Research Update: Irrigation and Growing Almonds

December 9, 2015
Continuing Education Credits

- Continuing Education Credits are available for many of today’s symposiums. To receive CCA credit, you must sign in before and after each individual symposium at the back of the room.
Speakers

Bob Curtis, Almond Board (Moderator)

**University of California, Davis**

Bruce Lampinen  Shrini Upadhyaya
Matthew Gilbert  Ken Shackel
Astrid Volder  Amelie Gaudin
Patrick Brown  Georgia Drakakaki
Daniel Schellenberg  David Smart
Fraser Shilling  Tom Gradziel

Blake Sanden, UCCE – Kern County
Roger Duncan, UCCE – Stanislaus County
Bruce Lampinen,
University of California, Davis
Development and Testing of a Mobile Platform for Measuring Canopy Light Interception and Water Stress in Almond

Mobile platform lightbar is used in numerous research trials

2nd Generation mule light bar

- GoPro camera
- Protective cage
- 3d tilt sensor
- Reference PAR sensor
- Infrared thermometers
- Spring loaded section
- LIDAR
- GPS antenna
- datalogger
- PAR sensors

Adjustable from 7 to 32 feet in width
Mobile platform is run through the orchard at midday in mid-summer and path is plotted on Google Earth

Normal speed of travel is 6.2 miles/hr so we can map about 12.4 miles within 1 hour of midday

We set up a portable weather station with temp, RH, windspeed and PAR sensors outside orchard
Heads up display allows marking plot boundaries which are then shown on Google Earth

Data is then exported to an Excel file
Weigh trailer with load cells, the same GPS and an autosampler are then use to pick up same area.
Mobile platform lightbar is used in numerous research trials

- Rootstock trials
- Variety trials
- Pruning/training trials
- Mechanical hedging trials
- Methyl bromide alternative trials
- Nutrition trials
- Water production function trials
- Remote sensing trials
- Ground water recharge trials
Stanislaus County Pruning/Spacing/rootstock trial

Light interception at end of year 12 is a good predictor of the cumulative yield by treatment and variety.

Light interception tended to peak at about 11 years of age at all in row tree spacings.

Row spacing = 22 feet
Water production function trials—yield and yield per unit light interception data are essential for interpreting results.
Example from McFarland Variety Trial Kern County

Spacing 18’ x 20’
Ave. yield/PAR
59.4 for Nonpareil
47.8 for pollenizers

<table>
<thead>
<tr>
<th>Variety</th>
<th>Height (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marcona</td>
<td>25.1 a</td>
</tr>
<tr>
<td>Nonpareil 7</td>
<td>24.2 b</td>
</tr>
<tr>
<td>Nonpareil 6</td>
<td>24.1 b</td>
</tr>
<tr>
<td>Nonpareil 38270</td>
<td>23.6 bc</td>
</tr>
<tr>
<td>Kochi</td>
<td>23.2 cd</td>
</tr>
<tr>
<td>Sweetheart</td>
<td>23.1 cd</td>
</tr>
<tr>
<td>Nonpareil Nico</td>
<td>23.0 cd</td>
</tr>
<tr>
<td>Nonpareil 5</td>
<td>23.0 cd</td>
</tr>
<tr>
<td>Nonpareil Newel</td>
<td>22.7 de</td>
</tr>
<tr>
<td>Nonpareil Dr</td>
<td>22.1 e</td>
</tr>
<tr>
<td>Nonpareil J</td>
<td>21.9 e</td>
</tr>
<tr>
<td>Kahl</td>
<td>21.9 e</td>
</tr>
<tr>
<td>Chips</td>
<td>21.8 f</td>
</tr>
<tr>
<td>2-19e (Kester)</td>
<td>20.9 f</td>
</tr>
<tr>
<td>Winters</td>
<td>20.0 g</td>
</tr>
</tbody>
</table>
At midday tree height differences are irrelevant
Mid-morning and mid-afternoon, taller trees capture more light
GoPro camera images of orchard floor shadows taken (2 photos per second)
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GoPro camera images of orchard floor shadows taken (2 photos per second)
These photos of ground shadows were used to calibrate iPhone app
iPhone app is released on trial basis to farm advisors and select growers and should be in the Apple store in the next couple of months.
iPhone app will allow you to assess your orchard performance

Orchard well below line?
Usual reasons
- Irrigation problems?
- Pruning?
- Nutrition problems?
- Poor bloom weather?
More information on the iPhone app at poster session as well as at the Lampinen lab website-
http://ucanr.edu/sites/LampinenLab/Canopy_Management/iPAR/
Shrini Upadhyaya, University of California, Davis
A Leaf Monitoring System for Continuous Measurement of Plant Water Status to Assist with Irrigation Management of Specialty Crops

• Shrini K. Upadhyaya, Professor; Francisco Rojo, Post Doc; Seluk Ozmen, Visiting Scholar; Erin Kizer, Graduate Student; Channing Ko-Madden, Under Graduate Student; Mike Delwiche, Emeritus Prof., Bio. And Agr. Eng. Dept.

• Bruce Lampinen, Ext. Specialist, Plant Sciences Dept.
Soil Moisture/Plant water Status

\[ y = 0.5479x^2 - 0.2573x + 0.0397 \]

\[ R^2 = 0.7507 \]
Management Zone based Precision Irrigation
Tree Response to Irrigation in Zone #1
Tree Response to Irrigation in Other Zones

Stress Based Zone 1

Grower Zone 1

Grower Zone 2
Results/Conclusions

Zone 1: 80% of ET or 70% of grower application
Zone 2: 105% of ET or 90% of grower application

Acknowledgements
CDFA & Almond Board of California

Thank You!
Matthew Gilbert,
University of California, Davis
Applying new sap flow technology to almonds (2015) and Evaluation of almond leaf heat tolerance (2014)

Matthew E. Gilbert, Heather Vice and Nicolas Bambach
Dept. Plant Sciences, UC Davis
Applying a new sap flow technology to almonds

• Why is a new technology needed?
• Where can it be used?
• How does it work?
• What will it be used for?
Applying a new sap flow technology to almonds

- Why is a new technology needed?
- Where can it be used?
- How does it work?
- What will it be used for?

Data courtesy of Gerardo Spinelli
Applying a new sap flow technology to almonds

- Why is a new technology needed?
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- How does it work?
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Sensors constructed by Heather Vice
Applying a new sap flow technology to almonds

- Why is a new technology needed?
- Where can it be used?
- How does it work?
- What will it be used for?
Evaluation of almond leaf heat tolerance

• What does leaf heat tolerance mean?
• How does it vary between available almond varieties?
Evaluation of almond leaf heat tolerance

- What does leaf heat tolerance mean?
- How does it vary between available almond varieties?

Modeling by Nicolas Bambach
Heat tolerance

• What does leaf heat tolerance mean?

• How does it vary between available almond varieties?

Thanks to:
Tom Gradziel
Richard Rosecranse
Franz Niederholzer
Craig Ledbetter
Ken Shackel, University of California, Davis
Winter Water Management in Almond
2 “Goldilocks” questions about winter soil water and almonds:

1) How much water is too much?
   - If fully dormant almonds (Dec/Jan) can tolerate saturated soil conditions, maybe we can use almond orchards as groundwater recharge sites.
   - This project is currently sampling soils and instrumenting 3 field sites to test this idea, no results yet. Helen Dahlke and others are discussing groundwater recharge today, 3:00 – 3:45 in room 307

2) How much water is not enough?
   - When should growers consider winter irrigation?
   - The same field sites will be used to winter irrigate if it is a dry winter, but in the meantime we are testing if potted plants can be used to answer this question.
Using a cover crop to dry the soil of a dormant potted almond tree.

(February/March, 2015)
As soil dries, so does the tree, whether the tree is dormant or not.
Trees in the drought treatment became progressively more stressed over time.
Trees in the drought treatment became progressively more stressed over time.

Drought reduced bloom, but also appeared to delay bloom development.

Different trees dried at different rates.
Progress of bloom for a control tree.

A: Flowering buds
N=26 (Feb 09)
Progress of bloom for a control tree.

B: Bloomed
n=17 (Feb 17)
Progress of bloom for a control tree.

C: Bloomed
n=19 (Feb 27)
Progress of bloom for a control tree.

D: Nut set (Mar 12)
Progress of bloom for a drought tree.

A: Flowering buds
N=27 (Feb 10)
Progress of bloom for a drought tree.

B: Bloomed
n=8 (Feb 20)
Progress of bloom for a drought tree.

C: (No nut set on any drought tree)
Observations and preliminary conclusions:

1) Water stress during bloom reduced bloom % and prevented set.

2) Some bloom did open at -20 bar SWP (!), and leafout also occurred. 
   - This suggests that prior to bloom, during dormancy, flower and vegetative buds 
     may be fairly tolerant of water stress.

3) If so, growers may be able to wait longer in the winter before 
   considering the need for a winter irrigation.
Thanks to my cooperators:
Jiong Fei
Bruce Lampinen
Astrid Volder
Helen Dhalke

Thanks for your support and attention!
Whole Tree Response to Water Stress
Question: how much water stress does it take to reduce orchard ET?

1) Imposing mild/moderate water stress (14-18 bars) at hull split is beneficial (less hull rot, better harvestability).

