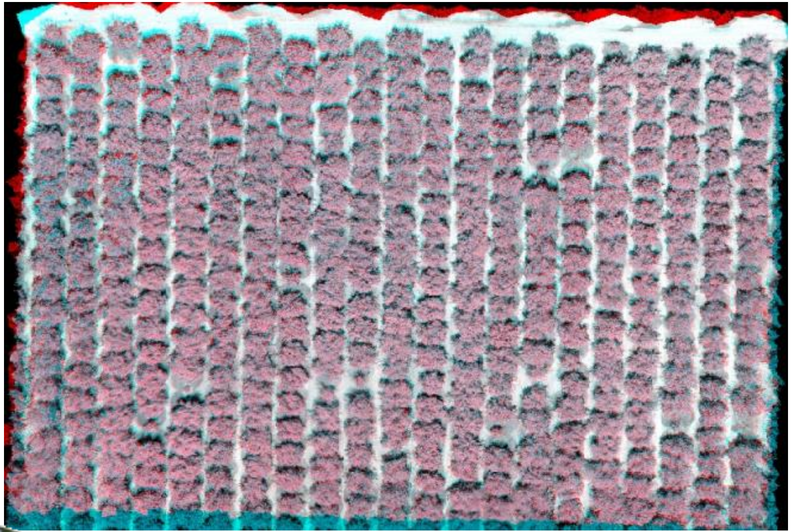
# Plant Base Monitoring

| | "Look and Feel" | Sap Flow Sensors | Dendrometers | Pressure Chamber | Aerial Imaging |
|---|---|---|---|---|---|
| Basic Operation | Look at newer growth | Measures Sap "flow" | Measures Expansion, Contraction | Measures Stem Water Potential | Measures canopy temperature |
| Requirement for Calibration | Yes | Yes | Yes | No | Yes |
| Monitoring Frequency | Except when blinking | Continuous | Continuous | Manual | Manual |
| Zone of Measurement | Few trees | Single Tree | Single Tree | Single to few trees | Entire Orchard |
| Replacement, Maintenance | None | Yes, 2-3 years | Yes | Minimal | None |
| Major Challenges | Too Late | Not refined for Almonds | Lack of Calibration | Time involved | Not refined for Almonds |

More information: http://anrcatalog.ucdavis.edu/pdf/8503.pdf

# Plant Based Monitoring Tools

Pressure Chamber



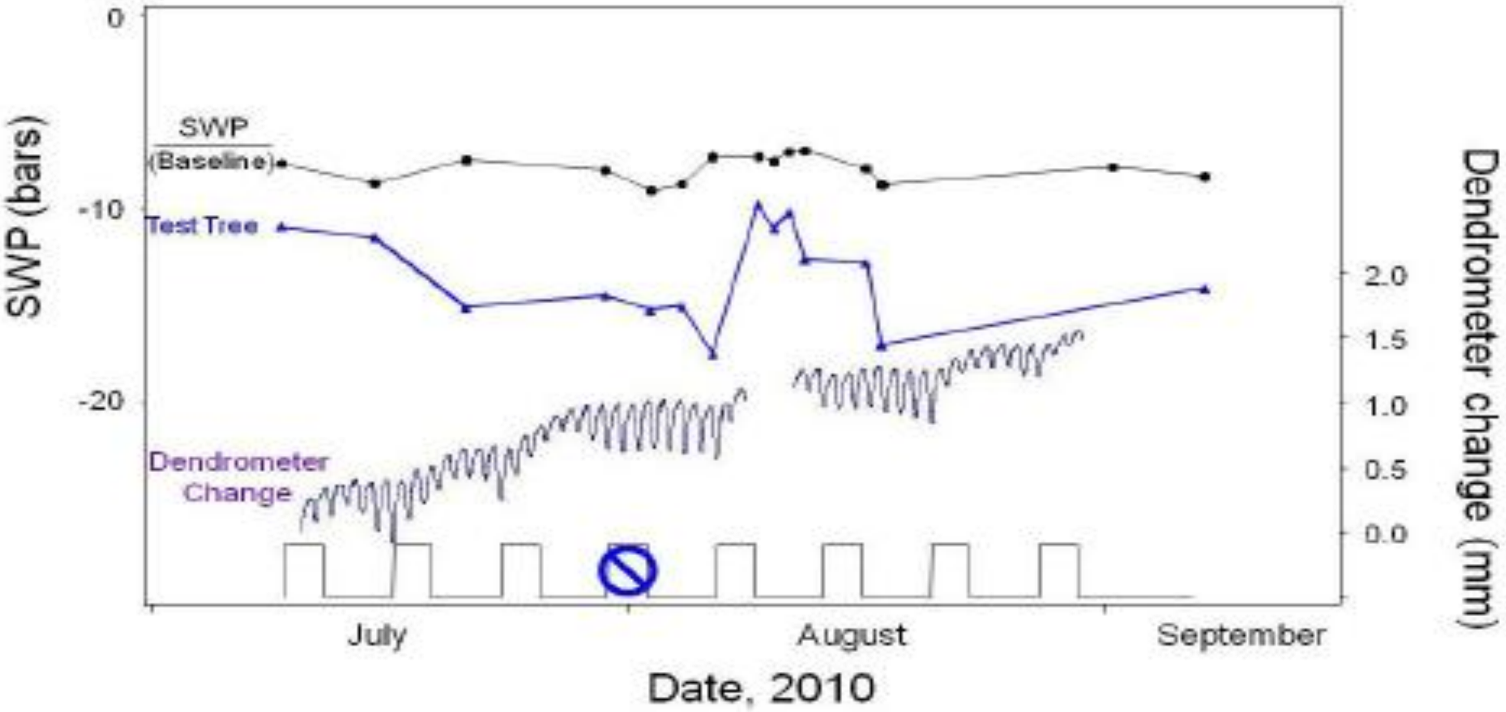
Aerial Imaging

Dendrometers

Sap Flow Sensors

Source: http://www.dynamax.com

# Plant Based Monitoring Tools




Many plant based tools lack "real-time" understanding of readings – except pressure chamber

