Precision nutrient management in California orchards

Orchard variability and its implications for fertility management.

Patrick Brown
University of California, Davis
Premises on which adoption of Site-Specific Management is Based.

Relevance to Tree Crops, Contrast to Field Crops.

- Significant within-field and between year variability exists.
  - Greater overall variability in trees than in field crops.
  - Greater, but more complex, dependency between years

- The causes of this variability can be identified, monitored and predicted and crop management practices can be adjusted accordingly.
  - Gross soil and topographical determinants can be addressed (deep tillage, leveling, drainage, amendments)
  - More management options in trees than in field crops (fertigation, foliar fertilization etc)

- The improvement in economic output or sustainability justifies the increased investment and ongoing management cost.
  - High value and long lived species provides greater time to recover investment in technology (fertigation systems etc).
  - Fertigation investment (>70%) allows ‘management’ of topography, soil characteristics, irrigation, nutrition and other yield determinants.
Constraints/Advantages to the Adoption of Precision in Management in Californian Orchards

- **Irrigation**
  - Engineered for uniformity of application
  - Irrigated to meet the demand of the most water demanding portion of the field.

- **Fertilization**
  - Generally uniform ‘whole field’ management . (esp. N, K)
  - Rates are based on crude and generic recommendations
  - Nutrient testing is inadequate and insensitive.
  - Fertilized to avoid deficiency in the most demanding portion of the field

*As fields get larger and fertigation becomes more common, site specific management becomes harder.*
Precision Nitrogen Management
-the 4 R’s-

- Applying the **Right Rate**
  - Determine demand and variability.
  - Account for all inputs (water, soil, plant).

- At **Right Time**
  - Determine when uptake from the soil occur.

- In the **Right Place**
  - Ensure delivery to the active roots.
  - Managing variability across the orchard.

- Using the **Right Source and Balance**
  - Balanced fertility
What do we know and how do we manage?

Leaf Sampling and Critical Value Analysis in Orchard crops
(based on Ulrich @ U Calif in 1950-70’s)

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, Ni, Cl, Mo)

Interpretation of results (NO R’S!)

- Leaf analysis results do not tell the grower how to respond.
- Decisions are generally based on experience and an “estimate” fertilizer needs
- Leaf analysis provides no information on “cause” of deficiency or inefficiency.
Almond and Pistachio Grower Survey
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
- Less than once/year: 43
- Once/ year: 307
- More than once/year: 98
- When problems are detected: 32
- I don't know: 5

>80% compliance

(California Agriculture July 2010 issue; Google:pistachio growers survey)
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?

- Yes: 150 respondents
- Somewhat: 183 respondents
- No: 51 respondents
- I don't know: 128 respondents

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

> Subsequent informal surveys suggest these issues are pervasive in tree crops.
Apparently tissue sampling is not trusted- Why?

Is the use of Plant Samples and the Critical Value or Critical Range appropriate for Trees/Vines?

Development of the Critical Value concept

  - analytical techniques have developed, principles/practices remain unchanged or have been diminished with time.

- 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.’ (Liebig, 1852)
  - thus, soil depletion to sub-optimal levels is a pre-requisite to fertilization
  - however, in high value crops allowing crops to become ‘just deficient’ is untenable.

- Limited consideration of unique characteristics of tree/vine crops.
  - Goal is to prevent deficiencies not correct deficiencies
  - Long life and high investment cost requires the practice of sustainable, balanced nutrient management.
Variability in Plant Tissue Response to Nutrient Supply

Effect of K on Yield in Almond

Above the critical value, tissue analysis is unreliable.

Secondary deficiencies (Liebig's law)
Shading and nutrient interactions
The relationship between leaf sampling and critical values with yield is complex. In trees the relationship is multi-year and ‘loose’.
Shoot Zn Distribution Through A Dormant Peach Tree (ppm)

16.3

19.1 - sun exposed

28.5 - sun exposed

47.9 - shaded

32.6

39.7 - sun exposed

70.3 - shaded

Problem with leaf sampling: Sampling challenges.

Standard Sample: Fully Exposed non-fruiting leaves in late summer

Courtesy Scott Johnson
Strong Yield Interactions
High Yield depresses Leaf Nutrients
Leaves near fruit are not collected – Valid?
Variability and Incorrect Interpretations

Incorrect!
if field average K Concentration = 1.7%, then 50% of the field is, by definition, deficient.

