Plant Nutrition Management in an Age of Expenses and Regulations (Part 1)
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Managing Nitrogen Efficiently

Patrick Brown
Why the focus on Nitrogen?

• Essential for plant growth and critical for crop yield
  • N is critical for photosynthesis, protein formation and growth
  • Almonds are among the most N demanding of any crop.

• Nitrogen that escapes the orchard is a pollutant
  • Negative impacts of N on Californian water and air resources are well documented.
  • Regulatory controls on its use are imminent.

• Nitrogen management is complex
  • Application of fertilizer N (inorganic and organic)
  • Current tools for monitoring and management are inadequate

Satisfy Demand-Prevent Losses-Maximize Efficiency?
Nitrogen is Essential for Almond Yields

Drip Irrigation

Kernel Yield (lb/ac)

Nitrogen Rate (lb/ac)

2009
2010
2011

N 125
N 200
N 275
N 350

3500
4000
4500
5000

2500
3000
3500
Nitrate concentrations in various California wells measured in 2007.

44 mg/L NO₃ = 10 mg/L NO₃-N

(some from animal manure)

(Ekdahl and others, 2009)
The Nitrogen Cycle: Nitrogen is essential for all agriculture and all forms of nitrogen (N-fixation, chemical and biological) are subject to loss to varying degrees.
Applying the Right Rate
• Match demand with supply (all inputs- fertilizer, organic N, water, soil).

At Right Time
• Maximize uptake minimize loss potential.

In the Right Place
• Ensure delivery to the active roots.

Using the Right Source
• Maximize uptake minimize loss potential.
The Basic Scientific Principles of Managing Crop Nutrients are Universal

1. Supply in plant available forms
2. Suit soil properties
3. Recognize synergisms among elements
4. Blend compatibility

1. Appropriately assess soil nutrient supply
2. Assess all available indigenous nutrient sources
3. Assess plant demand
4. Predict fertilizer use efficiency

1. Assess timing of crop uptake
2. Assess dynamics of soil nutrient supply
3. Recognize timing of weather factors
4. Evaluate logistics of operations

1. Recognize root-soil dynamics
2. Manage spatial variability
3. Fit needs of tillage system
4. Limit potential off-field transport
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4. Evaluate logistics of operations
What Do We Know and How Do We Manage?
Leaf Sampling and Critical Value Analysis

Table 26.2  Critical nutrient levels (dry-weight basis) in almond leaves sampled in July.

- Sampling protocols are well defined
- Non fruiting spur leaves
- July/August
- South West quadrant at 6’
- Contrast leaf analysis with standard Critical Values published in Almond Production Manual
  - Yield trials (N, K, B)
  - Leaf symptoms (P, S, Mg, Ca, Mn, Zn, Fe, Cu)
  - Unknown (Ni, Cl, Mo)

- Interpretation of results (NO R’ S!)
  - Leaf analysis can indicate a shortage but cannot define how to respond.
  - Thus: Fertilizer decisions are currently based on experience and an ‘estimate’ of fertilizer needs
  - No guidance on Rate, Timing, Placement or Source
Are Tissue Samples Collected and If So How Often?

On one of your typical almond orchards, how often are plant tissue samples collected? (Choose all that apply)

- Never: 40 respondents
- Less than once/year: 43 respondents
- Once/year: 307 respondents
- More than once/year: 98 respondents
- When problems are detected: 32 respondents
- I don't know: 5 respondents

>80% compliance

Brown et al, 2004
Do you think the University of California critical values are adequate to ensure maximal productivity in almonds?

>70% have little to no faith in the results or their use.

Brown et al, 2004
• Originally defined as a means to identify when a crop is ‘..just deficient..rather than just sufficient.. to define if, but not how much, fertilizer should be added..’
  • It was designed to detect deficiency.
  • It is not designed to determine how much fertilizer to apply
• The complexity of tissue sampling was recognized, but never adequately optimized for trees.
• Limitations of the method and the utility of the approach have been mostly forgotten.
Shoot Zn Distribution Through A Dormant Peach Tree (ppm)

Problem with leaf sampling: Sampling challenges.

- 16.3 - shaded
- 19.1 - sun exposed
- 28.5 - sun exposed
- 47.9 - shaded
- 39.7 - sun exposed
- 70.3 - shaded

Standard Sample: Fully Exposed non-fruiting leaves in late summer
Which leaf is the best leaf?

Not Deficient

Deficient
Critical Values are based on July/August sample. Early season CV’s have not been validated.

Current Practice: Late summer sample. Too late for current season response. Too early for next season planning (yield potential is defined by winter and spring weather)

**Challenge:** Develop early season sampling and interpretation methodologies.
Challenges of Sampling: Field Variability
(768 Individual Tree Samples. High Producing ‘Uniform’ Orchard)

Typical Sampling: 1 pooled sample per management unit
(Hypothetical) Field Mean 2.2% N (June): Critical Value 2.2% = OK?

No! Full productivity can only be achieved when all individuals are above 2.2%
What is the right target mean? (variability:response:cost:returns:yield)

Challenge: Develop sampling protocols that incorporate variability,
    have a clear cost:return basis, while remaining cost effective.
Summary: Tissue Testing for Almonds

Problems.

• Difficult to sample properly and hard to interpret. Sampling in the way most people currently do it, is a waste of money.

• Does not inform management practice

• UC critical values are probably correct at a tree level but a single ‘pooled’ sample does not provide enough information at an orchard level

Solutions

• Develop methodology for early season sampling and interpretation

• Establish statistically valid sampling patterns and interpretation

• Develop improved lower cost (remote sensing, hand held meters etc).

• Integrate sampling with a nutrient budget approach and an understanding of the processes.

Alternatives?
Alternate Approaches to Nutrient Management

Nutrient Budgeting:

Efficiently replacing nutrients removed from the field

Essential Components and Challenges:

Estimate current year demand (Last years yield, this years estimated yield, tree age, common sense)

- Improved techniques are under development (remote sensing, modeling etc)
- Yield monitoring

Measure and control inputs and losses (soil, fertilizer, irrigation, leaching, volatilization)

Manage efficiencies and interactions

- Synchronization and location of nutrient applications
- Monitoring crop response

How?
Daily accumulation rates and plant parts
(Russet Burbank potatoes, Oregon)
Potassium Aerial Accumulation
Wheat - California

K lbs / Ac

Yield 142 bu/ac

K: 4 – 10 lbs/ac/day

14% above ground

13% Grain

53% Head

20% Stem

14 ton Ha

Fig 2-1. The Feekes scale of wheat development.

GDU

Miller, 1990
Nutrient Demand: Whole tree

Harvesting:
5 mature trees x 5 times in a year
Whole Tree N Contents by Organ in Almond.

The scale of nutrient demand is determined by Yield.
The ability to predict yield and fertilize accordingly would greatly improve management.
Efficient Nutrient Management Approach
-the 4 R’s-

Applying the **Right Rate**
- Match demand with supply (all inputs - fertilizer, organic N, water, soil).

At **Right Time**
- Maximize uptake minimize loss potential.

In the **Right Place**
- Ensure delivery to the active roots.

Using the **Right Source**
- Maximize uptake minimize loss potential.
Thank You
Fertilizer prices have been increasing

Regulations on fertilizer use are increasing
- Water quality
- Air Quality
N, P, K fertilizer costs have more than doubled the last 10 years.

- **N cost directly tied to natural gas prices**
  - Natural gas US supply predicted to be stable but more costly to extract/produce
- **P & K prices tied to international market demand**
Trends in Fertilizer Costs

Prices also tied to oil prices (for extraction, formulation, transportation, etc.)

- Increasing energy use by Asia


Many types of crude oil are produced around the world. Variations in quality and location result in price differentials, but because oil markets are integrated globally, prices tend to move together.
Nitrogen Impacts the Environment

“Reactive Nitrogen” is every form of nitrogen other than N₂

EPA and CA agencies are regulating reactive nitrogen.

Forms of “reactive nitrogen”:

- NH₃⁻; NH₄⁺ (Ammonia) ➔ PM₂.₅, Water, N deposition
- N₂O (Nitrous Oxide) ➔ Greenhouse gas
- NOx (NO, NO₂ or Nitrogen Oxides) ➔ Ozone (Smog)
- NO₂⁻, NO₃⁻ (Nitrite, Nitrate) ➔ Ground and Surface Water
- Organic-N (N in organic matter) ➔ surface water
The Nitrogen Cascade

Galloway & Cowling, 2002; UNEP, 2003
Tainted water flows from taps of rural Valley homes

By Mark Grossi / The Fresno Bee
Saturday, Oct. 01, 2011 | 11:00 PM

TOOLEVILLE -- From her living room window, Valley resident Candace Cleaver looks south where pristine snowmelt flows to farm fields.