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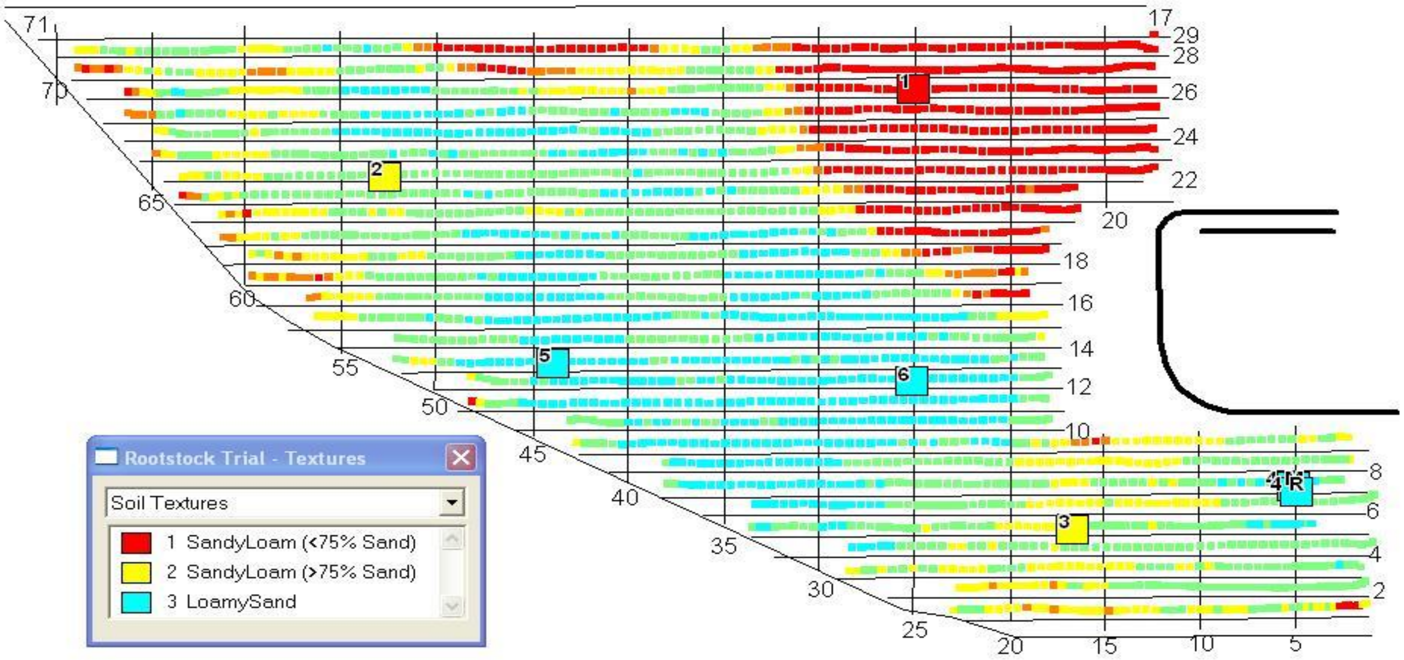
# Soil Variability = Monitoring Variability


http://Earth.google.com;

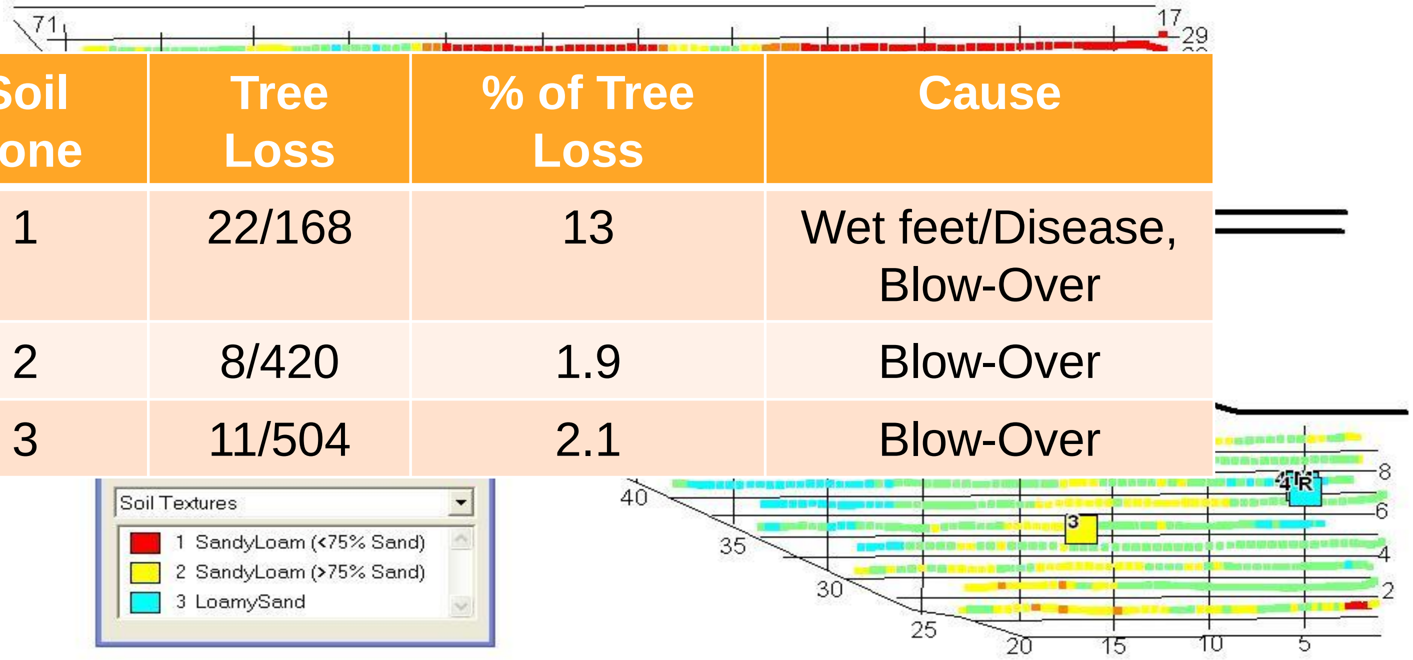
Soil Overlay: http://casoilresource.lawr.ucdavis.edu/drupal/

# Soil Variability = Monitoring Variability




Veris with Core sampling

# Soil Variability = Monitoring Variability




| Soil Zone | Tree Loss | % of Tree Loss | Cause |
|---|---|---|---|
| 1 | 22/168 | 13 | Wet feet/Disease, Blow-Over |
| 2 | 8/420 | 1.9 | Blow-Over |
| 3 | 11/504 | 2.1 | Blow-Over |

Veris with Core sampling

## Soil Variability = Monitoring Variability

# Not Managing Variability Leads to Crop Loss!

# Soil Variability = Monitoring Variability

**How to Manage?**

- Plant based – sample trees in differing soils
- Soil based:
  - Large plots: Place Multiple Sensors
  - Small plots:
    - Coarse soil: Place sensor in lowest holding capacity soil, short, frequent irrigations
    - Heavy Soil: Sensor in soil with lowest infiltration rate, longer, low GPM irrigation

