Almond Drought Strategies

How to best manage limited water

- Regulated Deficit Irrigation (RDI)
- Importance of stress timing

The almond production function

- Yield vs applied water

Specific drought irrigation schedules

- Water supplies from 12 to 36 inches

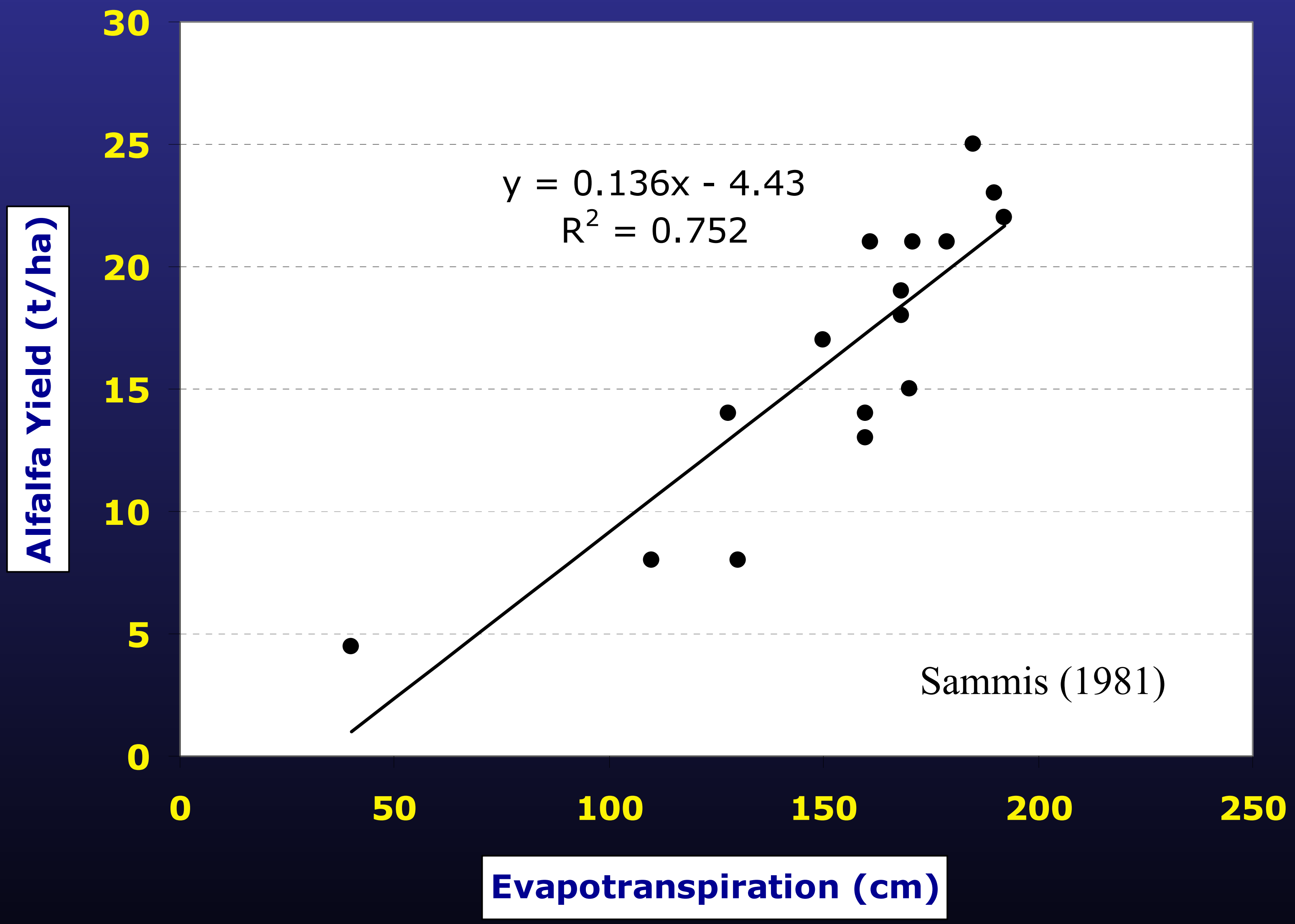
Roles of “stumping;” antitranspirants

Water Relations

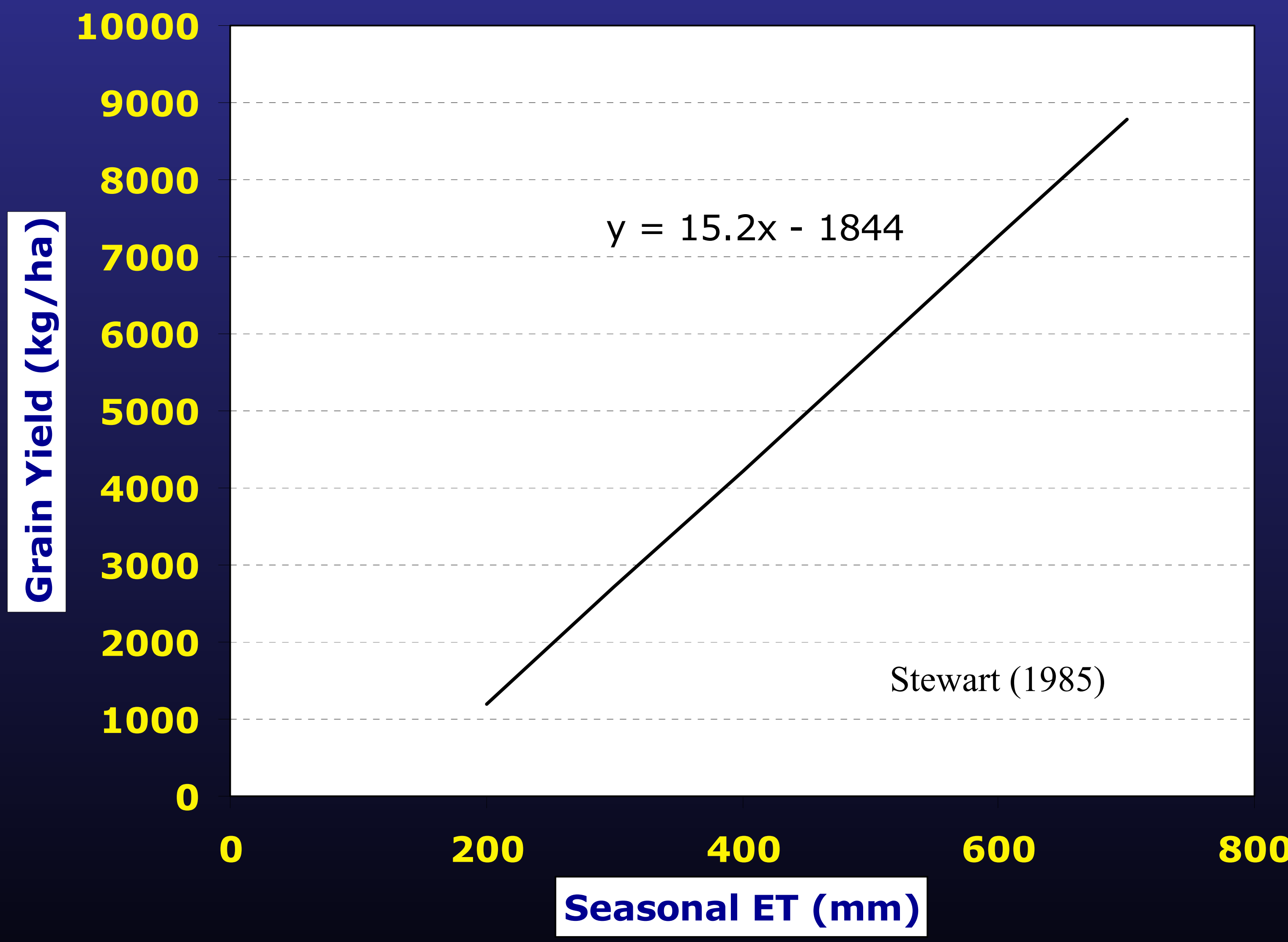
Water Requirements

Irrigation Scheduling

Alfalfa Production Function; New Mexico



Sorghum Production Function; S. Great Plains

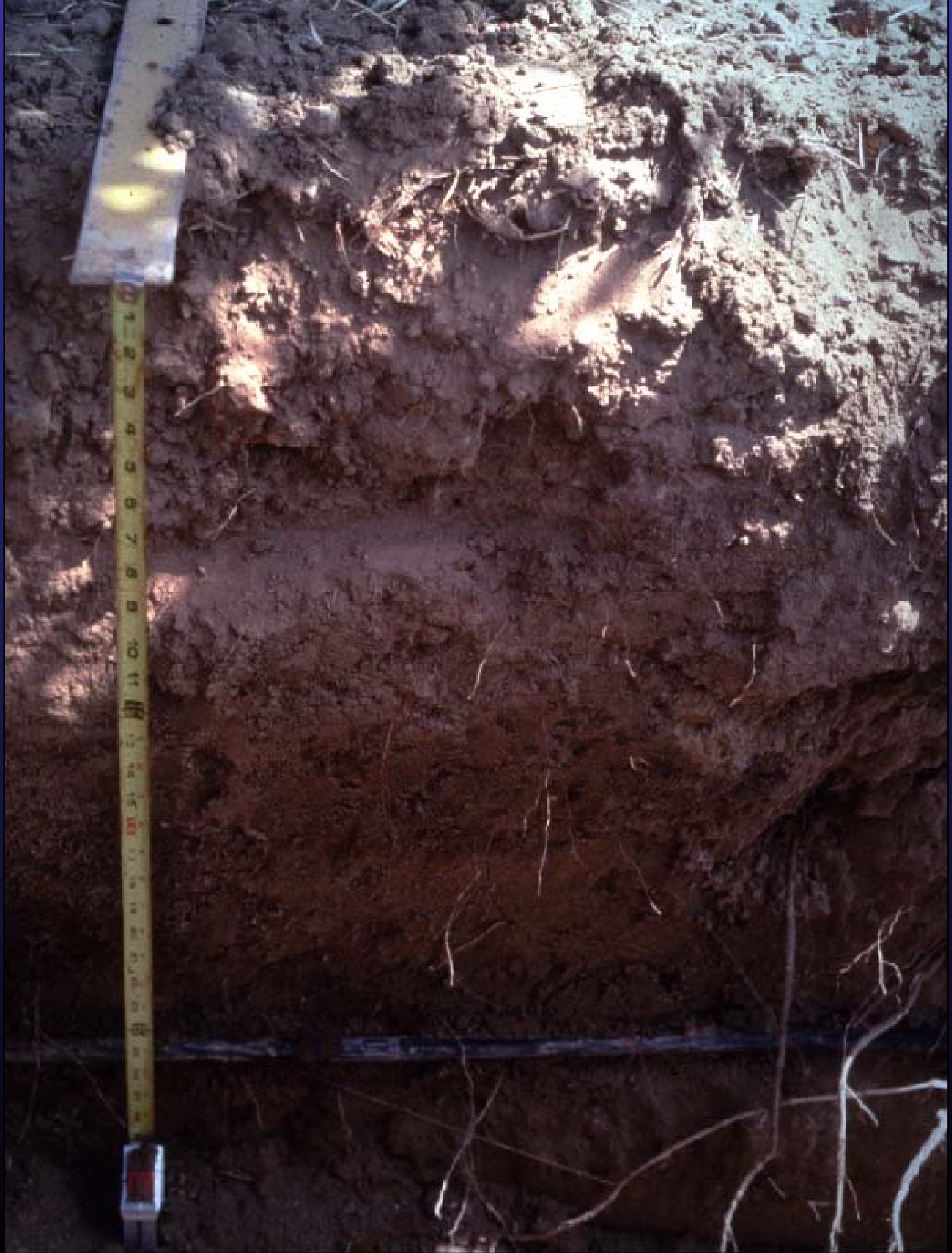


Can we reduce ETc:

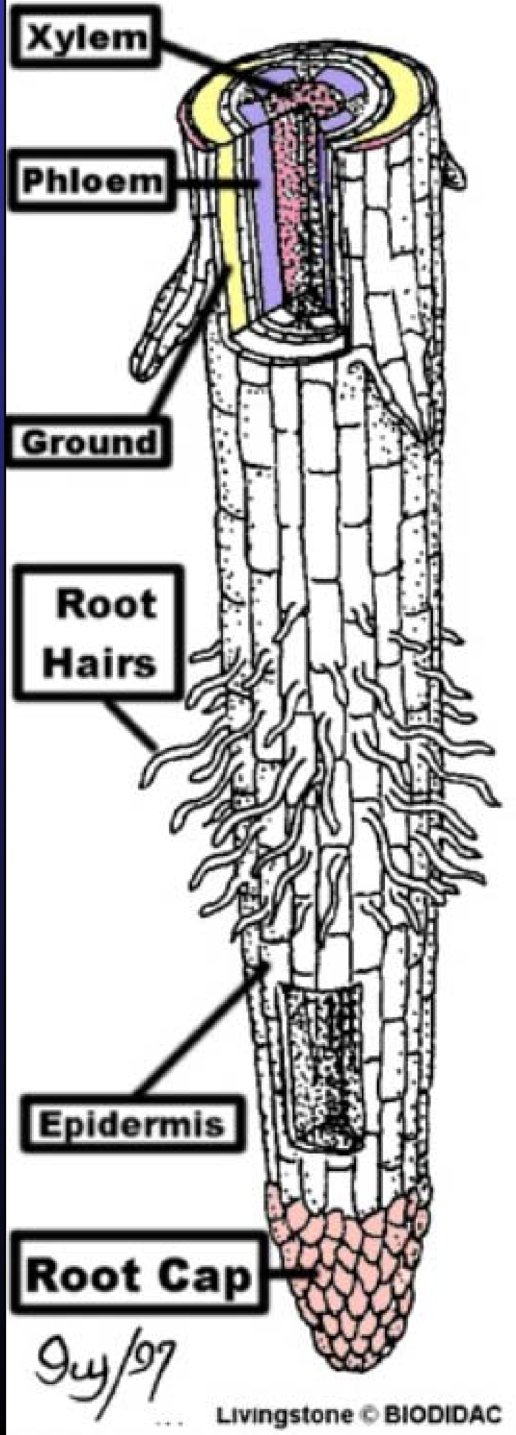
Options;decrease

E and/or T

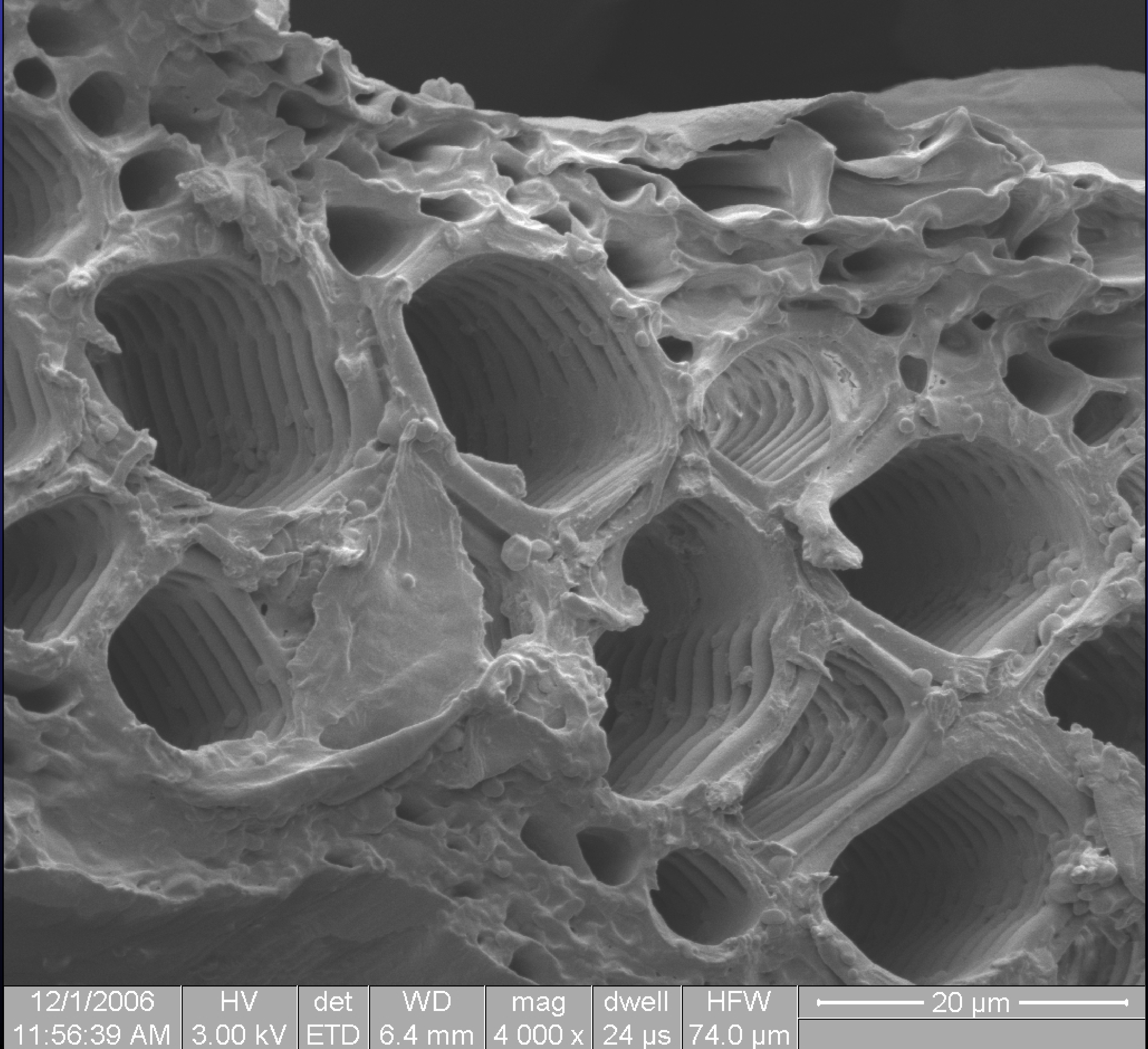

CATERPILLAR
QUINN

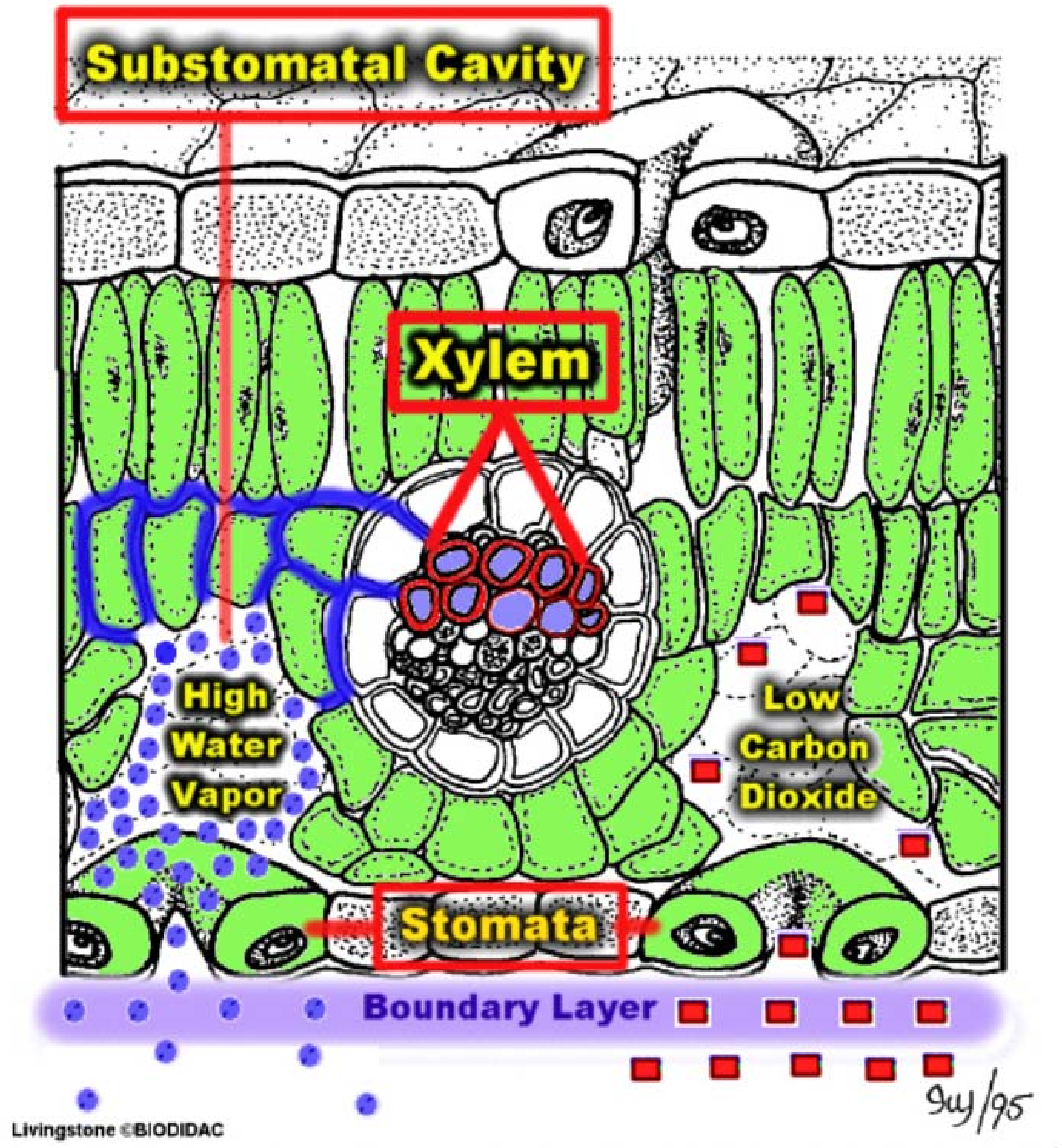


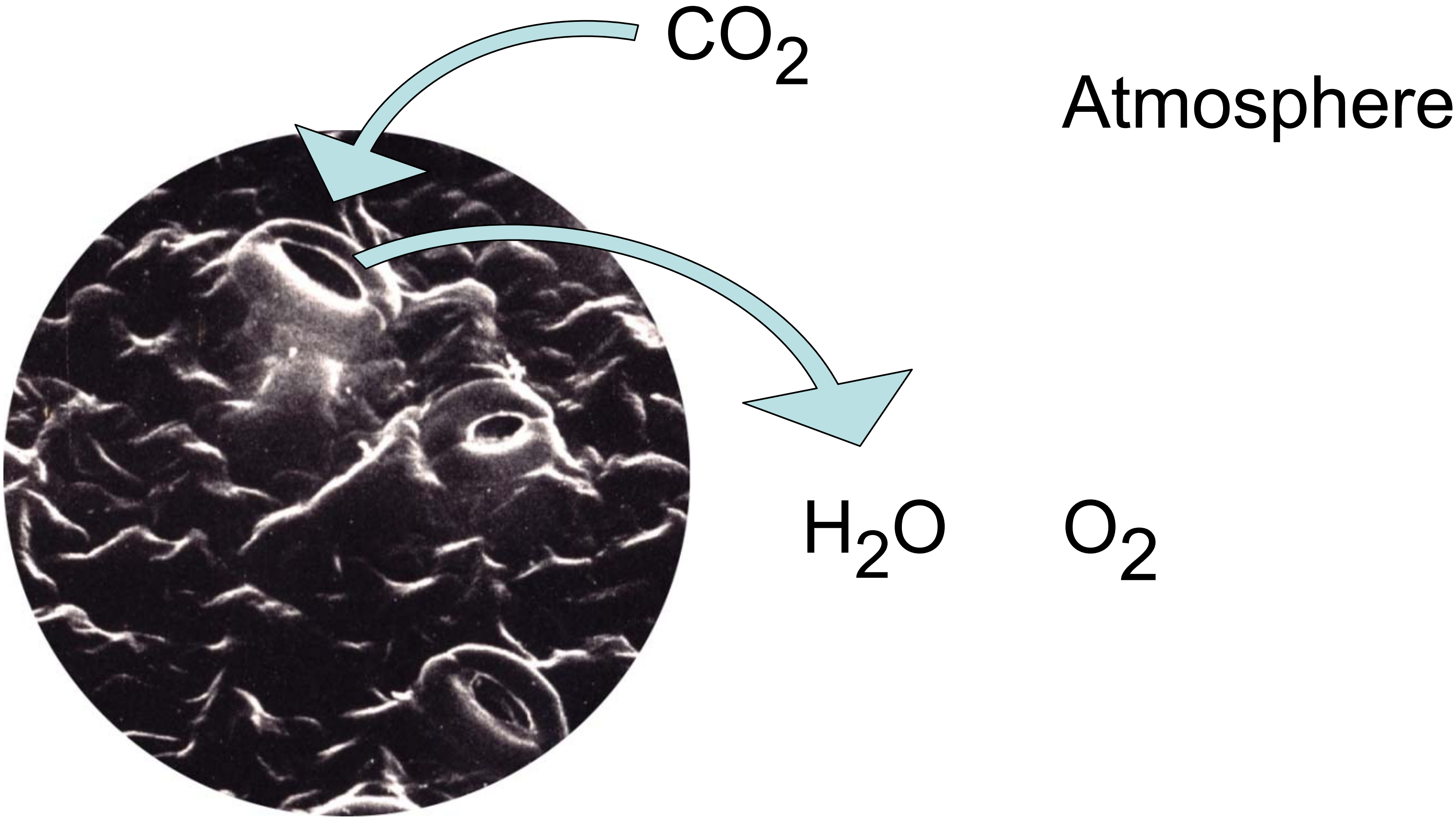
Can we reduce Transpiration?



Xylem
Phloem
Ground
Root
Hairs
Epidermis
Root Cap
Livingstone © BIODIDAC


12/1/2006
11:56:39 AM
HV
3.00 kV
det
ETD
WD
6.4 mm
mag
4 000 x
dwell
24 µs
HFW
74.0 µm
20 µm


Substomatal Cavity
Xylem
High
Water
Vapor
Low
Carbon
Dioxide
Stomata
Boundary Layer
Livingstone ©BIODIDAC



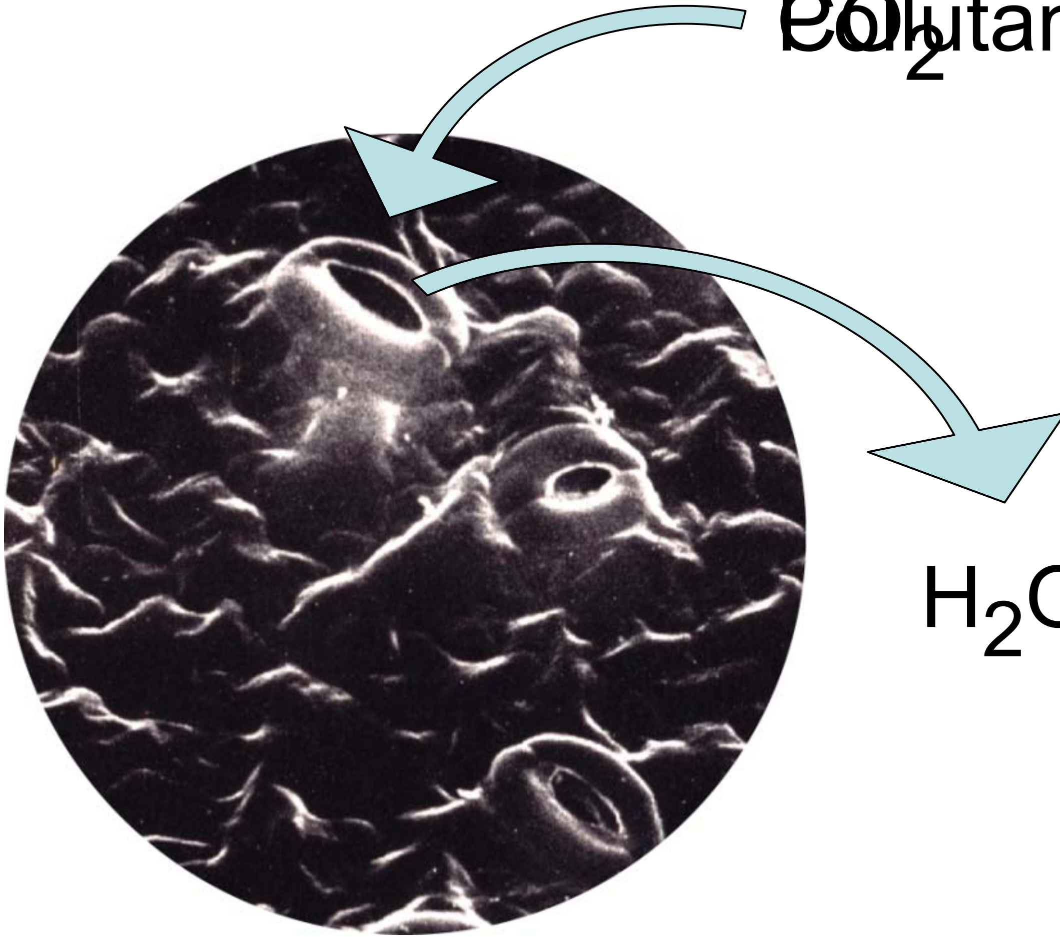
$$6\ CO_2 + 12\ H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

(Sugar)

Nobel Lecture

"So today, we dumped another 70 million tons of global-warming pollution (CO_2) into the thin shell of atmosphere surrounding our planet, as if it were an open sewer."