She loves walking along the canal, knowing the spring water is pure.

But with nearly 1 million acres of farming in Tulare County, fertilizers still are considered a prime suspect.

A group of UC Davis professors, led by hydrologist Harler, will try to figure out the extent of nitrate leaching from the farms to the canal.

But there are concerns that the nitrate problems may be getting worse.

Record 'dead zone' predicted in Gulf of Mexico

By Doyle Rice, USA TODAY
Updated 2011-06-17 3:52 PM

Click the globe to calculate your personal nitrogen footprint.

Personal N Footprint Calculator

But applied decades ago may still be washing into the canal some 70 miles south, and some of that could have sunk into the soil and eventually leached into the aquifer.
Permitting Program of the Central Valley Regional Water Board for agricultural discharges into surface waters

• Ground Water now added to the permit

• Main concern is nitrate and salt leaching into ground water
  • Nitrates exceed drinking water limits in some locations of the Central Valley (e.g. Tulare Basin)

• Report to the Legislature due early 2012 on Nitrate in Ground Water
  • UCD is assessing levels, sources, trends for Tulare and Salinas Basins
  • Discuss possible mitigation measures.
Ground Water: Nitrate Levels in Tulare Basin

Average: Non-Dairy

N max limit
Drinking Water
= 10 mg/L N

Data from Draft Report on Nitrate in Ground Water to Legislature (SBX2-1) by UC-Davis, May 3, 2011
Requirements of Expanded Irrigated Lands Program

1) Any grower with irrigated lands in the Central Valley will need to join a coalition

2) Each coalition will be responsible for finding mechanisms to reduce potential leaching/run off concerns
   • Will need documentation from growers of changed practices

3) Each grower expected to review their fertilizer practices and develop measures to reduce potential impacts from fertilizer inputs.

4) Where nitrates in ground water are a known issue, growers expected to develop and follow a Nutrient Management Plan.

Fees increasing as part of budget agreement
Nitrous Oxide ($N_2O$) is 300x more potent GHG than CO$_2$.

- Formed by bacteria in the soil.
- ARB had planned to regulate fertilizers

ARB now looking for off-set protocols for voluntary reductions in ag $N_2O$ emissions.

- Off-sets: voluntary reductions in greenhouse gases that can be bought by entities to meet mandated reductions
Role of Research

Current ABC funded research is critical for ensuring almond growers can continue to produce a high protein, highly nutritious food.

• Seeking refinements to increase N use efficiency.

• Seeking better tools to help assess when and how much N is needed by the trees.

• Developing data on actual N₂O emissions and possible carbon off-sets

• Nutrient Management Sustainability Module
Pollination Update
Leaf Sampling And Interpretation Methods For CA Almond Orchards.

Sebastian Saa, UC Davis
What Do We Currently Do To Manage Our Orchards?

Sample in July

Table 26.2  Critical nutrient levels (dry-weight basis) in almond leaves sampled in July.

<table>
<thead>
<tr>
<th>Nutrient (N)</th>
<th>Deficient below</th>
<th>Adequate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus (P)</td>
<td>Adequate</td>
<td></td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>Deficient below</td>
<td>Adequate over</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>Adequate over</td>
<td></td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>Adequate over</td>
<td></td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>Excessive over</td>
<td></td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td>Excessive over</td>
<td></td>
</tr>
<tr>
<td>Boron (B)*</td>
<td>Deficient below</td>
<td>Adequate</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>Adequate over</td>
<td></td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>Adequate over</td>
<td></td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>Deficient below</td>
<td></td>
</tr>
</tbody>
</table>

*Critical values for boron deficiency and toxicity are currently being revised. Hull boron >300 ppm is excessive. Leaf sampling is not effective to determine excess boron.
Problem Statement: Recall to Dr. Brown’s Lecture

Critical Value

Are tissue samples being used to guide fertilizer management?

Do you think the University of California critical values are adequate to ensure maximal productivity in almonds?

<table>
<thead>
<tr>
<th>Response</th>
<th># Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>150</td>
</tr>
<tr>
<td>Somewhat</td>
<td>183</td>
</tr>
<tr>
<td>No</td>
<td>51</td>
</tr>
<tr>
<td>I don't know</td>
<td>128</td>
</tr>
</tbody>
</table>
Possible Reasons To This Problem:

- Current Sampling Protocol is too late in year to make in season adjustments.
- Samples collected do not always represent the true nutrient status of the orchard as a whole.
- Our current CV’s may not apply in all cases or may be wrong.
Objectives:

- Develop methods to sample in April and relate that number to July critical value.

- Develop method for grower to sample his field (recognizing that typical practice is only 1 sample per field is generally collected).

- Reevaluate the current CV’s.
**Experiment:**

- **Four sites from California’s major almond producing regions**

<table>
<thead>
<tr>
<th>Location</th>
<th>Arbuckle</th>
<th>Modesto</th>
<th>Madera</th>
<th>Belridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varieties</td>
<td>NP – 50% B – 25% A – 12.5% C – 12.5%</td>
<td>NP – 50% A – 25% WC – 25%</td>
<td>NP - 50% C – 25% M – 25%</td>
<td>NP – 50% M – 50%</td>
</tr>
<tr>
<td>Spacing</td>
<td>22’ x 18’ (110 trees/ac)</td>
<td>21’ x 21’ (99 trees/ac)</td>
<td>21’ x 17’ (122 trees/ac)</td>
<td>24’ x 21’ (86 trees/ac)</td>
</tr>
<tr>
<td>Irrigation</td>
<td>Drip</td>
<td>Microsprinkler</td>
<td>Microsprinkler</td>
<td>Microsprinkler</td>
</tr>
</tbody>
</table>
Design and Sampling

- 114 trees x 4 Sites x 3 years.

- Yield.
  (About 1,130 data points)

- 5 in-season nutrient samples.
  (8,500 x 11 = 93,500 data points)
Approach: Multi site, multi year, multi tissue and multi element analysis.

Can we sample in April and predict July?
Two Models To Answer The Same Question

- Model one uses all the April information from F2 spurs to predict the July nitrogen value.
- Model two uses the nitrogen NF information from April to predict the July nitrogen value.
- Both models also predict what percentage of the trees are above or below the current July nitrogen critical value.
- Both models work well but we do not yet know which model is best (validation will be done next year).
## Results: Cross-Validation Model 1

<table>
<thead>
<tr>
<th>Site</th>
<th>Year</th>
<th>July Nitrogen Predicted</th>
<th>July Nitrogen Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arbuckle</td>
<td>8</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Belridge</td>
<td>8</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Madera</td>
<td>8</td>
<td>2.5</td>
<td>2.4</td>
</tr>
<tr>
<td>Modesto</td>
<td>8</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Arbuckle</td>
<td>9</td>
<td>2.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Belridge</td>
<td>9</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Madera</td>
<td>9</td>
<td>2.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Modesto</td>
<td>9</td>
<td>2.6</td>
<td>2.7</td>
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<tr>
<td>Arbuckle</td>
<td>10</td>
<td>2.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Belridge</td>
<td>10</td>
<td>2.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Madera</td>
<td>10</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Modesto</td>
<td>10</td>
<td>2.4</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Expected% of trees below 2.2% in July

Results: Model 2

Percentage of Trees Below 2.2% in July vs. Nitrogen (%) in April

- Black Line = predicted
- Blue Line = upper CI
- Pink Line = Lower CI
Objectives

- Develop methods to sample in April and relate that number to July critical value.

- Develop a protocol for growers to sample their fields properly (recognizing that only 1 sample per field is generally collected).

On one of your typical almond orchards, how often are plant tissue samples collected? (Choose all that apply)

- Never: 40 respondents
- Less than once/year: 43 respondents
- Once/year: 307 respondents
- More than once/year: 98 respondents
- When problems are detected: 32 respondents
- I don’t know: 5 respondents
If You Can Only Collect One Sample…

How do you represent the true nutrient status of your orchard as a whole? What is the best way to sample?

Distance from Tree to Tree

Number of trees

Criteria
We attempt to test if and when trees are ‘communicating’.