2) Is it valid to claim that almond orchards actually use less water at that time because of this practice?

3) Are the current estimates of almond Kc accurate?
The only direct method to measure ET: a lysimeter.

(Kearny Ag. Center, Fresno)
Big enough for trees
3 acres.

Orchard: 50% Nonpareil, 25% Wood Colony, 25% Monterey.


Photo: August 26, 2015.

Plan: establish the orchard first, then impose stress.
First year ET data.

Reference (ETo) data is from Parlier CIMIS.

Young almond tree ETc starts at about 0.1”/week, climbing to about 0.35”/week, as canopy grows.

Kc shows peaks when soil evaporation is high (rain).
Even though we didn’t plan on imposing any water stress, some trees were more stressed than others, and showed less vigorous growth.

Tree #1:
SWP through May: -12.6 bar
Emitter flow: 2.20 gph

Tree #2:
SWP through May: -9.3 bar
Emitter flow: 2.16 gph
In late August, some irrigation tests were performed on border trees.

36h microsprinkler irrigation (4” of water)
Increasing water (a lot) had no effect. No easy answer yet.
Observations and preliminary conclusions:

1) The lysimster scale is working properly and giving reliable data.

2) Most trees reached a height of about 8’, so 1st year growth was OK.

3) The reason(s) for lower-than-baseline SWP for much of the season is not clear. Nearby established (3rd leaf) almonds showed baseline values in the spring, when the 1st year trees were below baseline.
Thanks to my cooperators:

Gurreet Brarr
Bruce Lampinen
Jim Ayars

Thanks for your support and attention!
Almond Water Production Function
Question: how does almond yield respond to water?

How much irrigation is required for maximum yield?
Is it the same on different soils?
Do you get the same ‘crop per drop’ as irrigation increases?
…etc…

Best estimate so far: about 70 kernel pounds per acre increase for every inch of water
Water production function

3 sites.

3-4 irrigation levels per site, range: 70% to 110% ET.

Irrigation treatments since 2013.

Yield since 2012 (pre-treatment).
## Irrigation treatments and irrigation range in 2015

<table>
<thead>
<tr>
<th>Treatment target (%ET)</th>
<th>Applied water (inch) March 1 - September 1</th>
<th>Kern</th>
<th>Merced</th>
<th>Tehama</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>110</td>
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<td>43.4</td>
<td>42.8</td>
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<td>32.1</td>
<td>30.6</td>
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<tr>
<td>70</td>
<td></td>
<td>26.8</td>
<td>30.3</td>
<td>22.0</td>
</tr>
<tr>
<td><strong>High to Low Difference</strong></td>
<td></td>
<td><strong>16.6”</strong></td>
<td><strong>12.5”</strong></td>
<td><strong>12.9”</strong></td>
</tr>
</tbody>
</table>
Yield patterns

Yields did not start out as identical in 2012 (i.e., pre-treatment). Some yields have fluctuated over time. Solution: Trend Analysis
Trend analysis: yearly difference between the treatment yield and the mean yield

![Graph showing trend analysis of yield difference.](image)
Yield: Merced is the only site showing a clear trend of increasing yield with more water.

PAR: Only Merced and Tehama show small increases in canopy with more water.

Kernel weight: All sites show small increases in kernel weight with more water.
Conclusions thus far: is water “Different strokes for different folks?”

1) Yield may be responsive to water in some locations, not others.
   - Tree physiology (SWP) and kernel weight have been responsive at all locations, so it is important to determine what yield components are/are not changing and why.

2) None of the orchards have consistently achieved 50# per percent PAR.
   - Determining the reasons for this are very important to the industry, particularly so that a valid “Crop per Drop” calculation can be made.
Thanks to my cooperators:

Dave Doll
Allan Fulton
Bruce Lampinen
Blake Sanden

Thanks for your support and attention!
Astrid Volder,
University of California, Davis
Impact of Drought Stress on Roots
Fine roots

- Vast majority of absorptive surface are fine roots (<0.5 mm diameter)
- Lack of suberization and small diameter may leave fine roots vulnerable to drought
- Different types of drought may differentially impact fine roots
  - Severe drought may kill fine roots
  - Chronic mild drought (deficit irrigation) may alter root traits (diameter distribution, suberization)
- Suberized and/or larger diameter roots have reduced absorptive capacity
Root classification

Most external roots = absorptive roots
Objectives:

Survey fine root traits in existing irrigation trials

• Samples collected in Merced in July, November and March

Impact of irrigation on the ability of roots to acquire water & nutrients

• Established controlled test site at UC Davis
• 360 trees, comparing bare root versus potted trees (root pruning vs ellepot)
• Krimsky 86 rootstock, Nonpareil, Wood Colony and Monterey
• Edge row heading/pruning experiment in 2015

• Irrigation treatments to be started in 2016
Edge row heading/pruning experiment

- Planted Feb 2/3
- Four treatments (imposed Feb 14)
  - Headed at 32” (laterals below heading height left on)
  - Headed & pruned
  - Pruned, but not headed
  - Not headed or pruned
- Data collected:
  - Diameter growth
  - Stem water potential
  - Root growth (start in June)
One week interval
- fine laterals appear and disappear
- higher order root turns brown
In June, standing root length was reduced at depth in the headed/pruned trees.

3 x more root length < 40” in unheaded & unpruned trees.
Pot grown trees were the fastest growing trees

There was no effect of heading/pruning on stem area growth rate
Potential use of these data

• We will keep track of the longer-term development of the headed/pruned trees as well as the potted versus bare root trees

• These data will be used to develop a management strategy aimed at maintaining the most effective root system (not necessary highest root density) through
  – Water management
  – Canopy management
  – Nutrient management
Amelie Gaudin, University of California, Davis
Building soil health to mitigate environmental stresses

Amélie Gaudin
Assistant Professor of Agroecology, Department of Plant Science UC Davis
Complementary approaches to sustainable management

- Eliminate/reduce pests
  - Pesticides, repellents, IPM
- Decrease deficiencies and stresses
  - Water & nutrient management
- Improve tree traits / nut characteristics
  - Breeding & physiology

Developing best practices for tree nutrition and pest management

- Soil physical properties (Soil C)
- Soil microbial communities
- Nutrient and carbon cycling
Research on how to build and harness benefits of greater soil health to decrease inputs and reduce stresses. *Practices - Practical, Profitable*

- **Soil physical properties** (Soil C)
- **Soil microbial communities**
- **Nutrient and carbon cycling**

- **Sequester more carbon?**
  - Decrease GHG emissions

- **Integrated nutrient management?**
  - N regulation

- **Conserve more soil water?**
  - Deficit irrigation, water shortages

- **Decrease host attractiveness?**
  - Next generation IPM

Row crops / Integrated crop livestock systems
Cropping system diversity and organic amendments

Resilience to drought, insect pests and the virus they vector
Potential of Mycorrhizae to Mitigate Water Stress in Almond
Astrid Volder, Bruce Lampinen et al

Promote interactions between almond trees and the soil microbial community to improve water and nutrient use efficiency

- Does mycorrhizal inoculation improve water/nutrient uptake and tree water status under water stress?
- Are roots of commercial almond orchards colonized?
- Differences between rootstocks?
- Which management practices promote root colonization and benefits? Soil carbon?
First survey of mycorrhizal colonization of almond orchards in CA

7 Rootstocks
Organic
Conventional
Nickels RS

Organic
Conventional
B.Paddock, L.Ralston

Fumigation
D.Doll

Compost amendments
D.Schellenberg, P.Brown

Irrigation
A.Volder

Residue incorporation
B.Holz

Inoculated / non inoculated
Well watered / water stress

Pot experiment

Location 69
Research and knowledge network on alternative orchard management practices

agaudin@ucdavis.edu
Web: gaudin.ucdavis.edu
Remote Sensing for Tree Water Stress Using Aerial Imagery

Blake Sanden
UCCE Irrigation/Soils Advisor, Kern Co.
Multiple satellite platforms carry different cameras capable of varying spectral frequency monitoring. The GRACE satellites actually measure gravity to estimate groundwater reservoirs.
2 Main Objectives of Remote Sensing: Estimate –

Crop Water Stress/Use – ET (Evapotranspiration)

Plant Health/Cover – NDVI (Normalized Differential Vegetative Index)

Combining Weather and Satellite Data: Mapping of Crop Coefficients at Field Scales

\[ \text{ET}_\text{cb} = \text{ET}_0 \times K_{cb} \]

CIMIS (AgriMet, AZMET, CoAgMet)

satellite

Standard \(K_c\) Profile (manual)

TOPS-SIMS \(K_c\) Profile (Automated, Satellite-derived)

Figure credit: 2006 California Water Plan Update
Wavelength and different light spectrums for plant characteristics

- Simple calculation of Normalized Differential Vegetative Index (using measured reflectance in the Near Infrared and Red light spectra) used to estimate plant biomass and general vigor.
Satellite Irrigation Management Support Project
“Managing irrigation from space”, Forest Melton, et. al.

SIMS

Mapping Crop Coefficients and Indicators of Crop Water Requirements from Satellite Data

USDA studies provide basis for linking satellite vegetation indices (NDVI) to fractional cover.