Albert R. Gore
Nobel Prize Acceptance Lecture
Oslo, Norway, 10 December 2007



CO_2

Pollutant

Atmosphere

Open Sewer

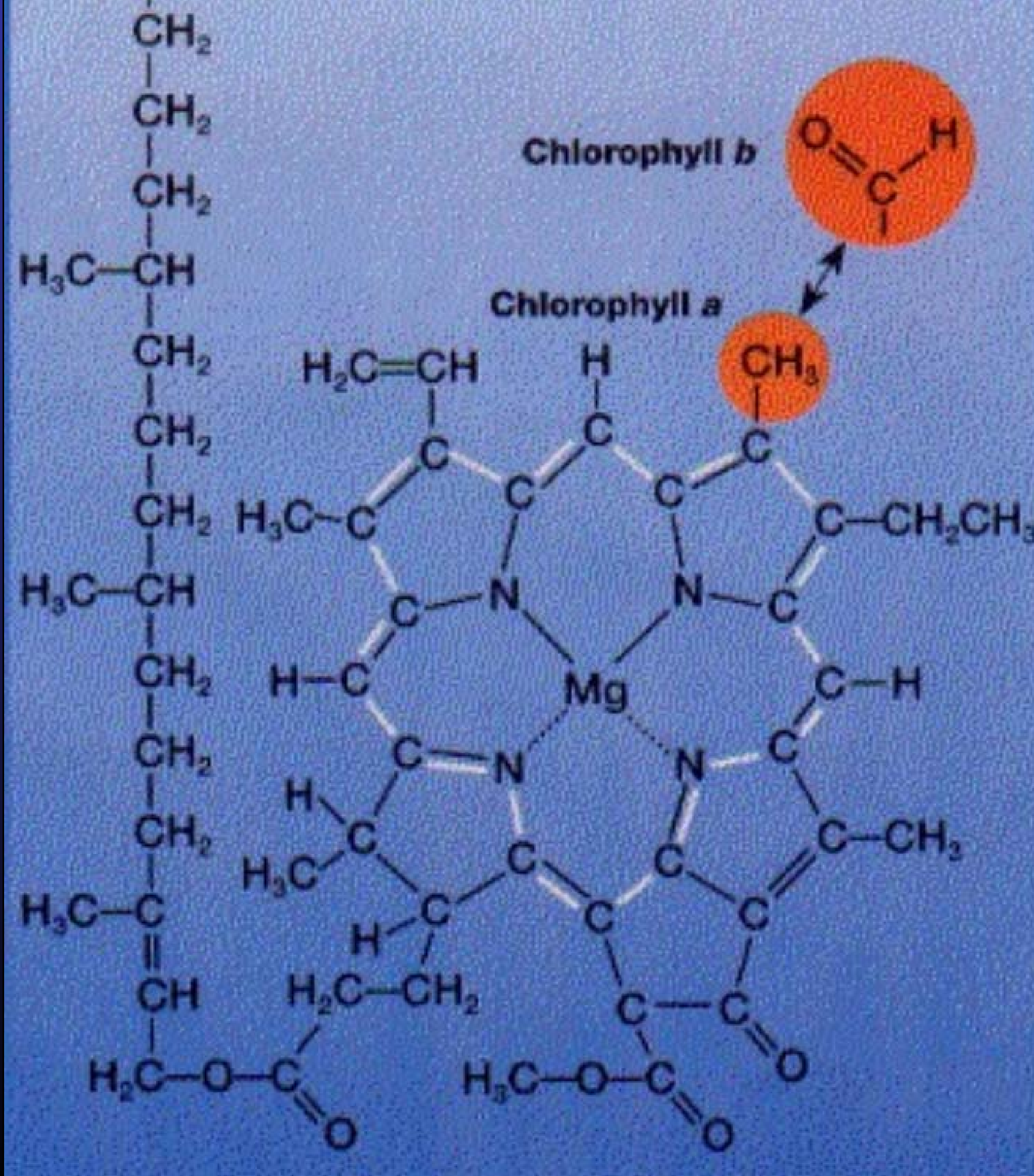
H_2O O_2

Light

$$6\ CO_2 + 12\ H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

Pollutant + $12\ H_2O \longrightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$

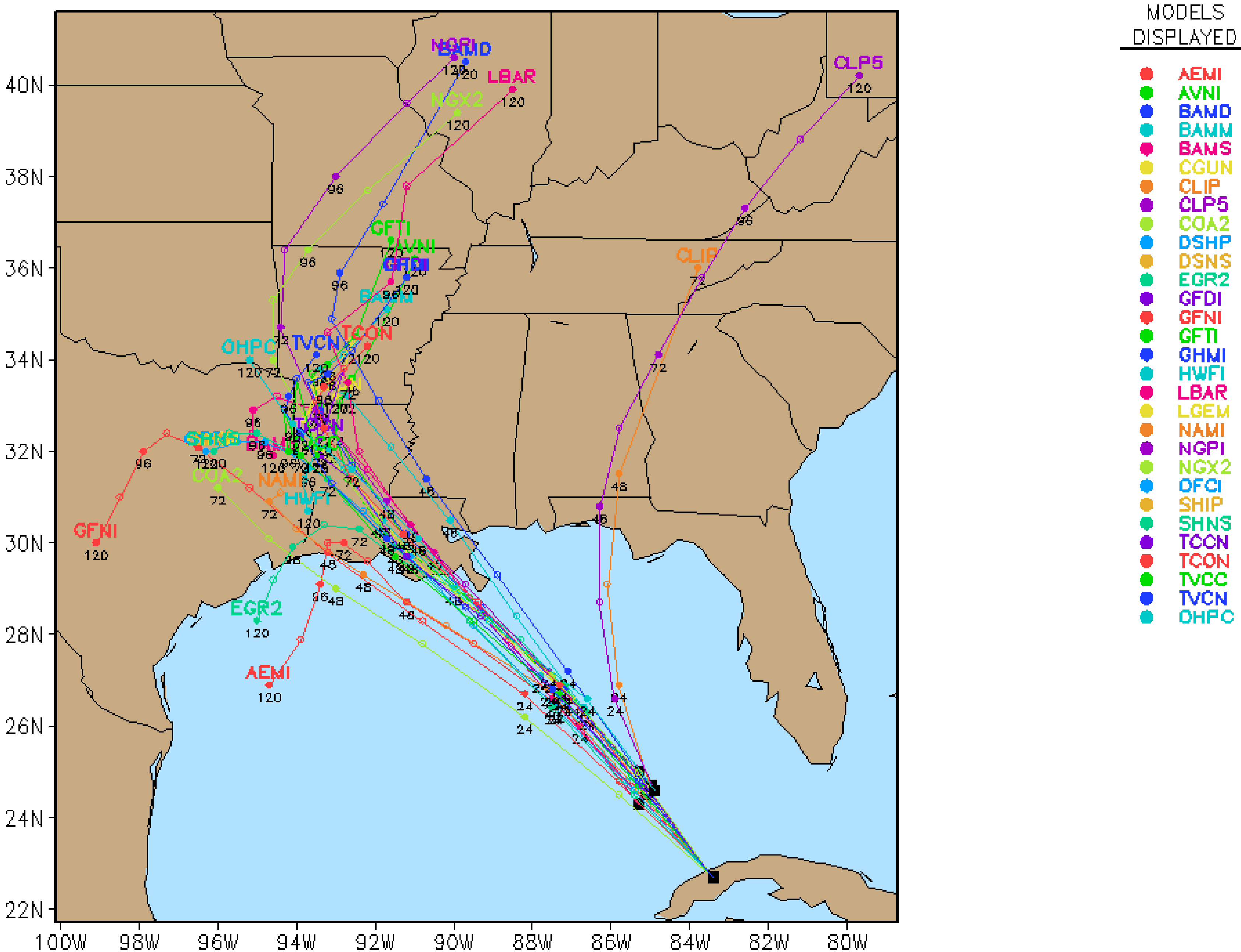
(Sugar)


Chlorophyll b
Chlorophyll a

“Al Gore’s just an opportunist. The person who is really responsible for this overestimate of global warming is Jim Hansen. He consistently exaggerates all the dangers.” Coal, he has written, “is the single greatest threat to civilization and all life on our planet.” Hansen has referred to railroad cars transporting coal as “death trains.”

Freeman Dyson, Eminent Physicist, 2009

Atlantic TC GUSTAV Model Tracks 00Z 31 August 2008



Tropical Cyclone Model Plots
http://moe.met.fsu.edu/~acevans/models/
Redistribution of these images is prohibited.

DISCLAIMER: Do not use this image in place of official sources!
The official NHC forecast is always available at http://www.nhc.noaa.gov.
Forecast points above are shown in 12 hr increments. Initial points denoted by black squares.

E.P.A. Moves Toward Regulating Greenhouse Gases

By Felicity Barringer

Published: March 23, 2009

In February, the E.P.A.'s administrator, Lisa P. Jackson, hinted strongly in an interview with The New York Times that the agency would take action on the issue before April 2. That date marks the second anniversary of a Supreme Court ruling ordering the agency to determine whether carbon dioxide and other greenhouse gases qualify as pollutants under the Clean Air Act.

The action, known as an endangerment finding, would allow federal regulation of motor vehicle emissions of greenhouse gases. If further action is taken by the E.P.A., it could open the door to regulatory controls over power plants, oil refineries, cement plants and other factories that emit such gases.

Demonizing CO_2

Beneficiaries:

1) Politicians
2) Wall Street
3) Anti-capitalists
4) Environmentalists
5) Researchers

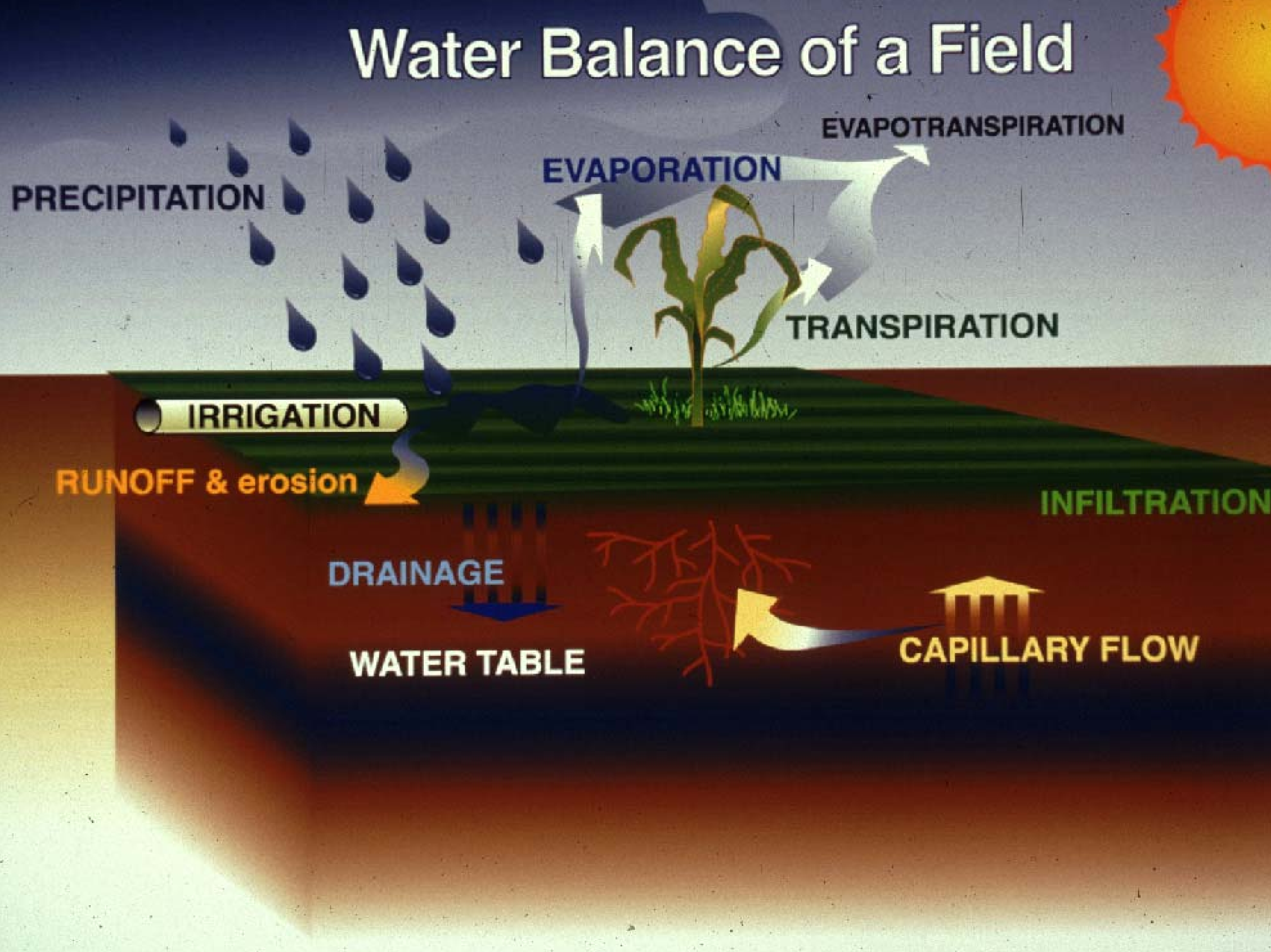
Demonizing CO_2

Losers:

1) Energy Users
2) Tax Payers

Scheduling Concepts

1) Soil/Plant based monitoring.
2) Water budget.


Water Balance of a Field
EVAPOTRANSPIRATION
EVAPORATION
PRECIPITATION
TRANSPIRATION
IRRIGATION
RUNOFF & erosion
INFILTRATION
DRAINAGE
CAPILLARY FLOW
WATER TABLE

Irrigation Scheduling Example

Crop: Almond (mature)

Location: Firebaugh

Tree Spacing: 21 x 24 ft (86 trees/ac)

Irrigation: Microsprinkler (11 gal/hr)

Two per tree (22 gal/tree/hr)

Application Efficiency: 90%

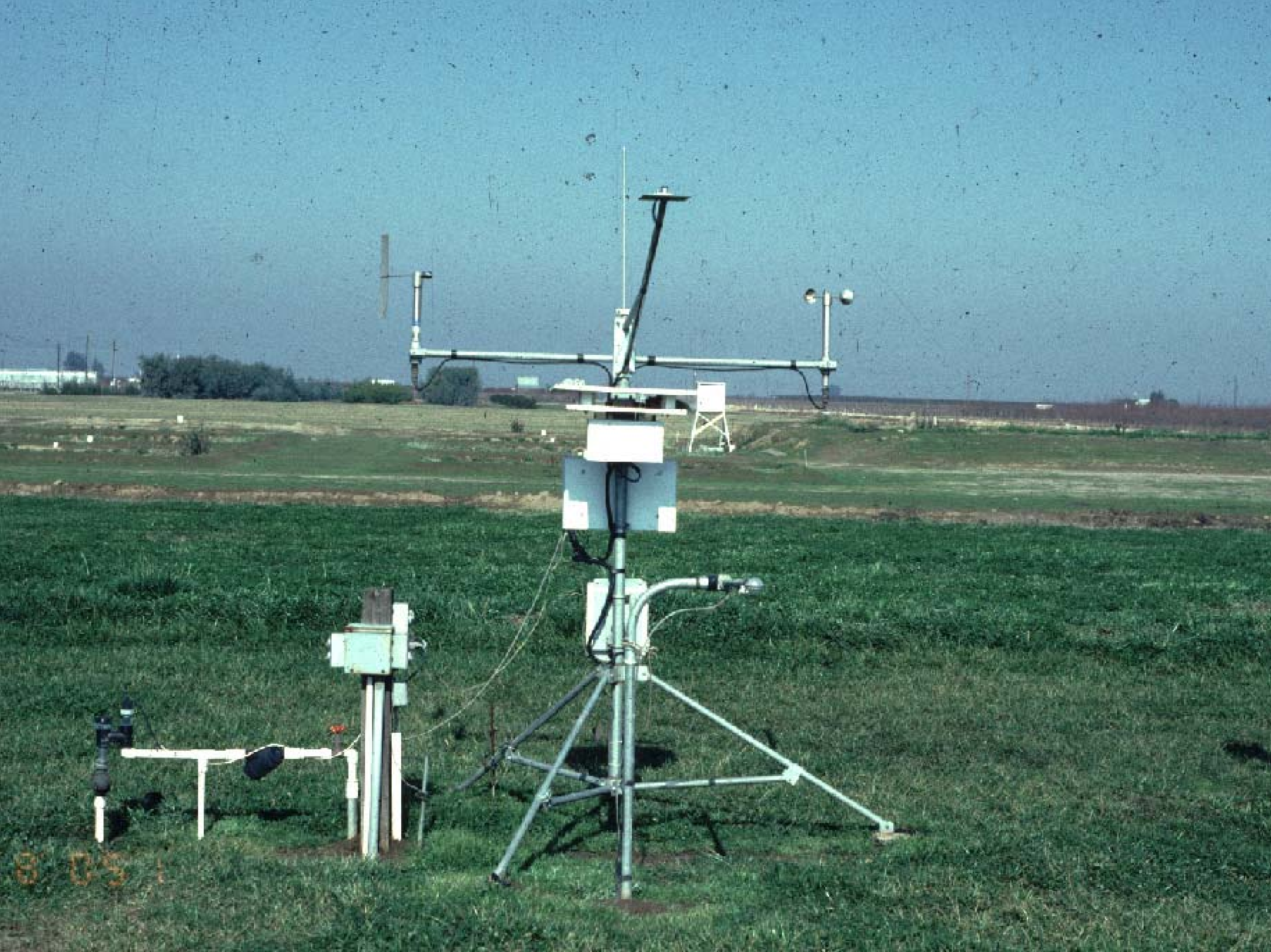
Water Budget

ETc = Kc x ETo

Orchard Water Use	=	Crop Coefficient	x	Reference Crop Water Use

Reference Crop Water Use (ETo)

1) Real time.
2) Long term, historical values.



Reference Crop Water Use (ETo)

www.cimis.water.ca.gov

California Irrigation Management Information System - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Search Favorites Media

Address http://www.cimis.water.ca.gov/ Go Links

CALIFORNIA THE GOLDEN STATE CALIFORNIA HOMEPAGE GOVERNOR'S HOMEPAGE

California Irrigation Management Information System

Department of Water Resources

DATA REPORTS | CIMIS SYSTEM | IRRIGATION | WEATHER STATIONS | ETo

HOME PAGE

SYSTEM NEWS

REGISTER

FAQ

DOWNLOAD

CONTACTS

LINKS

CIMIS (California Irrigation Management Information System)

Daily Report

Rendered in ENGLISH Units.
February 10, 2003 - February 16, 2003
Printed on February 17, 2003

Porterville - San Joaquin Valley - Station 169

Date	CIMIS ETo (in)	Precip (in)	Sol Rad (Ly/day)	Avg Vap (mBars)	Max Air Temp (°F)	Min Air Temp (°F)	Avg Air Temp (°F)	Max Rel Hum (%)	Min Rel Hum (%)	Avg Rel Hum (%)	Dew Pt (° F)	Avg wSpd (MPH)	Wnd Run (miles)	Avg Soil Temp (°F)
02/10/2003	0.08	0.00	304	6.2	62.2	29.3	46.1	85	32	59	32.4	3.1	73.7	50.6
02/11/2003	0.08	0.11	298	9.5	64.5	43.5	52.0	88	49	72	43.1	4.2	101.4	51.2
02/12/2003	0.00	0.66	47	11.7	55.0	44.7	50.9	94	88	92	48.7	3.5	85.4	52.3
02/13/2003	0.08	0.01	306	12.9	66.4	47.0	56.8	94	63	81	51.2	3.2	76.5	53.0
02/14/2003	0.03	0.00 R	67	12.5	62.6	32.0	57.2	93	67	78	50.4	2.8	66.5	54.5
02/15/2003	0.07	0.00	279	12.3	66.8	49.6	56.9	92	58	78	49.9	2.9	70.0	55.0
02/16/2003	0.06	0.13	227	11.5	63.3	47.8	55.4	92	59	77	48.2	3.4	81.8	55.9
Total	0.40	0.91	218	10.9	63.0	42.0	53.6	91	59	77	46.3	3.3	79.3	53.2

Flag Legend

Crop Coefficient (Kc) =

Evapotranspiration (ETc)

Reference Crop Water Use (ETo)

Literature and Other Almond Related Crop Coefficients

	UN FAO 24	Fereres and Puch	Sanden	Ayers et al.
	Deciduous	Deciduous	Almond	Peach
March	0.50	0.60	0.59	0.28
April	0.75	0.71	0.78	0.48
May	0.90	0.84	0.92	0.68
June	0.95	0.92	1.01	0.88
July	0.95	0.96	1.08	1.06
Aug	0.95	0.96	1.08	1.06
Sept	0.85	0.91	1.02	1.06
Oct	0.80	0.79	0.89	0.90
Nov	0.70		0.69	

Goldhamer at al. Almond Crop Coefficients (In Development)

	Crop Coefficient
	(Kc)
Mar 16-31	0.43
Apr 1-15	0.68
Apr 16-30	0.93
May 1-15	1.09
May 16-31	1.17
Jun 1-15	1.18
Jun 16-30	1.18
Jul 1-15	1.18
Jul 16-31	1.12
Aug 1-15	0.99
Aug 16-31	0.87
Sept 1-15	0.67
Sept 16-30	0.50
Oct 1-15	0.35
Oct 16-31	0.20

Developing an Irrigation Schedule; Firebaugh

	BiMonthly ETo
	(inches)
Mar 16-31	2.3
Apr 1-15	2.5
Apr 16-30	2.9
May 1-15	3.5
May 16-31	4.2
Jun 1-15	4.2
Jun 16-30	4.3
Jul 1-15	4.2
Jul 16-31	4.2
Aug 1-15	3.7
Aug 16-31	3.7
Sept 1-15	3.1
Sept 16-30	2.6
Oct 1-15	2.2
Oct 16-31	1.7
Total	

Developing an Irrigation Schedule; Firebaugh

	BiMonthly ETo	Crop Coefficient
	(inches)	(Kc)
Mar 16-31	2.3	0.43
Apr 1-15	2.5	0.68
Apr 16-30	2.9	0.93
May 1-15	3.5	1.09
May 16-31	4.2	1.17
Jun 1-15	4.2	1.18
Jun 16-30	4.3	1.18
Jul 1-15	4.2	1.18
Jul 16-31	4.2	1.12
Aug 1-15	3.7	0.99
Aug 16-31	3.7	0.87
Sept 1-15	3.1	0.67
Sept 16-30	2.6	0.50
Oct 1-15	2.2	0.35
Oct 16-31	1.7	0.20
Total		

Developing an Irrigation Schedule; Firebaugh

	BiMonthly ETo	Crop Coefficient	ETc In Period
	(inches)	(Kc)	(inches)
Mar 16-31	2.3	0.43	1.0
Apr 1-15	2.5	0.68	1.7
Apr 16-30	2.9	0.93	2.7
May 1-15	3.5	1.09	3.9
May 16-31	4.2	1.17	4.9
Jun 1-15	4.2	1.18	5.0
Jun 16-30	4.3	1.18	5.0
Jul 1-15	4.2	1.18	4.9
Jul 16-31	4.2	1.12	4.7
Aug 1-15	3.7	0.99	3.7
Aug 16-31	3.7	0.87	3.2
Sept 1-15	3.1	0.67	2.1
Sept 16-30	2.6	0.50	1.3
Oct 1-15	2.2	0.35	0.8
Oct 16-31	1.7	0.20	0.3
Total			45.1

Developing an Irrigation Schedule; Firebaugh

	BiMonthly ETo	Crop Coefficient	ETc In Period	ETc Daily
	(inches)	(Kc)	(inches)	(inch/day)
Mar 16-31	2.3	0.43	1.0	0.06
Apr 1-15	2.5	0.68	1.7	0.11
Apr 16-30	2.9	0.93	2.7	0.18
May 1-15	3.5	1.09	3.9	0.26
May 16-31	4.2	1.17	4.9	0.31
Jun 1-15	4.2	1.18	5.0	0.33
Jun 16-30	4.3	1.18	5.0	0.34
Jul 1-15	4.2	1.18	4.9	0.33
Jul 16-31	4.2	1.12	4.7	0.29
Aug 1-15	3.7	0.99	3.7	0.25
Aug 16-31	3.7	0.87	3.2	0.20
Sept 1-15	3.1	0.67	2.1	0.14
Sept 16-30	2.6	0.50	1.3	0.09
Oct 1-15	2.2	0.35	0.8	0.05
Oct 16-31	1.7	0.20	0.3	0.02
Total			45.1	

Converting depth to volume units

Example for peak demand

g/tree/d = in/day x (tree spacing) x 0.622

= 0.34 in/day x (21 x 24 ft) x 0.622

= 105 gal/tree/day

Developing an Irrigation Schedule; Firebaugh

	BiMonthly ETo	Crop Coefficient	ETc In Period	ETc Daily
	(inches)	(Kc)	(inches)	(inch/day)
Mar 16-31	2.3	0.43	1.0	0.06
Apr 1-15	2.5	0.68	1.7	0.11
Apr 16-30	2.9	0.93	2.7	0.18
May 1-15	3.5	1.09	3.9	0.26
May 16-31	4.2	1.17	4.9	0.31
Jun 1-15	4.2	1.18	5.0	0.33
Jun 16-30	4.3	1.18	5.0	0.34
Jul 1-15	4.2	1.18	4.9	0.33
Jul 16-31	4.2	1.12	4.7	0.29
Aug 1-15	3.7	0.99	3.7	0.25
Aug 16-31	3.7	0.87	3.2	0.20
Sept 1-15	3.1	0.67	2.1	0.14
Sept 16-30	2.6	0.50	1.3	0.09
Oct 1-15	2.2	0.35	0.8	0.05
Oct 16-31	1.7	0.20	0.3	0.02
Total			45.1	

Developing an Irrigation Schedule; Firebaugh

	BiMonthly ETo	Crop Coefficient	ETc In Period	ETc Daily	ETc* Per Tree
	(inches)	(Kc)	(inches)	(inch/day)	(gal/tree/day)
Mar 16-31	2.3	0.43	1.0	0.06	19
Apr 1-15	2.5	0.68	1.7	0.11	35
Apr 16-30	2.9	0.93	2.7	0.18	56
May 1-15	3.5	1.09	3.9	0.26	81
May 16-31	4.2	1.17	4.9	0.31	96
Jun 1-15	4.2	1.18	5.0	0.33	104
Jun 16-30	4.3	1.18	5.0	0.34	105
Jul 1-15	4.2	1.18	4.9	0.33	103
Jul 16-31	4.2	1.12	4.7	0.29	92
Aug 1-15	3.7	0.99	3.7	0.25	77
Aug 16-31	3.7	0.87	3.2	0.20	62
Sept 1-15	3.1	0.67	2.1	0.14	43
Sept 16-30	2.6	0.50	1.3	0.09	27
Oct 1-15	2.2	0.35	0.8	0.05	16
Oct 16-31	1.7	0.20	0.3	0.02	7
Total			45.1		

* Assumes 21 x 24 ft tree spacing; 86 trees/acre

Developing an Irrigation Schedule; Firebaugh

	BiMonthly ETo	Crop Coefficient	ETc In Period	ETc Daily	ETc* Per Tree
	(inches)	(Kc)	(inches)	(inch/day)	(gal/tree/day)
Mar 16-31	2.3	0.43	1.0	0.06	15
Apr 1-15	2.5	0.68	1.7	0.11	26
Apr 16-30	2.9	0.93	2.7	0.18	42
May 1-15	3.5	1.09	3.9	0.26	60
May 16-31	4.2	1.17	4.9	0.31	72
Jun 1-15	4.2	1.18	5.0	0.33	78
Jun 16-30	4.3	1.18	5.0	0.34	79
Jul 1-15	4.2	1.18	4.9	0.33	77
Jul 16-31	4.2	1.12	4.7	0.29	69
Aug 1-15	3.7	0.99	3.7	0.25	58
Aug 16-31	3.7	0.87	3.2	0.20	47
Sept 1-15	3.1	0.67	2.1	0.14	32
Sept 16-30	2.6	0.50	1.3	0.09	20
Oct 1-15	2.2	0.35	0.8	0.05	12
Oct 16-31	1.7	0.20	0.3	0.02	5
Total			45.1		

* Assumes 18 x 21 ft tree spacing; 115 trees/acre

Gross Applied Water Required

Example for peak demand

$$\frac{\text{Evapotranspiration}}{\text{Application Efficiency}}$$

$$\frac{\text{105 gal/tree/day}}{0.90} = \text{117 gal/tree/day}$$

Developing an Irrigation Schedule; Firebaugh

	Actual ETc* (gal/tree/day)
Mar 16-31	19
Apr 1-15	35
Apr 16-30	56
May 1-15	81
May 16-31	96
Jun 1-15	104
Jun 16-30	105
Jul 1-15	103
Jul 16-31	92
Aug 1-15	77
Aug 16-31	62
Sept 1-15	43
Sept 16-30	27
Oct 1-15	16
Oct 16-31	7

* Assumes 21 x 24 ft tree spacing; 86 trees/acre

Developing an Irrigation Schedule; Firebaugh

	Actual ETc* (gal/tree/day)	Applied Water (gal/tree/day)
Mar 16-31	19	22
Apr 1-15	35	39
Apr 16-30	56	63
May 1-15	81	90
May 16-31	96	107
Jun 1-15	104	116
Jun 16-30	105	117
Jul 1-15	103	114
Jul 16-31	92	103
Aug 1-15	77	86
Aug 16-31	62	69
Sept 1-15	43	48
Sept 16-30	27	30
Oct 1-15	16	18
Oct 16-31	7	7

* Assumes 21 x 24 ft tree spacing; 86 trees/acre

Irrigation Frequency

Example for peak demand

$$\frac{\text{Application Amount per Irrigation}}{\text{Gross Application Required}}$$

22 gal/tree/hr x 24 hr = 528 gal/tree/irrirgation

$$\frac{\text{528 gal/tree/irrigation}}{\text{117 gal/tree/day}} = \text{4.5 days}$$

Developing an Irrigation Schedule; Firebaugh

	Actual ETc* (gal/tree/day)	Applied Water (gal/tree/day)
Mar 16-31	19	22
Apr 1-15	35	39
Apr 16-30	56	63
May 1-15	81	90
May 16-31	96	107
Jun 1-15	104	116
Jun 16-30	105	117
Jul 1-15	103	114
Jul 16-31	92	103
Aug 1-15	77	86
Aug 16-31	62	69
Sept 1-15	43	48
Sept 16-30	27	30
Oct 1-15	16	18
Oct 16-31	7	7

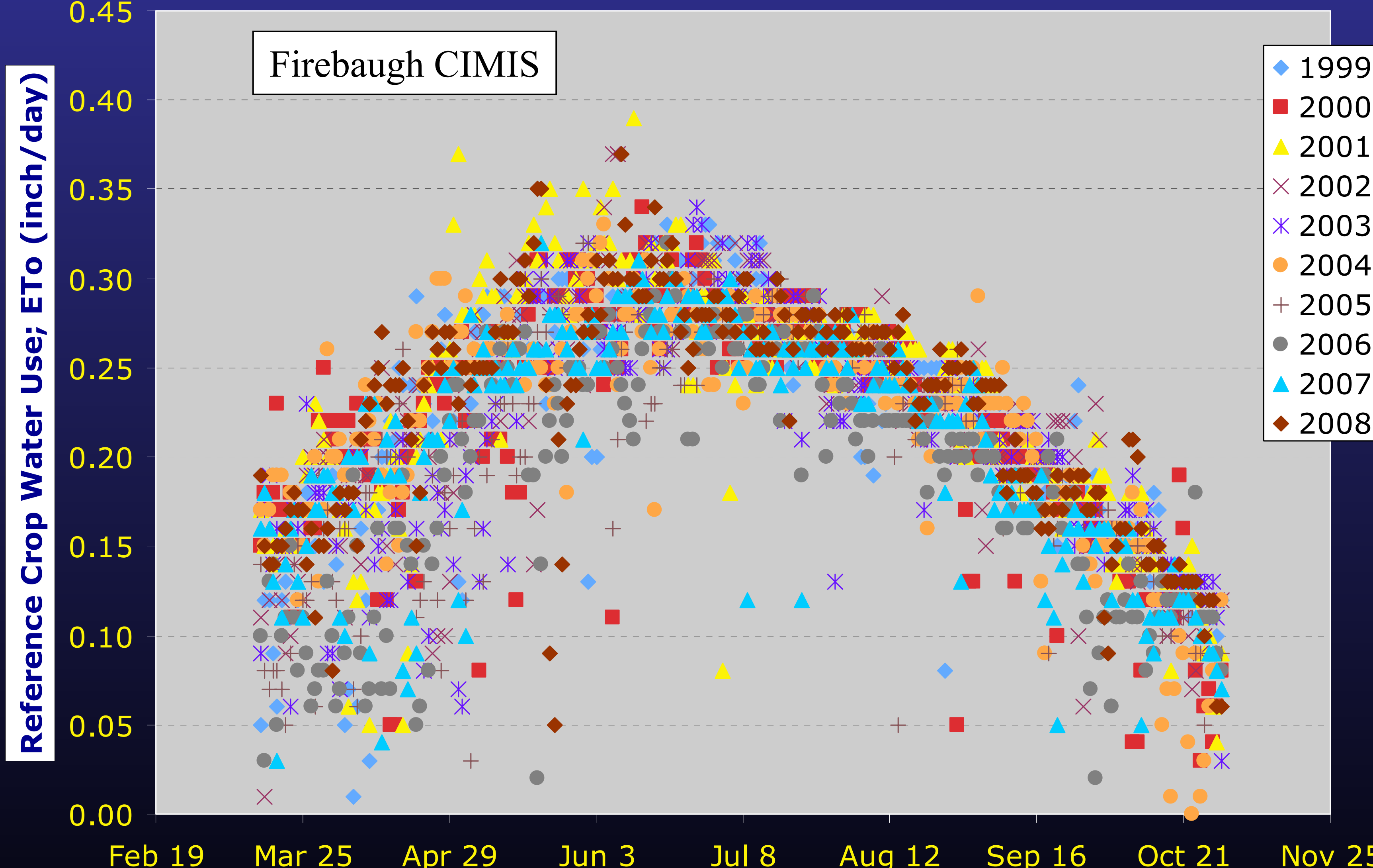
* Assumes 21 x 24 ft tree spacing; 86 trees/acre