Plot Map (same for all sites)

54 Grid Tree  80 Sub - Grid Tree

START

ABC  1  11  21  31  41  51  61  71  81

ABC  12  22  32  42  52  62  72  82

ABC  13  23  33  43  53  63  73  83

ABC  14  24  34  44  54  64  74  84

ABC  15  25  35  45  55  65  75  85

ABC  16  26  36  46  56  66  76  86

ABC  17  27  37  47  57  67  77  87

ABC  18  28  38  48  58  68  78  88

ABC  19  29  39  49  59  69  79  89

ABC  20  30  40  50  60  70  80

ABC  21  31  41  51  61  71  81

ABC  22  32  42  52  62  72  82

ABC  23  33  43  53  63  73  83

ABC  24  34  44  54  64  74  84

ABC  25  35  45  55  65  75  85

ABC  26  36  46  56  66  76  86

ABC  27  37  47  57  67  77  87

ABC  28  38  48  58  68  78  88

ABC  29  39  49  59  69  79  89

ABC  30  40  50  60  70  80

ABC  31  41  51  61  71  81

ABC  32  42  52  62  72  82

ABC  33  43  53  63  73  83

ABC  34  44  54  64  74  84

ABC  35  45  55  65  75  85

ABC  36  46  56  66  76  86

ABC  37  47  57  67  77  87

ABC  38  48  58  68  78  88

ABC  39  49  59  69  79  89

ABC  40  50  60  70  80

ABC  41  51  61  71  81

ABC  42  52  62  72  82

ABC  43  53  63  73  83

ABC  44  54  64  74  84

ABC  45  55  65  75  85

ABC  46  56  66  76  86

ABC  47  57  67  77  87

ABC  48  58  68  78  88

ABC  49  59  69  79  89

ABC  50  60  70  80

ABC  51  61  71  81

ABC  52  62  72  82

ABC  53  63  73  83

ABC  54  64  74  84

ABC  55  65  75  85

ABC  56  66  76  86

ABC  57  67  77  87

ABC  58  68  78  88

ABC  59  69  79  89

ABC  60  70  80

ABC  61  71  81

ABC  62  72  82

ABC  63  73  83

ABC  64  74  84

ABC  65  75  85

ABC  66  76  86

ABC  67  77  87

ABC  68  78  88

ABC  69  79  89

ABC  70  80

ABC  71  81

ABC  72  82

ABC  73  83

ABC  74  84

ABC  75  85

ABC  76  86

ABC  77  87

ABC  78  88

ABC  79  89

ABC  80

1000 ft

= 1st set of sampling trees (3 spur types)

= Experimental trees not sampled

= Nut sampled tree underneath star

Rows ↔
Spatial Correlation Conclusions

For the case of nitrogen, we could not detect tree to tree ‘communication’ in distances farther than 30 yards. *(CA almond trees do not talk to each other much).*

However, we do not know if there is ‘communication’ at shorter distances.

Then, “as conservative protocol” we propose that samples are collected at least 30 yards away.
Number of Pooled Trees Needed In April To Estimate The True Mean of Nitrogen.

<table>
<thead>
<tr>
<th>Number of Acres</th>
<th>Trees needed at 95% Confidence</th>
<th>Trees needed at 90% Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>25</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
<td>19</td>
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<tr>
<td>10</td>
<td>28</td>
<td>19</td>
</tr>
<tr>
<td>50</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>100</td>
<td>28</td>
<td>20</td>
</tr>
</tbody>
</table>

Note: 1 acre is assumed to be 100 trees

Pooled trees = Number of trees from which leaves must be collected and pooled into a single bag for a single nutrient analysis.
Preliminary Sampling Criteria

- Collect leaves from 18 to 28 trees in one bag.
- Each tree sampled at least 30 yards apart.
- In each tree collect leaves around the canopy from at least 8 well exposed spurs located between 5-7 feet from the ground.
- In April, collect samples at 8121 GDH +/- 1403 (43 days after full bloom (DAFB) +/- 6 days).
- If you would like to collect samples in July, then collect samples at 143 DAFB +/- 4 days.
Objectives

- Develop methods to sample in April and relate that number to July critical value.
- Develop method for grower to sample his field (recognizing that only 1 sample per field is generally collected).
- Reevaluate the current CV’s ➔ integrate with nutrient budget approach described in the next talk.
Conclusions: In The Past

- We only had the Almond Fruit Production Manual table.
Conclusions: In The Present

- We have developed two models to predict July Nitrogen concentration using April data.

- Both models measure orchard variability and calculate the percentage of the trees that will be above or below the current July critical value.

- In other words, both models can provide the information needed to maximize productivity.
Conclusions: In The Present

- ...However, guaranteeing maximal productivity does not guarantee maximal profitability nor best management.

- We have assumed that field variability exists and cannot be managed – that is not correct.

- To really optimize sustainability, leaf sampling and analysis and subsequent management must also consider economic and environmental factors.
Conclusions: In The Future

- We must not only recognize and interpret orchard variability, we should attempt to control (or reduce) it.
Thanks!

Sebastian Saa
Emilio Laca
Patrick Brown
Applying the Right Rate
• Match demand with supply (all inputs- fertilizer, organic N, water, soil).

At Right Time
• Maximize uptake minimize loss potential.

In the Right Place
• Ensure delivery to the active roots.

Using the Right Source
• Maximize uptake minimize loss potential.
Determining the Right Rate

Nutrient Budget Approach

• Knowledge of growth and development to develop nutrient demand curves

• Knowledge of nutrient rate and timing
Suitability of Almond for Nutrient Budget Management

- Mature almond tree is relatively determinate in growth pattern
- Majority of nutrients are partitioned to fruit
- Irrigation systems and fluid fertilizers have made on demand fertilizer application easy

Patrick Brown unpublished data
Fertility Experiment

Treatments
- 4 Nitrogen rates – 125, 200, 275 and 350lb/ac
- 2 Nitrogen Sources- UAN 32 and CAN 17
- 3 Potassium Source- 100, 200 and 300lb/ac
- 3 Potassium Sources- SOP, SOP+KTS and KCl @200lb/ac

Irrigation Types
- Fan Jet and Drip

Fertigation
- 4 times during the season
  - 20, 30, 30 and 20% in February, April, June and October

Samples Collection
- Leaf and Nut samples collected from 768 individual trees five time in season
- All trees individually harvested
Large experiment covering approximately 100 acres.

768 trees individually monitored for nutrients, yield, light interception, disease, water.

Trees were 9 leaf in 2008.

Nonpareil - Monterey
Preliminary Findings
Leaf Nutrient Content 2010

- Nitrogen (%)
- Phosphorus (%)
- Potassium (%)
- Calcium (%)
- Magnesium (%)
- Sulfur (ppm)

Leaf Nutrient Concentration vs. Days After Full Bloom
No effect of K application rate or tissue K has been observed.
## Kernel Yield (lb/ac)

### 2010

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>N UAN 32</th>
<th></th>
<th></th>
<th></th>
<th>N CAN 17</th>
<th></th>
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<tr>
<td></td>
<td>125</td>
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<td>275</td>
<td>350</td>
<td>125</td>
<td>200</td>
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<tr>
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<td>3,453</td>
<td>3,765</td>
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<td>2,622</td>
<td>3,313</td>
<td>3,960</td>
<td>3,728</td>
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<td>2,584</td>
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### 2011

<table>
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<tr>
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<th></th>
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<th>N CAN 17</th>
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<td>350</td>
<td>125</td>
<td>200</td>
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<tr>
<td>Drip</td>
<td>3,732</td>
<td>4,229</td>
<td>4,696</td>
<td>4,775</td>
<td>3,564</td>
<td>4,365</td>
<td>4,833</td>
<td>4,969</td>
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<td>c</td>
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<tr>
<td>Fan Jet</td>
<td>3,744</td>
<td>4,048</td>
<td>4,480</td>
<td>4,406</td>
<td>3,746</td>
<td>4,161</td>
<td>4,420</td>
<td>4,361</td>
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<td>b</td>
<td>a</td>
<td>a</td>
</tr>
</tbody>
</table>

Means not followed by the same letter are significantly different at 10%. Statistics are only within irrigation type.
Yield Response to Nitrogen