NDVI vs. Fc

R² = 0.97

Trout et al., 2008; Johnson & Trout, 2011

Recent studies by Allen & Pereira (2009) and others provide basis for linking fractional cover to Kc for a range of crops. Additional studies ongoing in collaboration with CSU Fresno and UC West Side Research & Extension Center

Coverage includes ~15 million acres of farmland in the Central Valley and coastal agricultural valleys
Resolution of Satellite Imagery

Landsat 5 and 7 (TM / ETM+)
30m pixel size = 0.22 acres

Terra (MODIS)
250m pixel size = 15.4 acres
“Expert” water monitoring/control telemetry systems promise precision management from your desktop.

SMARTFIELD infrared sensor to measure canopy temperature.
Almond ET/Yield Production Function

Ken Shackel, David Doll, Allan Fulton, Bruce Lampinen, Blake Sanden
Tehama, Merced and Kern County Locations


TREATMENTS: 70, 80, 90, 100 and 110% ET irrigation with Hull Split Regulated Deficit Irrigation

Objectives:

1) Quantify kernel yield in lbs/inch ET (applied water + depletion – leaching) under non-limiting fertility levels by varying depths of applied irrigation. (Primary objective common to all 3 sites.)

2) Quantify the interaction of hull-split Regulated Deficit Irrigation on the yield function with a simplified 50% ET irrigation application from mid-June to Nonpareil harvest irrigation cutoff – about 6 weeks.

3) Assess the yield benefit of “pulsed” (6 hours on, 6 hours off for 4 cycles over 48 hours) vs. continuous (24 hour set) irrigation.

4) Assess the grower friendliness, benefits and accuracy of in-situ data collection using web-based monitoring of trunk diameter (Phytech dendrometers), infrared sensed canopy temperature (Smartfield) and soil water content (Rainbird Climate Minder capacitance probes, Hortau tensiometers).

5) Assess the accuracy and relationship to kernel yield of remotely sensed aerial imagery used to calculate crop water stress (Conductance) and tree biomass/vigor (NDVI, normalized differential vegetative index) using images supplied by CERES Imaging.

6) Assess the feasibility, final water use and yield of high frequency “on-demand” plant stress and soil moisture triggers for irrigation scheduling (Unavailability of extra water due to drought canceled these treatments.)
CONTINUOUS vs. PULSED IRRIGATION:

This north tier production acreage to be irrigated @ 100% using existing manifolds & valves wired to controller

SAMPLE TREE LOCATIONS & NUMBERS

Note: Sample tree numbers are used for nutrients, SWP and neutron probe readings but are NOT the same numbers for flowmeters in the GALLEO Controller.

Smartfield Infrared
Canopy Temp Sensor
Pyhtech Dendrometer, etc.★
Climate Minder H
Hortau

REPLICATED PLOTS: The southern 3 tiers are divided into 6 replicated blocks with plots arranged in a "line-source" design with each plot having 6 rows by 30 or 31 trees/trees.

SPLIT-LOT -- CONTINUOUS vs. PULSED IRRIGATION: a dual valve system shall be installed down the middle of each tier with the southern 15 trees irrigated continuously for the prescribed depth of water and the northern 15 trees irrigated with "pulsed" irrigation -- say 1/2 hr on and 1/2 hr off -- to achieve the same depth of irrigation. See manifold detail sheet.
Our technology optimizes water and fertilizer

The old way of irrigating (60 acre almond orchard)

Farmer picks one spot (out of ~10k trees) to measure soil moisture and decides water application

Irrigation with our water stress prototype

Farmer gets optimized calculation of water to apply + tactical field recommendations

The user interface and “smart” software to analyze “big data” still has a long way to go.
Aerial image comparison: Differential irrigation commenced spring 2013

Google Earth July 2013

Google Earth March 2015
CERES website image (6/17/2015) of CONDUCTANCE water stress for ETPF trial
"CONDUCTANCE" AERIAL IMAGERY SHOWING WATER STRESS USING CANOPY TEMP & RELATIVE HUMIDITY CALCULATION

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

Canopy Temp/Water Stress by Irrigation Treatment (CERES Spectral Imaging 6-3-14, Shackel, et al. Yield Production Function Trial)
6/3-9/30/14 average almond plot water conductance by 2014 applied irrigation

Canopy Temp/Water Stress by Irrigation Treatment (CERES Spectral Imaging 6/17/2015, Shackel, et al. Yield Production Function Trial)
Correlation of individual tree conductance to pressure chamber stem water potential was marginal in 2015.

\[ y = 7.5876 \ln(x) - 60.759 \]
\[ R^2 = 0.2936 \]

4/30/15
\[ y = 0.0153x - 20.384 \]
\[ R^2 = 0.1999 \]

6/17/15
\[ y = 0.0091x - 19.456 \]
\[ R^2 = 0.0311 \]

7/8/15
\[ y = 0.0148x - 18.086 \]
\[ R^2 = 0.1817 \]

8/27/15
\[ y = 0.007x - 14.211 \]
\[ R^2 = 0.0006 \]

9/22/15
\[ y = 0.006x - 16.219 \]
\[ R^2 = 0.0139 \]

Cond (mmolH2O/m^2/sec) vs. SWP (bar) by separate dates:
- 4/30/2015
- 6/17/2015
- 7/8/2015
- 8/27/2015
- 9/22/2015
SOIL MOISTURE 70% IRRIGATION

SOIL MOISTURE 100% IRRIGATION

70% Irrigated

70% grew 0.20 inch

100% grew 0.31 inch

Trunk diameter of 100% grew 0.31 inch from bloom to July 31.

SOIL MOISTURE TENSION 70 & 100%

DENDROME TER – TREE GROWTH
NDVI (vigor/biomass) not as strongly correlated with applied water

\[ y = 0.0038x + 0.3761 \]
\[ R^2 = 0.2639 \]

3/25-9/22/2015 average almond plot NDVI by 2015 applied irrigation (10 flyovers)

NDVI/Biomass by Irrigation Treatment

(CERES Spectral Imaging 6/17/2015, Shackel, et al. Yield Production Function Trial)
Both CONDUCTANCE & NDVI were poorly correlated to final kernel yield. Bloom density and other factors can be just as important as stress on your final yield.
Sodium, Chloride and Boron Accumulation in Almonds

Blake Sanden
UCCE Irrigation/Soils Advisor, Kern Co.
Pushing the salinity limits on 3rd leaf almond on the westside

Yard 35.643929° x -119.805796°

• Project site
May 2015 Google Earth aerial photo of quarter section 3rd leaf project field. The scattering of missing trees appears uniform across the block – or is it!
Conductance - Water stress
6/17/2015

Aerial imagery (6/17/2015) and Areas 1 to 4 salinity sampling locations
Trees compared

Area 1 – larger trees
Soil ECe 1.7 dS/m
B 1.0 ppm

Area 4 – smaller trees
Soil ECe 6.1 dS/m, B 1.0 ppm, a few trees with bad gummosis

No leaf burn!
VARIOUS SOIL AND PLANT DATA COMPARED

Various Soil Salts 11/18/2015

Various Tree Data 6/8/15 to 11/18/2015

EC (dS/m) | Na (meq/l) | Cl (meq/l) | B (ppm)
---|---|---|---
Area 1 | Area 2 | Area 3 | Area 4

Avg Circum. 6/8/15 (cm) | Avg Circum. 11/18/15 (cm) | Height (m) | Yield (lbs/10 trees)
---|---|---|---
Area 1 | Area 2 | Area 3 | Area 4

312 lb/ac
137 lb/ac
Location of surfactant amendment trial
1st application 5/21/2015

4 TREATMENTS:
1) Control
2) Aquatrol Water Max (surfactant + Agrigator)
3) H-2-H Soluble Organics
4) WetSol (surfactant only)

Plot Size:
4 rows x 10 trees
(2 rows Nonpareil, 2 rows Monterey)
0.323 acres

Total acres/treatment = 1.293 ac

Conductance–Water stress
9/22/2015

NDVI – biomass
9/22/2015

Location and plot design for amendment trial
East (Area 1) to West (Area 4) showed a major trend in water stress (COND) and plant biomass/vigor (NDVI)

There was no significant benefit as of 9/22/2015 from any of the surfactant amendments to reduce water stress. Nor was there any yield benefit or differences in tissue salt concentration.
Various leaf and wood tissue samples showed no real correlation to soil salinity, except scion and leaf K decreased as Na increased.
Physiology of Salinity Stress in Almond

Umit Baris Kutman, Francisco Acevedo, Patrick Brown
Introduction

• Main experiments on grafted trees grown outdoors in 7-gal pots with Turface as growth medium
  – 3 salinity levels: control (~1 dS/m), low (~3 dS/m), high (~5 dS/m)
  – 1st season data in 2014 and 2nd season data in 2015
  – Rootstock experiment: Nemaguard, Hansen536, Empyrean-1, Viking
  – Cultivar experiment: Nonpareil, Mission, Monterey, Fritz
  – Salt type experiment: NaCl, KCl, Na₂SO₄
  – Double-grafting experiment: Nonpareil & Mission on Nemaguard

• Recovery experiment (2015) on grafted trees grown outdoors in 2.5–gal pots with Turface
  – 3 salinity levels: control (~1 dS/m), low (~3 dS/m), high (~5 dS/m)
  – Rootstock: Nemaguard; Cultivars: Nonpareil, Monterey
  – 9 weeks of salinity treatment followed by 5 weeks of recovery treatment

• Split-root experiment (2015) on non-grafted rootstock cuttings grown hydroponically in greenhouse
  – Effects of non-uniform vs. uniform salinity on water uptake and tissue salt accumulation
  – Rootstocks: Nemaguard, Hansen536, Empyrean-1, Viking
Summary of 1st Season Results

• The main component of salinity stress for well-watered almond trees is Na and Cl toxicity.