Developing an Irrigation Schedule; Firebaugh

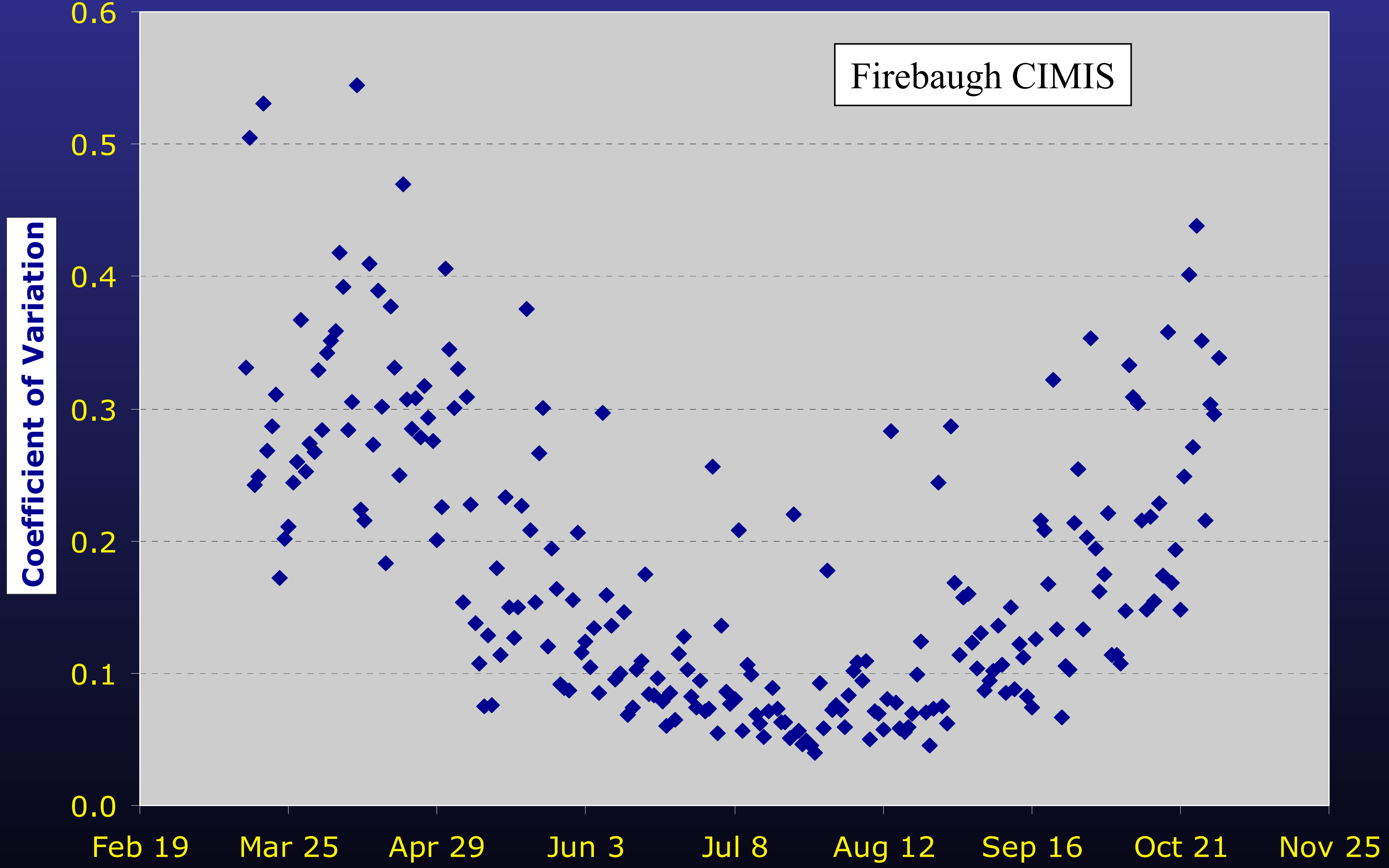
	Actual ETc* (gal/tree/day)	Applied Water (gal/tree/day)	Irrigation Frequency (days)
Mar 16-31	19	22	24
Apr 1-15	35	39	14
Apr 16-30	56	63	8
May 1-15	81	90	6
May 16-31	96	107	5
Jun 1-15	104	116	5
Jun 16-30	105	117	5
Jul 1-15	103	114	5
Jul 16-31	92	103	5
Aug 1-15	77	86	6
Aug 16-31	62	69	8
Sept 1-15	43	48	11
Sept 16-30	27	30	18
Oct 1-15	16	18	30
Oct 16-31	7	7	71

* Assumes 21 x 24 ft tree spacing; 86 trees/acre

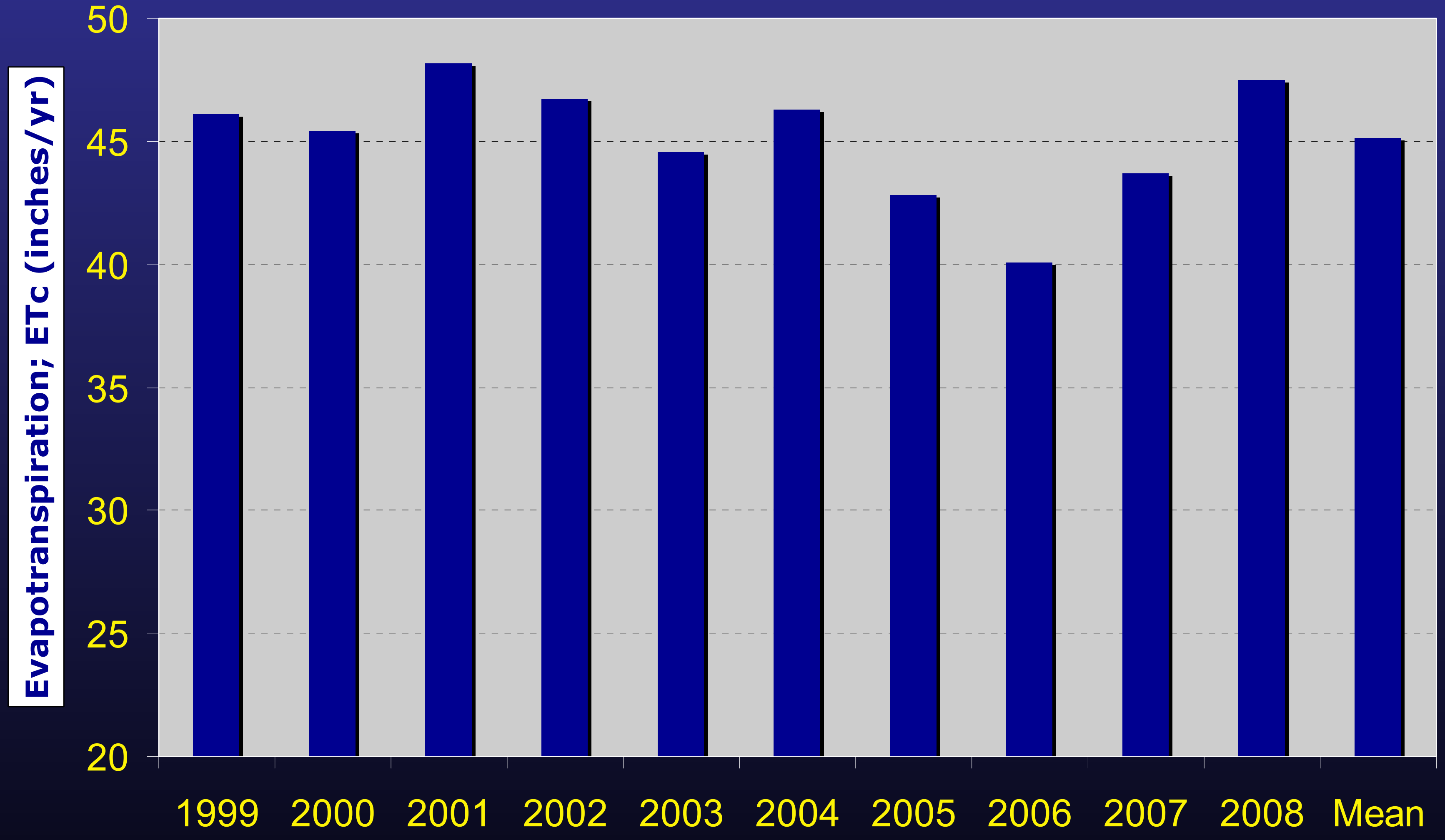
1999-2008 Reference Crop Water Use (ETo)

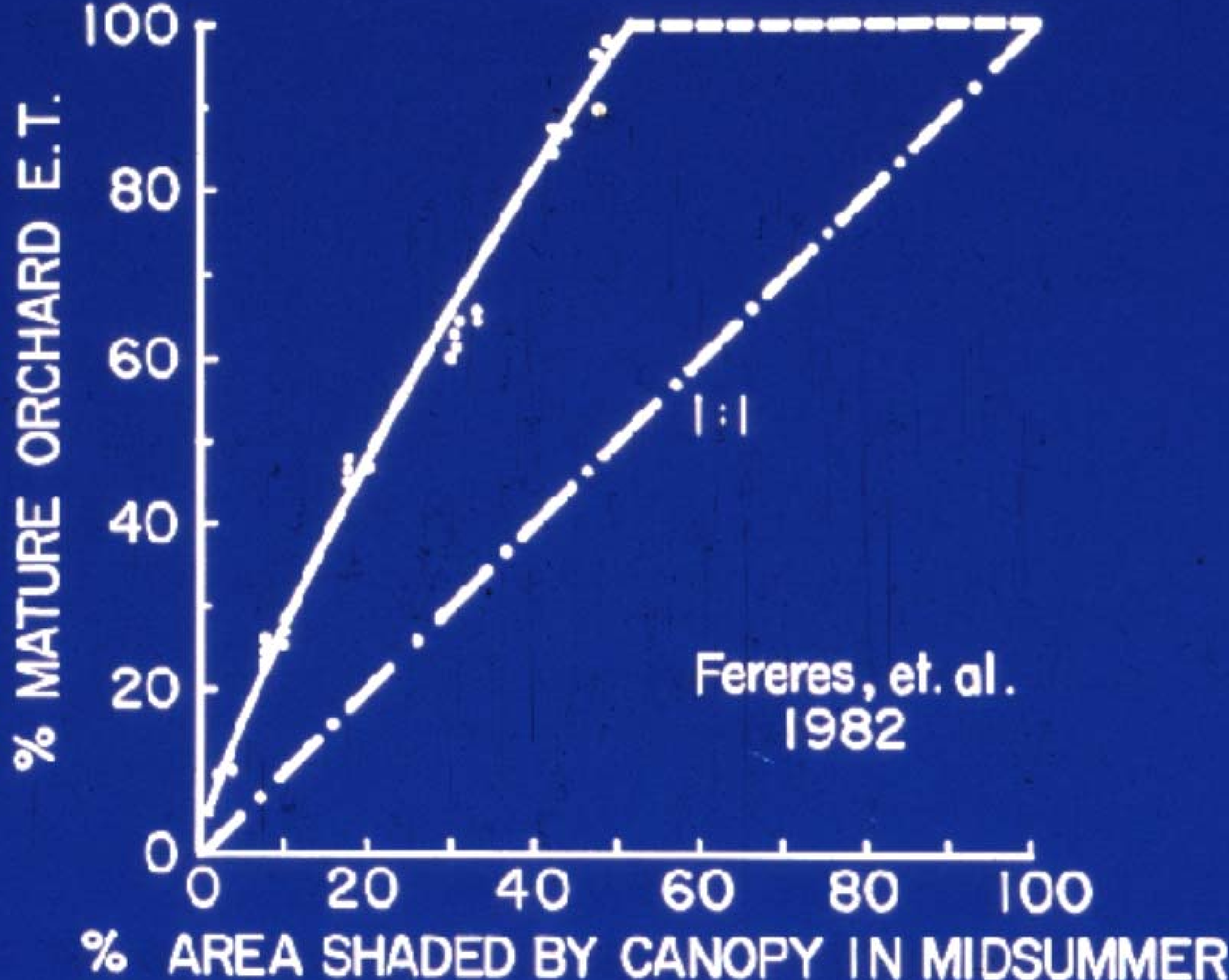


1999-2008 ETo Coefficient of Variation



1999-2008 Almond ETc; Firebaugh





% MATURE ORCHARD E.T.
100
80
60
40
20
0
0
20
40
60
80
100
% AREA SHADED BY CANOPY IN MIDSUMMER
1:1
Fereres, et. al.
1982

Monitoring water status

Soil

1) By hand
2) Tensiometers
3) Electrical resistance/capacitance
4) Neutron probe

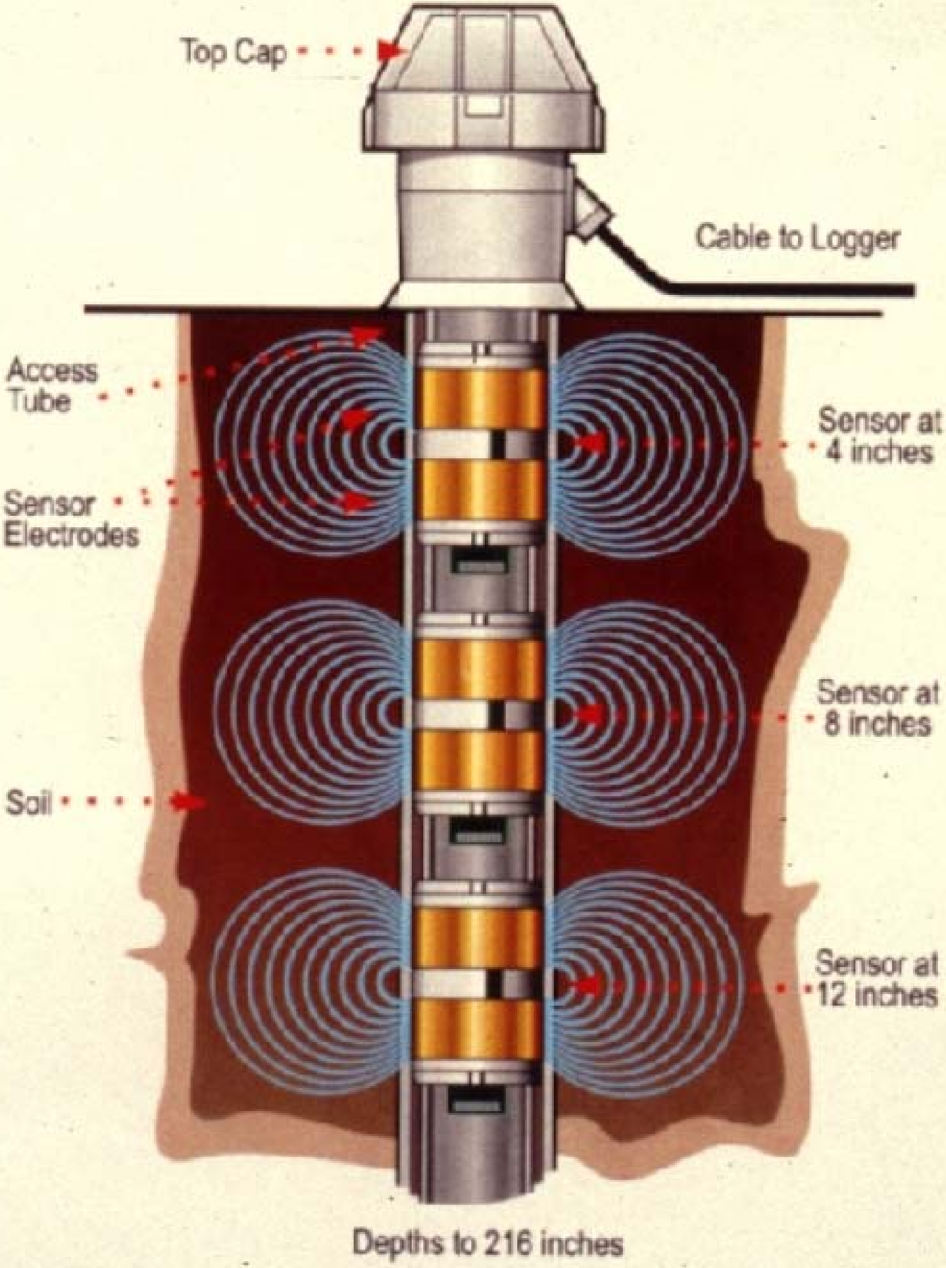
Plant

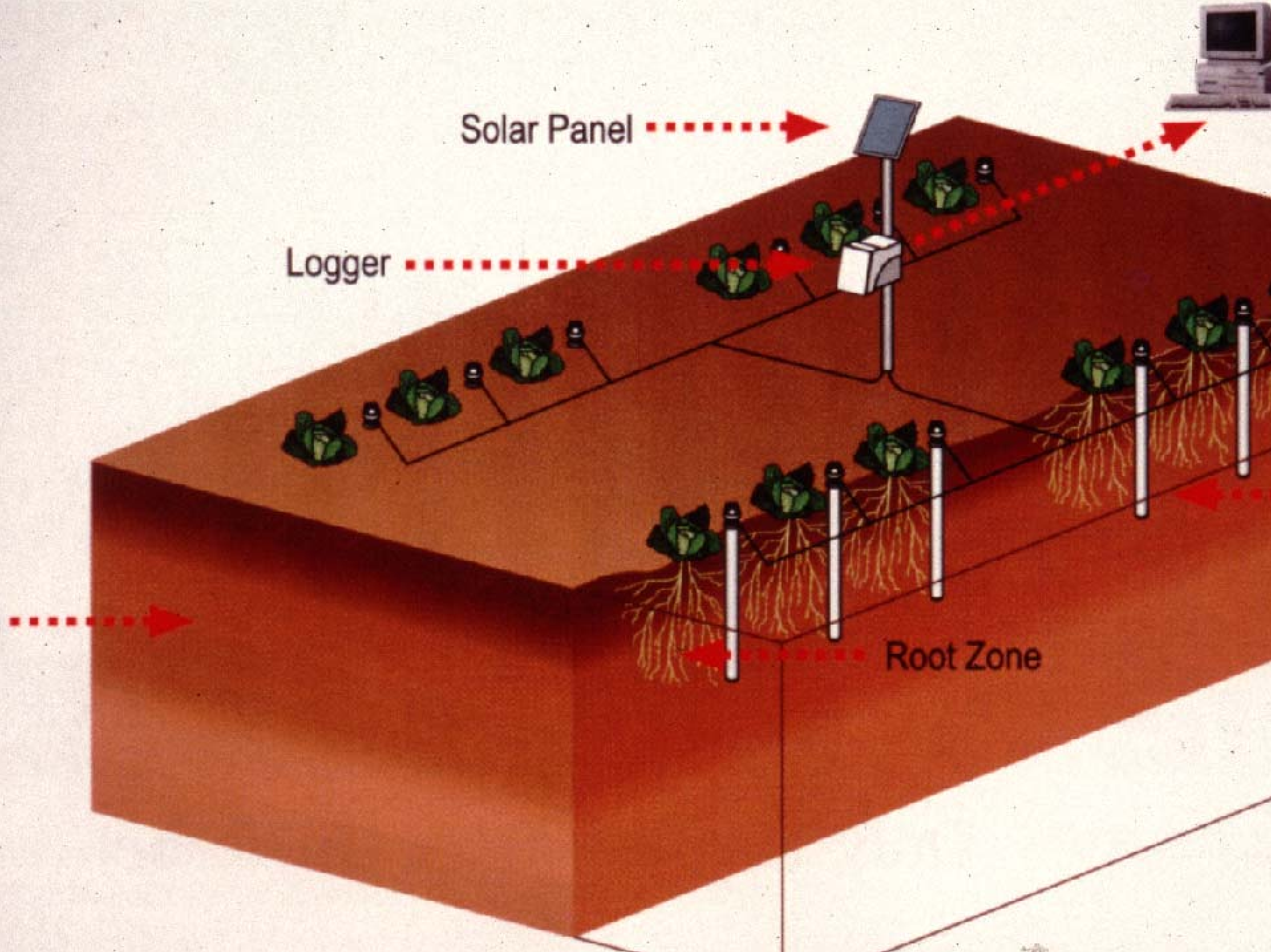
1) Pressure chamber
2) Infrared Thermometers

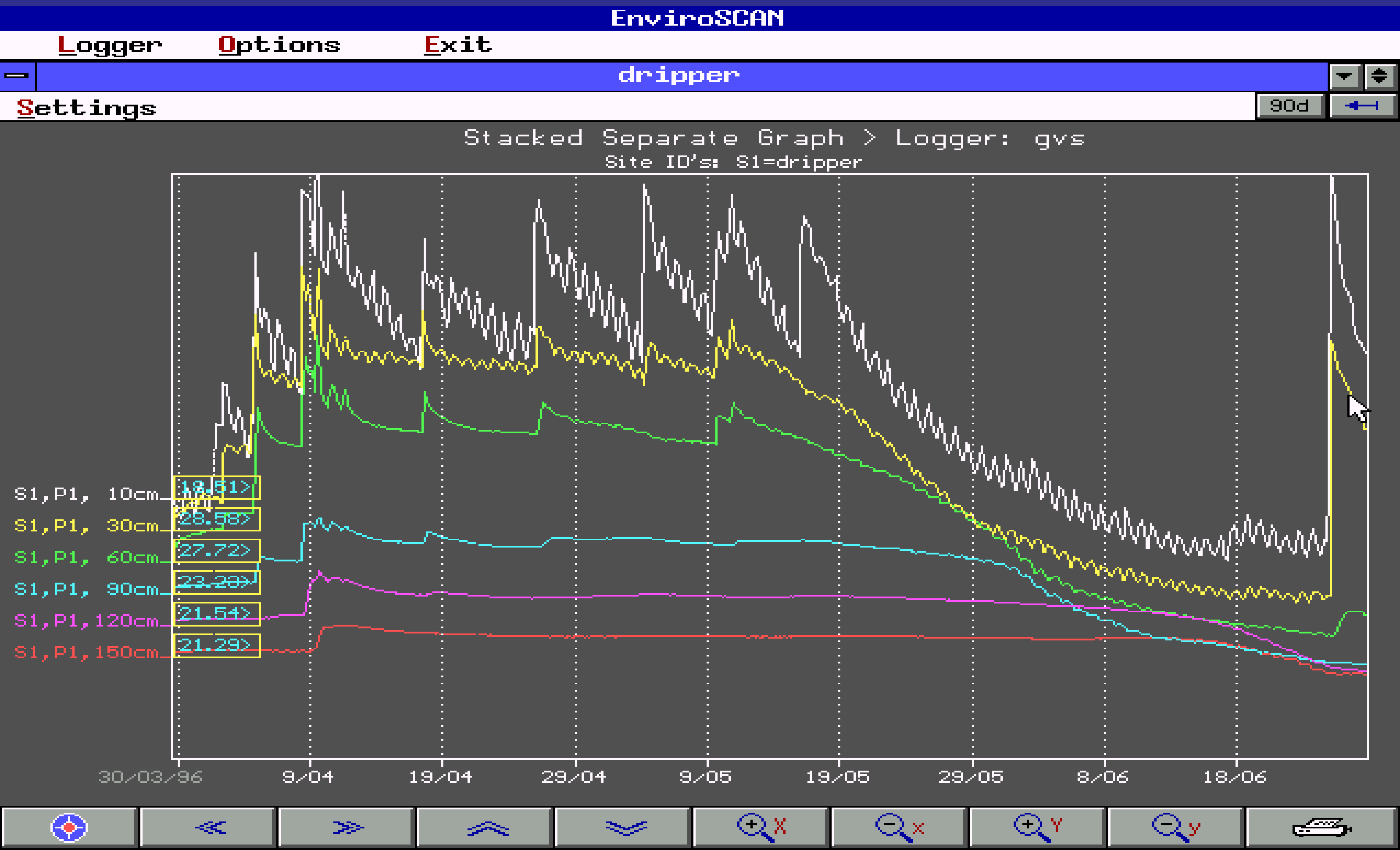

WATERMARK

EnviroSCAN Probe

Cut-away diagram to the 12 inch sensor. Sensors are available for depths of up to 216 inches.




Solar Panel
Logger
Root Zone

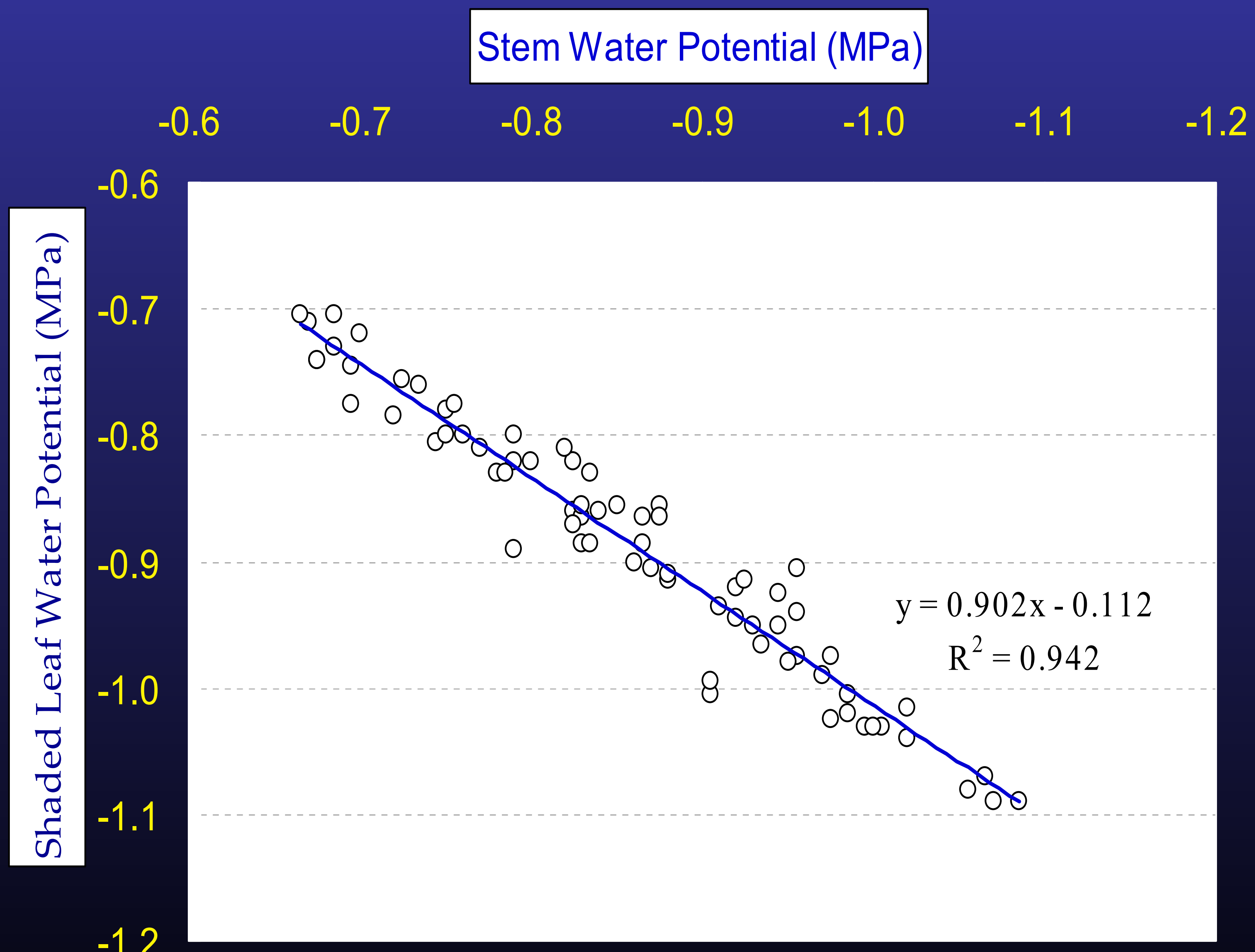

EnviroSCAN
Logger
Options
Exit
dripper
Settings
90d
Stacked Separate Graph > Logger: gvs
Site ID's: S1=dripper
S1,P1, 10cm
S1,P1, 30cm
S1,P1, 60cm
S1,P1, 90cm
S1,P1,120cm
S1,P1,150cm
13.51>
28.58>
27.72>
23.28>
21.54>
21.29>
30/03/96
9/04
19/04
29/04
9/05
19/05
29/05
8/06
18/06

Shortcomings of Soil Monitoring

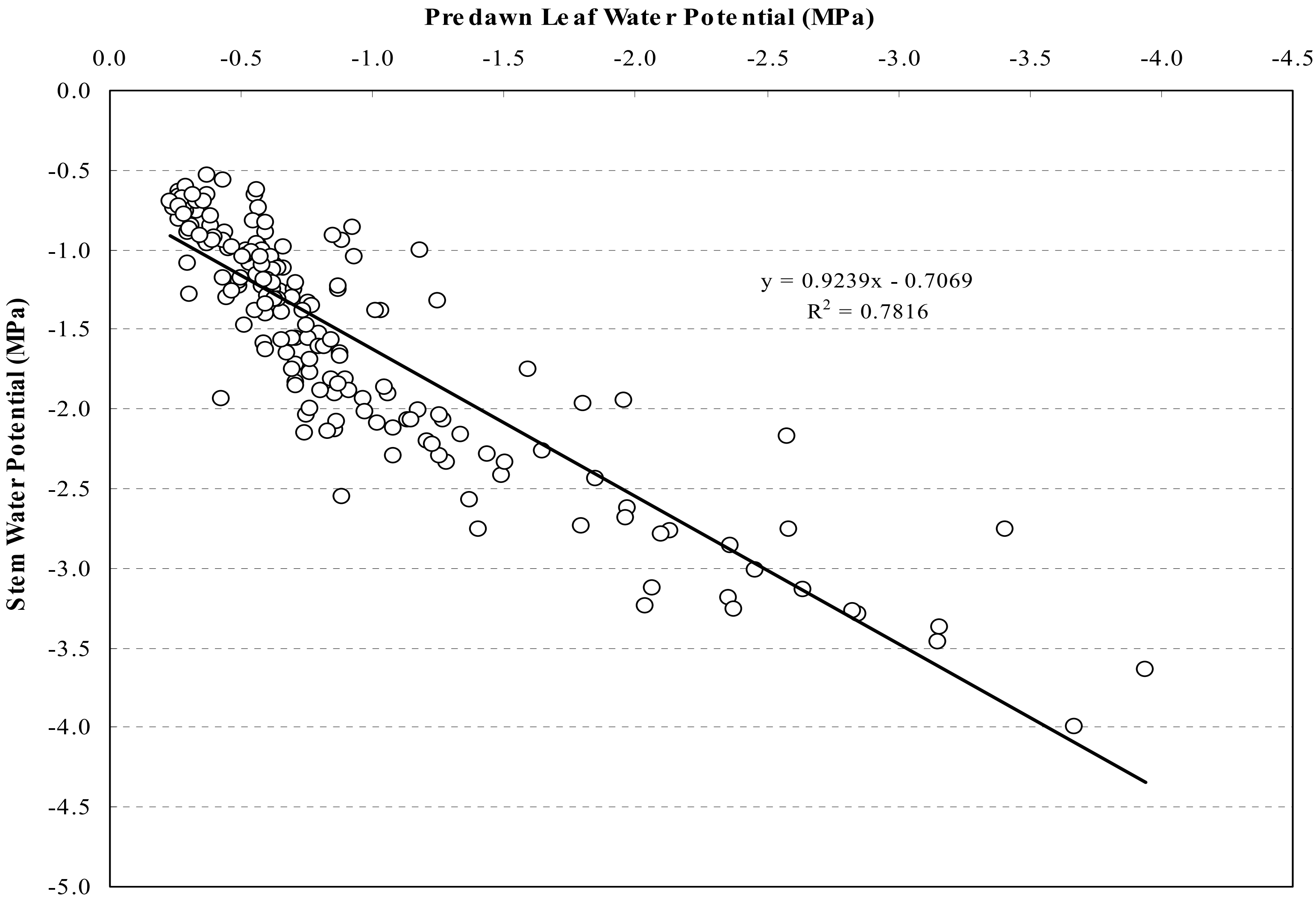
1) Interpretation of the data.
2) Accuracy of the data.
3) Costs.
4) Only a few measurements per acre possible; can't adequately characterize an entire field.

Plant-based monitoring

Pressure Chamber: Gives estimate of plant water status.