*UC Critical Value = 1.7%
**Field average K = 1.7%
Therefore current K program is optimum???

Average = 1.7%

Pistachio Yield
Growers worldwide invariably target higher tissue levels than supported by data. Why?

Leaf samples collected from an excellent grower and critic of UC critical values.

Grower target CV = 2.0% K (95% of trees are above 1.4% K)

University of California recommended CV = 1.4% K

Potassium leaf values, horizontal line indicates UC deficiency threshold

Courtesy Franz Neiderholzer
Variation in Yield over Time

Pistachio 4820 trees individually harvested.

Nitrogen export per tree (kgs)

- 1.0
- 0.8
- 0.6
- 0.4
- 0.2
- 0.0

6 year average N export (0.38 kg/tree)

Current annual Fertilizer N Rate (0.9 kg/tree)
How Widespread is this ‘Problem’?
Survey of leaf N distributions in Californian Orchards
Improved sampling techniques, remote or handheld testing, re-education, regulation will all fail if the rationale for grower behavior is ignored.

\[
\text{Fertilizer saved} > \text{Yield lost} > \text{Fertilizer saved}
\]
Managing Nutrition of High Value Crops

Avoid over-fertilization without under-fertilizing any. How?

Correct deficiencies

Avoid over fertilization without under-fertilizing any. How?

Correct deficiencies

July N concentration (%)
Spatial distribution of leaf N
Identification – Management - Economics

Safe area for fertilizer reduction
Spatial distribution of N
Sites of Excess Fertilization have the highest potential for Nitrous Oxide release

D. Smart et al
Spatial and Temporal Variability in Nitrous Oxide Release

February 19 to March 11, 2010

2/18  2/22  2/26  3/02  3/06  3/10

g N₂O-N m⁻² hr⁻¹

0  50  100  150  200  250

CAN  UAN

2009 - 2010

Sprinkler 10/30/2009

Distance from emitter (m)

Berm

Feburary 19 to March 11, 2010

N₂O Emissions (µg N₂O-N m⁻² hr⁻¹)

CAN32  CAN17
There is a growing consensus that nutrient management in tree crops is inadequate and that sustainability matters.

How much do you think potential environmental regulations will affect your fertilization practices in the future?

<table>
<thead>
<tr>
<th>Response</th>
<th># Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>not at all</td>
<td>11</td>
</tr>
<tr>
<td>a little</td>
<td>35</td>
</tr>
<tr>
<td>somewhat</td>
<td>108</td>
</tr>
<tr>
<td>a lot</td>
<td>206</td>
</tr>
<tr>
<td>tremendously</td>
<td>121</td>
</tr>
<tr>
<td>I don’t know</td>
<td>17</td>
</tr>
</tbody>
</table>
How much do you think market demands for best management practices will affect your fertilization practices in the future?

- **CDFA-Fertilizer Research and Education Program, Almond Board, Pistachio Commission** all rank improved nutrient management as their highest research priority.
- **Cal-ARB** has added N emissions from Agriculture as a target for reductions.
Summary: Tissue Testing for Horticultural Crops

- As currently practiced an inadequate technology for well managed high value crops.
  - Difficult to practice and hard to interpret (except in deficiency range – rare)
  - Does not inform management practice
  - Not suitable for detection of supra optimal fertilization (insensitive, uptake and NUE decrease with application in excess of needs and induces interactions)

- Grower dissatisfaction with approach is understandable
  - ‘Over’ fertilization is a logical response to uncertainty and lack of viable tools.
  - Improved tools or lower cost (remote sensing, hand held meters, increased sampling and testing, better standards) will help but are not enough.

Alternatives?
Supplemental Approaches to Nutrient Management in Horticulture

Nutrient Budgeting

Replacing nutrients removed from the orchard or vineyard

Essential Components and Challenges:

- Determine or estimate demand (Yield monitoring or simulation)
  - Nitrogen content in harvested crop (yield x nutrient concentration) (GIS/Remote sensing etc)
  - Losses (pruning, leaching, runoff, volatilization)

- Measure and control inputs (GIS Mapping, Remote Sensing etc.)
  - soil, fertilizer, irrigation

- Manage efficiencies and interactions (Variable rate fertilization)
  - Synchronize time and location of nutrient applications
  - Monitoring crop response

How?
Demand: Predicting Yield Potential in Almond and Walnut

Midday light interception (%)

Kernel yield (pounds/acre)