• While both Na and Cl are potentially toxic, Cl accumulates much faster than Na and is the dominant toxic ion when NaCl is used as the salinizing agent.

• There is wide variation among Prunus rootstocks and almond cultivars with respect to salinity tolerance.
  – **Rootstocks**: Na and Cl exclusion capabilities seem to correlate for rootstocks.
    Nemaguard < Hansen536 < Empyrean-1 ≈ Viking
  – **Cultivars**: Nonpareil is the best at excluding Na from leaves while Mission is the best at excluding Cl.

• Na can be stored in woody tissues, and this contributes to the Na tolerance of Nonpareil.
Rootstock Experiment – 2nd Season

Leaf Na Concentrations

Low Salinity (20 mM NaCl) (No Recovery Treatment)

High Salinity (40 mM NaCl) (With Recovery Treatment)

Leaf Cl Concentrations

Na and Cl levels due to last years salt
Following 2 months of salt in 2015

Na and Cl levels are low because we removed trees to no salt in Oct 2014
Cultivar Experiment – 2nd Season

Leaf Na Concentrations

Low Salinity
(20 mM NaCl)
(No Recovery Treatment)

High Salinity
(40 mM NaCl)
(With Recovery Treatment)
Double-Grafting Experiment: Nonpareil vs. Mission on Nemaguard

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Nonpareil</th>
<th>Mission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na (%)</td>
<td>0.72 ± 0.07</td>
<td>1.70 ± 0.07</td>
</tr>
<tr>
<td>Leaves</td>
<td>0.25 ± 0.04</td>
<td>0.02 ± 0.04</td>
</tr>
<tr>
<td>Bark</td>
<td>0.10 ± 0.01</td>
<td>0.02 ± 0.00</td>
</tr>
<tr>
<td>Xylem</td>
<td>0.04 ± 0.01</td>
<td>0.04 ± 0.02</td>
</tr>
<tr>
<td>Cl (%)</td>
<td>3.01 ± 0.48</td>
<td>3.92 ± 0.39</td>
</tr>
<tr>
<td>Leaves</td>
<td>0.47 ± 0.12</td>
<td>0.41 ± 0.10</td>
</tr>
<tr>
<td>Bark</td>
<td>0.04 ± 0.01</td>
<td>0.04 ± 0.02</td>
</tr>
<tr>
<td>Xylem</td>
<td>0.04 ± 0.01</td>
<td>0.04 ± 0.02</td>
</tr>
</tbody>
</table>
Recovery Experiment

9 weeks salinity treatment followed by 5 weeks recovery with no added salt.

Low Salinity (20 mM NaCl)

High Salinity (40 mM NaCl)
Summary of Findings & Poster Information

• In general, 2\textsuperscript{nd} season data are consistent with 1\textsuperscript{st} season data for the main rootstock experiment.
  – In order of decreasing leaf salt load: Nemaguard > Hansen536 > Empyrean-1\approx Viking
  – BUT: Leaf Cl differences between Hansen536, Empyrean-1 and Viking disappeared in season 2.

• Among tested cultivars, Nonpareil is the best one in excluding Na from leaves, while Nonpareil and Mission are the best two in excluding Cl from leaves.

• Na allocation to woody tissues plays a critical role in Na exclusion from leaves and contributes majorly to Na tolerance in Nonpareil.

• When found at equal concentrations, Cl accumulates faster to toxic levels in leaves than Na, and KCl is even more toxic than NaCl (counter-ion effect).

• In-season recovery treatment effectively reduces leaf and wood Na and Cl concentrations.

• Under non-uniform salinity, all rootstocks preferentially absorb water from the less-saline side.

• Partial root access to good-quality water significantly lowers the Na and Cl levels in shoot tissues.

• For further information and discussion, please visit Poster 45.
Subcellular and Molecular Characterization of Salinity Tolerance in Almonds with Novel Tools
Subcellular and Molecular Characterization of Salinity Tolerance in Almonds with Novel Tools

Georgia Drakakaki

Department of Plant Sciences, University of California, Davis

Collaborators: Thomas Wilkop, John Preece, Malli Aradhya, Bruce Lampinen, Patrick Brown, Tom Gradziel, Roger Duncan
Outline

• Our research interests and expertise

• Preliminary studies of sodium subcellular accumulation

• Our future work
Plants Can’t Move!!

Shindo et al. (2006) Genes and Development
The Endomembrane System Consists of:

- Numerous Compartments
  - Abiotic stress response
  - Plant development and cell wall biosynthesis [cell pattern formation, senescence, flowering]
  - Signal transduction
  - Hormonal responses
  - Plant pathogen resistance

Worden et al. 2012 JIPB
Questions in my Research Group:

- How does this membrane network controls response to biotic an abiotic stress?
- How do cell wall components reach their destination?

Wall polysaccharides and enzymes travel along the endomembrane system to the wall

Worden et al. 2012 JIPB
We Investigate Plant Cellular Processes
Appropaces Used in Our Lab

Proteomics
Chemical Genomics
Genetics
Outline

- Our research interests and expertise
- Preliminary studies of sodium subcellular accumulation
- Our future work
Motivation

Almond plants are relatively sensitive to salinity stress

Need for robust tools to screen for elite genotypes on salinity tolerance
Plant Vacuole and Ion Transport

Science 1999: vol. 285 no. 5431 1222-1223
Importance of The Plant Vacuole

- Detoxification - accumulation waste products
- Occupy up to 95% volume

Mature plants carry a central vacuole:

- How different rootstocks respond?
- What happens after different treatments?

Tamura et al. (2003) Plant J.
Na\(^+\) Accumulation in the Vacuole of Bread Wheat

Tolerant variety

Non tolerant variety

Salinity tolerance associated with sodium accumulation in the vacuole

Similar studies have been reported in citrus and pepper

Establish a method of sodium localization in pistachio plant tissues.

Characterize sodium localization in various rootstock seedlings tissues treated with NaCl.
Selectivity of CoroNa-Green with Sodium
Tissues Tested

Roots, leaves and stems were sectioned transversely and/or longitudinally into 1-2 mm sections.
Sodium Localization of in Pistachio Roots after NaCl Treatment

3 week treatment
Sodium Accumulation in Root Vacuole Upon NaCl Stress

This approach allows us to screen several genotypes under different treatments.
Sodium Localization in the Vacuole of Pistachio cells
Vacuolar Localization of Sodium in Developing Vacuole

Vacuole staining

Sodium staining

Overlay

Viotti C et al. Plant Cell 2013
Screen of Selected Almond Rootstocks

Hansen 0, 20, 40 mM NaCl
Sodium Localization in Almond Roots after NaCl Treatment

Hansen rootstock, 2 weeks treatment

Increased cellular accumulation of sodium is observed
Sodium Localization in Almond Roots after NaCl Treatment

Sodium Staining CoroNa-Green

Hansen rootstock, 2 weeks treatment
Altered cellular accumulation of sodium is observed
Potassium Localization in Almond Roots after NaCl Treatment

Potassium Staining Asante Potassium-Green

Hansen rootstock, 2 weeks treatment
Altered localization pattern of potassium is observed
The methodology for quantitative potassium and sodium localization in almond root cells has been established.

Increased cellular accumulation of sodium and altered potassium localization patterns were observed in salt treated rootstock seedlings.
Continuing Work:

- Establish a methodology for chloride detection
- Extend screen of almond rootstocks
- Mapping the structural morphology of almond roots in order to establish a reference
Longer Term Aims

- Incorporate the subcellular characterization of ion sequestration in currently developing genotypes that are undergoing phenotypic screening at the National Germplasm Repository.