# Shrini Upadhyaya, UC Davis

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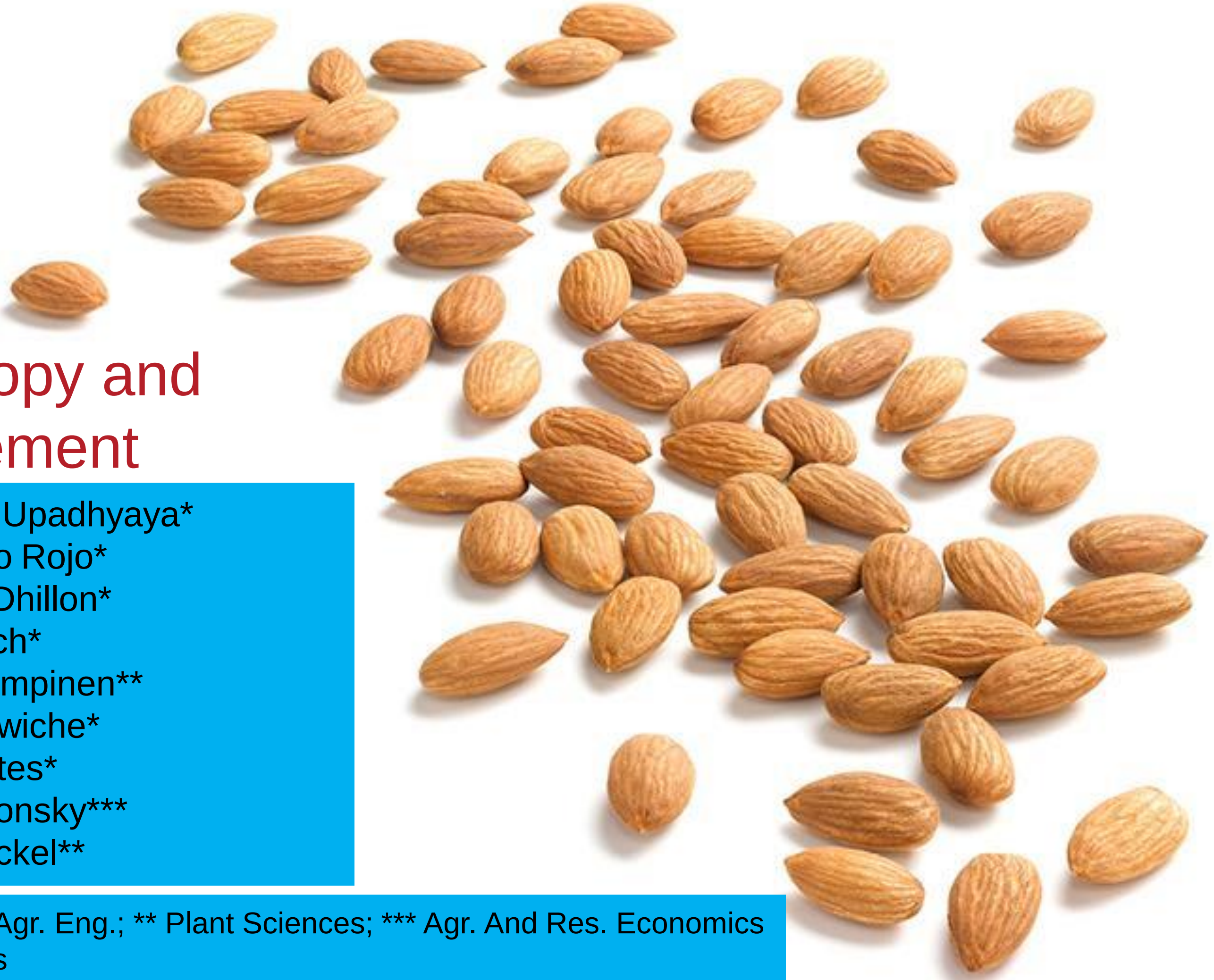

# Precision Canopy and Water Management

Shrini K. Upadhyaya*
Francisco Rojo*
Rajveer Dhillon*
Jed Roach*
Bruce Lampinen**
Mike Delwiche*
Bob Coates*
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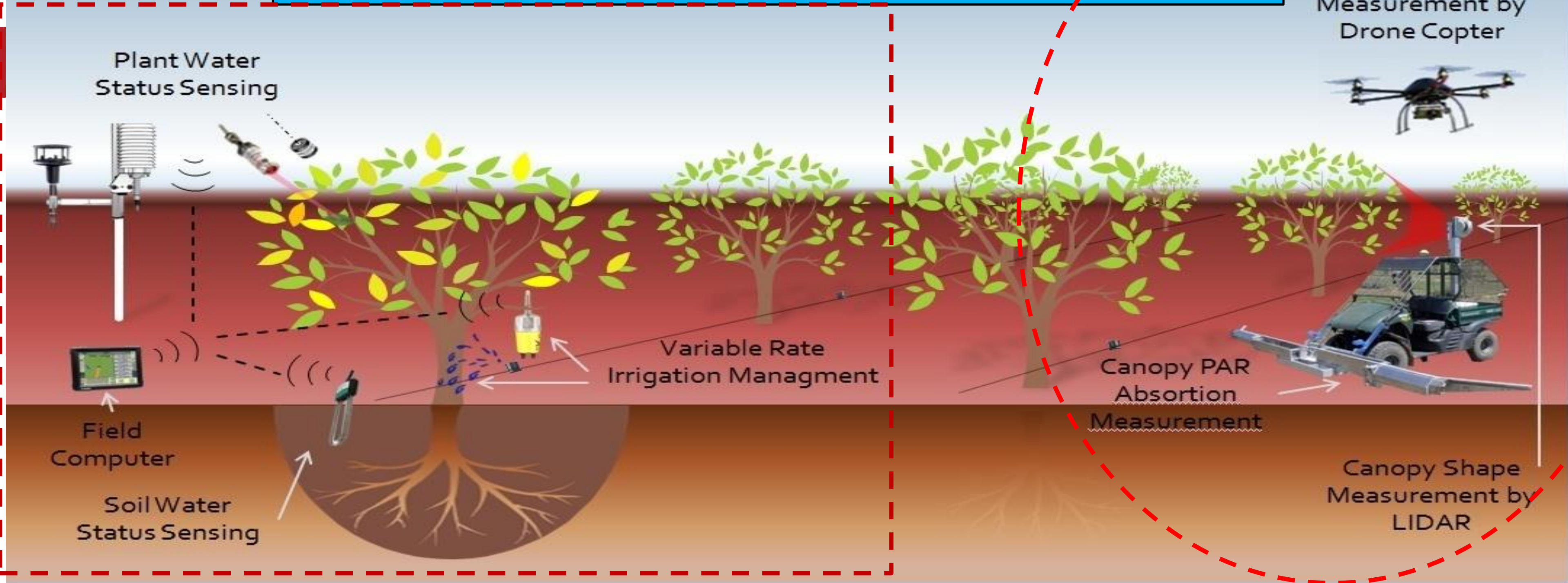
# Precision Canopy and Water Management of Specialty Crops through Sensor-Based Decision Making