Stem Water Potential (MPa)
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
Shaded Leaf Water Potential (MPa)
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
y = 0.902x - 0.112
$R^2 = 0.942$

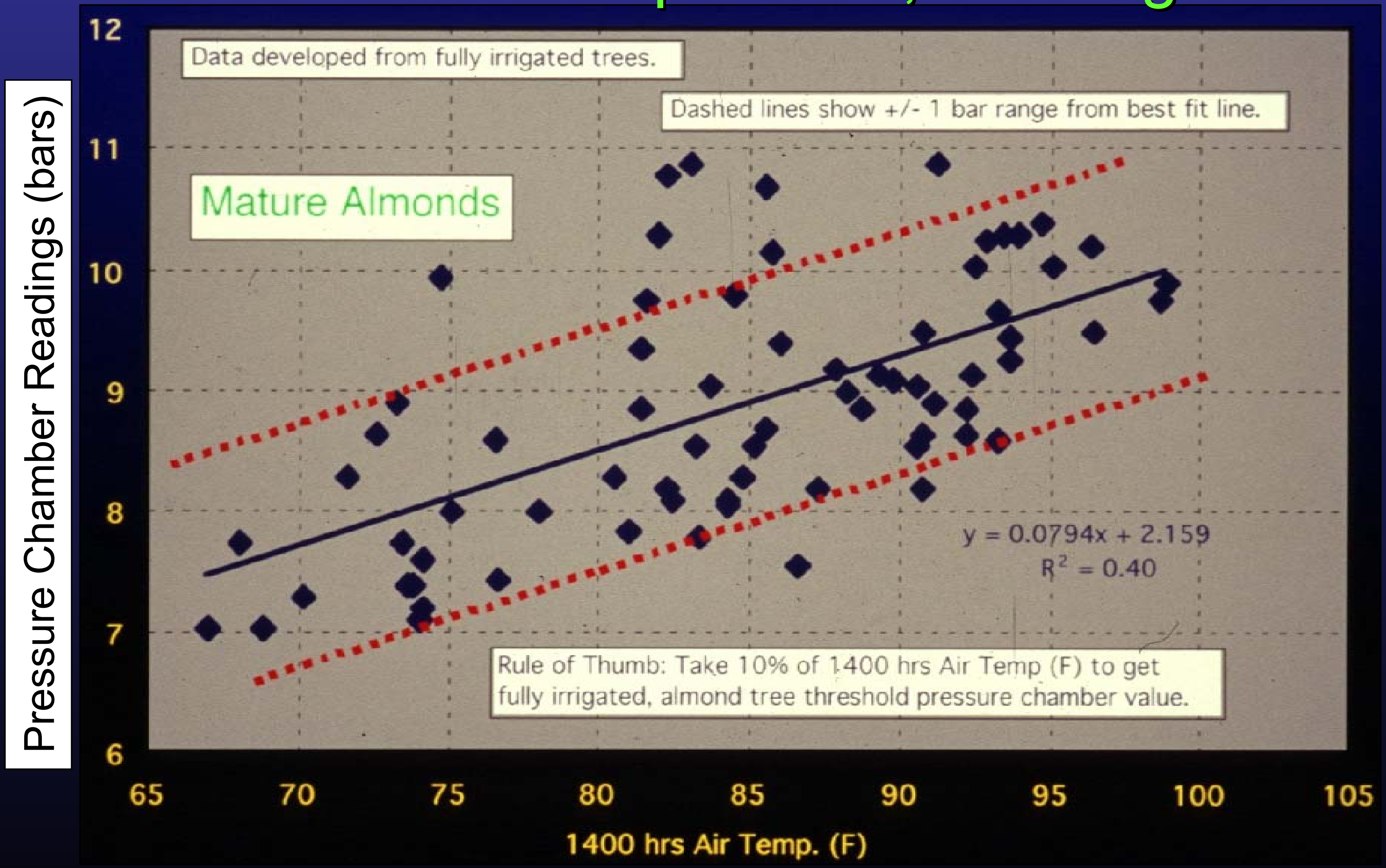

Predawn Leaf Water Potential (MPa)
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
Stem Water Potential (MPa)
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
-5.0
y = 0.9239x - 0.7069
R2 = 0.7816

Shortcomings of the Pressure Chamber

1) Manually taken; can't be automated.
2) Requires trips to the field and operator.
3) Limited time period to take measurements; noon-2:30 pm.

Thus, can't adequately characterize a field.

Midday Shaded Pressure Chamber vs. Maximum Air Temperature; Full Irrigation



Reducing consumptive use scenarios

Adequate Water Supply (Choice)

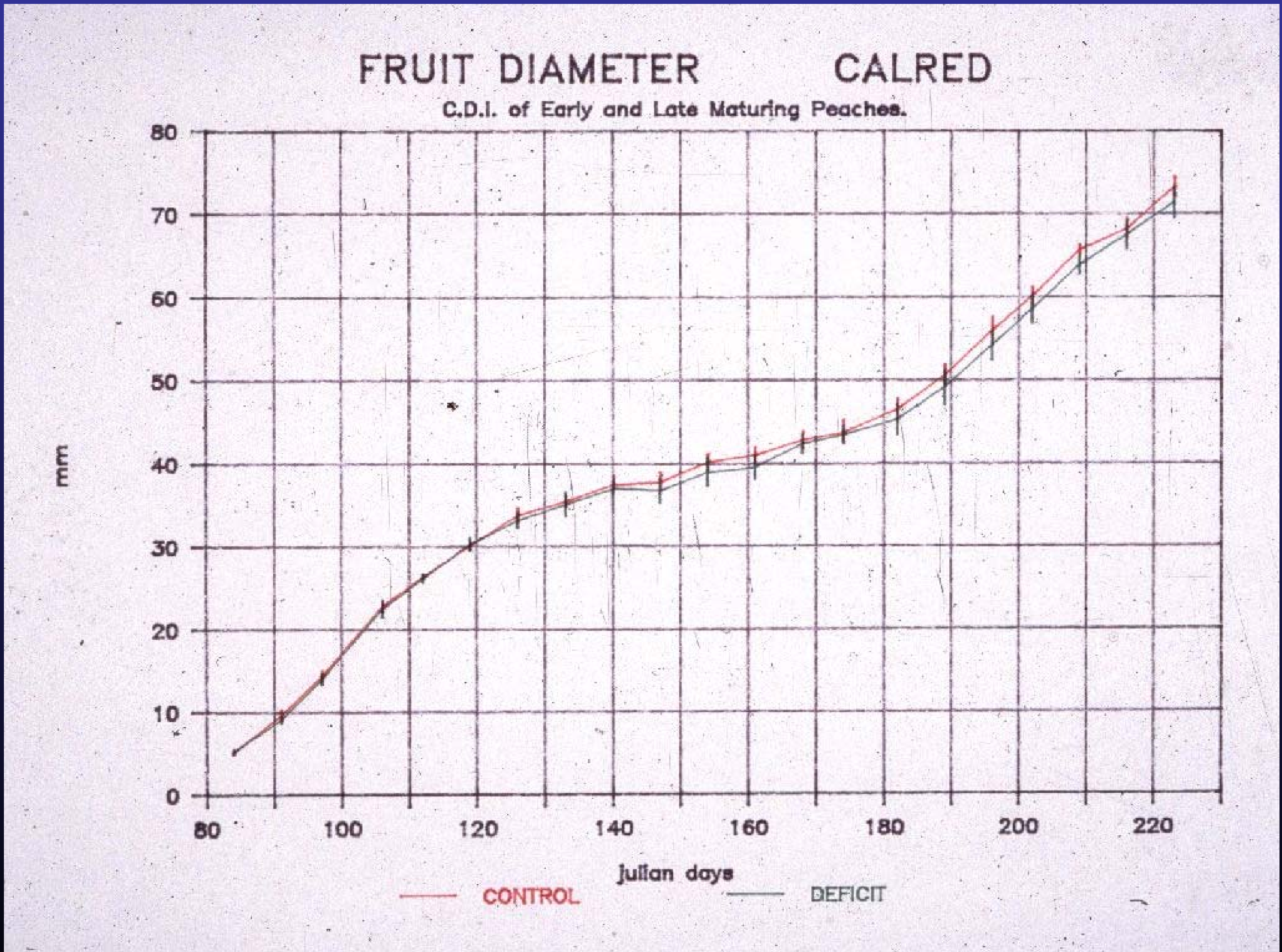
- Reduce water cost
- Be good stewards of the water

Droughts (No Choice)

- Minimize negative impacts on current and subsequent years production

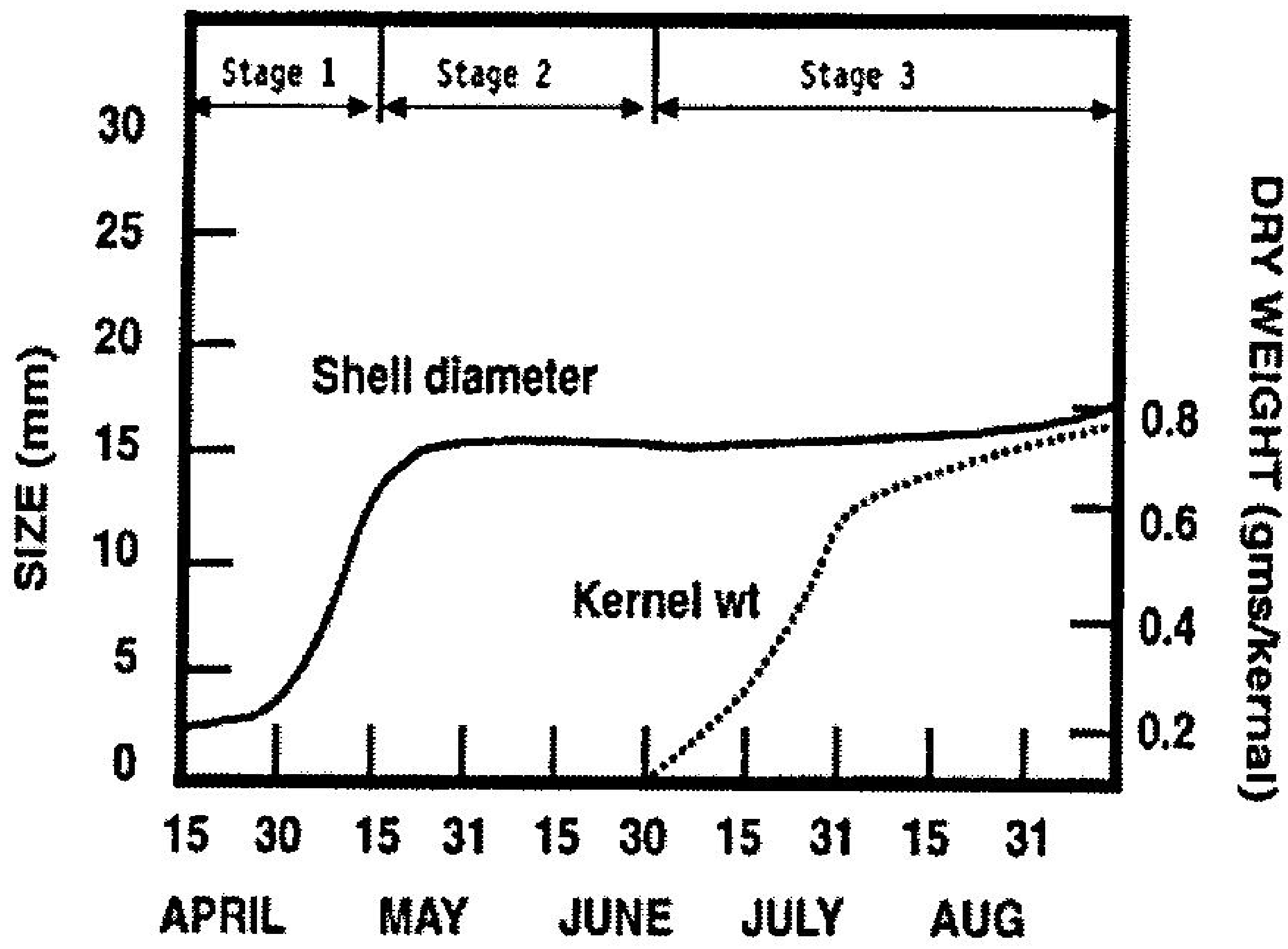
Regulated Deficit Irrigation (RDI)

Planned water deficits at specific crop developmental stages that are stress tolerant without negatively affecting production.

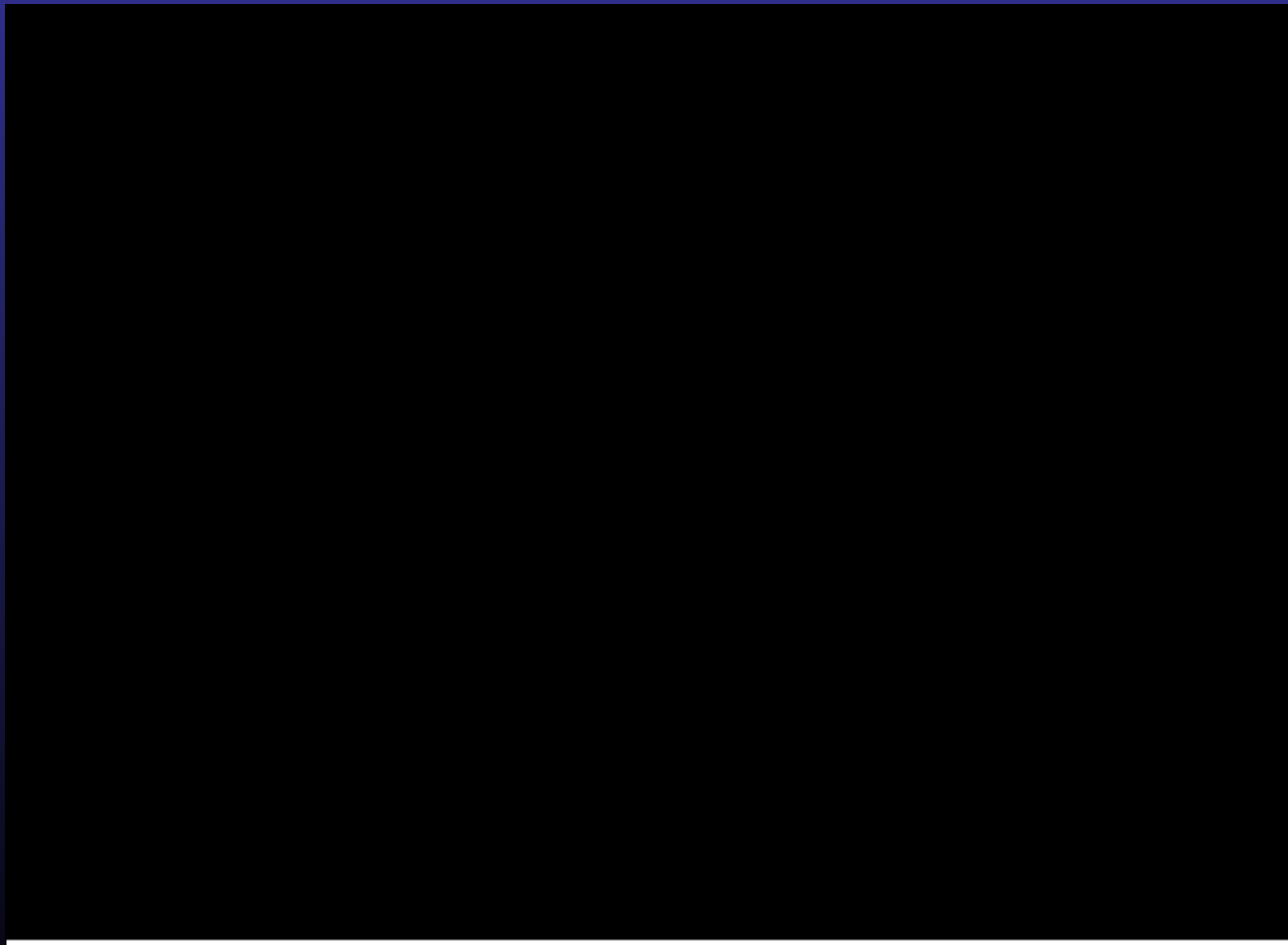


FRUIT DIAMETER CALRED
C.D.I. of Early and Late Maturing Peaches.
80
70
60
50
40
30
20
10
0
mm
80
100
120
140
160
180
200
220
julian days
CONTROL
DEFICIT

Pistachio Nut Growth Processes



Almond Nut Growth Processes



Influence of Preharvest Irrigation Cutoff

Full irrigation until irrigation cutoffs ranging from 53 to 4 days prior to shaking in 7 day increments

Thus, stress only preharvest; full postharvest irrgation

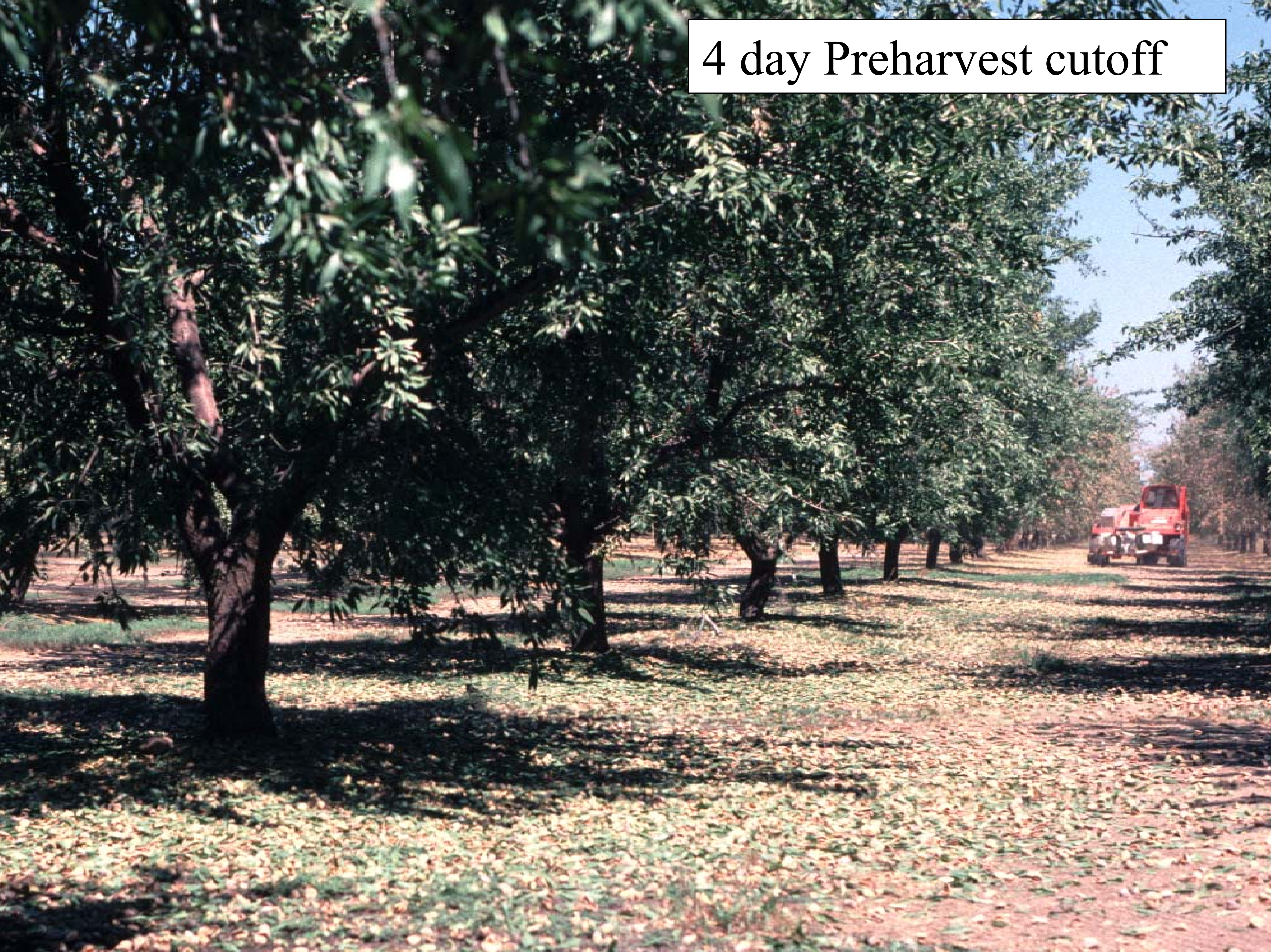
Total Rainfall

Yr. 1	3.0 inches
Yr. 2	6.4 inches
Yr. 3	6.9 inches

Influence of Preharvest Irrigation Cutoff

Irrig. Cutoff Date	Cutoff Duration (days)	Preharv. Applied Water (inches)	Jul 7 Predawn LWP (bars)	Jul 20 Predawn LWP (bars)	Jul 27 Predawn LWP (bars)
Jun 25	53	19.8	-25.1 a	-28.5 a	-40.0 a
Ju1 1	46	21.6	-24.4 a	-29.6 a	-35.3 a
Jul 8	39	23.4	-12.0 b	-21.8 b	-26.3 b
Jul 15	32	25.2	- 5.3 c	-17.3 b	-26.5 b
Jul 22	25	27.0		-10.5 c	-18.9 bc
Jul 29	18	28.8		- 5.7 c	-15.4 c
Aug 5	11	30.6			
Aug 12	3	31.5			


53 day Preharvest cutoff


4 day Preharvest cutoff

Cutoff; 3 Yr Mean; With Postharvest Irrigation

Irrigation Cutoff Date	Cutoff Duration (days)	Preharvest Applied Water (inches)
Jun 25	53	19.8
Ju1 1	46	21.6
Jul 8	39	23.4
Jul 15	32	25.2
Jul 22	25	27.0
Jul 29	18	28.8
Aug 5	11	30.6
Aug 12	4	31.5

Cutoff; 3 Yr Mean; With Postharvest Irrigation

Irrigation Cutoff Date	Cutoff Duration (days)	Preharvest Applied Water (inches)	Dry Kernel Wt. (g)
Jun 25	53	19.8	1.08 a
Ju1 1	46	21.6	1.11 a c
Jul 8	39	23.4	1.13 abc
Jul 15	32	25.2	1.18 abc
Jul 22	25	27.0	1.15 abc
Jul 29	18	28.8	1.13 abc
Aug 5	11	30.6	1.24 b
Aug 12	4	31.5	1.21 bc

Cutoff; 3 Yr Mean; With Postharvest Irrigation

Irrigation Cutoff Date	Cutoff Duration (days)	Preharvest Applied Water (inches)	Dry Kernel Wt. (g)	Nut Load (No./tree)
Jun 25	53	19.8	1.08 a	8640
Ju1 1	46	21.6	1.11 a c	9470
Jul 8	39	23.4	1.13 abc	8650
Jul 15	32	25.2	1.18 abc	7872
Jul 22	25	27.0	1.15 abc	9526
Jul 29	18	28.8	1.13 abc	8340
Aug 5	11	30.6	1.24 b	8368
Aug 12	4	31.5	1.21 bc	9530

NSD

Cutoff; 3 Yr Mean; With Postharvest Irrigation

Irrigation Cutoff Date	Cutoff Duration (days)	Preharvest Applied Water (inches)	Dry Kernel Wt. (g)	Nut Load (No./tree)	Dry Kernel Yield (lb/ac)
Jun 25	53	19.8	1.08 a	8640	1384
Ju1 1	46	21.6	1.11 a c	9470	1552
Jul 8	39	23.4	1.13 abc	8650	1456
Jul 15	32	25.2	1.18 abc	7872	1388
Jul 22	25	27.0	1.15 abc	9526	1684
Jul 29	18	28.8	1.13 abc	8340	1455
Aug 5	11	30.6	1.24 b	8368	1574
Aug 12	4	31.5	1.21 bc	9530	1723
				NSD	NSD


Hull Rot

Hull Rot; 3 Yr Mean; With Postharvest Irrigation

Irrig. Cutoff Date	Cutoff Duration (days)	Preharv. Applied Water (inches)	Visual Hull Rot (strikes/tree)
Jun 25	53	19.8	0.00 a
Jul 1	46	21.6	0.19 a
Jul 8	39	23.4	0.32 a
Jul 15	32	25.2	0.73 a
Jul 22	25	27.0	1.17 ab
Jul 29	18	28.8	3.73 bc
Aug 5	11	30.6	4.44 c
Aug 12	4	31.5	5.00 c

Hull Rot; Teviotdale et al.; 1997

	Hull Rot Strikes (#/tree)	Dead Wood (inches/tree)	Kernel Wt. (gms)	Shell Wt. (gms)	Hull Wt. (gms)	Whole Unit Wt. (gms)
Control	297	508	1.19	0.93	4.12	6.24
RDI	49	33	1.14	0.95	4.19	6.28
RDI % Di	-84.5	-93.5	-4.2	+2.2	+1.7	+0.6
	*	*	NSD	NSD	NSD	NSD

What is the impact of postharvest irrigation?

POSTHARVEST IRRIGATION OF ORCHARDS

Postharvest irrigation of orchards is determined by soil conditions, climate, soil moisture, the time of year harvest is completed, and the kind of fruit or nut crop grown. In general, however, the depletion of deep soil moisture in orchards makes irrigating after harvest desirable. A check of the actual soil moisture content must be made to see if the crop requires a postharvest irrigation to carry it through the remainder of the growing season.

Fruit bud set and food storage. During the early summer most orchard crops set buds for the next season's fruit and vegetative growth, so that a shortage of water during a particular growing season will reduce the size of fruit that season and reduce the bud set for the following crop. Orchard trees grow best and develop fruit buds when provided with an adequate supply of available soil moisture during the entire foliage period.

As long as leaves remain on the trees and abscission layers have not formed, trees continue to synthesize food which is then stored in limbs, trunk, and roots for future use. The processes of food storage and transpiration require an adequate supply of soil moisture.

Division of Agricultural Sciences
UNIVERSITY OF CALIFORNIA

LEAFLET
2767

PRINTED OCTOBER 1975

harvest to encourage fruit bud development during the late summer and early fall months.

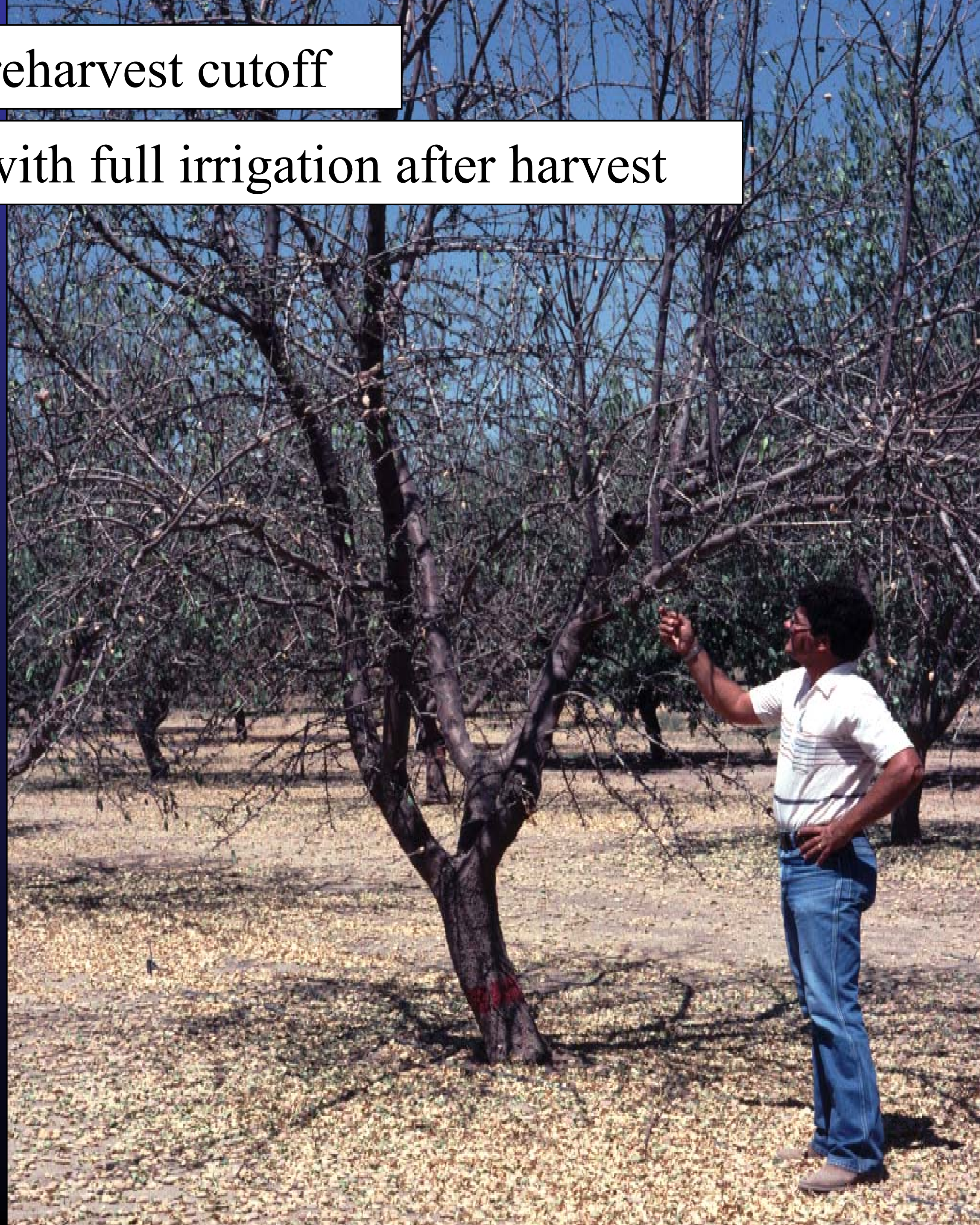
Almonds, prunes, and walnuts, if allowed to deplete soil moisture during harvest to the point of leaf-drop, should not be irrigated in September or October. Irrigation of these trees in partial or full leaf-drop condition may force premature postharvest flowering.