- On the genetic level, identify molecular markers for halotolerance in combination to other desired traits.
Acknowledgements

Almond Project:
Thomas Wilkop
Angelo Herringer

Collaborators:
John Preece,
Malli Aradhya,
Bruce Lampinen,
Patrick Brown,
Tom Gradziel,
Roger Duncan
Sierra Gold Nurseries

Pistachio project:
Thu Le
Victor Esteva
Juvenal Quezada
Thomas Wilkop

Collaborators:
Jessie Godfrey
Louise Ferguson
Maciej Zwieniecki
Nutrient Availability and Food Safety of Organic Matter Amendments

Daniel Schellenberg¹, Stephen Hart², Jeffery McGarvey³ and Patrick Brown¹

¹Department of Plant Sciences University of California Davis
²School of Natural Sciences University of California Merced
³USDA ARS Food Toxin Detection and Prevention Unit Albany
Project Objectives

• Compare sources of organic matter amendments
• Demonstrate food safe integrated nutrient management
• Estimate decomposition rates
• Evaluate potential soil moisture savings
• Contrast availability of nutrients (NPK)
Sources of Organic Matter Amendments

• Composted Dairy Manure
  – pH 8.0
  – EC 29 dS/m
  – C:N 12

• Green Waste Compost
  – pH 5.0
  – EC 23 dS/m
  – C:N 19

• Both Sources Free of Human Pathogens
Food Safe Approaches

- Composted Materials
- Testing for Human Pathogens
- Trials with Non-bearing Trees
- Application 120 days before Harvest
- Mulched on Tree Berm
- Placed in Wetted Zone
Decomposition Rate

![Graph showing the decomposition rate of organic matter amendment litter over the growing season of 2015. The graph compares the rate of decomposition for Composted Manure and Green Waste Compost. The x-axis represents the months from April to August, and the y-axis shows the organic matter amendment litter in grams per square meter. The data points are marked with error bars indicating the variability in the measurements.](image-url)
Soil Moisture Savings

Growing Season 2015

Volumetric Water Content (cm$^3$ H$_2$O cm$^{-3}$)

- Control
- Composted Manure
- Green Waste Compost

April
May
June
July
August

NS
AB
A
B
NS
NS
NS
NS
NS
NS

Growing Advantage
The Almond Orchard
Nutrient Availability – Nitrogen

![Graph showing nutrient availability over the growing season 2015. The x-axis represents the months April to August, and the y-axis represents the concentration of nitrogen (in ug N (NH₄⁺-N + NO₃⁻-N) 10 cm⁻² surface month⁻¹). The graph compares different treatments including Control, Composted Manure, and Green Waste Compost. There are significant differences (NS) in nutrient availability between these treatments throughout the growing season.]
Nutrient Availability – Phosphorus

![Graph showing nutrient availability over the growing season in 2015 for different treatments: Control, Composted Manure, and Green Waste Compost. The graph plots ug PO₄⁻³-P 10 cm⁻² surface month⁻¹ against time (April to August). The bars indicate significant differences (*) and similar results are denoted by the same letter (A, B, C).]
Nutrient Availability – Potassium

Growing Season 2015

 ug K⁺ 10 cm⁻² surface month⁻¹
Conclusions

- Viable option for partial substitution of fertilizers
- Decomposition of ~7-9 lb/acre/day during growing season
- Early season soil moisture savings
- Potential role of N storage
- Effective source for P and K fertilizer
Future Work

• Trial on 3rd leaf at Escalon site in San Joaquin County
• Join our Soil Health Network
  – Participate in Satellite trials
  – Use of Organic Matter Amendments
  – Trees on 1st to 5th leaf or older
  – Microirrigation system
  – Contact me by email dschel@ucdavis.edu
David Smart, University of California, Davis
N$_2$O Emissions From Almond
David R. Smart, Sharon Dabach, Rebekah Davis, Maria del Mar Alsina and Daniel Schellenberg
University of California, Davis
The Agriculture N Cycle: A balancing act.

Foliars
Leaves and prunings returned to orchard floor - N

Urea + NH₄⁺ + NO₃⁻ Organic-N

Optimize
Synchronize
Minimize

Harvested nuts and husks exported

Leaves and prunings returned to orchard floor

NH₃
Volatilization, denitrification from soil

N₂O, N₂

NH₄⁺ + NO₃⁻
Leaching
BMP Treatments:

Advanced Grower Practice (AGP)  
(split applications targeted to N demand)

High Frequency Low [N] (HFLC)  
(spoon feed, 20 split apps of 5-15 lbs acre⁻¹)

Pump and Fertilize (P&F)  
(AGP, compensating for well water N loads)
Spatially Modeling N$_2$O Emissions

Distance to water emitter (m)

-2 -1 0 1 2

-300 300

N$_2$O Flux (nmols m$^{-2}$ min$^{-1}$)

B

\[
\int \int f(x,y) \, dx \, dy \approx \sum_{x=-0.5}^{0.5} \sum_{y=-0.5}^{0.5} y_0 + y \\
\]
Scaling to Seasonal $\text{N}_2\text{O}$:

![Graph showing N$_2$O flux over time for UAN32 and CAN17 in 2009-2010](image-url)
<table>
<thead>
<tr>
<th></th>
<th>Almond (lb/acre)</th>
<th>Pistachio (lb/acre)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>AGP</td>
<td>HFLC</td>
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<tr>
<td>Yield (kernels)</td>
<td>2699</td>
<td>2869</td>
</tr>
<tr>
<td>Groundwater-N</td>
<td>73.8</td>
<td>73.8</td>
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<tr>
<td>Fertilizer-N</td>
<td>215</td>
<td>215</td>
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<tr>
<td>Compost-N*</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Kernel-N</td>
<td>119</td>
<td>130</td>
</tr>
<tr>
<td>Storage-N (wood)</td>
<td>25</td>
<td>25</td>
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<tr>
<td>N in Hulls</td>
<td>67</td>
<td>72</td>
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<tr>
<td>N₂O-N Loss</td>
<td>0.65</td>
<td>0.29</td>
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<tr>
<td>NUE</td>
<td>0.72</td>
<td>0.78</td>
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<td>72</td>
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<tr>
<td>(\text{N}_2\text{O-N loss (CO}_2\text{ eq)})</td>
<td>62.1</td>
<td>27.9</td>
</tr>
<tr>
<td>NUE</td>
<td>0.51</td>
<td>0.69</td>
</tr>
</tbody>
</table>
Conclusions:

• In general, N$_2$O emissions from almond and pistachio orchards in the arid West are much lower than for other crops.

• Only the HFLC N, “spoonfeed”, N application treatment lowered emissions of the greenhouse gas N$_2$O. When factored into NUE calculations, showed slightly superior CA emission factor.

• In terms of lowering carbon offsets, we still have some work to do in terms of identifying Best Management Practices.
Optimizing Use of Groundwater Nitrogen for Nut Crops

David R. Smart, Patrick H. Brown, Thomas Harter & Jan Hopmans

University of California
Acknowledgements

Fertilizer Research and Education Program
California Pistachio Research Board
Almond Board of California

Dept of Viticulture & Enology
Dept of Plant Sciences
Dept of Land, Air & Water Resources

University of California, Davis
Climate Change ● Sustainable Farming
Environmental Quality ● Remote Sensing
The Agriculture N Cycle: A balancing act.

- Foliars: Leaves and prunings returned to the orchard floor - N
- Urea + NH$_4^+$ + NO$_3^-$: Organic-N
- NH$_3$: Volatilization, denitrification from soil
- N$_2$O, N$_2$: Leaching

- N-Supply
- N-Demand
- N-Loss

Optimize Synchronize Minimize
BMP Treatments:

Advanced Grower Practice (AGP)  
(split applications targeted to N demand)

High Frequency Low [N] (HFLC)  
(spoon feed, 20 split apps of 5-15 lbs acre\(^{-1}\))

Pump and Fertilize (P&F)  
(AGP, compensating for well water N loads)
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<tr>
<td>Groundwater-N</td>
<td>73.8</td>
<td>73.8</td>
<td>73.8</td>
<td>14.3</td>
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<td>Fertilizer-N</td>
<td>215</td>
<td>215</td>
<td>186</td>
<td>174</td>
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<td>2</td>
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<td>Storage-N (wood)</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>N in Hulls</td>
<td>67</td>
<td>72</td>
<td>67</td>
<td>5</td>
</tr>
<tr>
<td>NO₃-N (1.3-3.0 m)</td>
<td>197.3</td>
<td>144.3</td>
<td>56.7</td>
<td>na</td>
</tr>
</tbody>
</table>
Conclusions:

1) There were no detectable effects on production between AGP, HFLC and P&F and therefore supports the hypothesis that a lb of N in well water acts like a lb of synthetic N fertilizer.

2) The P&F treatment seemed to lower potential leachable NO₃⁻-N below the rooting zone but this result will require further scrutiny because of extreme heterogeneity in soil NO₃⁻ concentrations.
California Almond Water Footprint

Fraser Shilling & Julian Fulton
UC Davis
What is Water Footprint?

**Blue Water** refers to applied water, whether from surface or ground sources, that is utilized in orchard development.

**Green Water** refers to rainwater and residual soil moisture that is utilized in orchard development.

**Gray Water** refers to contamination and is expressed as the volume of water needed to dilute non-utilized nutrients and other pollutants to acceptable levels.
Objectives

- Calculate an accurate water footprint for California almonds
- Compare almond water footprint to economic benefits gained from almond production and sales
- Compare water footprint to food value
- Analyze the effects of variation in evapotranspiration rates
- Compare the water footprint to other types of footprint and life cycle analysis to improve management
Denominator is important

\[
\text{Water Footprint} = \frac{\text{Consumptive Water Use}}{\text{Yield}}
\]
What are we finding?