(SCRI-USDA-NIFA-NO. -2010 – 01213)

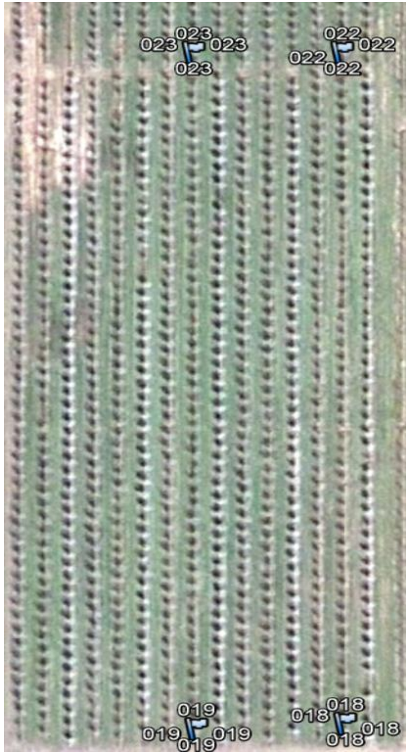
UC Davis, U Arizona, Oregon State Univ., New Mexico State Univ., Washington State Univ., Ag. Informatics LLC., Trimble Navigation Ltd., and VERIS Technologies Inc.



# Light Interception Information – What can it do for us?

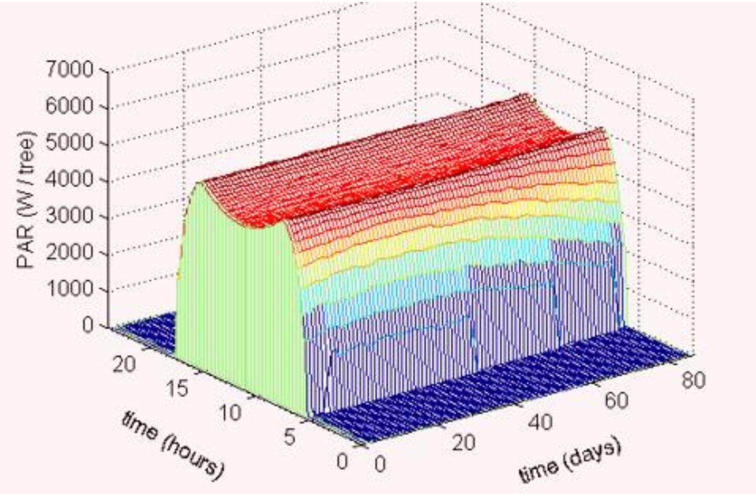
- **Assist in canopy management – Optimize light capture**
- **Assist in row spacing and tree spacing with in the row (-replanting)**
- **Provide an idea of optimum yield (-nutrient management)**
- **Provide an estimate of  potential transpiration (-irrigation management)**

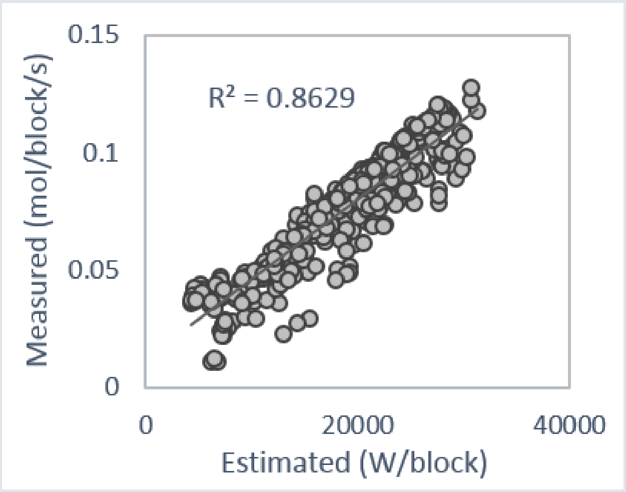
# Nickels Estate – PAR Interception Study




Light bar

# PAR Interception Validation

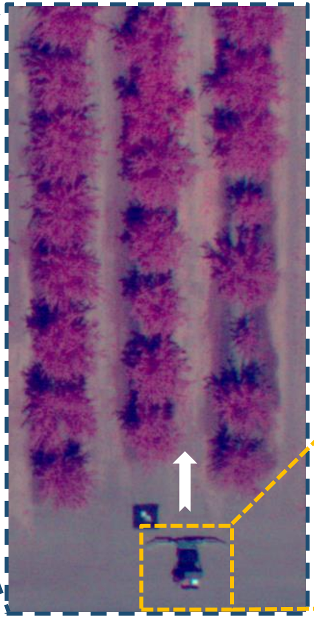



➔ The integrated light interception over the whole season can be shown to be related to potential yield and transpiration

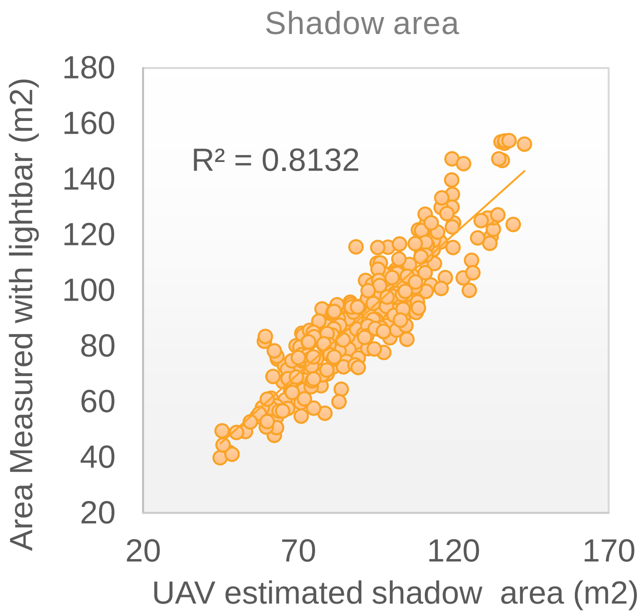
# Estimation of Canopy Light Interception Using UAV