Drip Irrigation

- 2009
- 2010
- 2011

N 125, N 200, N 275, N 350
<table>
<thead>
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<th></th>
<th></th>
<th></th>
<th>N CAN 17</th>
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<th>125</th>
<th>200</th>
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</thead>
<tbody>
<tr>
<td>Drip</td>
<td>9,328</td>
<td>10,642</td>
<td>11,667</td>
<td>12,356</td>
<td>8,796</td>
<td>10,298</td>
<td>11,844</td>
<td>12,139</td>
<td></td>
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<td></td>
<td>d</td>
<td>c</td>
<td>b</td>
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<td>c</td>
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<td>a</td>
<td>a</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Fan Jet</td>
<td>9,156</td>
<td>10,245</td>
<td>11,201</td>
<td>11,314</td>
<td>9,563</td>
<td>10,345</td>
<td>11,539</td>
<td>11,109</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>c</td>
<td>b</td>
<td>a</td>
<td>a</td>
<td>c</td>
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<td>a</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means not followed by the same letter are significantly different at 10%. Statistics are only within irrigation type.
Nutrient Export By 1000lb Kernel

- **Nitrogen**
- **Phosphorus**
- **Potassium**
- **Calcium**
- **Magnesium**
- **Sulfur**

Days After Full Bloom:
- Nitrogen: 20, 40, 60, 80, 100, 120, 140, 160, 180, 200
- Phosphorus: 20, 40, 60, 80, 100, 120, 140, 160, 180, 200
- Potassium: 20, 40, 60, 80, 100, 120, 140, 160, 180, 200
- Calcium: 20, 40, 60, 80, 100, 120, 140, 160, 180, 200
- Magnesium: 20, 40, 60, 80, 100, 120, 140, 160, 180, 200
- Sulfur: 20, 40, 60, 80, 100, 120, 140, 160, 180, 200

Nutrient Accumulation by 1000lb Kernel (lb):
- Nitrogen: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20
- Phosphorus: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20
- Potassium: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20
- Calcium: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20
- Magnesium: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20
- Sulfur: 0, 0.8, 1.2, 1.6, 2.0, 2.4, 2.8
NPK Export by 1000lb Kernel in 2009-10 (lb)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nitrogen Rate (lb/ac)</td>
<td>Nitrogen Rate (lb/ac)</td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>200</td>
</tr>
<tr>
<td>N</td>
<td>53</td>
<td>56</td>
</tr>
<tr>
<td>P</td>
<td>7.5</td>
<td>7.4</td>
</tr>
<tr>
<td>K</td>
<td>75</td>
<td>73</td>
</tr>
</tbody>
</table>

Means not followed by the same letter are significantly different at 10%.
Nitrogen Fertilization And Fruit N Content (2010)

The graph illustrates the fruit nitrogen content (%) over days after full bloom for different nitrogen fertilization levels. The data shows a decline in fruit nitrogen content as the days after full bloom increase. The nitrogen fertilization levels are represented by different colors:
- N 125lb/ac
- N 200lb/ac
- N 275lb/ac
- N 350lb/ac

Each line represents the mean nitrogen content for the respective fertilization level, with error bars indicating the variability. The graph demonstrates the impact of nitrogen fertilization on fruit nitrogen content throughout the growth period.
July Leaf N and Hull+Shell and Kernel N at harvest

**July Leaf N vs Hull+Shell N**

- N 125lb/ac
- N 200lb/ac
- N 275lb/ac
- N 350lb/ac

<table>
<thead>
<tr>
<th>July Leaf Nitrogen (%)</th>
<th>Nitrogen in Hull+Shell at Harvest (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.9</td>
<td>0.5</td>
</tr>
<tr>
<td>2.0</td>
<td>0.6</td>
</tr>
<tr>
<td>2.1</td>
<td>0.7</td>
</tr>
<tr>
<td>2.2</td>
<td>0.8</td>
</tr>
<tr>
<td>2.3</td>
<td>0.9</td>
</tr>
<tr>
<td>2.4</td>
<td>1.0</td>
</tr>
</tbody>
</table>

- **R2**: 0.31
- **R2 Adj**: 0.27

**July Leaf N vs Kernel N**

<table>
<thead>
<tr>
<th>July Leaf Nitrogen (%)</th>
<th>Nitrogen in Kernel at Harvest (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.9</td>
<td>3.4</td>
</tr>
<tr>
<td>2.0</td>
<td>3.5</td>
</tr>
<tr>
<td>2.1</td>
<td>3.6</td>
</tr>
<tr>
<td>2.2</td>
<td>3.7</td>
</tr>
<tr>
<td>2.3</td>
<td>3.8</td>
</tr>
<tr>
<td>2.4</td>
<td>3.9</td>
</tr>
<tr>
<td>2.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>

- **R2**: 0.49
- **R2 Adj**: 0.46
Fruit and Kernel weight

Fruit weight (gram/fruit)

Kernel weight (gram/kernel)
N Fertilization increases Shelling Percentage

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>N UAN 32</th>
<th></th>
<th></th>
<th></th>
<th>N CAN 17</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>125</td>
<td>200</td>
<td>275</td>
<td>350</td>
<td>125</td>
<td>200</td>
<td>275</td>
<td>350</td>
</tr>
<tr>
<td>Drip</td>
<td>25.8</td>
<td>28.7</td>
<td>28.4</td>
<td>29.8</td>
<td>25.5</td>
<td>27.4</td>
<td>29.9</td>
<td>28.0</td>
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<tr>
<td></td>
<td>b</td>
<td>a</td>
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<td>a</td>
<td>c</td>
<td>b</td>
<td>a</td>
<td>b</td>
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<tr>
<td>Fan Jet</td>
<td>26.2</td>
<td>28.0</td>
<td>28.3</td>
<td>28.2</td>
<td>26.6</td>
<td>27.5</td>
<td>30.4</td>
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<td>a</td>
<td>b</td>
<td>b</td>
<td>a</td>
<td>b</td>
</tr>
</tbody>
</table>

Means not followed by the same letter are significantly different at 10%.
Statistics are only within irrigation type.
Shelling percentage is on the basis of clean 4lb sample.
Effect Of N Fertilization On Hull Rot

Treatments
A= N 125lb/ac
B= N 200lb/ac
C= N 275lb/ac
D= N 350lb/ac
Nitrogen Use Efficiency 2008 - 2010

NUE = N Export in Fruit/N Applied
Relative Greenhouse Gas Generation by Almond, Wheat and Maize

(Schellenberg et al. Submitted; Linquist et al. 2011)
Conclusions

- 1000lb kernel removes from 55 (at a leaf N of 2.0% in July) - 70lb N (at a leaf N of 2.4% in July), 8lb P and 80lb K.

- 80% of N, 75% of P and K accumulates in the fruit before 120 DAFB (mid June in 2010).

- In this trial a N rate of 275lb/ac maximized yield (4,700 lb acre) and there was no benefit from N application in excess of this value.

- A Nutrient Use Efficiency (N removed in harvest/N applied) of 75-85% was observed for N rate 275lb/ac rate.

- Although significant differences in leaf K status were observed in 2010, however; no statistically significant differences in yield have been observed.
In this orchard we have approached the 4 R’s

Applying the **Right Rate**
- Match demand with supply (all inputs- fertilizer, organic N, water, soil).

At **Right Time**
- Fertigate coincident with demand.

In the **Right Place**
- Ensure delivery to the active roots.

Using the **Right Source**
- Soluble, compatible and balanced.
An NUE of 65-75% is Among The Highest Ever Measured In Agriculture – Is That Good Enough?

75% efficiency = 50 lbs N/acre/yr (x 500,000+ acres)
= 25,000,000 lbs N/yr

However small changes make a big impact.
• A 25 lb reduction in N application or 15% increase in efficiency reduces loss by 50%.

**Next Steps:**
Adapt fertilization to real yield potential (next step)
Apply N coincident with tree demand (see Brown and Hopmans posters)
Keep fertilizer N in the root zone (see Sanden, Brown and Hopmans posters)
Manage variability (next step)
Monitor for soil and plant accumulation (see Brown poster)
Thank You
Poster Session 2 and Coffee Break: Dedicated Trade Show
Great Salt Lake Minerals Corporation
A Compass Minerals Company
Follow us on Twitter @almondboard

Be sure to use #almondconf on all your conference tweets
Plant Nutrition Management in an Age of Expenses and Regulations (Part 2)
Plant Nutrition Management in an Age of Expenses and Regulations (Part 2)

Moderator: Bob Curtis, ABC
Gabriele Ludwig, ABC

Presenters:
Blake Sanden, UC Cooperative Extension
Jan Hopmans, UC Davis
Will Horwath, UC Davis
Almond Irrigation: Strategies & Alternatives

Blake Sanden – Irrigation Advisor, Kern County
http://cekern.ucdavis.edu/Irrigation_Management/
1: something basic <the essentials of astronomy>

2: something necessary, indispensable, or unavoidable (Merriam-Webster's Dictionary)

3: making 4,000 lb/ac nut meats!
   (Westside almond growers)
“Essential” is just the basics, right? So can flood irrigation with 8 inch alfalfa valves @ 200 gpm be optimal?
What about 18 inch valves @ 2000 gpm?
Micro-irrigation system capable of injecting fertilizer and applying 0.6 to 1.5 inches/day
... or do you need this kind of system ...
... and this much technology?
YES ...
NO ...