Water shortage. During the years of limited water supply, one may have to decide

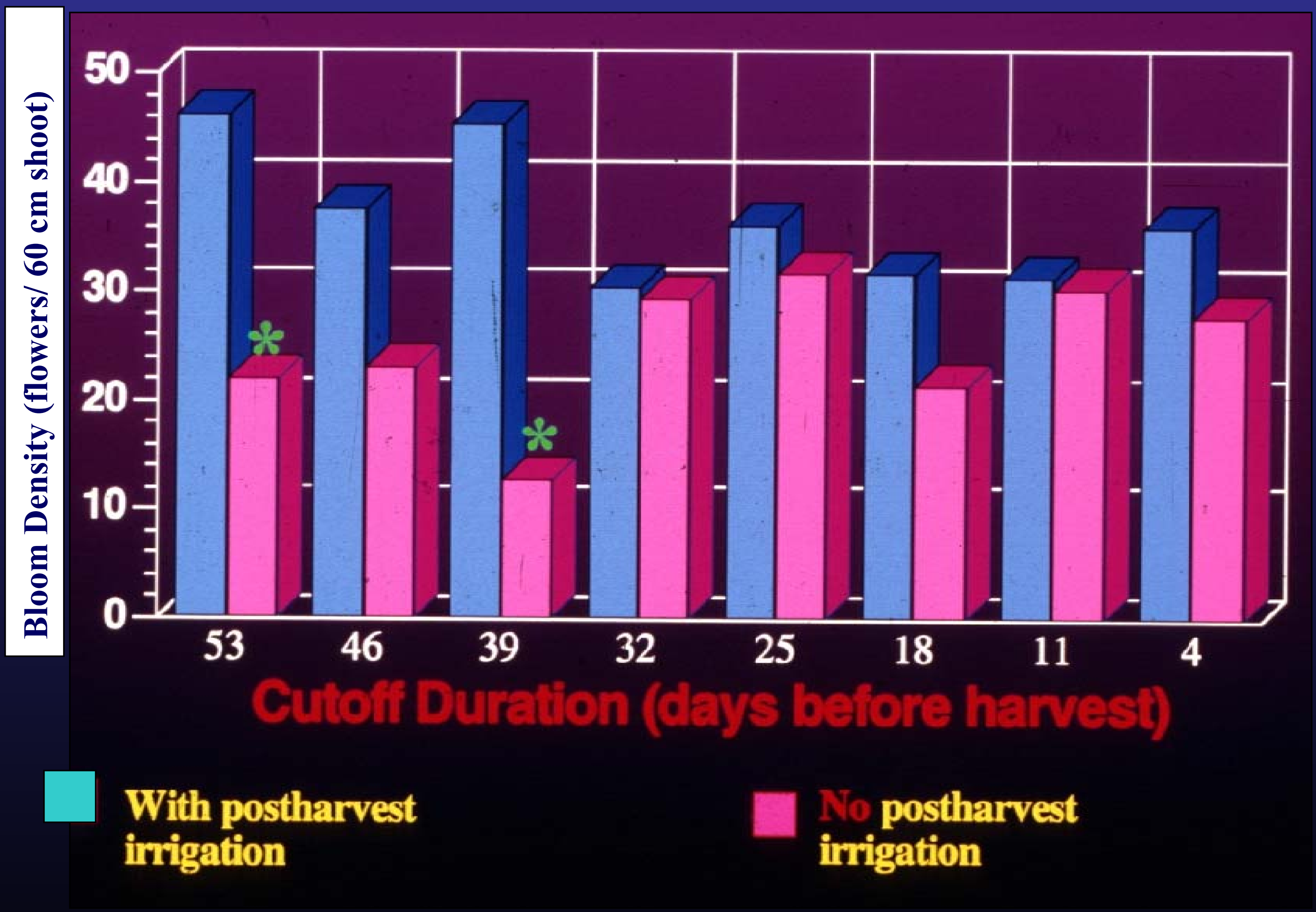
Divided experiment to test full postharvest irrigation vs. no postarvest irrigation

53 day Preharvest cutoff

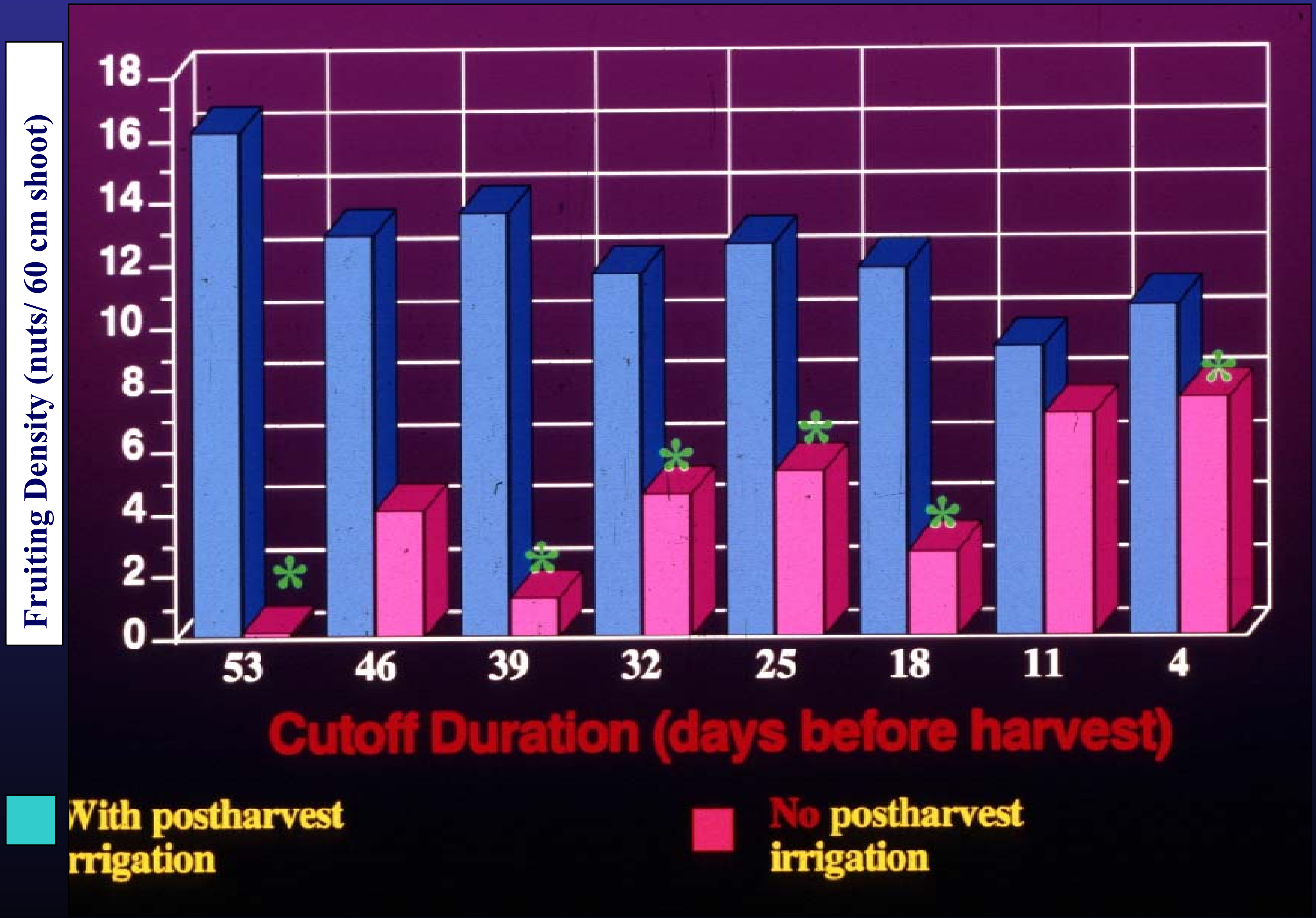
Refoliated with full irrigation after harvest



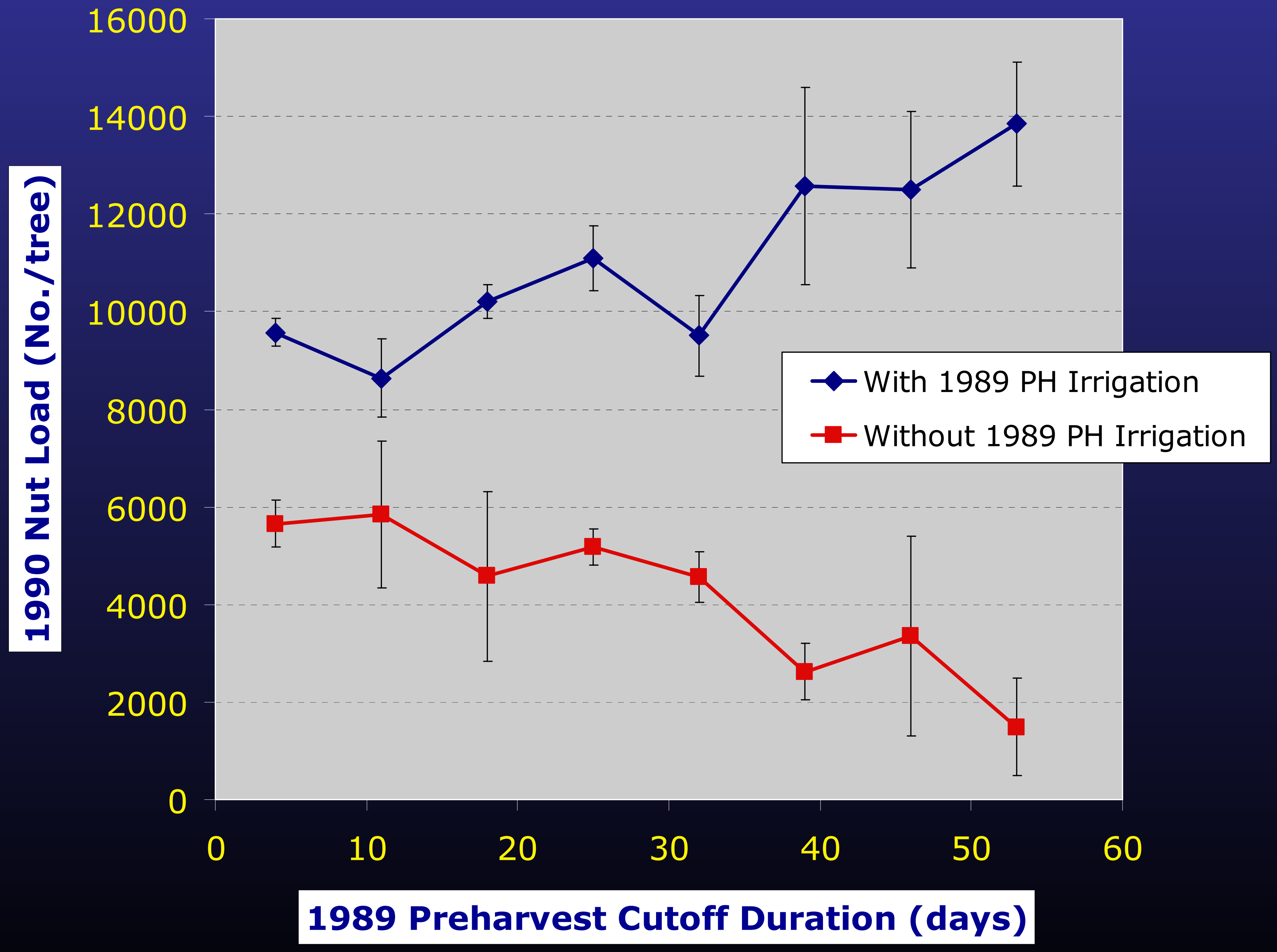
Second Year Bloom Density



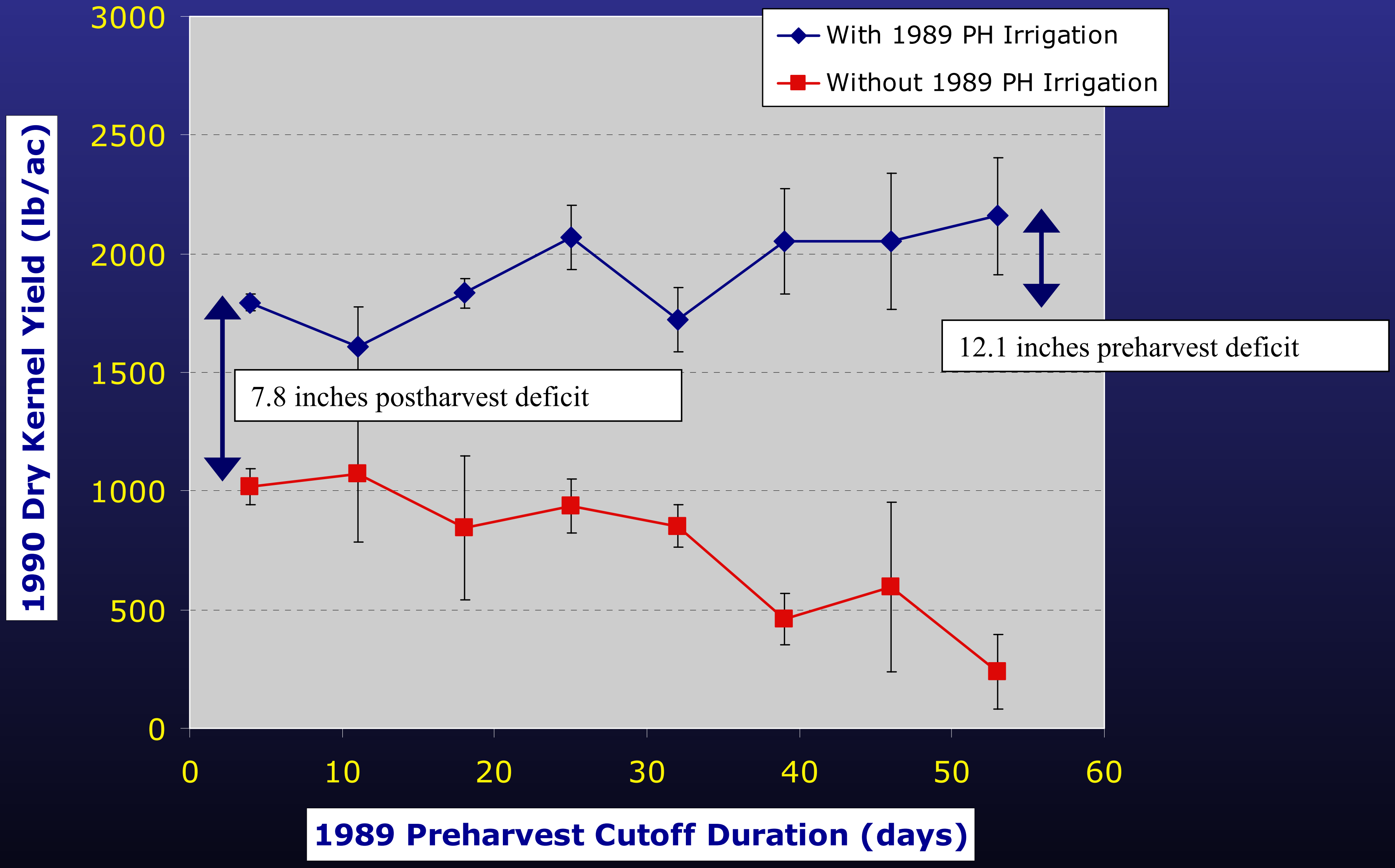
Second Year Fruiting Density



Second Year Nut Load



Second Year Dry Kernel Yield



HILGARDIA

A JOURNAL OF AGRICULTURAL SCIENCE

PUBLISHED BY THE

CALIFORNIA AGRICULTURAL EXPERIMENT STATION

VOL. 1 MAY, 1925 No. 1

FRUIT-BUD DIFFERENTIATION IN DECIDUOUS FRUITS

BY

WARREN P. TUFTS AND E. B. MORROW

Fruit-bud formation, upon which fruit production is dependent, is undoubtedly influenced by such orchard practices as pruning, irrigation, and cultivation. For a successful study of the influence of these various practices upon fruit-bud formation, therefore, an intimate knowledge of the time of differentiation must be available. This paper is the report of studies which have been made under different California conditions over a period of nine years.

TIME OF FRUIT-BUD DIFFERENTIATION

It had been known in a general way that the flowers producing fruit in any year were formed some time during the preceding growing season, but it remained for Goff[6] to recognize definitely the initial stages of flower-bud formation in deciduous orchard fruits. He determined by morphological studies the time when differentiation into flower-buds first occurs and traced the successive stages of development until the unfolding of the blossoms in the spring.

Differences amounting to several days or weeks have been found to occur in the date of the initiation of fruit-bud formation with regard to both climatic influences, and to varieties and types of fruit.

Goff,[6] in a comparison of apple varieties, found a variation of as much as five weeks in the time of flower-bud formation.

Kramer[10] worked with several varieties each of the apple, pear, and cherry and found marked varietal differences, especially in the apple and pear. Little or no variation occurred in the cherry varieties studied. Kramer's work was conducted at Oppenheim, Germany.

Tuffs and Morrow; Hilgardia 1(1):10

Species	Variety	Date of Differentiation
Almond	Non Pareil	Late Aug-Early Sept
Apple	Gravenstein	Mid June
Apricot	Royal	Early Aug
Cherry (Sweet)	Napoleion	Late June-Early July
Peach	Elberta	Late July
Pear	Bartlett	Late June-Early July
Plum	French	Late July-Early Aug

PostHarvest Amount Study

Used Control plots that previously had full irrigation for the entire season and imposed 6 single year PostHarvest treatments.

PostHarvest Amounts Study

Last Post Harvest Irrigation	Post Harvest Applied Water (inches)
Aug 28	0.9
Sep 4	1.8
Sep 18	2.7
Sep 25	3.6
Oct 3	4.5
Oct 29	7.2

PostHarvest Amounts Study

Last Post Harvest Irrigation	Post Harvest Applied Water (inches)	Next Year Flower Density (No./60 cm)
Aug 28	0.9	13.8 ab
Sep 4	1.8	18.1 bc
Sep 18	2.7	15.5 b
Sep 25	3.6	13.6 ab
Oct 3	4.5	9.8 a
Oct 29	7.2	22.9 c

PostHarvest Amounts Study

Last Post Harvest Irrigation	Post Harvest Applied Water (inches)	Next Year Flower Density (No./60 cm)	Next Year Fruit Density (No./60 cm)
Aug 28	0.9	13.8 ab	1.5 a
Sep 4	1.8	18.1 bc	1.5 a
Sep 18	2.7	15.5 b	3.2 ab
Sep 25	3.6	13.6 ab	4.5 b
Oct 3	4.5	9.8 a	4.5 b
Oct 29	7.2	22.9 c	10.0 c

PostHarvest Amounts Study

Last Post Harvest Irrigation	Post Harvest Applied Water (inches)	Next Year Flower Density (No./60 cm)	Next Year Fruit Density (No./60 cm)	Next Year Fruit Set Set (%)
Aug 28	0.9	13.8 ab	1.5 a	11.5 ab
Sep 4	1.8	18.1 bc	1.5 a	7.0 a
Sep 18	2.7	15.5 b	3.2 ab	20.3 b
Sep 25	3.6	13.6 ab	4.5 b	34.2 c
Oct 3	4.5	9.8 a	4.5 b	48.8 d
Oct 29	7.2	22.9 c	10.0 c	43.7 cd

PostHarvest Amounts Study

Last Post Harvest Irrigation	Post Harvest Applied Water (inches)	Next Year Flower Density (No./60 cm)	Next Year Fruit Density (No./60 cm)	Next Year Fruit Set Set (%)	Next Year Nut Load (No./tree)
Aug 28	0.9	13.8 ab	1.5 a	11.5 ab	2814 a
Sep 4	1.8	18.1 bc	1.5 a	7.0 a	1920 a
Sep 18	2.7	15.5 b	3.2 ab	20.3 b	5693 b
Sep 25	3.6	13.6 ab	4.5 b	34.2 c	5936 b
Oct 3	4.5	9.8 a	4.5 b	48.8 d	7269 c
Oct 29	7.2	22.9 c	10.0 c	43.7 cd	8122 c

PostHarvest Amounts Study

Last Post Harvest Irrigation	Post Harvest Applied Water (inches)	Next Year Flower Density (No./60 cm)	Next Year Fruit Density (No./60 cm)	Next Year Fruit Set Set (%)	Next Year Nut Load (No./tree)	Next Year Kernel Yield (lb/ac)
Aug 28	0.9	13.8 ab	1.5 a	11.5 ab	2814 a	671 a
Sep 4	1.8	18.1 bc	1.5 a	7.0 a	1920 a	436 a
Sep 18	2.7	15.5 b	3.2 ab	20.3 b	5693 b	1285 b
Sep 25	3.6	13.6 ab	4.5 b	34.2 c	5936 b	1365 bc
Oct 3	4.5	9.8 a	4.5 b	48.8 d	7269 c	1634 cd
Oct 29	7.2	22.9 c	10.0 c	43.7 cd	8122 c	1727 d

Almond Drought (RDI); Three Supply Scenarios

22, 28, and 34 inches available for season
Each supply amount applied three ways

a) Bias stress preharvest (22A, 28A, 34A)
b) Bias stress postharvest (22B, 28B, 34B)
c) Stress throughout season (22C, 28C, 34C)

Fully Irrigated Control

Mature, Non Pareil

Mean Rainfall: 7.4 inches

22A Non Pareil Late August

22B Non Pareil Late August

22C Non Pareil Late August

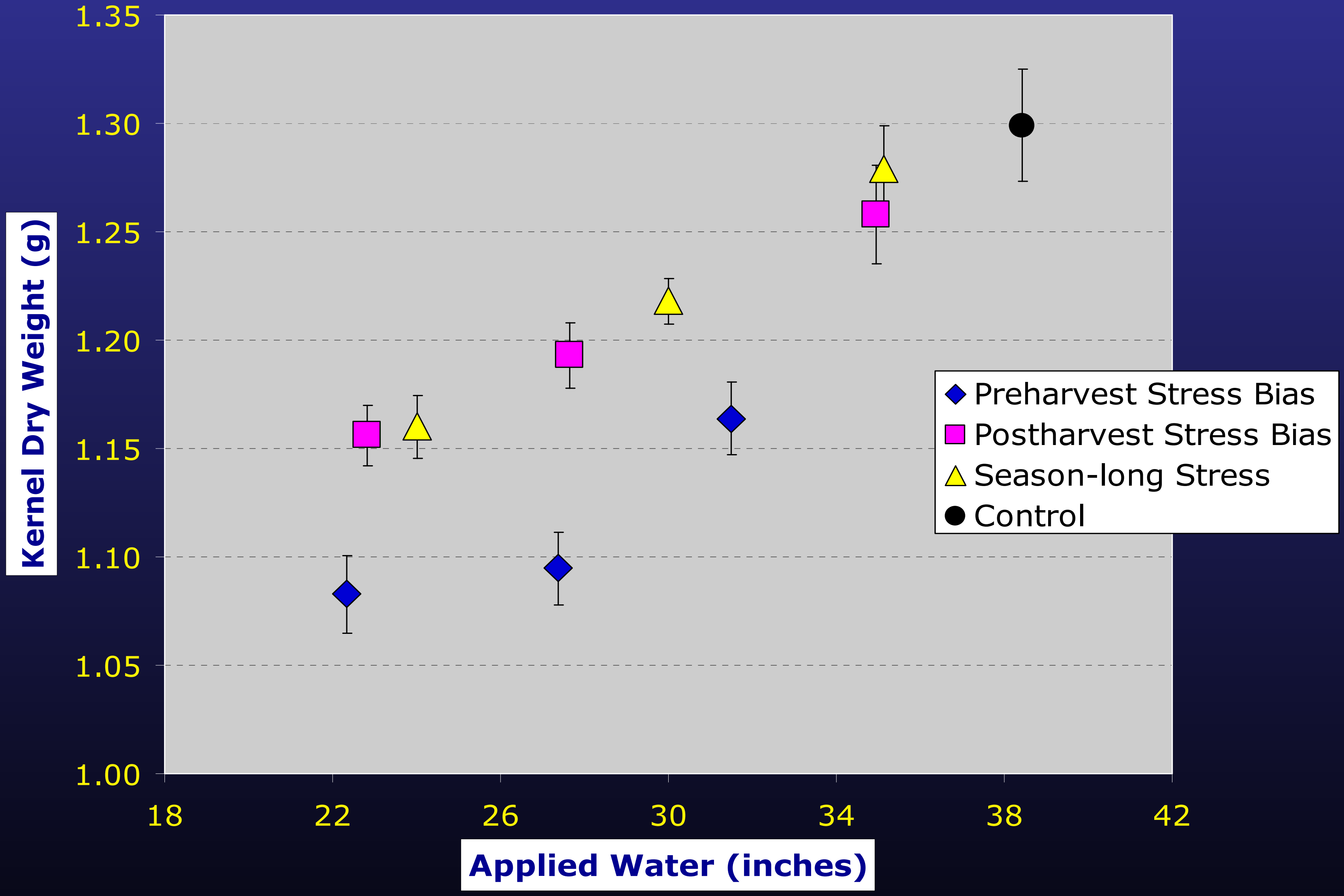
28A Non Pareil Late August

28B Non Pareil Late August

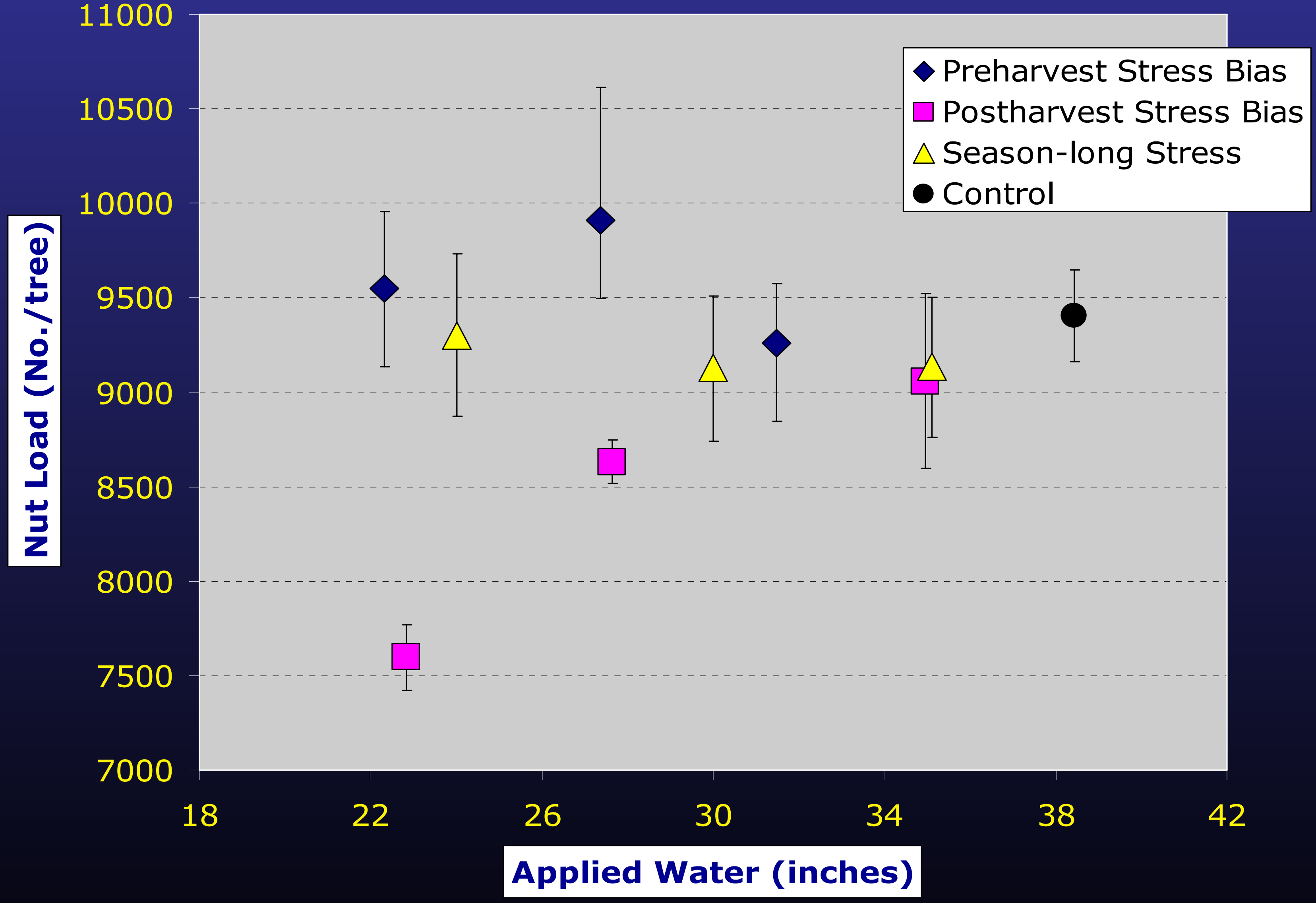
28C Non Pareil Late August

Control Non Pareil Late August

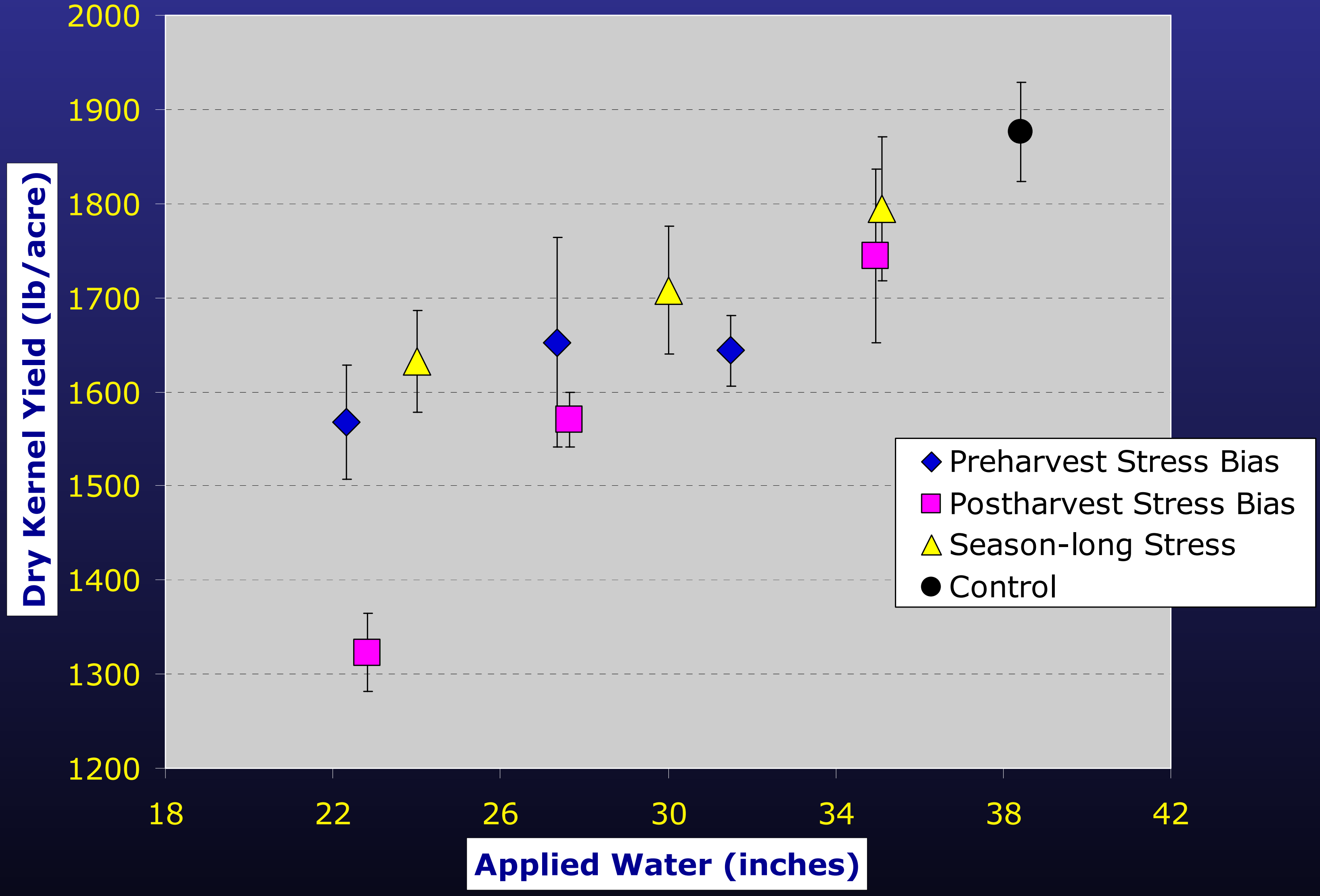
Dry Kernel Weight; RDI; Mean of Last Two Years



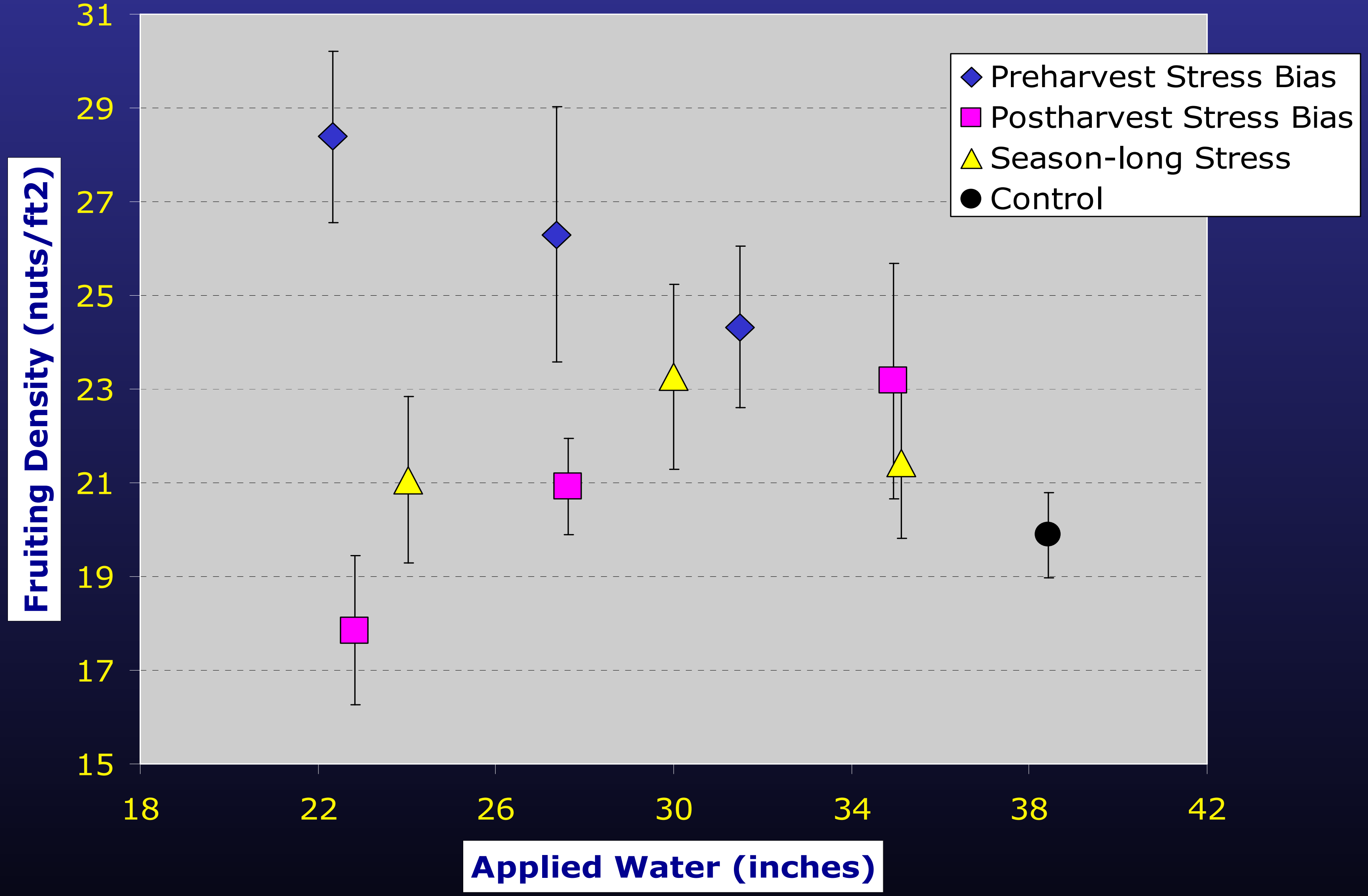
Nut Load; RDI; Mean of Last Two Years



Kernel Yield; RDI; Mean of Last Two Years



Fruiting Density; RDI; Mean of Last Two Years



Simulated One Year Drought (Smith)

Assume 16 inches available during season
4 additional inches applied late winter; 5 inches rain

1) 100% ETc until 16 inches applied
2) 75% ETc until 16 inches applied
3) 50% ETc until 16 inches applied
4) Fully irrigated Control

Drought trees returned to full irrigation the following two seasons.