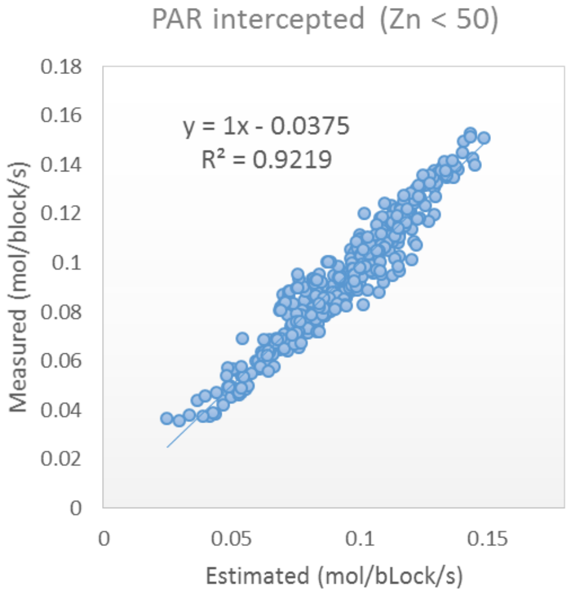
UAV



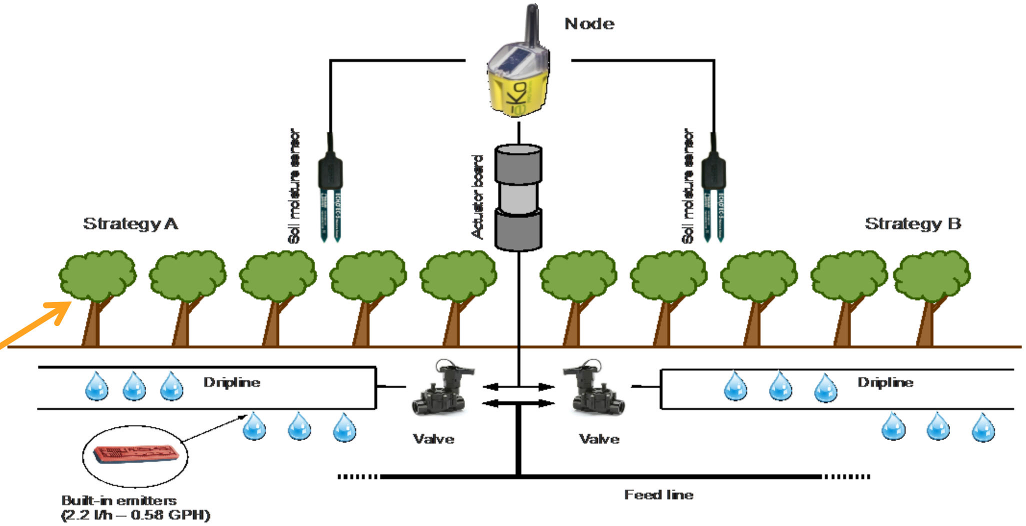
Light bar system

# Shadow's Area Estimated by UAV and Zenith Angle. (diurnal data was used)



# Precision Irrigation or Variable Rate Irrigation:
# ➔ Plant Water Status or Soil Moisture Content?

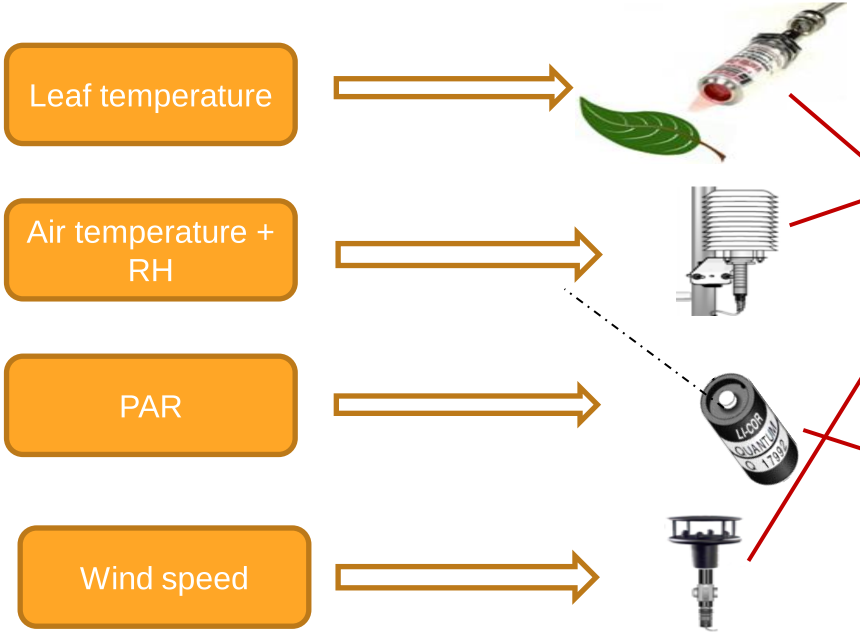



- Because of extensive root zone of orchard/vineyard crops, soil moisture measured at a particular depth may not be sufficient to indicate the amount of moisture available for crop growth.

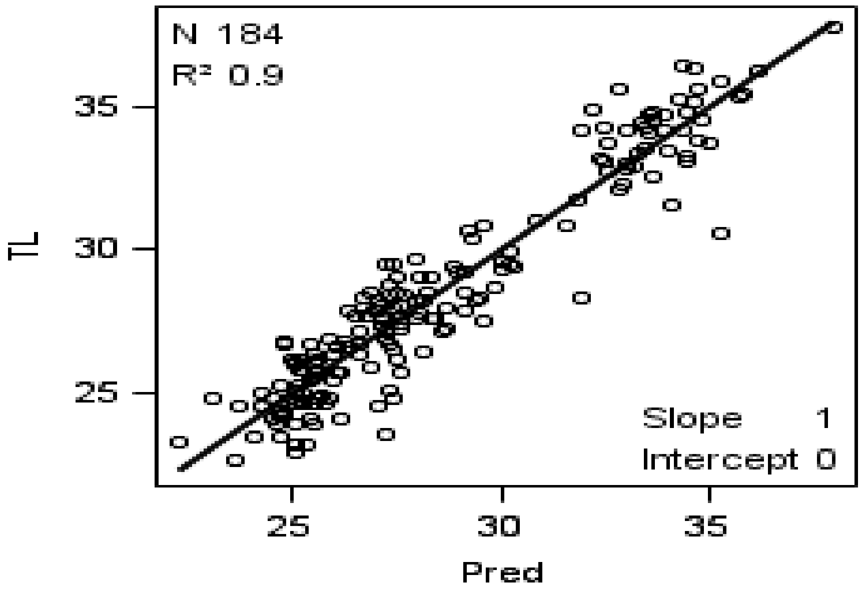
Plant water status

✓ Plant Water Status indicates the current stress level in the plant and can be a valuable piece of information for irrigation management.