Walnut yield (tons/acre)

0 20 40 60 80 100

Walnut
Almond- Nonpareil Spur Dynamics
Almond- Nonpareil RAVTs
Almond- Nonpareil- Duncan trial

5.0

Bruce Lampinen, UCD
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.
Nutrient Demand and Seasonal Dynamics in Almond Export from Orchard in Crop (3,500 lb.ac⁻¹)

Replace or Estimate?
Nutrient Removal in Kernels, Shell and Hulls

(does not include prunings and other losses. 8yo, Nonpareil test orchard)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Nutrient Removal (lbs / 3560 kernel lb)</th>
<th>Nutrient Removal (lbs / 1000 kernel lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>204</td>
<td>58</td>
</tr>
<tr>
<td>P</td>
<td>24</td>
<td>7</td>
</tr>
<tr>
<td>K</td>
<td>180</td>
<td>51</td>
</tr>
</tbody>
</table>

Critical Baseline Information: How Efficient can Almond be??
Almond

NITROGEN USE EFFICIENCY
(N removed in harvested fruit / N applied 118 trees measured in 2008)

Fertigated: 5 times in-season times with tree demand
Low rainfall, neutral soils.

An NUE of 70-80% is among the most efficient ever measured in agriculture

Standard Practice (250-275 lb N ac)
NUE = 0.7 to 0.8
Nutrient Use Efficiency Declines with N Rate.

Matching supply (fertilizer) with demand (yield) is the best way to enhance efficiency.

How does yield vary across a field and between years?

Table 27.4 Influence of nitrogen (N) application on yield of Nonpareil almond and amount of N removed.

<table>
<thead>
<tr>
<th>N in fertilizer (lb N/acre)</th>
<th>Kernel N (% dry weight)</th>
<th>Yield (kernel lb/acre)</th>
<th>N removed (lb/acre)</th>
<th>Crop*</th>
<th>Prunings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.0</td>
<td>2,290</td>
<td>89</td>
<td>3.3</td>
<td>3.9</td>
</tr>
<tr>
<td>56</td>
<td>3.2</td>
<td>3,158</td>
<td>133</td>
<td>3.9</td>
<td>3.9</td>
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<tr>
<td>112</td>
<td>3.6</td>
<td>3,651</td>
<td>170</td>
<td>3.9</td>
<td>3.9</td>
</tr>
<tr>
<td>225</td>
<td>3.8</td>
<td>3,830</td>
<td>194</td>
<td>3.9</td>
<td>3.9</td>
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<tr>
<td>450</td>
<td>3.9</td>
<td>3,679</td>
<td>198</td>
<td>3.9</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Source: K. Uriu and W. C. Micke, unpublished data.

>80% NUE<sub>(PNB)</sub>  
<45% NUE<sub>(PNB)</sub>
Pistachio Yield Monitor: UC Davis and Paramount Farming Company

Uriel Rosa (UCD - BioAgEng)
Results: Yield Maps
(4,280 to > 10,000 trees harvested each year)

- 2002: 89 lbs
- 2003: 73 lbs
- 2004: 49 lbs
- 2005: 95 lbs
- 2006: 15 lbs
- 2007: 105 lbs
Nutrient Use Efficiency and Variability in Pistachio.

4850-9650 individual Tree NUE estimations (N removed in harvested fruit / applied)

12 year Mean NUE = 0.72 (0.82-2006)

60,000 lb total 6yr N application (40 ac).
41,000 lb exported in yield.
7,000est lb pruning, leaf loss and growth
12,000 lb ‘lost’ 50 lb ha⁻¹ yr⁻¹

24 yo Pistachio, 5 inch rainfall zone, no deep percolation.
Silt loam, pH 6.7-7.0, OM 0.6%, 2 ppm NO₃N (100cm). Fertigated with five in-seasons split apps.
10 yr ave yield = 4,000 lb ac= 180 lb N ac in exported fruit
Mean N application 250.
Influence of Precision Management on Fertilizer Losses – first steps.

Nitrogen unaccounted for in yield (60,000 lb N applied)

To maximize NUE, fertilization should be adjusted for:

1. Expected/actual yield
   1. Yield Monitoring
   2. Yield Prediction

2. Variability across and between fields
   1. Remote sensing, sampling and GIS mapping etc

- Adjust fertilizer application rate to annual demand. 65% reduction in N loss
- Adjust fertilizer application rate for spatial demand. (-45%)
- Spatial and annual (-72%)
Yield is not uniform in any field.