DEPENDS.
What’s the critical process that keeps the crop growing?

- Optimal photosynthesis
- Maximum carbon dioxide uptake
Reduced water, deficit irrigation, causes less turgor pressure in the plant, reduces the size of stomatal openings; thus decreasing the uptake of carbon dioxide and reducing vegetative growth.
3-point sermon:

- Understanding soil water holding characteristics, irrigation system characteristics & monitoring
- Crop water requirements (ET), CIMIS
- Fertigation options (just a teaser)
- Irrigation & crop salinity tolerance
Creating The Efficient Field Water Balance – Your Soil Moisture Checking Account!

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

**The Water Budget Method of Irrigation**

1. When?--------After 7 days
2. How much?--Apply 2.10 inches of water + losses (Efficiency consideration)
The “dirt” is the thing. Know your soil!

IDEAL: deep, well drained, non-alkali sandy to sandy clay loam
Soil Texture Determines Available Water Holding Capacity

SOIL TEXTURE
“FEEL METHOD”

AWHC = %Volume = \frac{\text{inch depth of water}}{1 \text{ foot depth of soil}}
The Soil & Irrigation System Are The “ESSENTIAL” Integrating Factors For Creating An Optimal Water Balance.

California crops sit most firmly on a chair with 4 legs!
So Point 1: If I understand my soil water holding capacity and schedule accordingly, then can flood irrigation be as “effective” as micro/drip?

(1st leaf almonds needing to grow as much vegetative matter as possible)
Irrigation non-uniformity can have severe impacts on water use and yields
Field measured DU for 1,351 irrigation systems on 152,721 acres in Kern County, 1988 to 2005.

NW Kern RCD Mobile Irrigation Lab Irrigation Systems Distribution Uniformity
1988-92 vs. 2001-05
How do I calculate total available water with microsprinklers @ 1.5 in/day?...
Summed 0-6 ft water content 6/24/09 after 24 hour irrigation
.... or account for “subbing” in a double-line drip?
Estimating Water Holding Capacity & Microirrigation Set Times for Orchards

### Refill Times for Different Soil Textures and Micro Systems

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Available Soil Moisture (in/ft)</th>
<th>Avg Drip Subbing Diameter from 1 to 4' Depth (ft)</th>
<th>Dble-Line Drip 1-gph, 10 per tree (irrig hrs)</th>
<th>Moisture Reserve @ 0.28&quot;/day (days)</th>
<th>10 gph Fanjet, 1 per tree (irrig hrs)</th>
<th>Moisture Reserve @ 0.28&quot;/day (days)</th>
<th>14 gph Fanjet, 1 per tree (irrig hrs)</th>
<th>Moisture Reserve @ 0.28&quot;/day (days)</th>
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<tbody>
<tr>
<td>Sand</td>
<td>0.7</td>
<td>2</td>
<td>2.2</td>
<td>0.3</td>
<td>11.6</td>
<td>1.6</td>
<td>12.5</td>
<td>2.4</td>
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<td>Loamy Sand</td>
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<td>3</td>
<td>7.8</td>
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<td>19.6</td>
<td>2.7</td>
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<td>4</td>
<td>17.5</td>
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<td>3.6</td>
<td>28.3</td>
<td>5.4</td>
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<td>5</td>
<td>35.9</td>
<td>4.9</td>
<td>37.1</td>
<td>5.0</td>
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<td>7.3</td>
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<td>6</td>
<td>43.1</td>
<td>5.8</td>
<td>39.7</td>
<td>5.4</td>
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<td>1.3</td>
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<td>31.1</td>
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<td>3.9</td>
<td>29.5</td>
<td>5.6</td>
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<td>Sandy Clay</td>
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<td>7</td>
<td>44.7</td>
<td>6.0</td>
<td>37.6</td>
<td>5.1</td>
<td>38.3</td>
<td>7.2</td>
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<td>54.3</td>
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<td>42.6</td>
<td>5.8</td>
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<td>9</td>
<td>68.2</td>
<td>9.2</td>
<td>50.6</td>
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<td>9.6</td>
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<td>Silty Clay</td>
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<td>86.2</td>
<td>11.6</td>
<td>64.0</td>
<td>8.6</td>
<td>63.8</td>
<td>12.1</td>
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<tr>
<td>Clay</td>
<td>2.2</td>
<td>10</td>
<td>87.8</td>
<td>11.9</td>
<td>62.3</td>
<td>8.4</td>
<td>61.5</td>
<td>11.6</td>
</tr>
</tbody>
</table>

Note: Peak water use @ 0.28"/day and 20 x 22' spacing = 74 gallons/day/tree. 0.20"/day = 55 gallons/day/tree.

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

---

1Based on a tree spacing of 20 x 22'. Drip hoses 6' apart. 10 gph fanjet wets 12' diameter. 14 gph fanjet @ 15' diameter.
So how do I look into the crop rootzone to optimize my field water & fertilizer budget?
Hand-powered twist augers

3 foot push or slide hammer-type probe
A device using low levels of radiation, the neutron probe, was developed in the 1960’s for checking soil moisture. Used mostly by researchers and irrigation consultants, it is often the standard check for the accuracy of other instruments -- largest sample “volume” to estimate moisture.
Checking reliability of dry readings on tensiometers with a soil core obtained with a 3 foot hammer probe

Sandy Clay Loam, slightly calcareous
Tensiometers, Watermarks for Soil Moisture Tension (matric potential)
A variety of loggers can be used for various sensors: Costs from $100 (Hobo) to $5,000 (Campbell)
Watermark Readings from AM400 logger, reading 3x/day

**FRITZ**

**Soil Moisture Tension (cb)**

- 18"
- 36"
- 60"

**Almond (Fritz)**

- Almond (Fritz)
- Sandy clay loam

**NONPAREIL**

**Soil Moisture Tension (cb)**

- 18"
- 36"
- 60"

**Almond (Non Peril)**

- Almond (Non Peril)
- Sandy clay loam
Electronics, data loggers, weather stations and multi-stage sensors can increase the cost rapidly up to $5,000 to $10,000. Does this degree of sophistication pay off?
PureSense Comprehensive Soil Moisture & Irrigation Summary for Almonds
Equipment for checking soil Moisture

• Seat of the pants still most common method
3-point sermon:

- Understanding & monitoring soil water holding characteristics
- Crop water requirements (ET), CIMIS
- Fertigation options (just a teaser)
- Irrigation & crop salinity tolerance
Crop water use is made up of EVAPORATION (E) From The Wet Soil And Leaves And TRANSPIRATION (T), hence ET.
Calculating ET for crops:

\[ E_{T_{crop}} = E_{T_0} \times K_c \times E_f \]

- \( E_{T_0} \) = reference crop (tall grass) ET
- \( K_c \) = crop coefficient for a given stage of growth as a ratio of grass water use. May be 0 to 1.3, standard values are good starting point.
- \( E_f \) = an “environmental factor” that can account for immature permanent crops and/or impact of salinity. May be 0.1 to 1.1, determined by site.
The whole Central Valley covers Zones 12 to 16: for an “normal year” ETo of 53.3 to 62.5 in/yr, with most area @ 53 to 58 inches.
Do almonds really need as much water as alfalfa – 52 to 56 inches?

The old recommendation was 42-45 inches?

What’s the right ET?
Fertigation: Case study of interaction of water and nutrient management in almonds: 2008-2012

Blake Sanden – Irrigation & Agronomy, Kern County

Collaborative USDA Specialty Crops and California Almond Board Project
Measuring nutrient and irrigation response under Microsprinklers and Double-line Drip.
What are Optimal Almond Kc’s And crop ET?