• Average (10-year) values for California are:

  • **Blue water** = \( \frac{4.3 \text{ acre-feet/acre}}{1.2 \text{ tons kernels/acre}} \times \frac{1 \text{ ton}}{2,000 \text{ lbs}} \times \frac{325,851 \text{ gallons}}{1 \text{ acre-feet}} = 610 \ \frac{\text{gallons}}{\text{lb kernels}} \)

  • **Green water** = \( \frac{0.6 \text{ acre-feet/acre}}{1.2 \text{ tons kernels/acre}} \times \frac{1 \text{ ton}}{2,000 \text{ lbs}} \times \frac{325,851 \text{ gallons}}{1 \text{ acre-feet}} = 87 \ \frac{\text{gallons}}{\text{lb kernels}} \)

  • **Grey water** = \( \frac{3.2 \text{ acre-feet/acre}}{1.2 \text{ tons kernels/acre}} \times \frac{1 \text{ ton}}{2,000 \text{ lbs}} \times \frac{325,851 \text{ gallons}}{1 \text{ acre-feet}} = 464 \ \frac{\text{gallons}}{\text{lb kernels}} \)
Almond irrigation water use varies by county

- Evapo-transpiration of irrigation water, modeled by DWR (CalSIMETAW)
Almond ETc varies by region

- 01-North Coast
- 02-San Francisco Bay
- 03-Central Coast
- 04-South Coast
- 05-Sacramento River
- 06-San Joaquin River
- 07-Tulare Lake
- 08-North Lahontan
- 09-South Lahontan
- 10-Colorado River
Water Footprint varies by county

CA Almond Water Footprint
(gal/lb kernel, 10 year average)

- 665 - 850
- 850 - 1100
- 1100 - 1350
- 1350 - 1600
- 1600 - 1887

0 50 100 200 Miles
N
Water footprint is declining

Gallons per pound kernels

- Green Water
- Blue Water
- Grey Water

Years: 2004 to 2014
Contacts
Julian Fulton (julianfulton@gmail.com)
Fraser Shilling (fmshilling@ucdavis.edu)
Almond Variety Development

Tom Gradziel, UC Davis
Is this the future for California almonds?
Cultivated almonds is very adaptive; its wild relatives even more so.
New germplasm = New traits = New solutions

Crosses: 2014-15

cv. Ferragnes/P. webbii

P. webbii (Iran)
P. persica (Korea)
P. fenzliana (Syria)
P. argentea (Turkey)
P. mira

P. webbii/P. persica
P. fenzliana/P. webbii
P. mira
Breeding objectives: focused improvement yet maintain diversity (future options)

Self-fertile almonds now in Regional Testing.

Leaf analysis Dr. Matthew Gilbert
Captured germplasm

UCD Breeding Germplasm

Kester almond: new UCD release.

New germplasm = new risks (14+yrs reg. testing).
Thank you

Almond Variety Development

Cooperators:
B. Lampinen,  S. Metcalf,  M. Billings,
S. Marchand,  J. Adaskaveg,  J. Connell,
F. Niederholzer,  J. Fresnedo,  M. Viveros,
R. Duncan, M. Gilbert &  M. González.
Rootstock Germplasm
Tom Gradziel, UC Davis
This is the Future (and present) for California Almond Rootstocks
Wild *P. fenzliana* thriving in Syrian desert.
New almond rootstocks are species-hybrids to complex species multi-crosses.

<table>
<thead>
<tr>
<th>Name</th>
<th>Genetic background</th>
</tr>
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<tbody>
<tr>
<td>Adefuel P. dulcis x P. persica</td>
<td></td>
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<tr>
<td>Atlas</td>
<td>peach, almond, plum, apricot interspecific</td>
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<tr>
<td>Bright Hybrid-1 P. persica x P.dulcis</td>
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<tr>
<td>Cadaman P. persica x P. davidiana</td>
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<tr>
<td>Citation OP Red Beaut Plum-OR- Siberian C x (plum x almond)</td>
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<tr>
<td>Cornerstone P. persica x P.dulcis</td>
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<td>Empyrean#1 (Barrier 1) P. persica x P. davidiana</td>
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<td>Empyrean#2 (Penta) O.P. P. domestica</td>
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<td>GxN 15(Garnem) P. dulcis x P. persica (Nemared)</td>
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<td>Hansen 536 [Okinawa x (P. davidiana x peach PI 6582)] x almond</td>
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<td>Ishtara (P. cerasifera x P. saliciana) x (P. persica x P. cerasifera)</td>
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<td>Krymsk #1 (VVA 1) P. tomentosa x P. cerasifera</td>
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<td>Krymsk 2 P. incana x P. tomentosa</td>
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<tr>
<td>Krymsk#86 (Kuban 86) P. persica x P. cerasifera</td>
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<td>Marianna 2624 P.munsoniana x P. cerasifera (Kester: cerasifera</td>
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<tr>
<td>Nemaguard P. persica x P. davidiana</td>
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<tr>
<td>Nickels P. dulcis x P. persica</td>
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<tr>
<td>Paramount (=GF677) P. persica x P.dulcis</td>
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</tr>
<tr>
<td>Titan Nemaguard x pollen sterile Titan almond</td>
<td></td>
</tr>
<tr>
<td>Viking peach, almond, plum, apricot interspecific</td>
<td></td>
</tr>
</tbody>
</table>
Most wild germplasm remains untested and so under-utilized

- *P. scoparia* in Iran
- *P. bucharica* in Turkey
- *P. webbii* in Iran
- *P. tangutica* in Tibet (?)
From drought tolerance to cold & rain tolerance.

*P. nana* in Central Asia
Resistance Screening: DNA Marker-Based Approach

*DNA test outcomes* identify resistant seedlings before field planting

- **Resistant parent**
- **Susceptible parent**

DNA testing

- Field disease phenotype
Multiple Resistance/Tolerance Alleles
Pyramided using DNA Tests

DNA tests used to monitor inheritance both disease resistance and quality from the donor parent.

Donor parent with pyramided alleles

Elite parent
- e.g. ‘Nemaguard’
- susceptibility
- Desirable alleles for fruit quality & productivity

DNA testing for both resistance and tolerance ...and quality, productivity

Field disease phenotype
- durable resistance!

...and superior horticultural quality

RosBREED Combining Disease Resistance with Horticultural Quality in New Rosaceous Cultivars
Accuracy of molecular markers in wide crosses

- Generally effective in closely related crosses
- Lose accuracy as crosses become wider.
  - Useful for specific trait tagging & paternity

<table>
<thead>
<tr>
<th>Parents</th>
<th>Progeny-1</th>
<th>Progeny-2</th>
<th>Progeny-3</th>
<th>Progeny-4</th>
<th>Progeny-5</th>
<th>Progeny-6</th>
<th>Progeny-7</th>
<th>Progeny-8</th>
<th>Progeny-9</th>
<th>Progeny-10</th>
<th>Progeny-11</th>
<th>Progeny-12</th>
<th>Progeny-13</th>
<th>Progeny-14</th>
</tr>
</thead>
</table>
Problem: Traits complex (Hybrid vigor) Genetic control - complex

Drought tolerance

Novel traits: modify Nonpareil shape or size
Thank you

Rootstock Germplasm

Cooperating Personnel:
J. Preece, T. Michailides, M. Aradhya,
C. Ledbetter, G. Browne, J. Adaskaveg,
S. Marchand, D. Kluepfel & J. Slaughter.
Roger Duncan,
UCCE – Stanislaus County
Field Evaluation of Almond Rootstocks

Roger Duncan, UCCE Farm Advisor, Stanislaus County
Joe Connell, UCCE Farm Advisor Emeritus, Butte County
David Doll, UCCE Farm Advisor, Merced County
Katherine Pope, UCCE, Yolo, Solano, Sacramento
High Boron Rootstock Trial

Katherine Pope, UCCE Yolo, Solano, Sacramento Counties
Boron Rootstock Trial – Yield Highly Correlated with Rootstock

Marvin silty clay loam
Water: <1 - 3.1 mg/l B
Soil: 1.3-2.2 mg/l B
cv. Nonpareil
Nursery grafted
Planted: Feb, 2011
(Titan Apr 2011 not rep’d)
Spacing: 22’ x 18’

Different letters indicate statistical diff. values when compared in same year.
Boron Rootstock Trial – Hull B Content Highly Correlated with Rootstock

The diagram shows the Lbs Per Acre for different rootstocks: Nickels, Titan SG1, FxA, Brights 5, Hansen, Rootpac-R, Viking, Krymsk 86, and Lovell. The data is presented for two years: 2015 and Hull B 2014. The rootstocks are ranked based on their Hull B content, with different letters indicating significant differences in their performance.
Boron Rootstock Trial – Bloom Vigor Highly Correlated with Rootstock

Bloom Vigor was rated (1-5 scale) based on flowers per unit canopy, not flowers in whole canopy. In other words, a large canopy didn’t necessarily mean a higher bloom rating.

Bloom Vigor = 1 (Lovell)  
Bloom Vigor = 5 (Nickels)
Boron Rootstock Trial – Canopy Size Highly Correlated with Rootstock
Are Higher Yields *Just* Result of Vigorous Rootstocks → Larger Trees? *No.*

- True, larger trees → higher yield ($p < 0.001$). PAR alone predicts 60% of the variability in yield.
- But, Hull B content explains 14% of the yield variability that PAR does not explain ($p < 0.01$)*.
- Worst combination is low vigor + high hull B: Lovell (& Krymsk)

*R² contribution averaged over orderings among regressors. R relaimpo, lmg*
Boron Rootstock Trial – Summary (So Far)

- **Poor Yield** related to **Canopy Size**, **Bloom Vigor**, **Hull Boron**. Points to two potential rootstock effects:
  - Vigorous rootstocks $\rightarrow$ Larger Trees
  - Boron tolerant rootstocks decrease B to scion $\rightarrow$ Decrease B at growing points (flowers, nuts) where it can do damage.