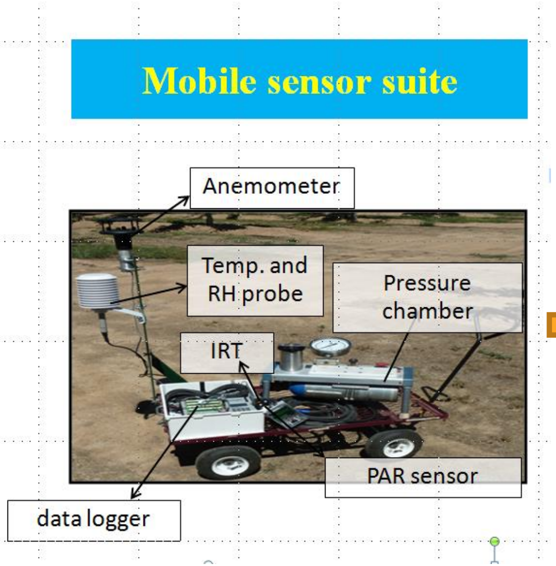
# Sensor Suite System

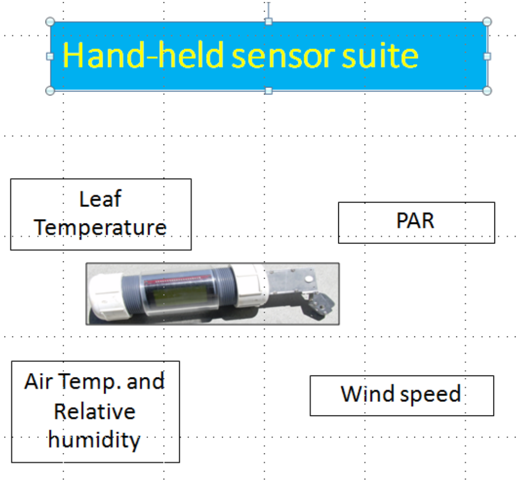


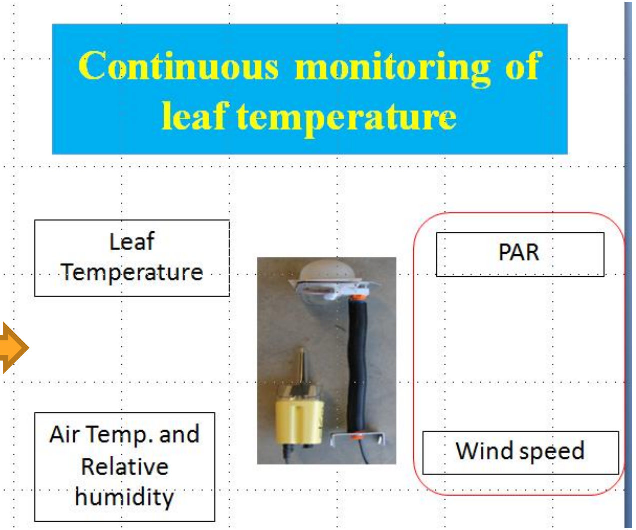

## Results for shaded almond leaves



# Further Developments

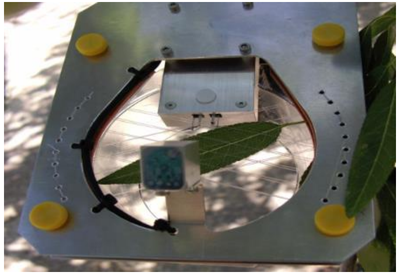


# Installation of Leaf Monitor

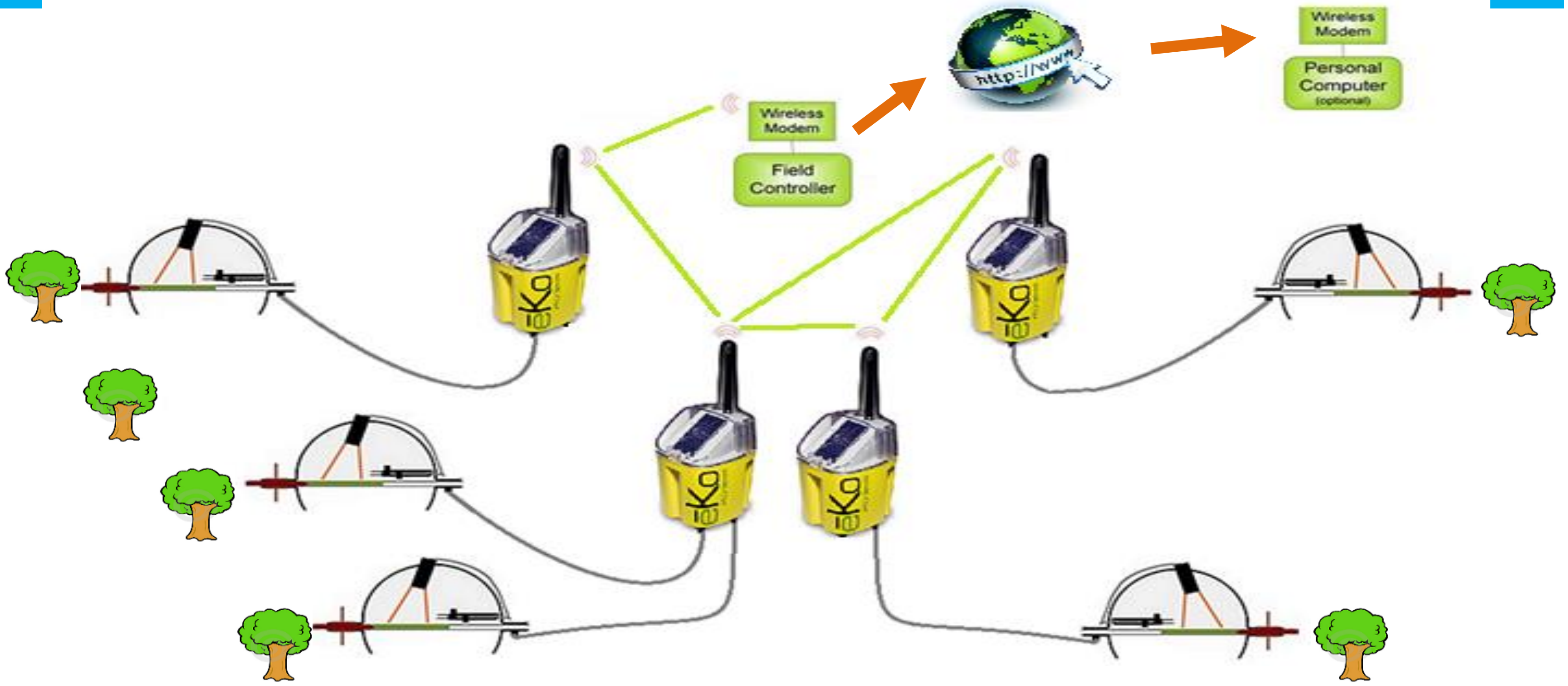
Diffuser
Dome



Almond leaf close up

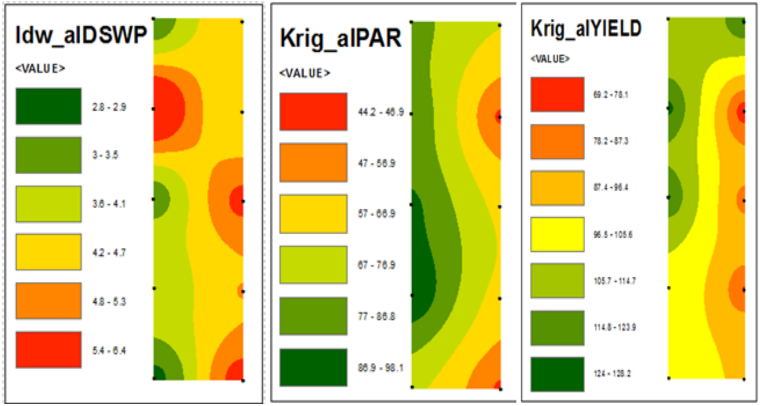
Leaf monitor in almond orchard