One Year Simulated Drought; 16 inches Applied During Season

Year	Irrigation Regime	Water Applied thru	Kernel Weight (g)	Nut Load (No./tree)	Kernel Yield (lbs/ac)
Drought Year	Full Irri	Season	1.24 a	7100 a	1653 a
	100% ETc	Jun 19	0.97 b	8160 a	1362 b
	75% ETc	Jul 11	1.10 bc	6340 a	1236 b
	50% ETc	Aug 28	1.03 bc	7000 a	1448 ab

One Year Simulated Drought; 16 inches Applied During Season

Year	Irrigation Regime	Water Applied thru	Kernel Weight (g)	Nut Load (No./tree)	Kernel Yield (lbs/ac)
Drought Year	Full Irri	Season	1.24 a	7100 a	1653 a
	100% ETc	Jun 19	0.97 b	8160 a	1362 b
	75% ETc	Jul 11	1.10 bc	6340 a	1236 b
	50% ETc	Aug 28	1.03 bc	7000 a	1448 ab
Recover Year 1	Full Irri	Season	1.04 a	12850 a	2730 a
	100% ETc	Season	1.03 a	4770 b	911 b
	75% ETc	Season	0.99 ab	8250 c	1493 c
	50% ETc	Season	0.89 b	11690 a	2010 d

One Year Simulated Drought; 16 inches Applied During Season

Year	Irrigation Regime	Water Applied thru	Kernel Weight (g)	Nut Load (No./tree)	Kernel Yield (lbs/ac)
Drought Year	Full Irri	Season	1.24 a	7100 a	1653 a
	100% ETc	Jun 19	0.97 b	8160 a	1362 b
	75% ETc	Jul 11	1.10 bc	6340 a	1236 b
	50% ETc	Aug 28	1.03 bc	7000 a	1448 ab
Recover Year 1	Full Irri	Season	1.04 a	12850 a	2730 a
	100% ETc	Season	1.03 a	4770 b	911 b
	75% ETc	Season	0.99 ab	8250 c	1493 c
	50% ETc	Season	0.89 b	11690 a	2010 d
Recover Year 2	Full Irri	Season	0.97 a	9890 a	2358 a
	100% ETc	Season	1.02 a	9200 a	2327 a
	75% ETc	Season	1.02 a	7900 b	1975 b
	50% ETc	Season	1.13 b	7050 b	1949 b

One Year Simulated Drought; 16 inches Applied During Season

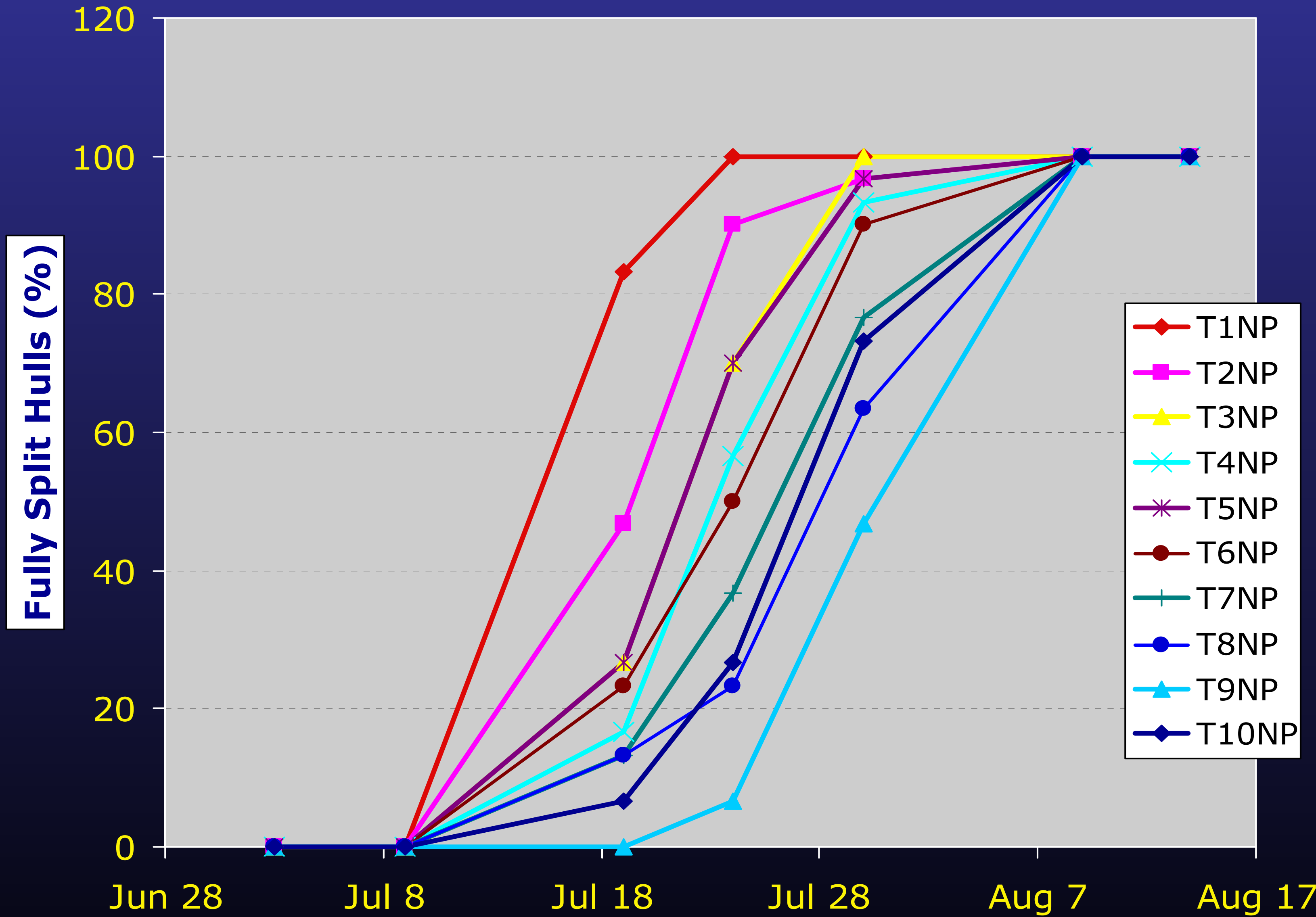
Year	Irrigation Regime	Water Applied thru	Kernel Weight (g)	Nut Load (No./tree)	Kernel Yield (lbs/ac)
Drought Year	Full Irri	Season	1.24 a	7100 a	1653 a
	100% ETc	Jun 19	0.97 b	8160 a	1362 b
	75% ETc	Jul 11	1.10 bc	6340 a	1236 b
	50% ETc	Aug 28	1.03 bc	7000 a	1448 ab
Recover Year 1	Full Irri	Season	1.04 a	12850 a	2730 a
	100% ETc	Season	1.03 a	4770 b	911 b
	75% ETc	Season	0.99 ab	8250 c	1493 c
	50% ETc	Season	0.89 b	11690 a	2010 d
Recover Year 2	Full Irri	Season	0.97 a	9890 a	2358 a
	100% ETc	Season	1.02 a	9200 a	2327 a
	75% ETc	Season	1.02 a	7900 b	1975 b
	50% ETc	Season	1.13 b	7050 b	1949 b
3 Year Mean	Full Irri		1.08 a	9948 a	2247 a
	100% ETc		1.01 a	7378 b	1534 b
	75% ETc		1.04 a	7498 b	1568 b
	50% ETc		1.02 a	8581 b	1802 c

Almond Production Function Development

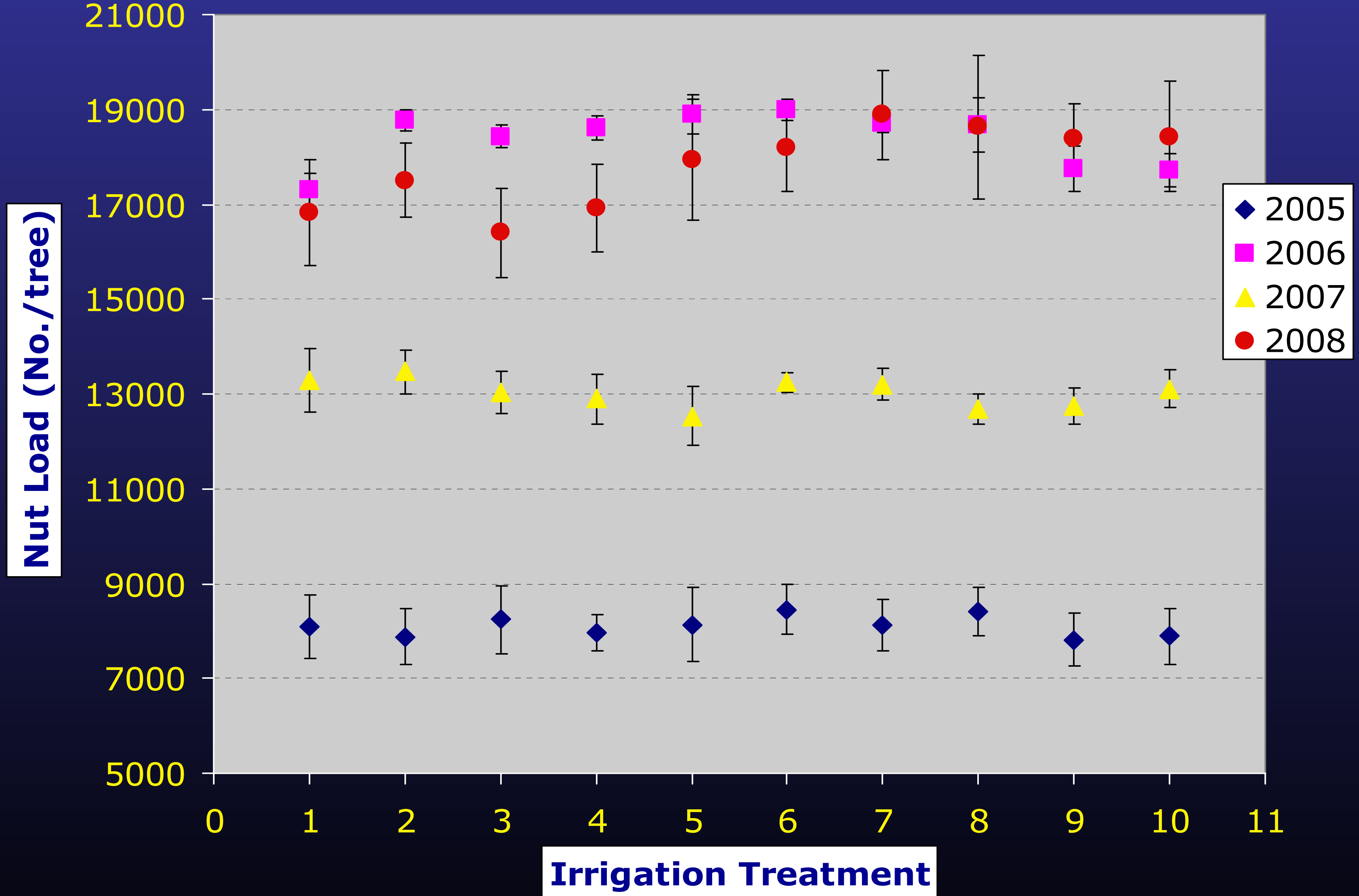
Identification of optimal Crop Coefficient

* 10 irrigation regimes that applied from 38 to 54 inches in about 1.5 inch increments. All stress imposed preharvest
* Microsprinkler irrigation
* Mature Non Pareil; 8 replications of each treatment; Lost Hills; 4 yr duration

Hull Split Rate

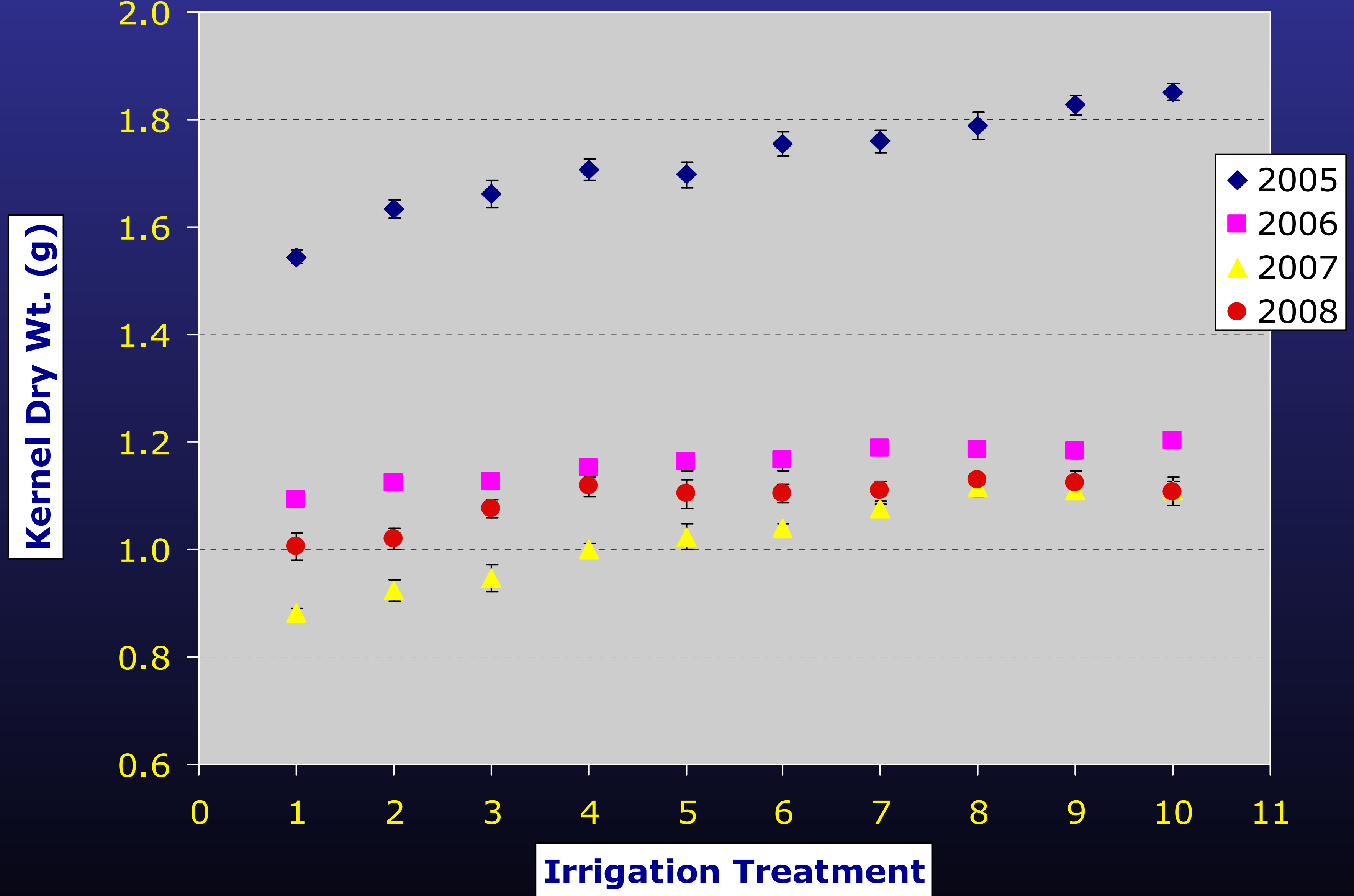


Nut Load

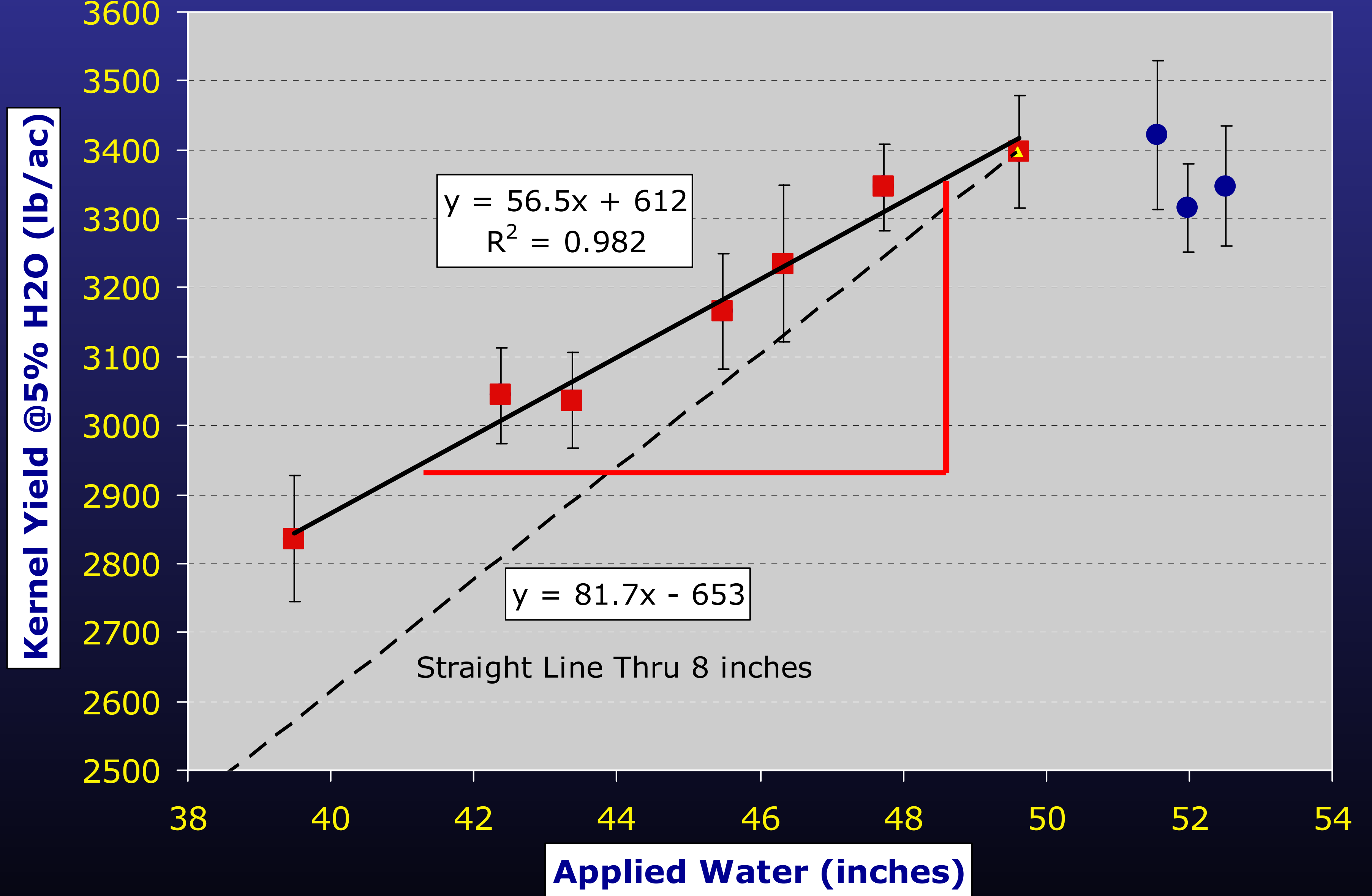


21000
19000
17000
15000
13000
11000
9000
7000
5000
Nut Load (No./tree)
0
1
2
3
4
5
6
7
8
9
10
11
Irrigation Treatment
2005
2006
2007
2008

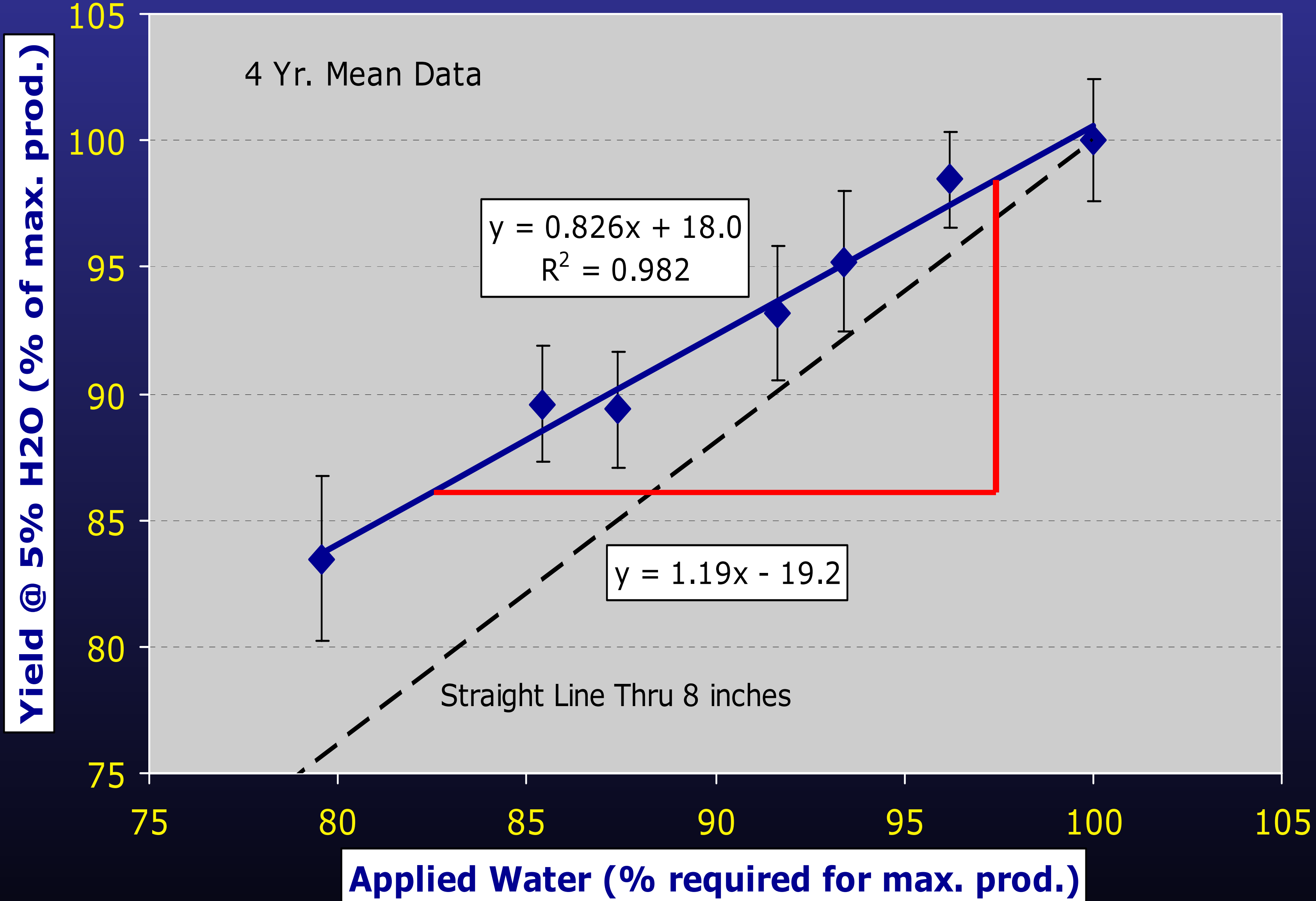
Kernel Dry Weight

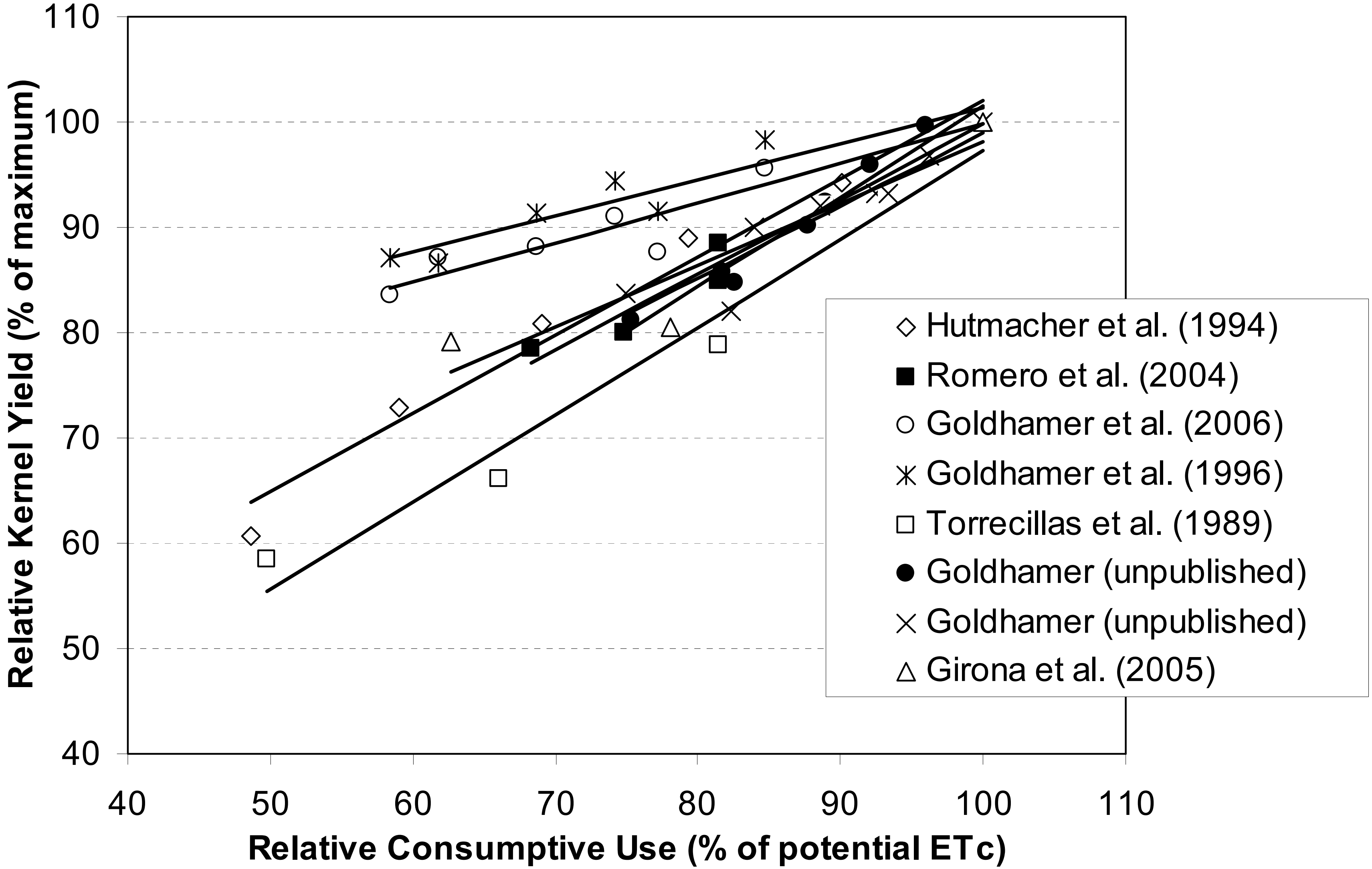


Kernel Yield; 5% H2O; 4 Yr. Mean



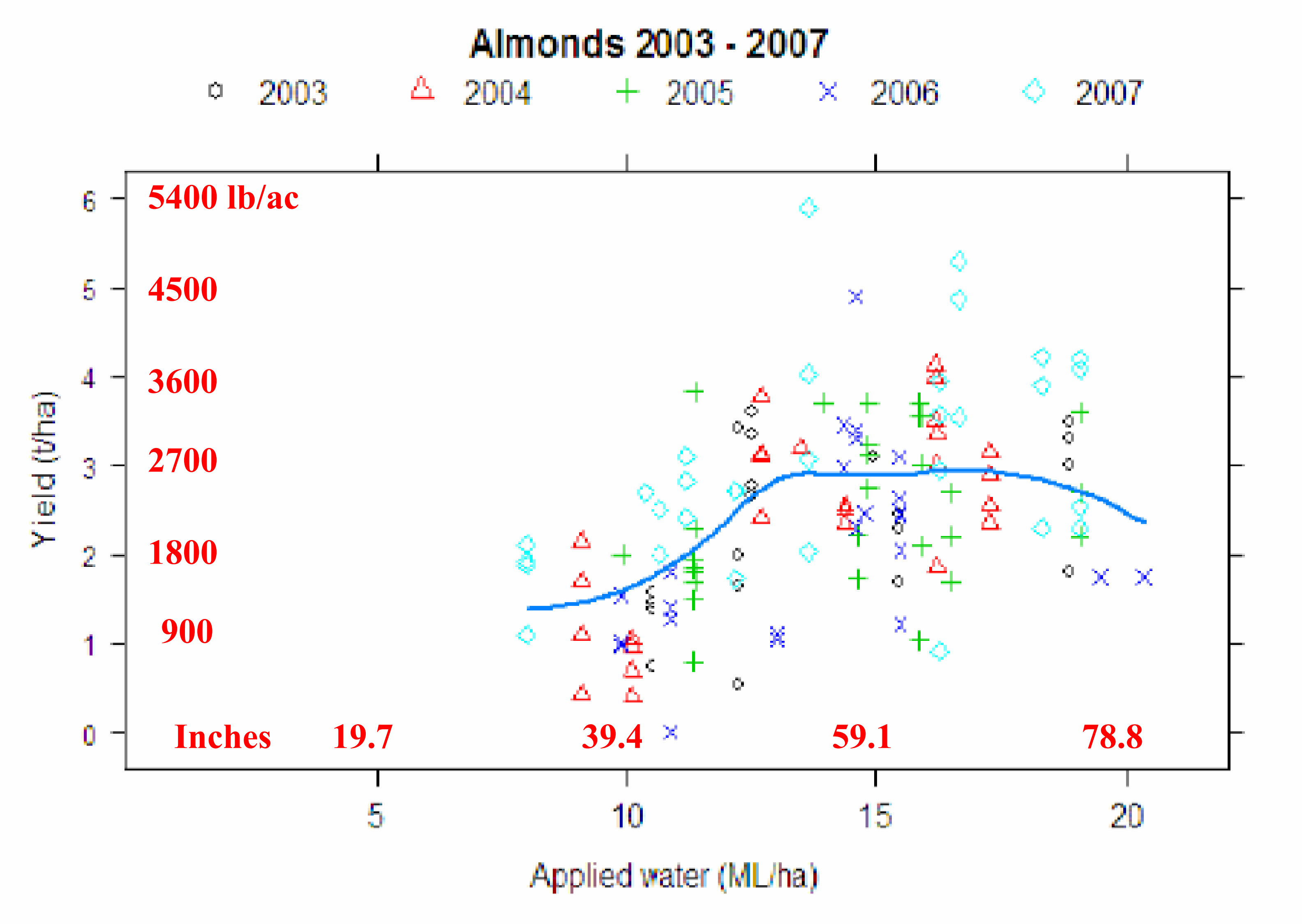
Almond Production Function





Relative Kernel Yield (% of maximum)
Relative Consumptive Use (% of potential ETc)
40
50
60
70
80
90
100
110
Hutmacher et al. (1994)
Romero et al. (2004)
Goldhamer et al. (2006)
Goldhamer et al. (1996)
Torrecillas et al. (1989)
Goldhamer (unpublished)
Goldhamer (unpublished)
Girona et al. (2005)

AlmondsAustralia; Yield vs. Applied Water



Suggested Drought Strategies

Crop: Almond (mature)

Location: Firebaugh

Tree Spacing: 21 x 24 ft (86 trees/ac)

Irrigation: Microsprinkler (11 gal/hr)

Two per tree (22 gal/tree/hr)

1.7 inches/24 hr irrigation

Application Efficiency: 90%

Firebaugh

		36 inch Case		30 inch Case		24 inch Case	
	ETc in Period (inch)	Irri. Rate (%)	Applied Amount (inch)	Irri. Rate (%)	Applied Amount (inch)	Irri. Rate (%)	Applied Amount (inch)
Mar 16-31	1.0	75	0.7	70	0.7	70	0.7
Apr 1-15	1.7	75	1.3	70	1.2	70	1.2
Apr 16-30	2.7	75	2.0	70	1.9	70	1.9
May 1-15	3.9	75	2.9	50	1.9	30	1.2
May 16-31	4.9	75	3.7	50	2.4	30	1.5
Jun 1-15	5.0	75	3.7	50	2.5	30	1.5
Jun 16-30	5.0	75	3.8	50	2.5	30	1.5
Jul 1-15	4.9	50	2.5	50	2.5	30	1.5
Jul 16-31	4.7	100	4.7	100	4.7	100	4.7
Aug 1-15	3.7	100	3.7	100	3.7	100	3.7
Aug 16-31	3.2	100	3.2	75	2.4	75	2.4
Sep 1-15	2.1	100	2.1	75	1.6	75	1.6
Sep 16-30	1.3	100	1.3	75	1.0	50	0.6
Oct 1-15	0.8	100	0.8	75	0.6	50	0.4
Oct 16-31	0.3	0	0.0	0	0.0	0	0.0
Total (inch)	45.1		36.3		29.5		24.2

Firebaugh

	ETc in Period (inch)	18 inch Case Irri. Rate (%)	18 inch Case Applied Amount (inch)	12 inch Case Irri. Rate (%)	12 inch Case Applied Amount (inch)
Mar 16-31	1.0	40	0.4	25	0.2
Apr 1-15	1.7	40	0.7	25	0.4
Apr 16-30	2.7	40	1.1	25	0.7
May 1-15	3.9	25	1.0	25	1.0
May 16-31	4.9	25	1.2	25	1.2
Jun 1-15	5.0	25	1.2	25	1.2
Jun 16-30	5.0	25	1.3	25	1.3
Jul 1-15	4.9	25	1.2	25	1.2
Jul 16-31	4.7	75	3.5	25	1.2
Aug 1-15	3.7	75	2.8	25	0.9
Aug 16-31	3.2	75	2.4	50	1.6
Sep 1-15	2.1	25	0.5	25	0.5
Sep 16-30	1.3	25	0.3	25	0.3
Oct 1-15	0.8	25	0.2	0	0.0
Oct 16-31	0.3	0	0.0	0	0.0
Total (inch)	45.1		17.8		11.8

Irrigations per Season

Seasonal ETc: 45.1 inches

Determine Gross Irrigation

$$\frac{45.1 \text{ inches}}{0.90} = 50.1 \text{ inches}$$

Determine Irrigation Number

$$\frac{50.1 \text{ inches}}{1.7 \text{ inches/24 hr irrig.}} = 30 \text{ irrigations}$$

Adjust Irrigation Frequency; Not Duration

Assume you have 28 normal irrigations

If you have 75% of normal water:

28 irrigations x 0.75 = 21 irrigations

If you have 50% of normal water:

28 irrigations x 0.50 = 14 irrigations

Almond Drought Strategies Summary

- Recognize the differences in stress sensitivities and time irrigations accordingly.
- Reproductive bud differentiation occurs very late; Aug-Sept., and is stress-sensitive.
- Fruit size is less sensitive to stress than following season's fruit load.
- With limited water supplies; don't be afraid of partial preharvest defoliation.