- Older Published Kc
- Sanden SSJV Kc
- 2008 - 11 Measured Kc

Avg Kc 4/1 - 11/15
Older Avg Kc = 0.81  Calculated Avg ET
Sanden Avg Kc = 0.93  42.3 in  (4/1 - 11/15)
Measured Avg Kc = 1.04  52.3 in (year)

(Using CIMIS Zone 15 "Historic Eto" = 57.9 in)
So, if I give the tree 60 inches of water do I get more yield?
Single Tree Yield By Tree Neutron Probe Depletion + Applied Irrigation ET

![Graph showing the relationship between single tree yearly ET by soil water depletion and kernal yield over the years 2008 to 2011. The graph includes data points for each year and trend lines for 2008, 2009, 2010, and 2011.](image-url)
3-point sermon:

- Understanding & monitoring soil water holding characteristics
- Crop water requirements (ET), CIMIS
- Fertigation options (just a teaser)
- Irrigation & crop salinity tolerance
Winter banding of sulphate of potash
($K_2SO_4$, or simply SOP, @ 125 lb/ac K)
Chemigation: Getting It In

- **Venturi (Mazzei):** chemical injected into vacuum created by pressure differential, usually fertilizer, but injection rate easily adjusted for small volume.
Main fertility trial:
Direct injection 4x/year
Bloom  20%
April  30%
June   30%
Post Harvest  20%
2011 installation of 5 Grundfos dosing pumps for “spoon-feed” fertigation trial
2011 Nonpareil Yields for Episodic vs. Continuous Fertigation

4 fertigations / yr treatments

Whole Plot Kernal Yield (final lb/ac)

Continuous “spoon-feed” fertigation treatments

T1: F300 Zero K
T2: F300 75KTS
T3: F300 75KN
T4: C300 200SOP
T5: C300 75KN
T6: C300 200KN
T7: C300 300KN
T8: C300 150KCL 150KN

Treatment -- K type/rate

Drip
Fanjet
Conclusions

• Know soil AWHC and volumetric storage
• Know net infiltration and/or system application capacity to avoid stress and fertilizer leaching
• Organize system & ET data for records
• Plan irrigations using “normal year” ET and CIMIS – update with real-time soil and tree water status monitoring to maximize yield & efficiency
• Have reasonable estimate of crop nutrient demand given realistic field yield expectations
• Know fertilizer injection rates and match to tree nutrient uptake – most in by July
Technology is helpful, but the most valuable thing you can put in the field is your shadow...
...because pigeons happen despite our best plans!!

Paul’s plan to deliver his Valentine via carrier pigeon goes horribly wrong.
Optimizing Root Uptake

Jan Hopmans, UC Davis
Subsurface is Highly Complex System

- Spatially variable soils (texture & layering), root distribution, irrigation water application;
  Leaching Fraction concept revisited – Local leaching
  General background + Paramount Farms results

- Mechanisms of root water and nitrate uptake are not well understood:
  a) Is water stress in one part of root system compensated for by additional uptake in non-stressed part of the root system?
  b) Is root water uptake directly coupled with nitrate uptake?

- How to monitor root water/nutrient uptake?

  Paramount Farms
Movement of Water and Nutrients in Soils

- **WATER FLOW**
  - Gravity
  - Capillary Forces

- **NUTRIENT TRANSPORT**
  - Root Water/Nitrate Uptake
  - Advection (with water)
  - Diffusion
  - Dispersion
  - Adsorption to Soil

- **Non-uniform water applications**
  - Clay
  - Loam
  - Sand
**The Soil System Simplified**

(Subsurface Drip: Model HYDRUS)


![Diagram of soil system](image)

- **Soil surface**
- **Soil**
  - Drip emitter (1 cm diameter)
  - Soil wetting
  - Solute distribution

- **Dimensions:**
  - 30 cm
  - 70 cm
  - (100 cm)

- **Flow Rate:**
  - \( Q = 1.65 \text{ L/h} \)
Wetting Front After Applying 6.3 L Water in Dry Soil

Gravity

Capillary Forces

silt

clay

Sand

Silt

Layered
Fertigation Strategies

Concentration is 2.3 g/L nitrate

Strategy A

Start water

End water + nitrate

Start solute

Time (h)

0 1 2 3 4 5 6 7

Strategy B

Start water + nitrate

End solute

End water

Time (h)

0 1 2 3 4 5 6 7
Increase in Soil Nitrate After 10 Hours (Sand)

Strategy A - end

7%
2.8 kg N/ha

Gravity - dominated

20 kg N/ha more than 30 cm below emitter

Strategy B - beginning

16%
6.4 kg N/ha

Capillary - dominated

93%
37.2 kg N/ha

84%
33.6 kg N/ha

Strategy A - end

7%
2.8 kg N/ha

Gravity - dominated

20 kg N/ha more than 30 cm below emitter

Strategy B - beginning

16%
6.4 kg N/ha

Capillary - dominated
Paramount Farms (Lost Hills): Fanjet Versus Surface Drip

Non-uniform Water Application for both Micro-irrigation systems
Leaching Fraction (LF) Revisited

\[
\text{LF (field scale)} = \frac{\text{Water Applied} - \text{EvapoTranspiration (ET)}}{\text{Water Applied}}
\]

- Field-wide approach to estimate LF is **not appropriate** for application to drip irrigation, as irrigation water is applied to only fraction of the orchard area;

- Significant leaching may occur for water applications much less than 100% ET (field-scale), because of localized leaching.

- Note: roots grow where the soil is wetted.

### Soil Layering – Paramount Farms

<table>
<thead>
<tr>
<th>Fan Jet</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>Sand (%)</th>
<th>Depth (cm)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy clay loam</td>
<td>21</td>
<td>18</td>
<td>61</td>
<td>10</td>
<td>73</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Loam</td>
<td>27</td>
<td>26</td>
<td>47</td>
<td>30</td>
<td>75</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Clay</td>
<td>21</td>
<td>26</td>
<td>53</td>
<td>50</td>
<td>72</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>28</td>
<td>27</td>
<td>45</td>
<td>80</td>
<td>37</td>
<td>32</td>
<td>31</td>
</tr>
<tr>
<td>Loam</td>
<td>54</td>
<td>27</td>
<td>19</td>
<td>90</td>
<td>43</td>
<td>38</td>
<td>19</td>
</tr>
<tr>
<td>Clay</td>
<td>19</td>
<td>25</td>
<td>56</td>
<td>100</td>
<td>48</td>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td>Sandy clay loam</td>
<td>23</td>
<td>32</td>
<td>45</td>
<td>110</td>
<td>21</td>
<td>37</td>
<td>42</td>
</tr>
<tr>
<td>Loam</td>
<td>14</td>
<td>12</td>
<td>74</td>
<td>120</td>
<td>37</td>
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<td>34</td>
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<tr>
<td>Clay</td>
<td>44</td>
<td>47</td>
<td>6</td>
<td>130</td>
<td>200</td>
<td>62</td>
<td>19</td>
</tr>
<tr>
<td>Silt clay</td>
<td>29</td>
<td>37</td>
<td>34</td>
<td>140</td>
<td>230</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Clay loam</td>
<td>20</td>
<td>210</td>
<td>250</td>
<td>240</td>
<td>260</td>
<td>270</td>
<td></td>
</tr>
<tr>
<td>Sandy loam</td>
<td>270</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Similar soil types between two experimental sites of Fan Jet and Surface Drip**
- **More sandy in top 4 ft for Drip site; with both sites relatively coarse-textured;**
- **Finer Textured clay at 4 ft (Fan Jet) and at 6 feet (Surface Drip).**
Similar soil types between two experimental sites of Fan Jet and Surface Drip

- More sandy in top 4 ft for Drip site; with both sites relatively coarse-textured;

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Soil Layering – Paramount Farms

- Similar soil types between two experimental sites of Fan Jet and Surface Drip
- More sandy in top 4 ft for Drip site; with both sites relatively coarse-textured;
- Finer Textured clay at 4 ft (Fan Jet) and at 6 feet (Surface Drip).
How to Monitor? (Paramount Farms)

- Use a three-dimensional grid of sensors to capture soil and root heterogeneities;
- Assume that single quadrant is representative for the whole tree;
- Experimental data will be used to train 3-dimensional HYDRUS model to simulate water and nitrate transport in rooting zone.