# Wireless Mesh Network of Leaf Monitors

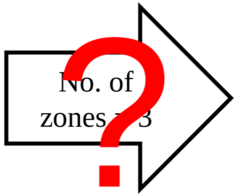


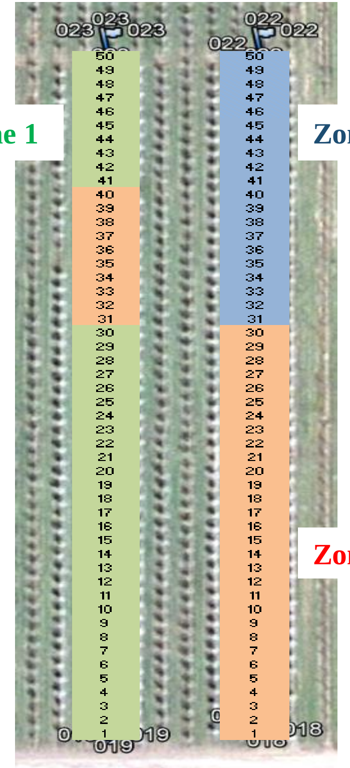
# Management Zones based on Light Interception, Leaf Temperature and Yield.

## Spatial variability




Measured DSWP | Canopy size | Measured Yield



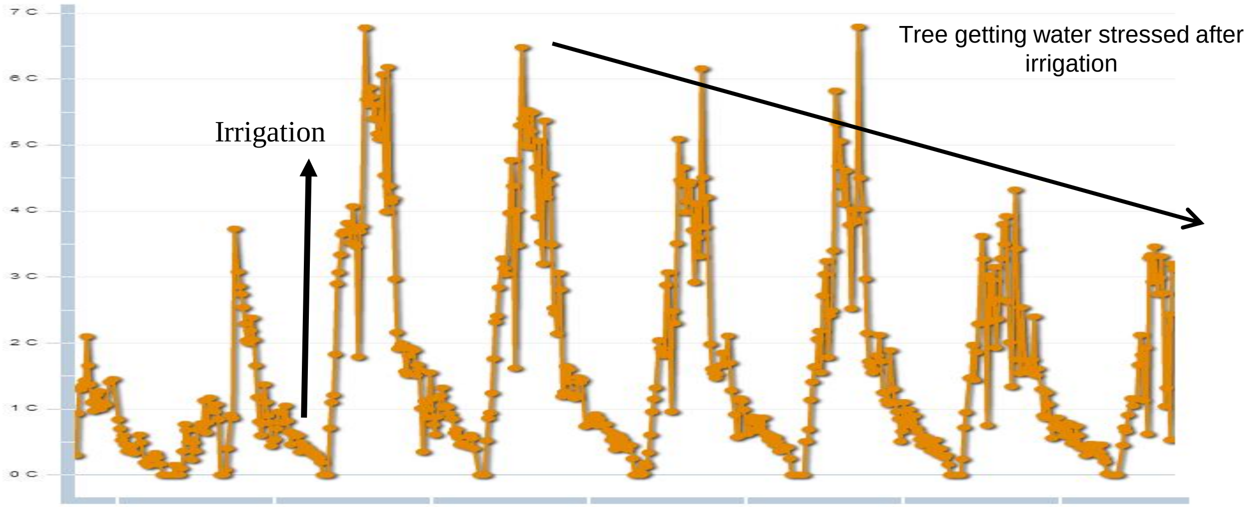

** Number represent trees*

➔ Three treatments in each zone:

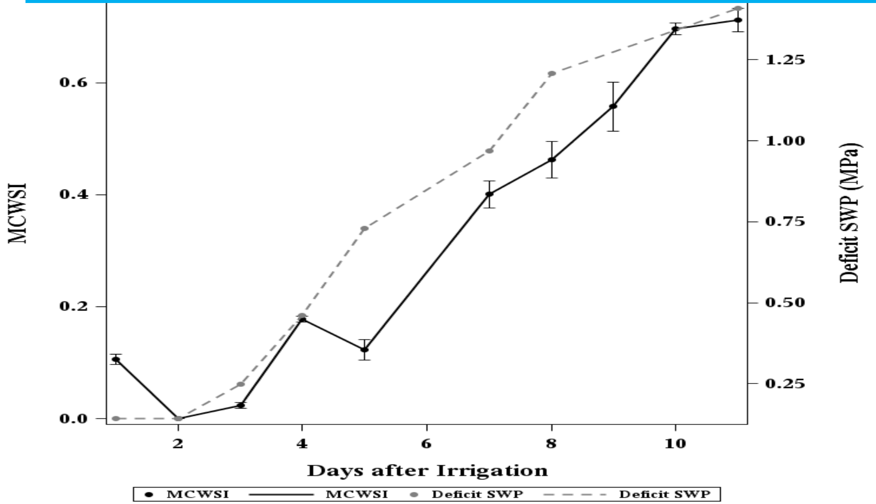
❖ (i) Grower based, (ii) Stress based, and (iii) Deficit ET (60%)