Should I use poor quality water in a pinch?

Is “stumping” (dehorning) an appropriate almond drought strategy?

Severe Pruning Study; Tree Survival

Mature, Non Pareil

Pruning Treatments:

a) Severe
b) Moderate
c) None (Control)

Irrigation Treatments:

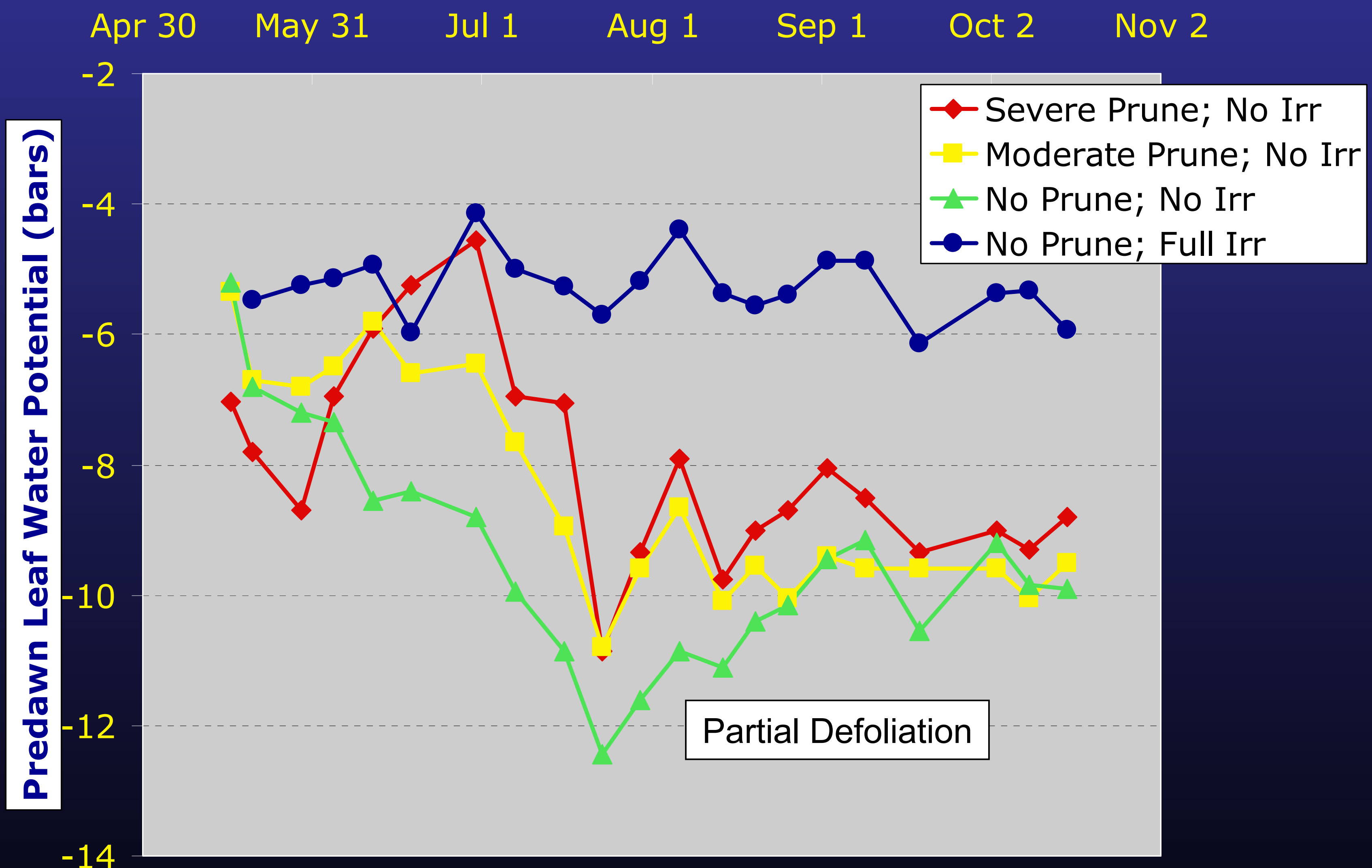
a) None
b) Mid Jul; 2.9 inches
c) Mid Jul and Late Aug; 2.9 inches each

Rainfall: 12.1 inches

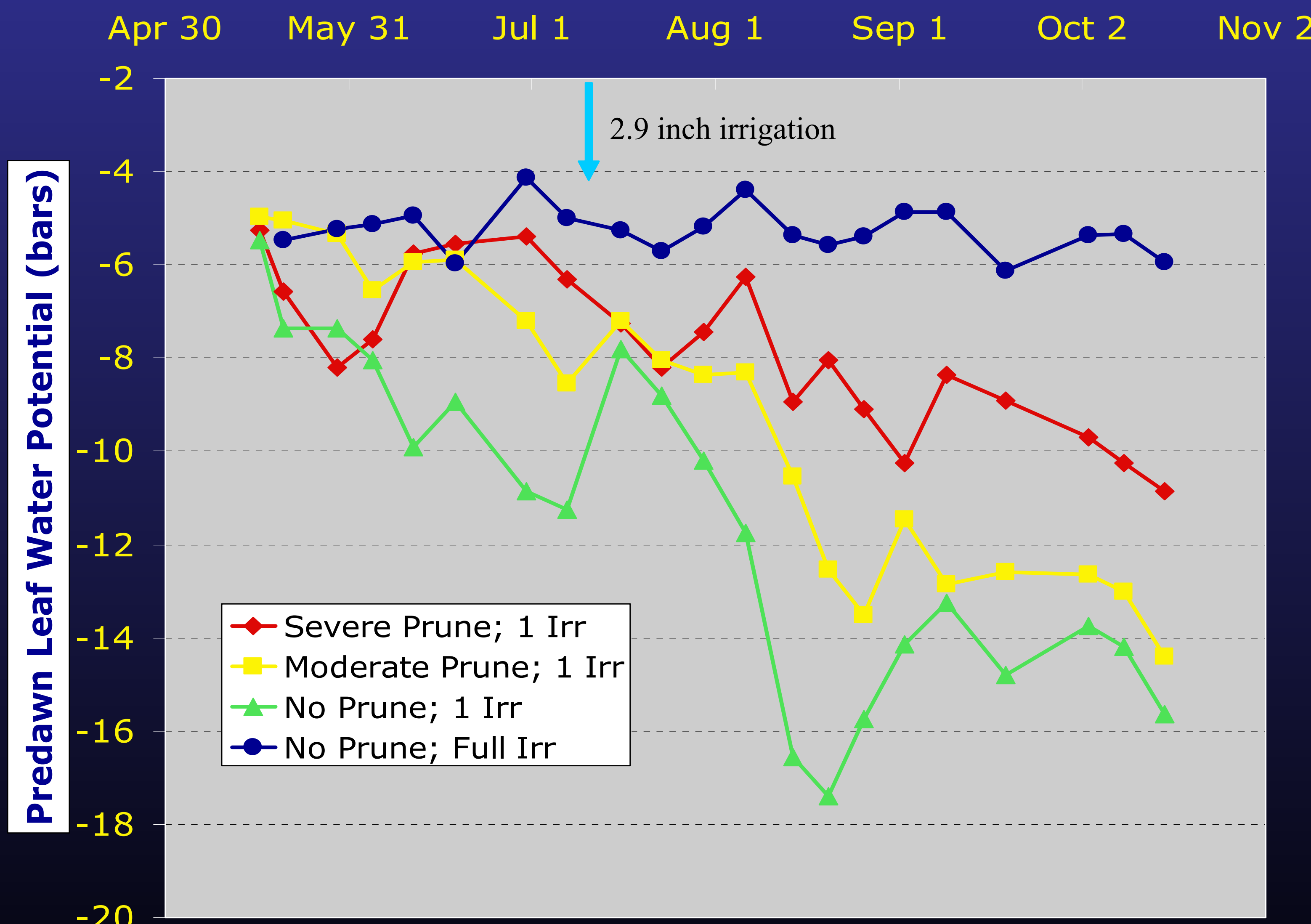

Severe


Moderate

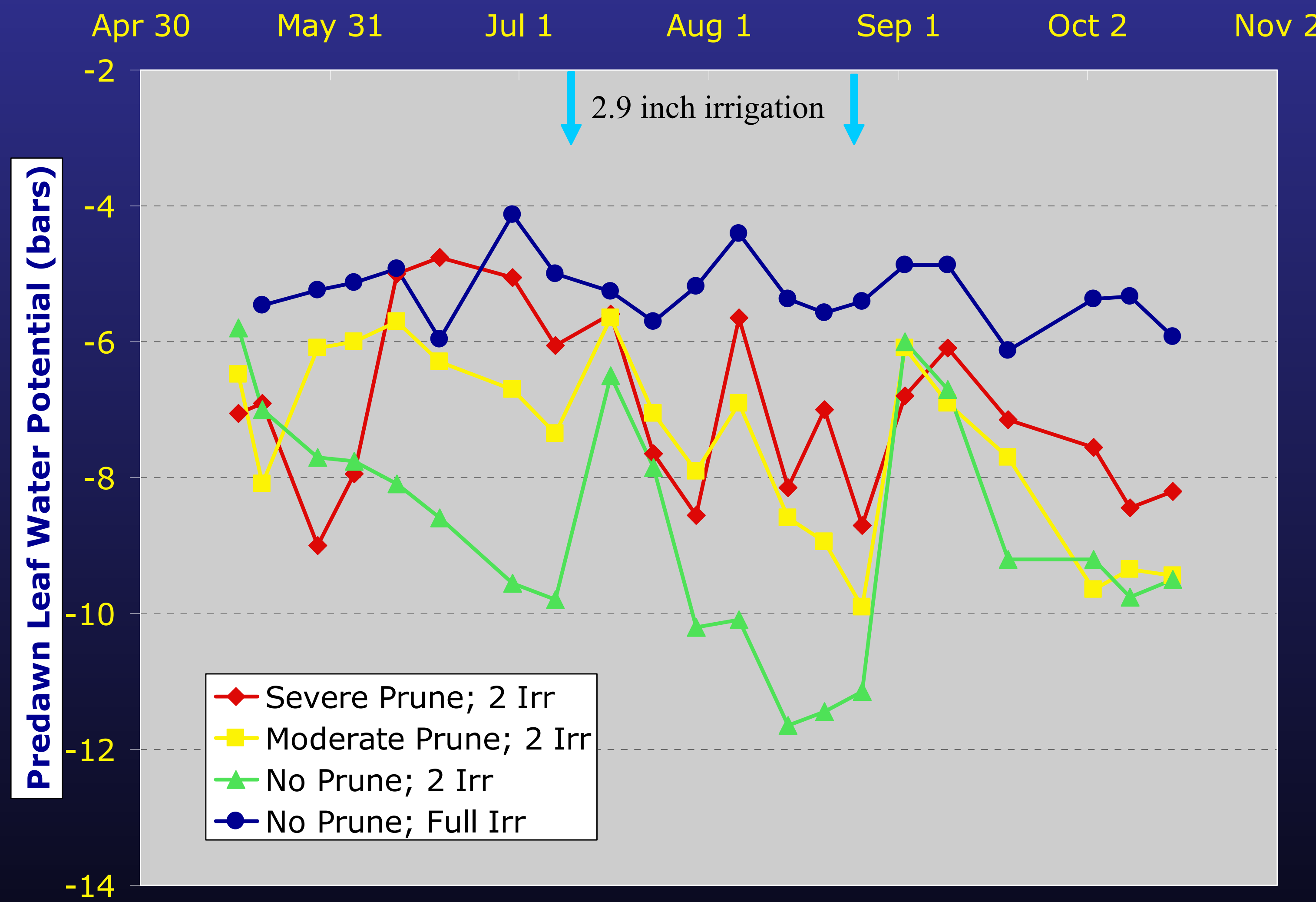
Pruning Impact on Predawn LWP; No Irrigation



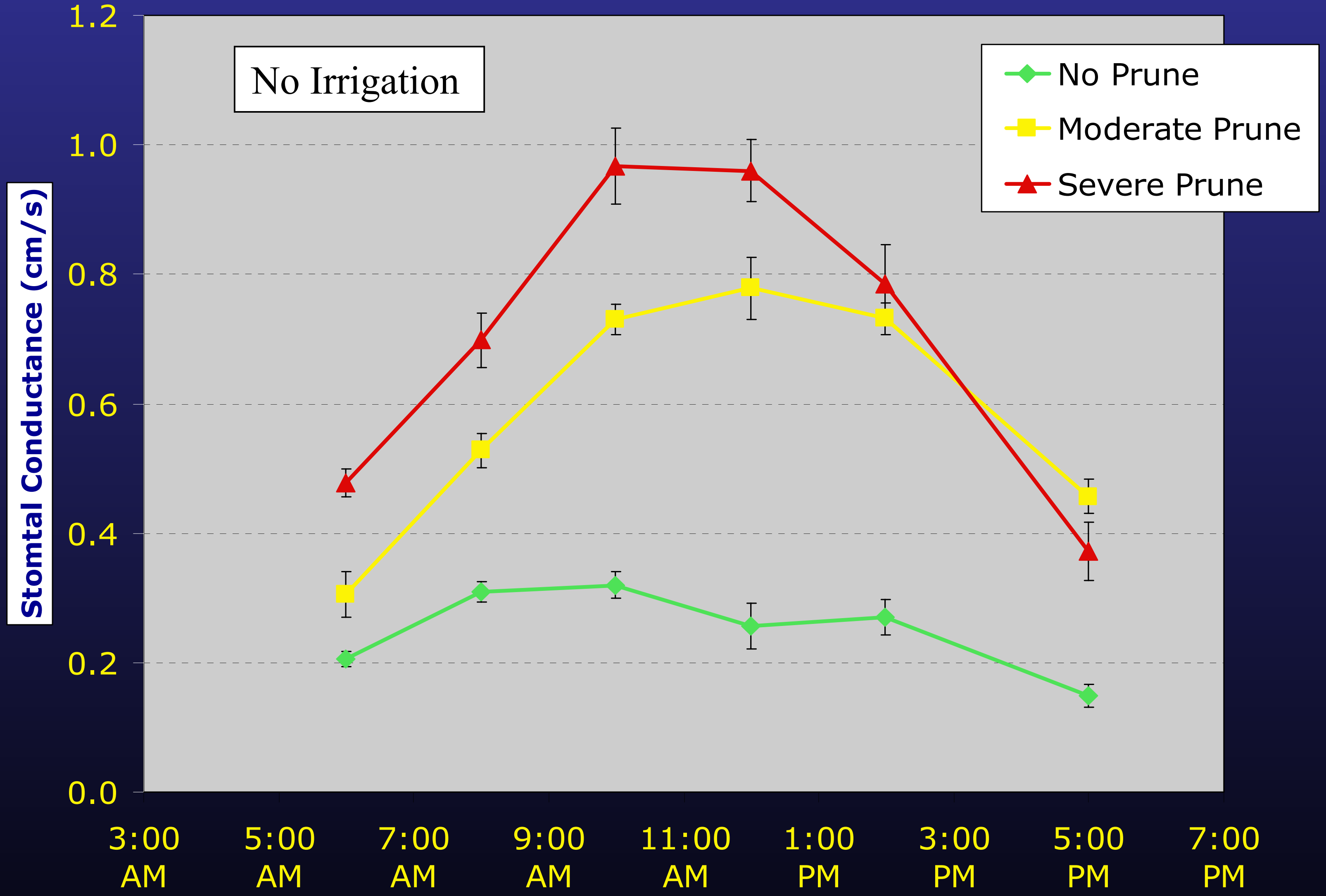
Pruning Impact on Predawn LWP; July Irrigation



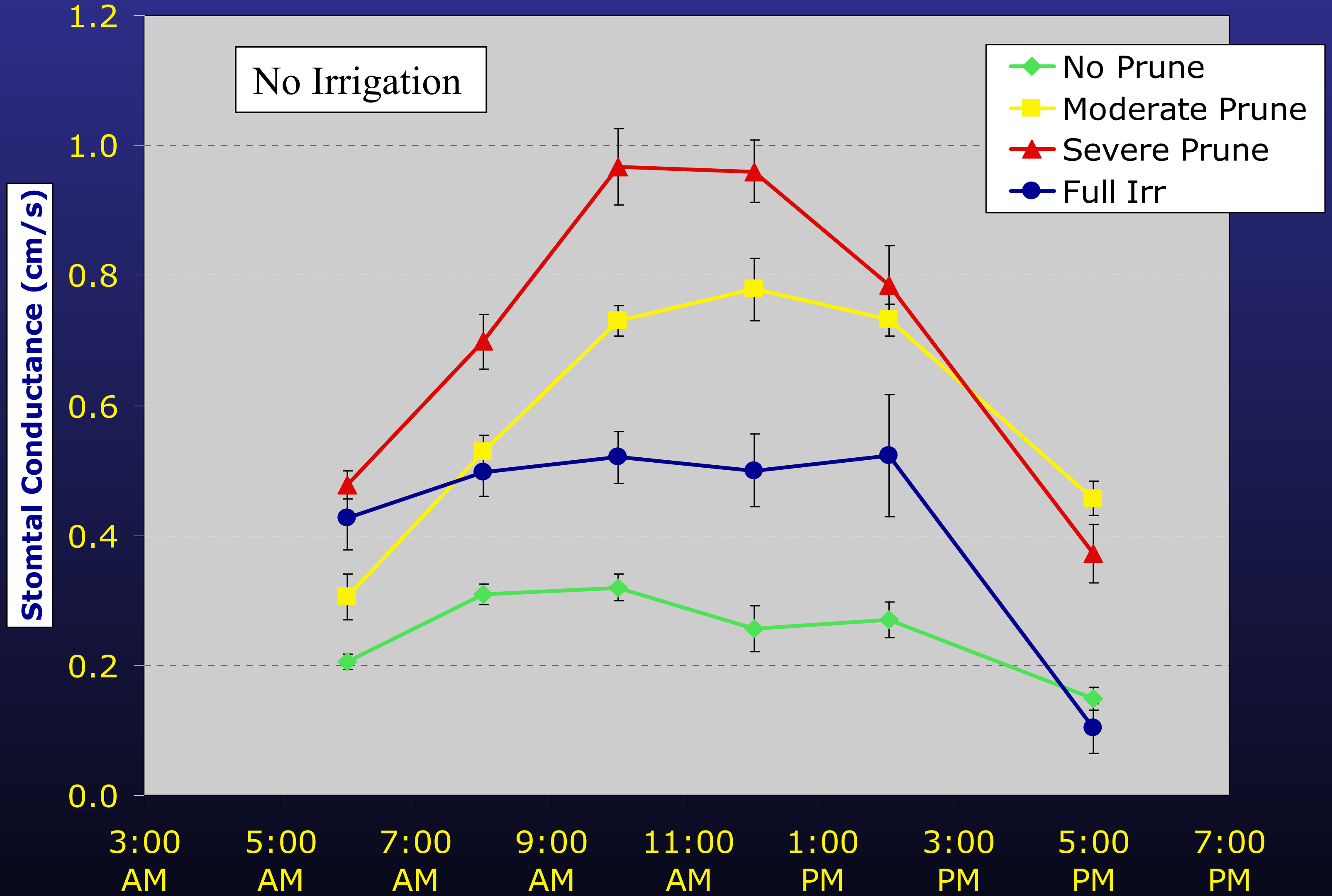
Pruning Impact on Predawn LWP; July, Aug Irrigation



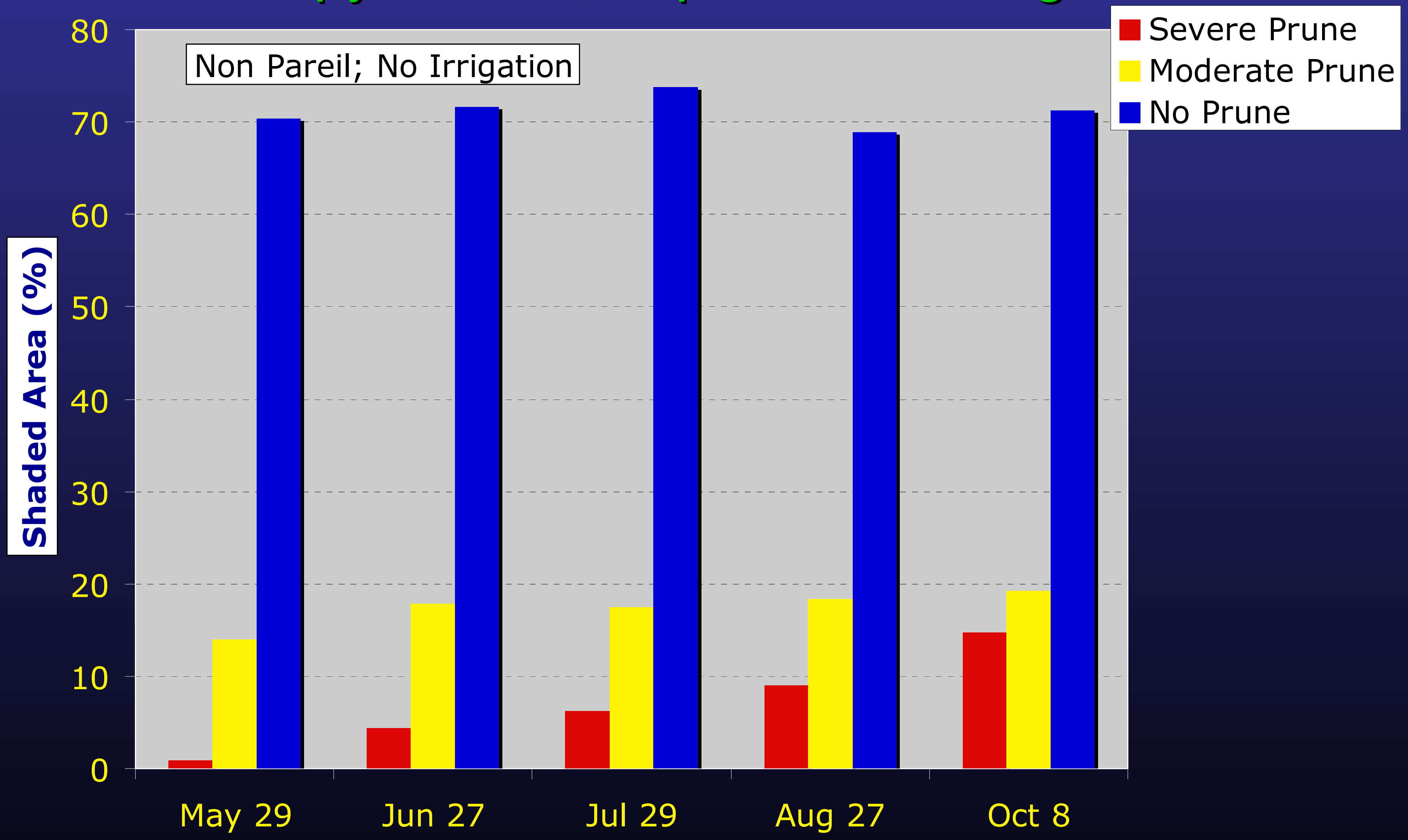
Pruning Impacts on Stomatal Conductance; Jun 17



Pruning Impacts on Stomatal Conductance; Jun 17



Canopy Growth; Impact of Pruning



Stumping Summary

- 12 inches of stored winter rainfall; no tree death.
- Minimized stress; magnitude in relation pruning severity.
- Created “super” leaves; extremely rapid growth even without irrigation.

1.5 million acres of almonds in Spain; most dryland.

Are antitranspirants an appropriate drought strategy for almond?

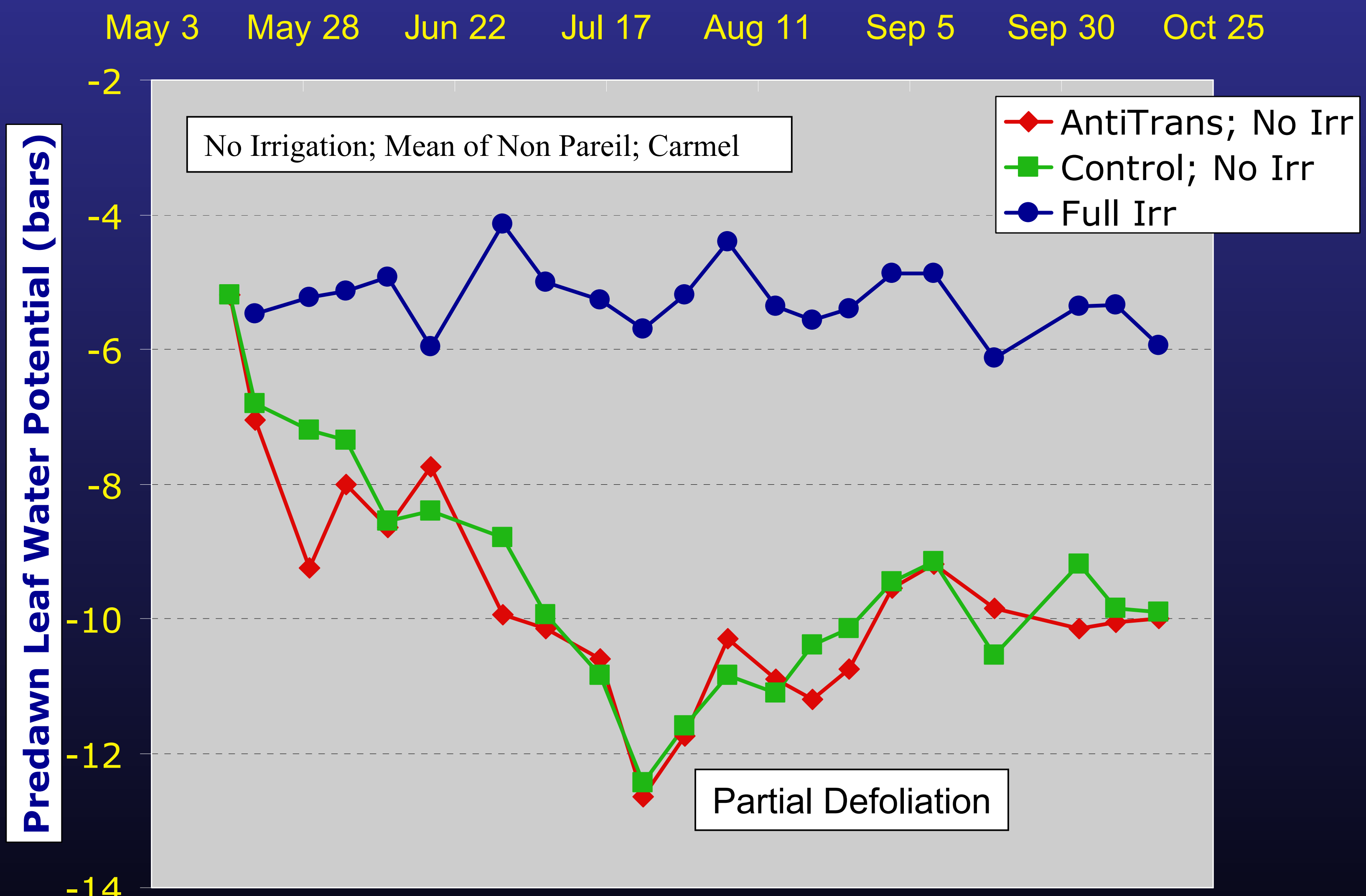
AntiTranspirant Experiment

- May, June, July, Aug, Sept Applications; 1 gal/105 gal water; Non Pareil, Carmel

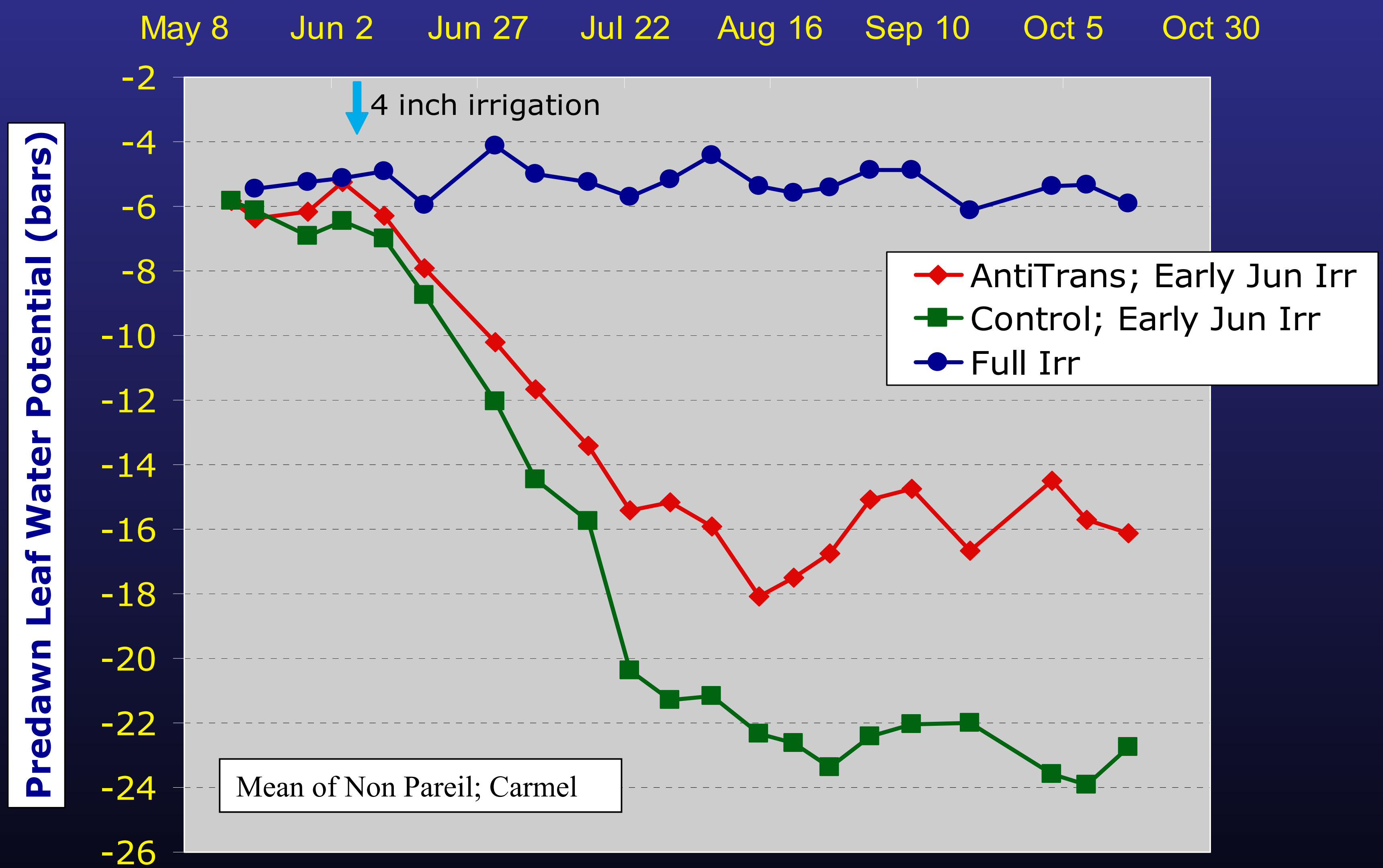
- Three Irrigation Regimes
  a) None
  b) Early Jun; 4 inches
  c) Mid Jul; 2.9 inches
  d) Mid Jul and Late Aug; 2.9 inches each