Yield of 16040 trees Pistachio trees (40 ha)

**Yield is the primary determinant of fertilizer demand, therefore knowledge of variations in yield is essential for optimal management.**

**but**

*How do we fertilize a field such as this?*
Individually controlled microsprinkler system.

Robert Coates, Michael Delwiche, Patrick Brown

Individual microsprinkler with controller. Current version integrates wires into pipe, and valve and actuator into sprinkler head.
Nitrogen Demand by 20 acre block

Whole Field Average N demand = 150 lbs N
Managing for Spatial Variability

*Introduces greater complexity in management*

*Is it worth it?*

- >5,000 lbs yield
  - 40 acre = 3,200 lb N
- <2000 lbs yield
  - 40 acre = 1,500 lb N

**Difference in real N demand = 1,700 lb N**

**Difference in 1 year profit = $120,000**

Image: Pistachio Yield Map with yield ranges and nutrient demand differences indicated.

- Variability within a tree and orchard is substantial. Rigorous standardization increases reproducibility but not relevance.
- Leaf sampling is not adequately sensitive at supra optimal nutrient concentrations.
- Sampling protocols and interpretation have been misused.
- As a consequence orchard level critical values are difficult to interpret.
Alternate Practices: Nutrient Budgeting and Spatial and Temporal Fertilization

- Acceptable yield prediction, and hence nutrient demand, can be achieved with existing technologies and could be improved significantly.
- Variability within an orchard and over time is substantial, but poorly documented and understood.
- Under good management, high NUE’s are observed in Californian Almond and Pistachio orchards.
- Managing nutrients by managing for spatial and temporal variability is critical to efficiency.

Modeled and measured yield prediction is viable

Temporal and spatial variability is significant. Overall NUE can be very high.

Biological basis for variable production remains poorly understood.

Site specific management is promising and viable.
Site Specific Management - Optimizing Fertilization by applying the 4 R’s. – What is Needed?

APPLYING THE **RIGHT RATE** (estimate demand)
- Determine total demand (Inputs - Outputs)
  - Inputs (**fertilizers**, N in irrigation (0 - 80 lb N Acre yr))
  - YIELD MONITORING OR PREDICTION
  - MAPPING
  - NUTRIENT MONITORING – REMOTE/HANDHELD/QUICK
  - VARIABLE RATE/PLACEMENT TECHNOLOGY

AT THE **RIGHT TIME** (fertilize according to nut growth rate)
- Timing of demand is reasonably well defined by biology
  - FERTIGATION
  - VARIABLE RATE/PLACE TECHNOLOGY

IN THE **RIGHT PLACE** (fertilize active roots and ‘hungry’ trees)
- FERTIGATION/FOLIARS/VRT, SYNCHRONIZE
Given the high value and long life of perennial systems, and the inadequacy of current practices, now is an ideal opportunity to re-invent our approach to nutrient management.

This will require: Research, Technology, Engineering, Tools

• Yield Measurement and Prediction – Integrated mathematical, biological, engineering and ecological approaches.

• Determination of Spatial Variability - Statistical and geo-statistical tools, sampling and sensing technologies, improved experimental designs.

• New Management Tools – Rapid yield and nutrient measurement techniques. New approaches to precision application -sub sector fertigation to single tree fertigation; VR devices and materials (surface/liquid).

Almond Board-USDA-CDFA funded projects are ongoing.

Adoption will require development of sound information, packaged with an approachable technology that simplifies management.
Estimate N and Water Demand

- Validate ETa models (SEBAL, NCAR-WRF), estimate orchard water needs (Ustin, Sammis)
- Remote Sensing of yield, phenology, crop development (Slaughter, Upadhyaya, Whiting)
- Develop fertilizer response curve (Brown, Sanden, Lampinen)
- Physiological/soil environmental controls on N and water uptake (Hopmans, Shukla, Lombardini)
- Gaseous, sub-soil N losses (Smart, Brown)
- Develop phenology and yield based nutrient demand model (Brown, Sanden, Lampinen)
- Interactive effects of irrigation and nutrient status on plant water use and plant response (Shackel, Brown, Sanden)
- Modeling of crop nutrient and water demand
  - Climate/phenology based yield modeling (Whiting, Ustin)
  - N and water modeling in pecan and almond (Sammis, Wang)
Determine N and Water Status