- **Nickels, Titan and FxA** continue to perform **better** than other rootstocks under high boron conditions

- **Lovell, Krymsk 86** continue to perform **poorly** under high boron conditions

- Looks like Lovell combines worst combination: Low vigor with high B
Evaluation of Rootstocks for the Westside

Roger Duncan, UCCE, Stanislaus County
Challenge: Heavy, high pH soil with sodium, chloride and boron in water

Soil:
- Zacharias clay loam soil
- Soil pH 7.6
- Boron 0.5 ppm
- EC 2.96 dS/m
- Na 12.1 meq/l
- Cl 14.1 meq/l
- Following decades of tomatoes, melons, row crops

Water:
- EC: 1.86
- Adj. SAR: 8.80
- Chloride: 8.90 meq / L
- Boron: 0.84 mg / L
## 2014 Trunk Circumference – 3rd Leaf

<table>
<thead>
<tr>
<th>Variety</th>
<th>Trunk Circumference (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAC9908-02</td>
<td>37.7 a</td>
</tr>
<tr>
<td>Empyrean 1</td>
<td>36.8 a</td>
</tr>
<tr>
<td>Flordaguard X Alnem (FxA)</td>
<td>36.3 a</td>
</tr>
<tr>
<td>Rootpac R</td>
<td>36.1 a</td>
</tr>
<tr>
<td>Hansen x Monegro (HM2)</td>
<td>35.8 a</td>
</tr>
<tr>
<td>BB 106</td>
<td>35.8 a</td>
</tr>
<tr>
<td>Hansen</td>
<td>35.7 a</td>
</tr>
<tr>
<td>Brights 5*</td>
<td>33.2 b</td>
</tr>
<tr>
<td>Nemaguard</td>
<td>33.1 b</td>
</tr>
<tr>
<td>Atlas</td>
<td>32.9 b</td>
</tr>
<tr>
<td>Viking</td>
<td>32.8 b</td>
</tr>
<tr>
<td>HBOK 50*</td>
<td>32.6 b</td>
</tr>
<tr>
<td>Paramount</td>
<td>32.9 bc</td>
</tr>
<tr>
<td>Krymsk 86</td>
<td>31.8 bc</td>
</tr>
<tr>
<td>Lovell</td>
<td>31.5 bc</td>
</tr>
<tr>
<td>Cadaman*</td>
<td>30.2 c</td>
</tr>
</tbody>
</table>

*Indicates planted as potted trees which are younger and smaller than bare root
## Rootstock Effect of Sodium, Chloride & Boron in Leaf and Hull Tissue

<table>
<thead>
<tr>
<th>Variety</th>
<th>% Cl</th>
<th>% Na</th>
<th>B (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lovell</td>
<td>0.73 a</td>
<td>0.08 ab</td>
<td>180 a</td>
</tr>
<tr>
<td>Krymsk 86</td>
<td>0.65 b</td>
<td>0.05 abc</td>
<td>152 bc</td>
</tr>
<tr>
<td>Nemaguard</td>
<td>0.43 c</td>
<td>0.06 abc</td>
<td>153 bc</td>
</tr>
<tr>
<td>Atlas</td>
<td>0.37 cd</td>
<td>0.07 abc</td>
<td>158 ab</td>
</tr>
<tr>
<td>Empyrean 1</td>
<td>0.32 de</td>
<td>0.09 a</td>
<td>133 cd</td>
</tr>
<tr>
<td>Cadaman</td>
<td>0.32 de</td>
<td>0.06 abc</td>
<td>170 ab</td>
</tr>
<tr>
<td>HBOK 50</td>
<td>0.30 def</td>
<td>0.06 abc</td>
<td>158 ab</td>
</tr>
<tr>
<td>PAC9908-01</td>
<td>0.28 defg</td>
<td>0.06 abc</td>
<td>108 e</td>
</tr>
<tr>
<td>Viking</td>
<td>0.25 efg</td>
<td>0.07 abc</td>
<td>109 e</td>
</tr>
<tr>
<td>Rootpac R</td>
<td>0.25 efg</td>
<td>0.08 ab</td>
<td>132 cd</td>
</tr>
<tr>
<td>Hansen</td>
<td>0.23 efg</td>
<td>0.05 abc</td>
<td>126 de</td>
</tr>
<tr>
<td>Brights 5</td>
<td>0.22 fgh</td>
<td>0.06 abc</td>
<td>106 e</td>
</tr>
<tr>
<td>BB 106</td>
<td>0.20 gh</td>
<td>0.05 c</td>
<td>102 e</td>
</tr>
<tr>
<td>Paramount</td>
<td>0.20 gh</td>
<td>0.05 bc</td>
<td>120 de</td>
</tr>
<tr>
<td>F x A</td>
<td>0.20 gh</td>
<td>0.07 abc</td>
<td>104 e</td>
</tr>
<tr>
<td>HM2</td>
<td>0.18 h</td>
<td>0.07 abc</td>
<td>116 de</td>
</tr>
</tbody>
</table>
2015 Nonpareil Yield: 4th Leaf

Spacing: 16’ x 20’

Pounds / Acre


- Brights 5
- Emperian 1
- Rootpac R
- HM2
- F x A
- Atlas
- BB 106
- Hansen
- PAC9908-01
- Viking
- Paramount
- Krymsk 86
- HBOK 50
- Nemaguard
- Lovell

Legend:
- a
- ab
- b
- c
- cd
- d
HM2 (Hansen x Monegro) not acceptable – poor anchorage
Merced County Rootstock Trial

David Doll, Andrew Ray, and Vivian Lopez; UCCE Merced County
Merced County Rootstock Trial

**Background:**
Planted in January 2011, trial currently in fifth leaf (third harvest).
Spacing 22’ x 18’
13 rootstocks tested on ‘Nonpareil.’
7 rootstocks tested on varieties ‘Monterey,’ and ‘Fritz.’

**Challenges:**
Sandy soil near Atwater, CA, low cation exchange capacity, history of nematodes
Irrigated with groundwater with high nitrates and moderate sodium

<table>
<thead>
<tr>
<th>‘Nonpareil,’ ‘Monterey,’ and ‘Fritz’</th>
<th>‘Nonpareil’ only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlas</td>
<td>BB106</td>
</tr>
<tr>
<td>BH5</td>
<td>Cadaman*</td>
</tr>
<tr>
<td>Empyrean-1</td>
<td>Cornerstone*</td>
</tr>
<tr>
<td>Hansen 536</td>
<td>Floridaguard x Alnem</td>
</tr>
<tr>
<td>Nemaguard</td>
<td>Krymsk-86</td>
</tr>
<tr>
<td>Red Titan</td>
<td>RootPacR</td>
</tr>
<tr>
<td>Viking</td>
<td>TemproPac</td>
</tr>
</tbody>
</table>
Merced County Rootstock Trial

Yields:

- Harvested annually since third leaf
- With the exception of Nemaguard, trees perform in respect to canopy size
- Significant branch losses within vigorous trees from crop-load and tree structure
Merced County Rootstock Trial

Nematode Susceptibility:

- Prior to planting, soil had detectable levels of Rootknot, Ring, and Lesion (P. vulnus) and grower strip fumigated with Telone-II
- Populations have been increasing over time within some rootstocks:
  - White: None Detected (Good thing!)
  - Green: Low (<25 per 500 g of soil)
  - Yellow: Medium (25-100 per 500 g of soil)
  - Red: High (100-250 per 500 g of soil)
  - Black: Very High (> 250 per 500 g of soil)
- Results suggest Krymsk-86 is susceptible to all plant parasitic nematodes, some P/A hybrids susceptible to Ring (e.g. Hansen, BH5)

<table>
<thead>
<tr>
<th>Rootstock</th>
<th>Rootknot</th>
<th>Ring</th>
<th>Lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlas</td>
<td>Medium</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>BB106</td>
<td>Medium</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>BH5</td>
<td>High</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Cadaman</td>
<td>Medium</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Empyrean-1</td>
<td>Medium</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Cornerstone</td>
<td>Medium</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Hansen 536</td>
<td>Very High</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>FloridaguardxAlnem</td>
<td>Low</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Nemaguard</td>
<td>Very High</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Krymsk-86</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Red Titan</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>RootPacR</td>
<td>Low</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>TemproPac</td>
<td>Medium</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Viking</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
Exploring Alternative Rootstocks in Butte County

Joe Connell, UC Farm Emeritus, Butte County
Nonpareil on Six Rootstocks

- Lovell
- Atlas
- Empyrean 1
- Rootpac R
- Krymsk 86
- Nickels
Tree Size as Measured by Trunk Circumference

- ‘Empyrean 1’ is the largest, followed by those on ‘Nickels’.
- Trees on ‘Lovell’ and ‘Krymsk 86’ are similar in trunk circumference.
- ‘Rootpac-R’ rooted trees are numerically smallest but statistically similar to trees on ‘Krymsk 86’.
Lovell, Krymsk 86 & Rootpac R are noticeably smaller after 5 seasons

Google Earth Photo of April 14, 2015.
5th leaf yield is mainly related to tree canopy size based on rootstock vigor (tree spacing is 24’x16’ or 113 trees per acre).