Soil moisture sensors

Tensiometers and nitrate solution sampling

Surface drip

Fan jet
- Near surface sensors respond to irrigation events, but not in the berm;
- Lowest water content in top 60 cm (black/red), because of root water uptake and sandy soil;
- Clay layer at about 6-7 ft (green);
- 120 (blue) and 180 cm (green) deep sensors respond to winter rains, with 180 cm delayed;
- Deep sensors at 180 cm remain uniformly wet during the summer – indication of absence of leaching below 7 feet;
- Shallow sensors at 30 cm (red) respond to irrigation, except at emitter location, but less than drip site, because of larger wetted soil surface area; **NOTE: higher water content than drip**;
- Clay layer at about 120 cm (blue), resulting in uniform high water content at or above 120 cm;
- Uniform low water content at 180 cm (green) depth – **indicates absence of leaching**
- More uniform water application – **less likelihood of leaching of water and nitrates**
Three-dimensional spatial distribution of root water uptake for a drip-irrigated almond tree (Andreu, Schwankl and Hopmans, 1997) at Nichols Ranch.

Shifting of uptake pattern in time, controlled by local water stress conditions

Magnitude of compensation may depend on crop/tree species and level of stress

If uptake compensation occurs, the spatial root distribution becomes less important
Root Excavation – Kings River
Experimental Watershed – White Fir
Root Distribution and Root Water/Nitrate Uptake

Trench wall method & Soil Coring
Andres Olivos / Patrick Brown

Inverse modeling, whereby local soil water content and nitrate solution measurements will be matched with HYDRUS model results. End result is spatial distribution of effective root water and nutrient uptake.
Nitrate will be monitored by soil solution samplers, installed at various depths (30 – 60 – 90 cm), including some at larger depths.
Something to Think About:

- Accept that there is no one solution for all situations, and adjust design for different soil types;
  - Match design and management to soil type and crop needs;
  - Manage water application rates - want wide radius and managed vertical depth of wetting;
  - Manage fertigation - want to keep nutrients in root zone.

- Leaching is minimized by:
  - Irrigating more frequently with less water so as to minimize reliance on soil water storage for ET between irrigation events, thereby reducing probability of leaching;
  - Using micro-sprinkler rather than drip, if using same amounts and frequency, as larger soil and rooting volume is accessed with sprinkler irrigation;
  - Presence of soil layering.

- How can we group soils hydraulically and chemically for development of guidelines which minimize leaching of water and nitrate?
  Use soil properties: texture, structure, layering, chemical properties together with HYDRUS simulations and simplify.
Acknowledgements:
CA Almond Board
UC Davis and
Agricultural Experiment Station
NSF

Graduate Students:
Maziar Kandalous
Andres Olivos
For each small root zone element $i$:

$$S' = f_1 S c + f_2 N$$

- $S'$ – Total Nutrient uptake (g/day)
- $S$ – passive nutrient uptake (coupled with root water uptake)
- $c$ – nitrate concentration in soil solution
- $N$ – active nutrient uptake (independent of root water uptake)

Values of $f_1$ and $f_2$ partition total nitrate uptake between passive ($S$) and active ($N$).

The relative magnitude of $N$ (active uptake) may be controlled by (1) availability of nitrate by root water uptake ($S$), relative to total tree nutrient demand.
Fate of Urea/Ammonium/Nitrate Fertilizer, As Applied By Surface Drip System - HYDRUS


Distance From Drip Line (cm)
Organic matter considerations: How to Manage Organic Matter for Tree Nutrition

William R. Horwath, Department Land, Air and Water Resources
The founding fathers were infatuated with manure.
Talking Points

Soil organic matter:
• What is it?
• What is its function?

Managing soil organic matter
• Cover crops, manure and compost

Manipulating nutrient availability
• Optimizing synchrony
• Preventing nutrient loss
Humus is a complex and recalcitrant mixture of brown and dark brown substances derived from plant biomass components and soil organisms.
Plant Residue Decomposition and Soil Organic Matter Formation

- Fresh Plant Residue
- Organo-mineral complex/Soil aggregate
- Humic Substances
- Particulate Organic Matter
Soil Organic Matter

- Cation Ion Exchange capacity
  - 300 to 700 cmol(+) / kg
- Capacity to chelate metals
- Enhance soil physical properties
  - Water Holding capacity
- Source of nutrients
  - C/N/S/P = 100/10/1/1
- Positive influence on soil properties
Soil Organic Matter
And It’s Role In Affecting The Efficacy Of Pesticides
### Soil Organic Matter

<table>
<thead>
<tr>
<th>Fraction</th>
<th>C:N Ratio</th>
<th>SOM Element %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOM</td>
<td>8-12:1</td>
<td>55% C</td>
</tr>
<tr>
<td>Plant Litter</td>
<td>20-400:1</td>
<td>4-5% N</td>
</tr>
<tr>
<td>Bacteria</td>
<td>4 to 7:1</td>
<td>0.5% P</td>
</tr>
<tr>
<td>Fungi</td>
<td>8 to 12:1</td>
<td>0.5% S</td>
</tr>
</tbody>
</table>

**Living**

- Soil Biomass (fungi, bacteria, fauna) 2-5%

**Nonliving**

- Non humic substances 20-30% of SOM
- Humic substances 60-80% of SOM
Stable SOM
>1000 years old

Very Stable
Organic Matter

Resistant SOM
~5 to 100 years old

Resistant Organic
Matter

Labile SOM
Active fraction
~2 year old

Light fraction/
Microbial biomass

Fonte SOM
Active fraction
~2 year old

Light fraction/
Microbial biomass

Resistant SOM
~5 to 100 years old

Resistant Organic
Matter

Stable SOM
>1000 years old

Very Stable
Organic Matter

UC DAVis
UNIVERSITY OF CALIFORNIA
Contribution of Soil Organic Matter Fractions to Available Soil Nitrogen

- Labile SOM
  - Active fraction
- Resistant SOM
- Stable SOM

Available nutrients
Nitrogen turnover in rice through operationally defined organic matter fractions

Fate of fertilizer N in CA Rice

Atom excess $^{15}\text{N}$ (%)

- LF
- MHA
- MAHA
- MFA
- Humin

Light Fraction 1-2 y
Humin >150 y
Relationship of soil Carbon to Microbial Carbon

- **Microbial C μg/g soil**
- **Soil Carbon (%)**

Graph shows a positive correlation between soil carbon content and microbial carbon content, with an increasing trend as soil carbon content increases.
Microbial Nutrients

Microbial Biomass after 10 years of organic, integrated and conventional management at SAFS

![Graph showing microbial biomass in different soil depths and management types.](image-url)
Cover crop usage and management for soil organic matter can prevent N losses.
Soil C Storage as a Function of Climate

California

<table>
<thead>
<tr>
<th>MAT (°C)</th>
<th>MAP (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>15</td>
<td>1000</td>
</tr>
<tr>
<td>20</td>
<td>104</td>
</tr>
<tr>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>1000</td>
</tr>
</tbody>
</table>

Carbon storage (kg m⁻²)
Soil Carbon Change over 10 years

80 to 90% of 10 year accumulation

Can soil organic matter be increased indefinitely?
Distribution of N and its location in a *Populus* plantation (tree and soil)

Figure 4.1. The distribution of C and N (g) in the *Populus*-soil system for July 19, 1990 labeled trees sampled August 2, 1990. The values in parentheses represent the amount of C and N for the November 2, 1990 sampling.
Fertilizer & Soil N Availability and Synchrony in Tree Crops

- Maximum uptake
- Reallocation
- Seed/fruit
- Leaves/branch
- Manure/cover crop
- Timing of incorporation
- Decomposition
- Quality (C/N)
- Amount
- Soil N not sufficient

Soil N

Availability

N Uptake
Fate of Plant Residue (cover crop, manure, compost) N During Decomposition

Initial N in plant residue at harvest

Period of N immobilization during decomposition

Period of mineralization producing available soil N

% N in decomposing residue

0

100

1

2

3

Time (y)
Long-Term Nitrogen Availability Under Consistent Management To Increase Soil Organic Matter

Nitrogen Availability increases

Immobilization

N mineralization

1 2 3 4

Years
Is fertilizer N directly taken up by trees?
No significant difference in N recovery

Fertilizer use highest in conventional management

% Recovery of Fertilizer N in Corn

Low-input Fertilizer
Low-input Fertilizer + Vetch
Conventional Fertilizer

Plant
Soil (2 m)
Fertilizer and Soil N Availability

Fertilizer N causes additional uptake of soil N
Nitrogen Mineralization Potential in Different Farming Systems

Cumulative N mineralized (mg/kg dry soil)

Days of incubation

I = std. dev.

conventional
organic
cover crop
Fertilizer management can change pathways and availability of N to the tree.
Summary

The management of soil organic matter is essential to increase and maintain almond productivity.

Soil organic matter provides a source of nutrients to ensure adequate tree nutrition (provides resiliency).