Relate ETa to plant water status (Shackel, Smart, Sanden)

Evaluate spectral measurements / correlate to crop status (Whiting, Lampinen, Slaughter, Upadhyaya)

Modeling of crop nutrient and water demand
- Climate/phenology based yield modeling (Whiting, Ustin)
- N and water modeling in pecan and almond (Sammis, Wang)

Re-evaluate leaf and orchard sampling methods and “Critical Value” concept (Brown, Lampinen)
Integration / validation

Development of web-based decision support toolkit “NutMan”
Nutrient Demand and Seasonality

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**Figure 4. Nutrient uptake dynamics throughout the season**

Data from the Belridge fertigation trial during the 2008 season
n=36 per date for 275 lbs/ac; n=30 per date for all other treatments
YIELD PREDICTION: Vegetation Index Tracking Orchard Phenology Through Biweekly Free Satellite Imagery

NDVI Variation within and between seasons, years and orchards and relationship to critical nutrients and crop yield
640 photodiodes active in PAR range
IR thermometers for soil surface temp
Sub meter GPS - used outside orchard
Radar used within orchard
Campbell Scientific CR3000
Display on dashboard
Adjustable to row widths from ~18-28 feet
Travel about 10km/hr - gives one scan about every 30 cm

Mule light bar

Infrared thermometers for measuring soil surface temperature
NASA DC-8 Orchard overflight 22 & 24 July 2009, ~10,000 ft. alt., MASTER sensor

MASTER airborne simulator instrument for MODIS and ASTER satellite sensors
Single Trees from Scan AO3

- NonPareil (“A”) tree on the right
- Monterey (“B”) tree on the left
ONGOING RESEARCH

• Yield Prediction and Monitoring, Rapid-Sensitive Nutrient and Water Analysis, Remote Sensing,

Ground and Aerial Imagery: In season nutrient status and yield prediction.

Early Season Sampling

Handheld Monitors
Rapid nutrient measurements
Large Scale Spatial Variability
2 Million Ha, 70% Fertigated, 10,000 growers, 5 Deg Latitude.
6 Almond Orchard Sites

All Sites: (>100 trees)

- 5 in-season full nutrient analysis
- 5 in-season Stem WP
- Soil water and irrigation volume
- Yield (100 + individual trees)
- Nitrogen Use Efficiency (NUE)
- Aerial and satellite imagery

Two Sites:
- Gaseous nitrogen loss
- NUE

One Site: 50 x 2 acre, (drip/FJ)
- Factorial 4N x 4K x source x Irrigation Trial

- 5 in-season full nutrient analysis, 5 in-season Stem WP, Soil water and irrigation volume, Yield (768 individual trees)
- NUE
- Canopy level imagery
- Aerial and satellite imagery
NutMan: Decision Support Using Predicted Yields, Real-time Field Data, Automated Analyses, and Information Delivered to Growers

Automated Monitoring

Models and Prediction

Remote Sensing

Real-time Field Monitoring Stations Deliver Data Wirelessly So Growers Know Field Conditions On Demand

Growers can Use their Office or Field Computers, Even Their Phones, to Access their Information

Remote Sensing

Provide Block Specific Decision Support in Easy to Use Format.
# Nitrogen Demand by 5 acre Plot

<table>
<thead>
<tr>
<th>Nitrogen Demand</th>
<th>Fertilizer Demand</th>
</tr>
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<tbody>
<tr>
<td>340 lbs</td>
<td>175 lbs</td>
</tr>
<tr>
<td>225 lbs</td>
<td>100 lbs</td>
</tr>
<tr>
<td>250 lbs</td>
<td>125 lbs</td>
</tr>
<tr>
<td>280 lbs</td>
<td>200 lbs</td>
</tr>
<tr>
<td>225 lbs</td>
<td>50 lbs</td>
</tr>
<tr>
<td>175 lbs</td>
<td>100 lbs</td>
</tr>
<tr>
<td>200 lbs</td>
<td>50 lbs</td>
</tr>
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</table>
Precision Nutrient Management Can Be Implemented In 2010 For Free

Right Rate
adjust N application to realistic yield expectation
Goal: Input = Demand

Right Time
Time N to match uptake
Goal: Fertilize during periods of growth

Right Place
Recognize and manage your field/block variability. Keep nutrients in root zone.
Goal: Precision
Acknowledgements

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Thank You

PATRICK BROWN
phbrown@ucdavis.edu
530 304 1390