  Rainfall: 12 inches

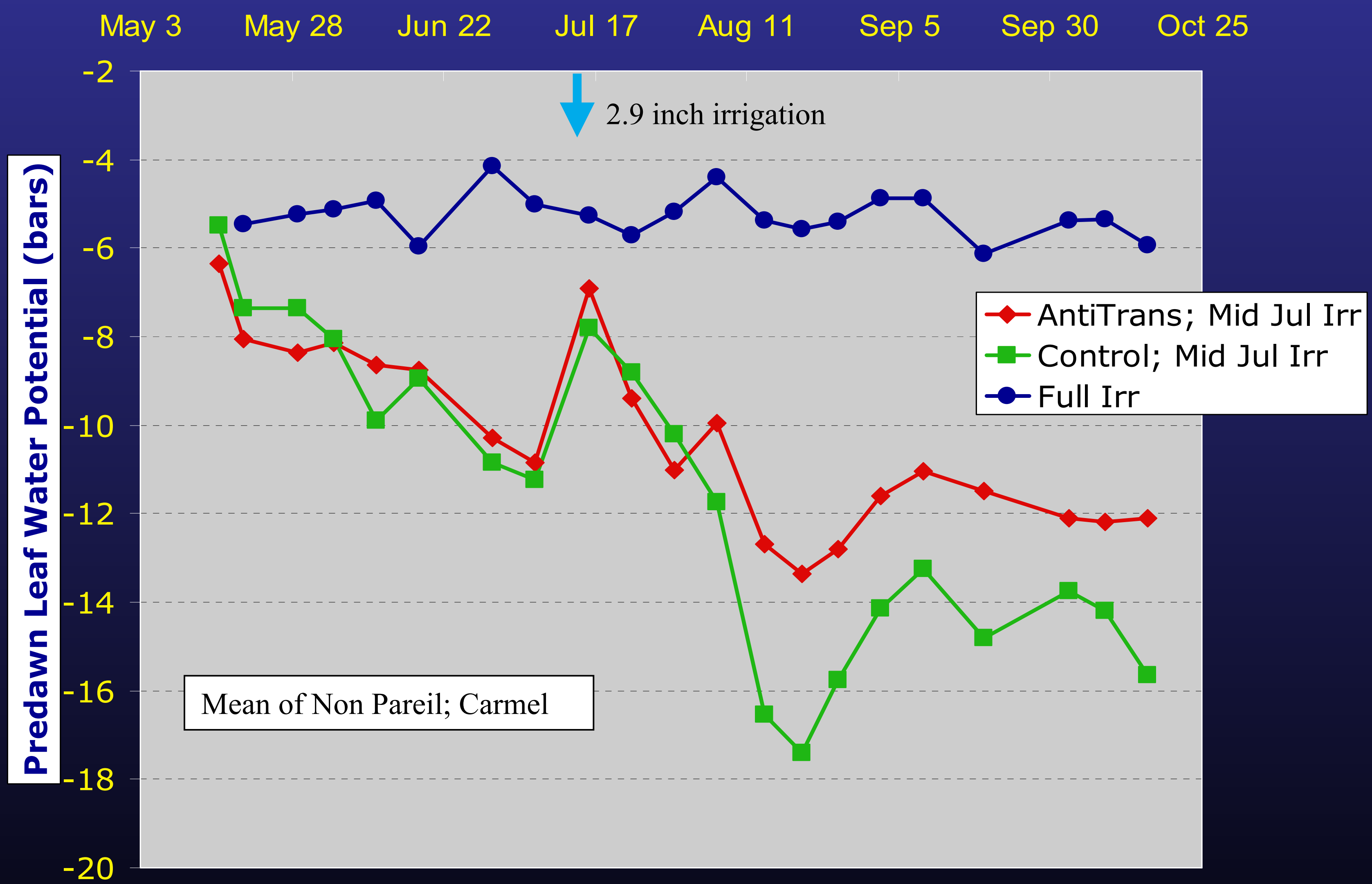
Impact of AntiTranspirant on Predawn LWP



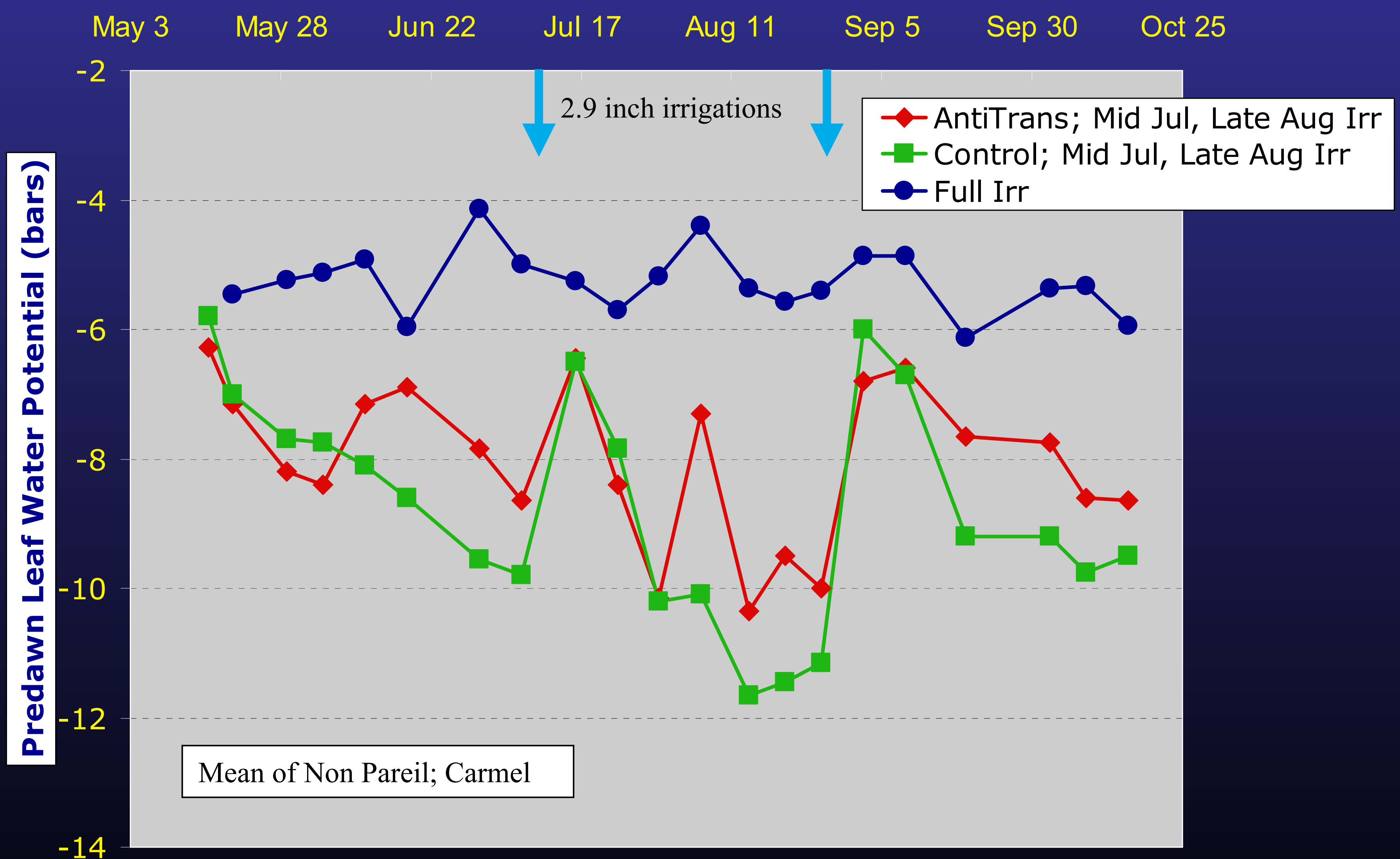
Impact of AntiTranspirant; Early Jun Irrigation



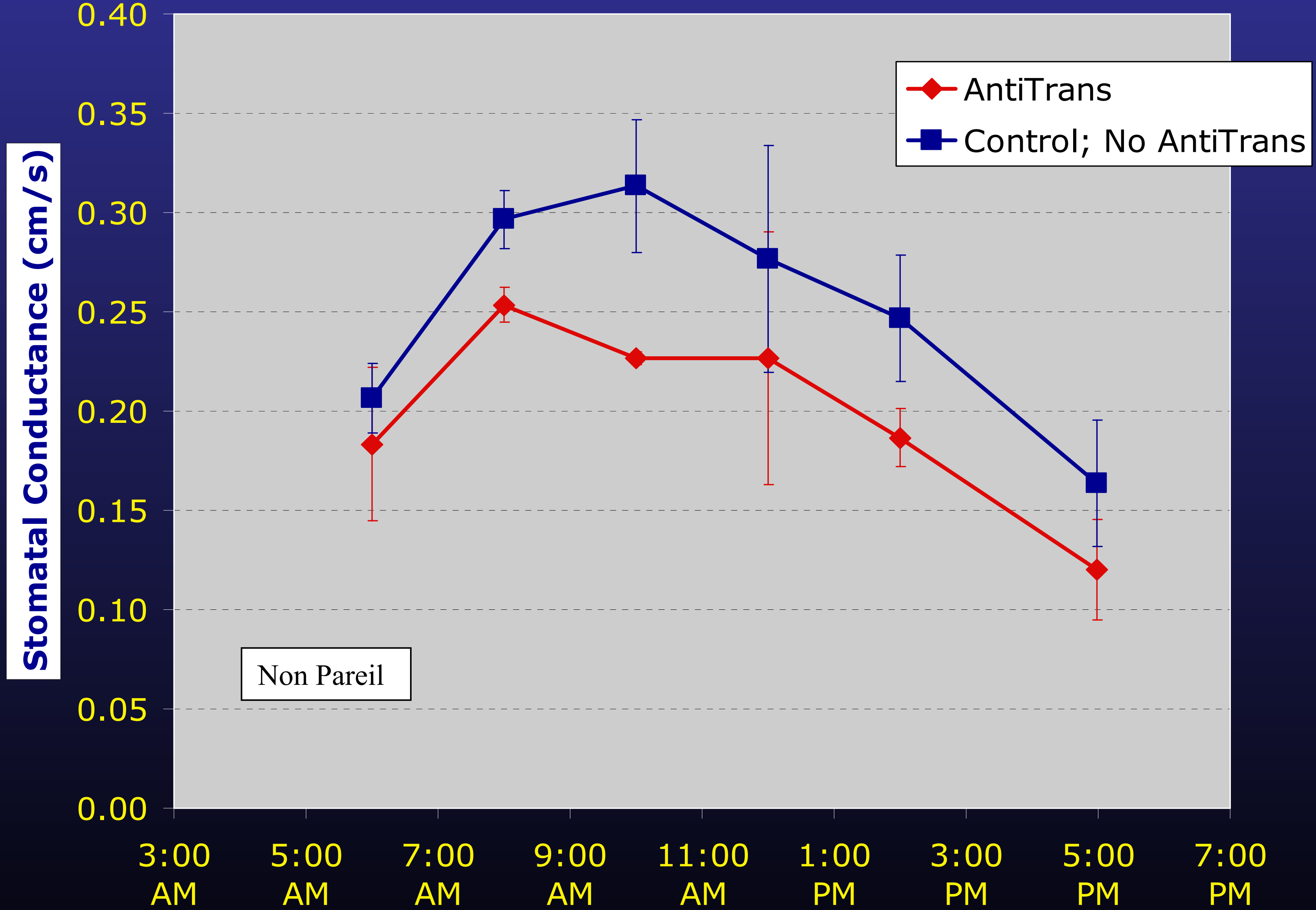
Impact of AntiTranspirant; Mid July Irrigation



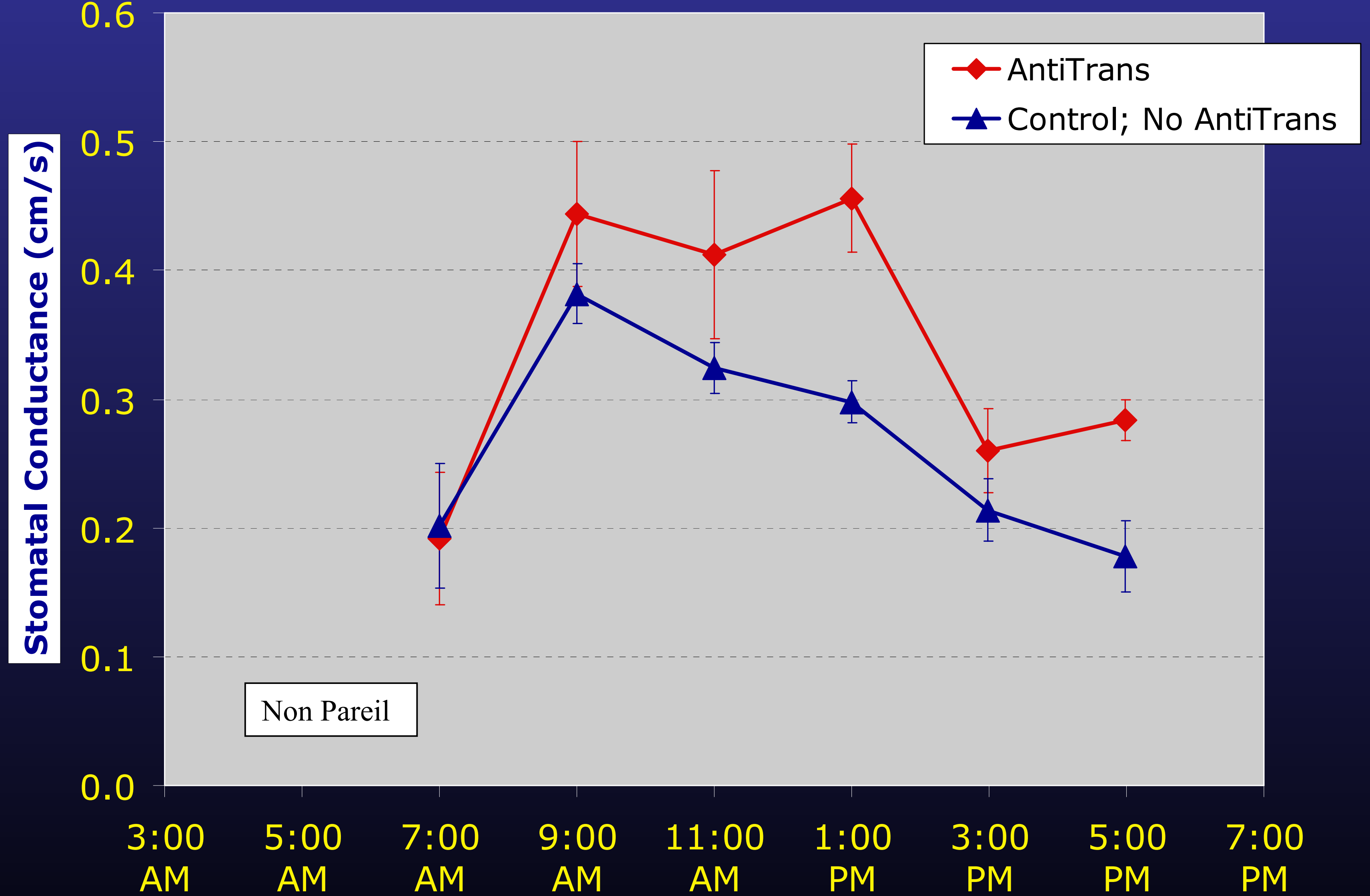
Impact of AntiTranspirant; Mid July; Late Aug Irrigation



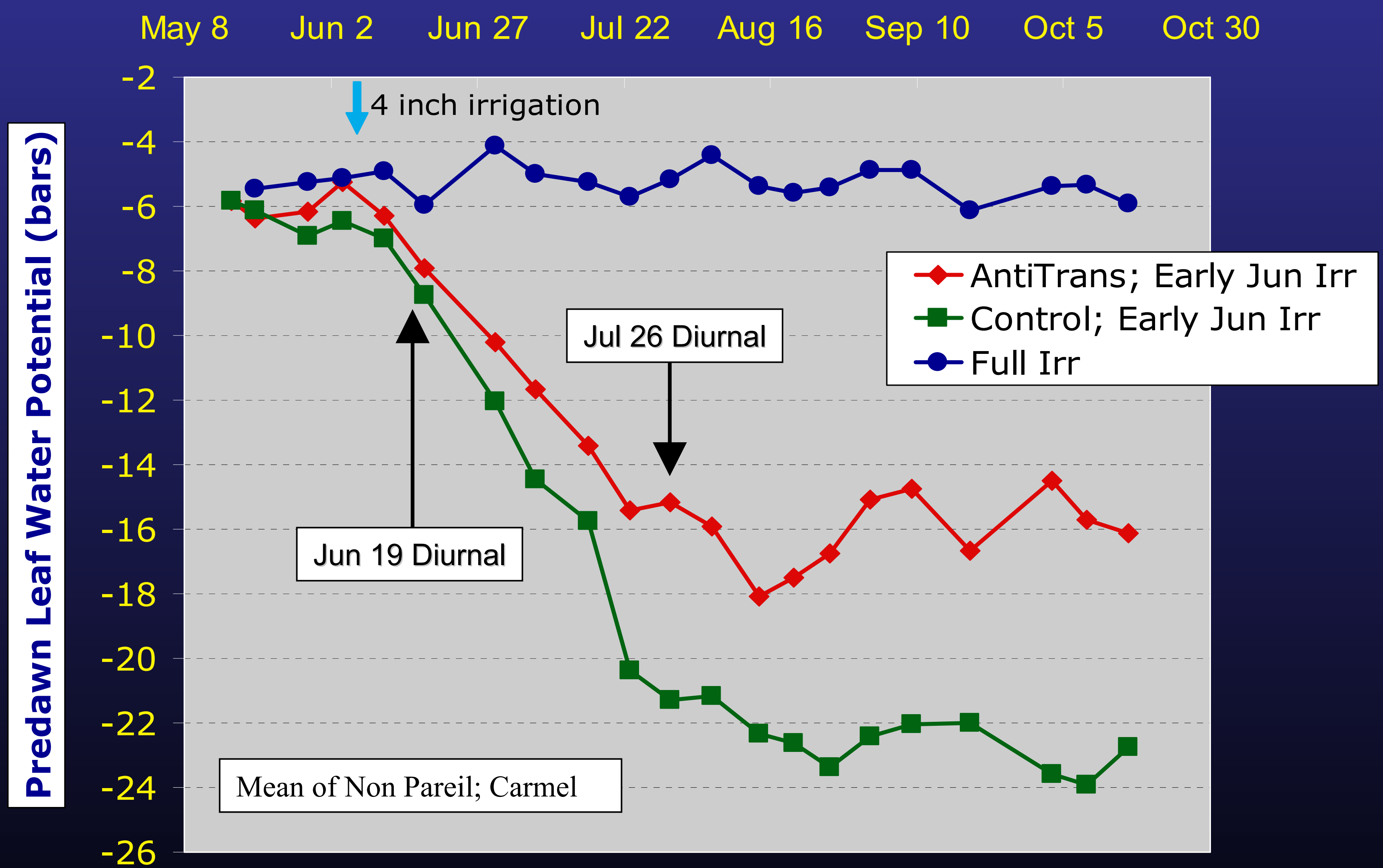
Stomatal Conductance; June 19; Early Jun Irrigation



Stomatal Conductance; July 26; Early Jun Irrigation

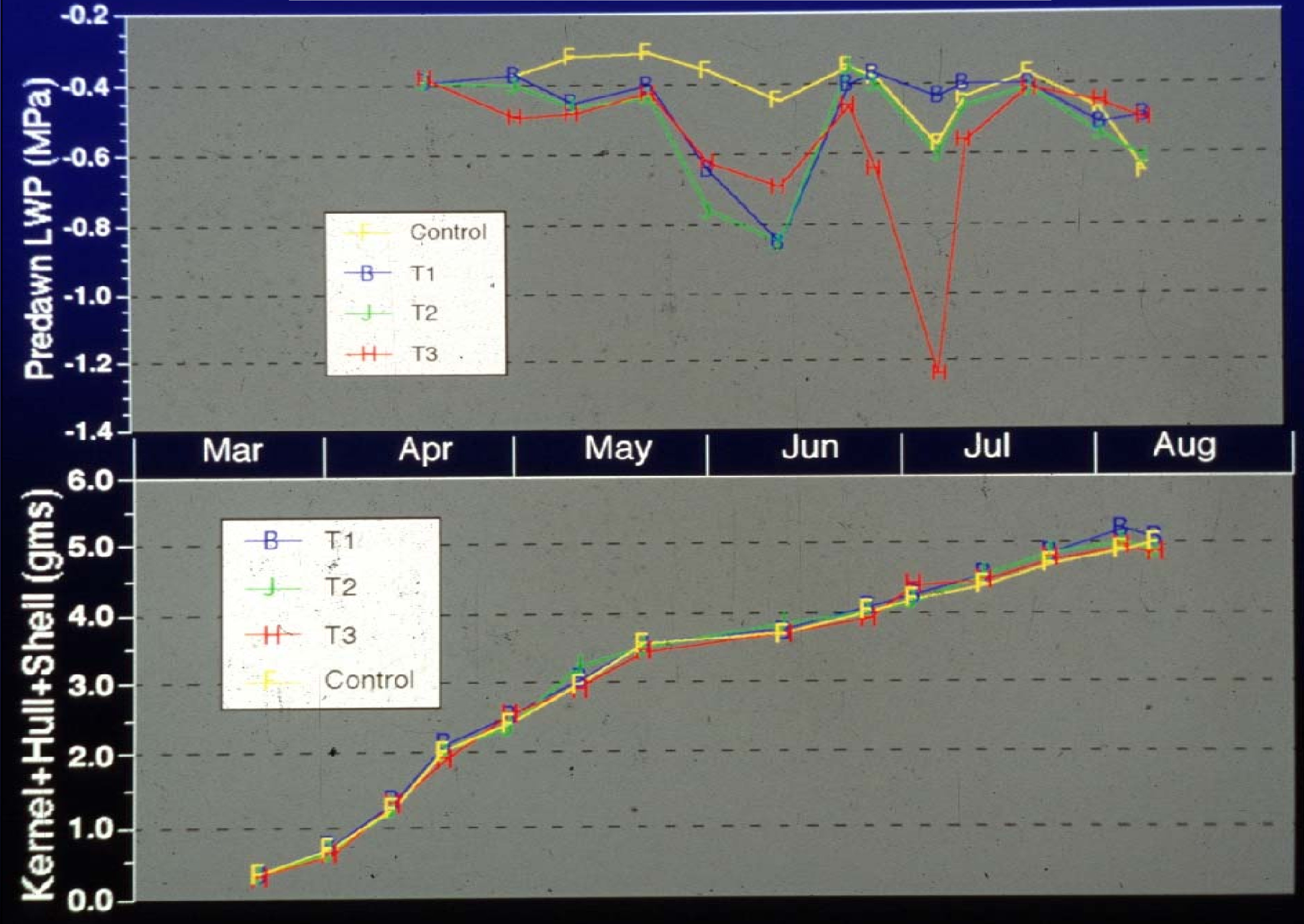


Impact of AntiTranspirant; Early Jun Irrigation



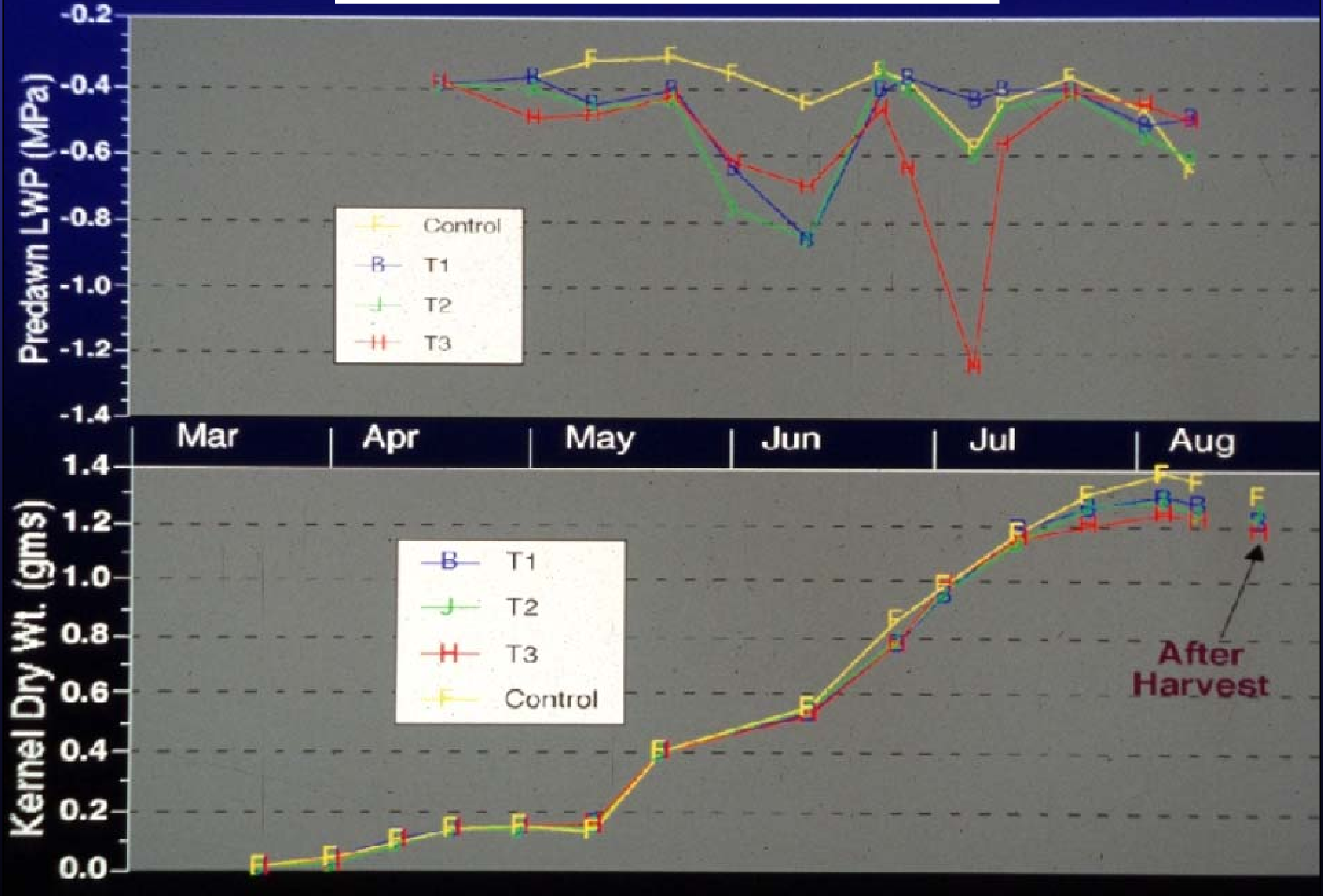
Why does mild stress reduce fruit size?

Dry Whole Nut Weight vs Time

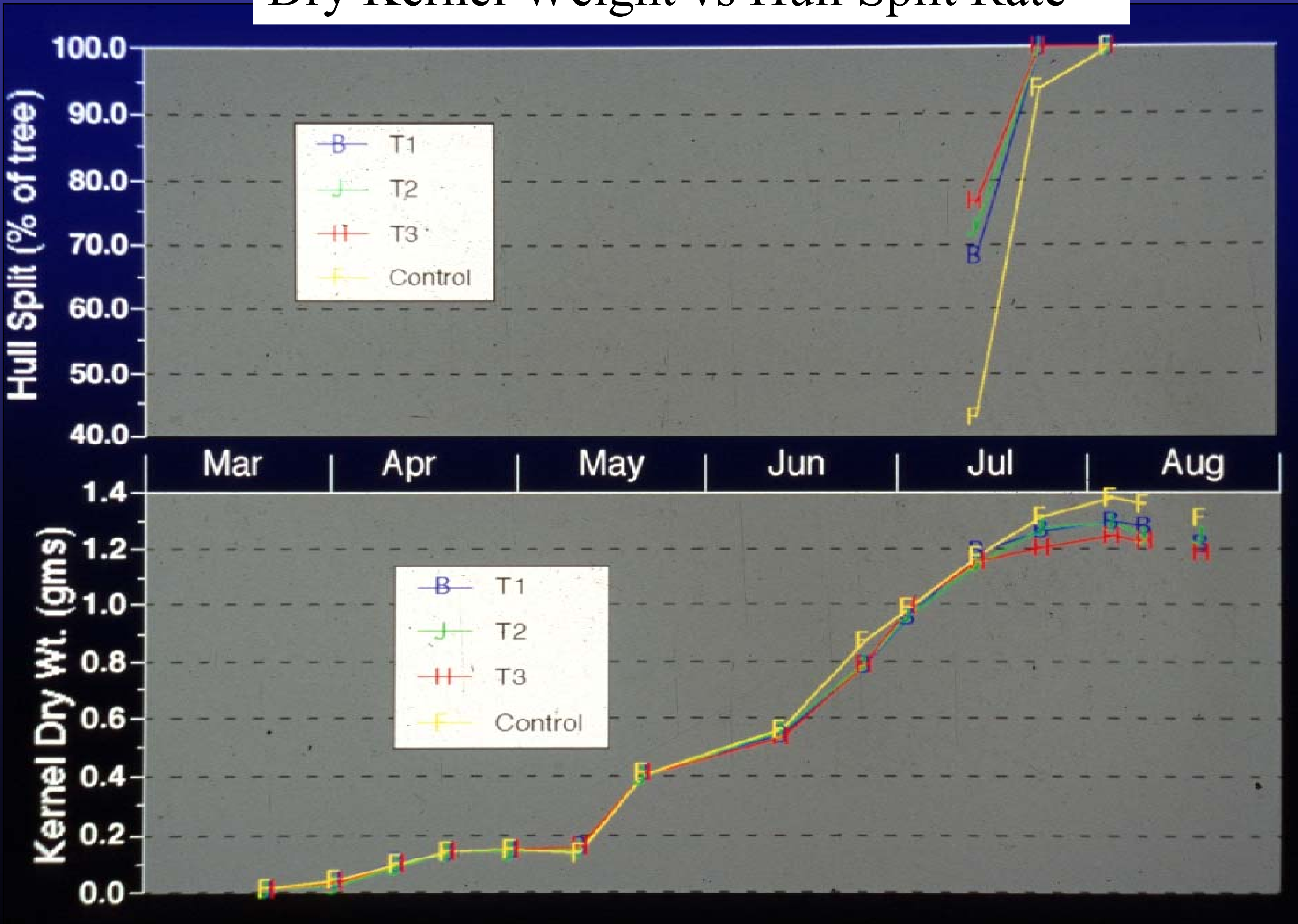


Dry Hull+Shell Weight vs Time

Dry Kernel Weight vs Time



Dry Kernel Weight vs Hull Split Rate



Impact of AntiTranspirant and Irrigation on Kernel Wt.