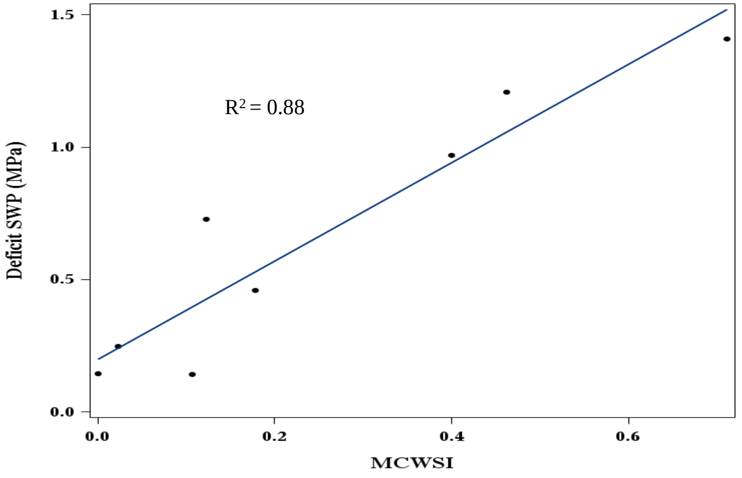
# Remote Access of Data

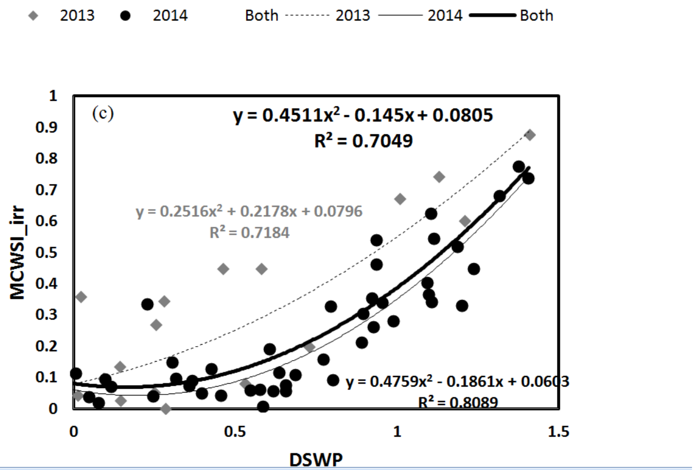
(T$_{air}$ – T$_{leaf}$) data following irrigation



# Comparison with Actual Water Stress

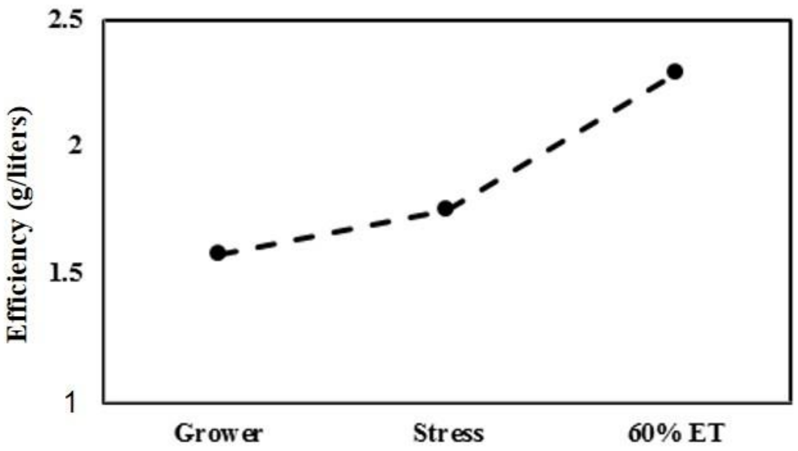


# Water Use Efficiency and Precision Irrigation Management → Preliminary Results

| Irrigation treatment | Liters | %age of ET | Yield (kg/tree) |
|---|---|---|---|
| **60% ET** | 11303.1 | 60.00 | 25.84 |
| **Stress based** | 15243.3 | 80.91 | 26.89 |
| **Grower based** | 19278.8 | 102.33 | 30.22 |



# Economics

| $ per Pound | Pounds per Acre | | | | |
|---|---|---|---|---|---|
| | 1400 | 1800 | 2200 | 2600 | 3000 |
| $1.00 | $ (1,136) | $(758) | $ (380) | $(2) | $ 376 |
| $1.50 | (436) | 142 | 720 | 1,298 | 1,876 |
| $2.00 | 264 | 1,042 | 1,820 | 2,598 | 3,376 |
| $2.50 | 964 | 1,942 | 2,920 | 3,898 | 4,876 |
| $3.00 | 1,664 | 2,842 | 4,020 | 5,198 | 6,376 |

**Effect of Price per pound and yield/acre if one node is used for 50 trees**

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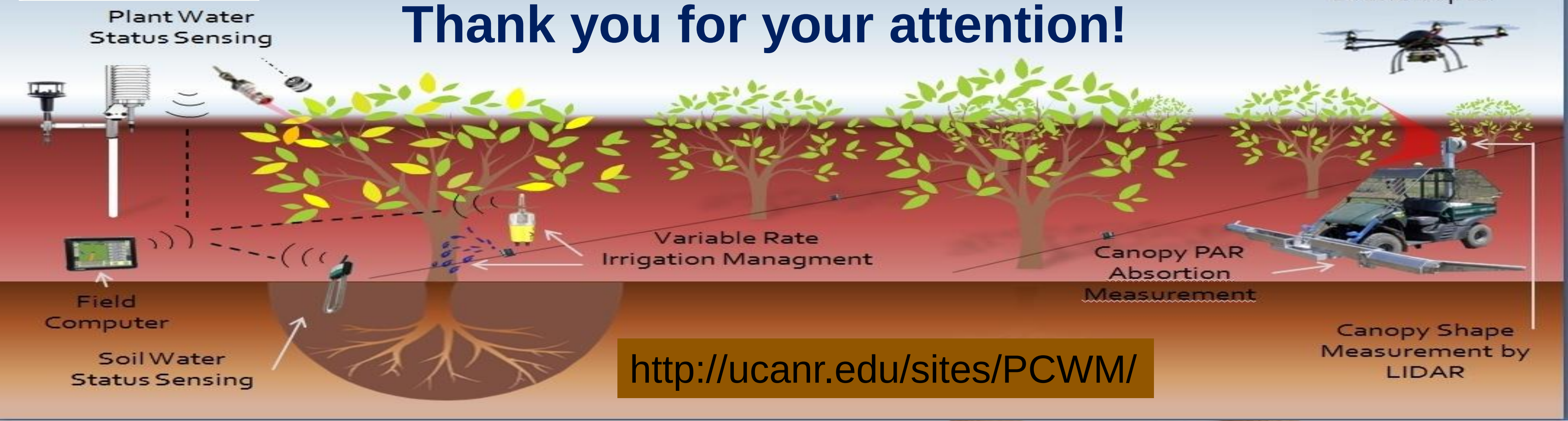
## Thank you for your attention!




http://ucanr.edu/sites/PCWM/

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