Appropriate combination of amendments can increase synchrony of nutrient delivery:

- Limiting factor is the soil can only store finite N
- Key is to manipulate the size of mineralizable N pool

Organic management prevents nutrient loss.

Interactions of amendments with other amendments and soil nutrient pools needs further research to fine tune nutrient delivery.
P2G Progressive Genetics Group

Moderator: Richard Waycott, ABC

Presenters:
Jack Poukish, Sierra Gold Nurseries
John Ireland, Fowler Nurseries
Chuck Fleck, Fowler Nurseries
John Duarte, Duarte Nursery
• Dave Weil, Varieties International
• Rootstocks from U.S., Europe, Russia
• 2007: P2G™ Founded with Four Member Nurseries
• P2G™ Mission:
  Dedicated to the Professional and Ethical Introduction of Novel Rootstocks and Varieties to the Diverse Orchard Industries
Four P2G™ Nurseries:
Why Is P2G™ of Interest to Almond Growers?

Why Should you Care?
P2G™ Works in Tandem with Breeding Programs Worldwide to Bring Interesting Plant Material to California for Testing.

From This Work... We Bring Information To Growers.
P2G™ is a Service Organization for the Industry.....Bringing New and Innovative Solutions to Almond Growers.

P2G™ Combines the Strength of Four California Nurseries.
Advantages of Clonal Rootstocks

- Uniform Vigor and Production
- Hybrids
  - Hybrid Vigor
  - Adaptation and Resistance Traits Associated with Both Hybrid Parents
P2G™ Rootstocks for Almonds

• Empyrean®1
  – Peach X Peach Hybrid
  – Originated in Italy

• Bright Hybrid®5
  – Peach X Almond Hybrid
  – Selected by Bright’s Nursery

• Krymsk®86
  – Peach X Plum Hybrid
  – Originated in Russia
Empyrean® 1 Rootstock

• High Vigor
  – Large Tree Canopy and Trunk Size

Trunk Cross Sectional Area:
5th Leaf, Stanislaus County:
- Nonpareil 151% of Nemaguard
- Carmel 152% of Nemaguard

Data from Roger Duncan, UCCE Stanislaus`

4th Leaf, Kern County:
- Nonpareil 126% of Nemaguard

3rd Leaf, Colusa County:
- Nonpareil 145% of Lovell
Empyrean® 1 Rootstock

• High Vigor
  – Large Tree Canopy and Trunk Size
  – Reaches Productive Harvests Sooner

<table>
<thead>
<tr>
<th>Year</th>
<th>Variety</th>
<th>Lbs/ Acre</th>
<th>% of Nemaguard</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Nonpareil</td>
<td>4381</td>
<td>161%</td>
</tr>
<tr>
<td></td>
<td>Carmel</td>
<td>2719</td>
<td>147%</td>
</tr>
<tr>
<td>2009</td>
<td>Nonpareil</td>
<td>3285</td>
<td>106%</td>
</tr>
<tr>
<td></td>
<td>Carmel</td>
<td>4155</td>
<td>190%</td>
</tr>
<tr>
<td>2010</td>
<td>Nonpareil</td>
<td>2668</td>
<td>137%</td>
</tr>
</tbody>
</table>

Data from Roger Duncan, UCCE Stanislaus
Empyrean® 1 Rootstock

• High Vigor
  – Large Tree Canopy and Trunk Size
  – Reaches Productive Harvests Sooner

• Good Anchorage
  – Vigorous Root System
Empyrean® 1 Rootstock
Empyrean® 1 Rootstock

• High Vigor
  – Large Tree Canopy and Trunk Size
  – Reaches Productive Harvests Sooner

• Good Anchorage
  – Vigorous Root System

• Adapted to Soils Suitable for Nemaguard
  – Root Knot Nematode Resistance Similar to Nemaguard
Empyrean® 1 Rootstock

• Fast Growing

• Quick to Achieve Impressive Harvests

• Medium and Lighter Soils

• Good Anchorage
Bright Hybrid®5 Rootstock

• Selected in an Orchard with High pH
• Vigor
  – Intermediate Between Nemaguard and Hansen 536
  – Tree Slightly Wider than Nemaguard

Trunk Cross Sectional Area:

5th Leaf - Stanislaus County:
  Nonpareil  110% of Nemaguard

3rd Leaf - Madera County:
  Nonpareil  122% of Nemaguard

3rd Leaf - Colusa County:
  Nonpareil  129% of Lovell
Bright Hybrid®5 Rootstock

- Selected in an Orchard with High pH
- Vigor
  - Intermediate Between Nemaguard and Hansen 536
  - Tree Slightly Wider than Nemaguard
- Productivity — Can exceed that of Nemaguard
- Good Anchorage - Similar to Hansen 536
- Root Knot Nematode Resistance
  - Similar to Nemaguard
- Wet soils performance
  - Similar to Nemaguard
Bright Hybrid®5 Rootstock

• Moderate Vigor

• Salty, Alkaline Soils

• Medium Texture and Lighter Soils

• Good Anchorage
Krymsk®86 Rootstock

- Peach x Plum Hybrid
- Amazing Root Strength and Outstanding Anchorage
- Good Compatibility with Almond*
- Productivity Similar to Lovell
Krymsk®86 Rootstock
Nonpareil Almond Nut Meats

Lbs/Acre

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Average</th>
<th>Krymsk® 86</th>
<th>Lovell</th>
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</thead>
<tbody>
<tr>
<td>Site &quot;V&quot;</td>
<td>3</td>
<td>3 Year</td>
<td>2043</td>
<td>1984</td>
</tr>
<tr>
<td>Site &quot;M&quot;</td>
<td>2</td>
<td>2 Year</td>
<td>2307</td>
<td></td>
</tr>
<tr>
<td>Site &quot;L&quot;</td>
<td>1</td>
<td>4th Leaf</td>
<td>2671</td>
<td>2478</td>
</tr>
<tr>
<td>Site &quot;C&quot;</td>
<td>3</td>
<td>3 Year</td>
<td>2059</td>
<td>1792</td>
</tr>
<tr>
<td>Nickels Lab</td>
<td>2</td>
<td>2 Year</td>
<td>1633</td>
<td>1593</td>
</tr>
</tbody>
</table>
Krymsk®86 Rootstock

- Peach x Plum Hybrid
- Amazing Root Strength and Outstanding Anchorage
- Good Compatibility with Almond*
- Productivity Similar to Lovell
- Adapted to Soils Suitable for Lovell and Heavier soils
**Krymsk®86 Rootstock**

- Resistant to Phytophthora Root Rot
- Wide Spreading Root System

- Tree Canopy ~ 90 to 95% of Lovell
  - Tree Spacing Can Be Decreased by 1 Foot

- Minor Amount of Suckering

- Susceptible to Root Knot Nematode

---

Krymsk®86

Nemaguard
**YCL**

**Yellow, Cupped Leaves**

- Rainy Springs of 2010 and 2011: 1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd}, and 4\textsuperscript{th} Leaf Monterey Trees Developed YCL
- Monterey Ranged from 0% to 35%
- Much Lower YCL Amounts in Nonpareil
  - Most Trees Recovered Over the Growing Season
- Most Monterey Show Recovering Trends
- A Small % of 1\textsuperscript{st} and 2\textsuperscript{nd} Leaf Monterey Have Not Recovered
Krymsk®86 Rootstock

Monterey Almond Nut Meats

Lbs/Acre

Site "C"  1 year  5th Leaf

- Krymsk® 86: 2262
- Lovell: 1566

Site "M"  3 Year Average

- Krymsk® 86: 2721
- Lovell: 2164
KRYMSK®86
vs.
MARIANNA 2624

Carmel / Krymsk®86

Carmel / Marianna
Krymsk®86

- Superior Anchorage
- Standard Productivity
- Diverse Soil Adaptation
- Nonpareil Compatibility
What’s To Come From P2G™:

• New Peach x Almond Hybrids for Drought and Salt Tolerance
  Tempropac®        HM-2 ®

• Testing New Rootstocks for Oak Root Fungus Resistance

• Testing New Rootstocks for Tolerance of Replant Disorder

• Newer Arrivals From Russia and Spain
AHPA General Meeting
*Pistache-Ginko*
4:30 – 5:30

Dedicated Trade Show
*Exhibit Hall and Tent*
4:50 – 5:30

Cocktail Reception
*Exhibit Hall and Tent*
5:30 – 7:30

Gala Dinner
*Grand North Tent*
7:00 – 9:00