<table>
<thead>
<tr>
<th>Rootstock</th>
<th>3rd Leaf</th>
<th>4th Leaf</th>
<th>5th Leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lovell</td>
<td>0.65 cd</td>
<td>9.22 cd</td>
<td>12.62 b</td>
</tr>
<tr>
<td>Atlas</td>
<td>1.00 a</td>
<td>10.53 ab</td>
<td>18.23 a</td>
</tr>
<tr>
<td>Empyrean 1</td>
<td>0.61 d</td>
<td>11.69 a</td>
<td>19.32 a</td>
</tr>
<tr>
<td>Rootpac-R</td>
<td>0.79 bcd</td>
<td>9.07 d</td>
<td>13.74 b</td>
</tr>
<tr>
<td>Krymsk 86</td>
<td>0.93 ab</td>
<td>9.00 d</td>
<td>13.49 b</td>
</tr>
<tr>
<td>Nickels Hybrid</td>
<td>0.85 abc</td>
<td>10.28 bc</td>
<td>19.08 a</td>
</tr>
</tbody>
</table>

Values followed by the same letters are not significantly different from one another at P< 0.05 using Fisher's least significant difference (LSD) procedure.
Integration of Higher Tree Density and Minimal Pruning for Efficient Almond Production

Roger Duncan, UCCE, Stanislaus County
Goal when designing an almond orchard - maximize yield potential by maximizing light capture:

• Capture as much sunlight as early and for as long as possible.

• Each 1% of intercepted sunlight = 50 pounds of yield potential.
Almond Spacing & Pruning Trial

• Planted fall, 1999
• 37 acres
• Four tree densities
  – 10’ x 22’ (198 trees / acre)
  – 14’ x 22’ (141 trees / acre)
  – 18’ x 22’ (110 trees / acre)
  – 22’ x 22’ (90 trees per acre)
• Overlaid with four pruning strategies and two rootstocks (Nemaguard & Hansen)
1) Standard trained, standard annual pruning

2) Standard trained, unpruned after 2nd dormant
3) Minimal training & pruning, topped 1rst summer

4) Untrained, unpruned
Standard trained & pruned vs. Untrained & unpruned.

End of 3\textsuperscript{rd} Season.
## The Effect of Pruning on 2015 (16th Leaf) & Cumulative Yield

<table>
<thead>
<tr>
<th>Training &amp; Pruning Strategy</th>
<th>Nonpareil 2015 Yield (lb. / a)</th>
<th>Nonpareil Cumulative</th>
<th>Carmel 2015 Yield (lb. / a)</th>
<th>Carmel Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trained to 3 scaffolds; Annual, moderate pruning</td>
<td>1691 a</td>
<td>34,228</td>
<td>1548 a</td>
<td>32,230</td>
</tr>
<tr>
<td>Trained to 3 scaffolds; Unpruned after 2nd year</td>
<td>1597 a</td>
<td>35,359</td>
<td>1646 a</td>
<td>34,576</td>
</tr>
<tr>
<td>Trained to multiple scaffolds; Three annual pruning cuts</td>
<td>1538 a</td>
<td>33,400</td>
<td>1536 a</td>
<td>33,984</td>
</tr>
<tr>
<td>No scaffold selection; No annual pruning</td>
<td>1542 a</td>
<td>35,167</td>
<td>1685 a</td>
<td>35,971</td>
</tr>
</tbody>
</table>
Light Interception Dynamics of Different Pruning Methods

1% PAR = 50 pounds yield potential

- Conv. Pruning
- 3 cuts annually
- Trained not pruned
- Untrained, unpruned
Effect of Pruning on Yield to Date

- Pruning has not increased or sustained yield. Conventional annual pruning has reduced yield in most years so far.

- 15 years x $150 pruning costs = $2250

- Decrease in yield by about 1000 to 3500 pounds = loss of ~$2000 - $7000 / acre
  - Cumulative loss from annual pruning likely $5,000 - $9,000 / acre
Effect of Pruning on Yield to Date

- Sometimes pruning is needed for safety, equipment access, removing limb cankers, etc.

- Reason to prune should justify expense and yield loss
22’ x 22’ 6th season
10’ x 22’ 6th season
Smaller variety on medium vigor rootstock: Cumulative yield directly related to tree spacing.
The Effect of Tree Spacing on Cumulative Yield Through 16\textsuperscript{th} Season

Nonpareil on Nemaguard

\begin{itemize}
  \item 10' x 22': 38,892 lb / a
  \item 14' x 22': 38,894 lb / a
  \item 18' x 22': 36,785 lb / a
  \item 22' x 22': 35,399 lb / a
\end{itemize}

3493 lb.
Light Interception Dynamics of Differently Spaced Trees

1% PAR = 50 pounds yield
The Influence of Tree Spacing on the Number of Replanted Trees (on all 37 acres)
The Influence of Tree Spacing on Missing Canopy

<table>
<thead>
<tr>
<th>Cumulative Number of Replants</th>
<th>Square Footage of Missing Canopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>10’ x 22’</td>
<td>35</td>
</tr>
<tr>
<td>14’ x 22’</td>
<td>62</td>
</tr>
<tr>
<td>18’ x 22’</td>
<td>98</td>
</tr>
<tr>
<td>22’ x 22’</td>
<td>120</td>
</tr>
</tbody>
</table>
Effect of Tree Density on Yield to Date:

• Yield advantage to tighter spacing is highly dependent on inherent tree vigor
  – Smaller trees (varieties, rootstocks, etc.) will benefit most from tight spacing
  – Benefit may persist throughout orchard’s life
  – Large, vigorous trees may not have substantially higher yields at higher density.

• Advantages other than yield (smaller trees, easier to shake, fewer structural problems, fewer mummies, etc.)

• No disadvantage to close spacing yet (other than planting costs)
Mechanical Topping of Nonbearing Almond Trees

Roger Duncan, UCCE Stanislaus County
Why mechanically top young trees? The assumptions are:

- Reduce training costs
- Create a shorter, bushier, higher (earlier?) yielding tree
Stanislaus County Trial Training Strategies:

1. Mechanically topped 1st “dormant” (Nov. 2014) + minimal scaffold selection (by hand)
2. Mechanically topped 1st & 2nd dormant + scaffold selection (by hand)
3. Mechanically topped 1st & 2nd dormant, no scaffold selection
4. Standard “medium-long pruned” training by hand
5. “Short pruned” by hand
6. No scaffold selection / pruning

The test orchard:

- Nonpareil / Monterey / Fritz on Titan P/A Hybrid
- Spacing: 16’ x 20’
- Near Westley, CA (Westside)
After topping, November 2014

Not Topped

Topped
Untrained

“Standard” long pruning

Butcher job

8’ – 9’

7.5’

5.5’
Cost per Acre for Various Training Strategies

$18

$71

$66

$30 + $18 = $48

$30 + $53 = $83

*Labor valued at $12 / hour. Does not include cost of stacking and shredding brush.
Parameters to Measure:

• Pruning time / costs
• Tree height
• Trunk circumference
• Canopy light interception
• Tree failure / leaning / falling over, etc.
• Yield (3rd & 4th leaf)
### Effect of Training Techniques on Tree Size (End of 2\textsuperscript{nd} Leaf)

<table>
<thead>
<tr>
<th>Training Technique</th>
<th>Tree Height (ft)</th>
<th>Trunk Circumference (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nonpareil</td>
<td>Monterey</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untrained</td>
<td>12.9 A</td>
<td>13.9 A</td>
</tr>
<tr>
<td></td>
<td>36.5 A</td>
<td>32.8 A</td>
</tr>
<tr>
<td>Topped no scaffold selection</td>
<td>12.7 A</td>
<td>13.5 AB</td>
</tr>
<tr>
<td></td>
<td>34.6 B</td>
<td>31.3 BC</td>
</tr>
<tr>
<td>Topped with scaffold selection</td>
<td>12.5 A</td>
<td>13.6 AB</td>
</tr>
<tr>
<td></td>
<td>35.2 AB</td>
<td>31.5 B</td>
</tr>
<tr>
<td>Hand trained (&quot;long&quot; pruned)</td>
<td>12.5 AB</td>
<td>13.5 AB</td>
</tr>
<tr>
<td></td>
<td>35.6 AB</td>
<td>30.3 CD</td>
</tr>
<tr>
<td>Hand trained (&quot;short&quot; pruned)</td>
<td>11.9 B</td>
<td>13.1 B</td>
</tr>
<tr>
<td></td>
<td>33.2 C</td>
<td>30.1 D</td>
</tr>
</tbody>
</table>
Conclusions (and concerns):

- Mechanically topped trees were not shorter than standard hand trained or unpruned trees at the end of one year.
- Mechanical topping plus follow up scaffold selection was the most expensive treatment.
Conclusions (and concerns):

• Mechanically topped trees were not shorter than standard hand trained or unpruned trees at the end of one year.

• Mechanical topping plus follow up scaffold selection was the most expensive treatment.

• Will heading cuts all at same height be a problem?