Diagnosing and Correcting Nutrient Deficiencies

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With invaluable information from Dr. Patrick Brown, Dr. Louise Ferguson, Dr. Steven Weinbaum, Dr. Richard Rosecrance, Bob Beede and others
A farm advisor observation

Tree nutrition is important, but it should not be pursued to the neglect of other crop cultural practices.
Feeding the tree is not as direct a process as feeding people.
Caution – This schematic is an oversimplification of how-to-grow pistachio!
Photosynthesis feeds the plant and fills the nuts.

- sunlight
- temperature
- tree health
- water
- nutrients
- pest pressure

Nutrient pools exist within the tree and within the soil.
Many factors, such as those listed above, can limit crop growth and yield. Find the most limiting factor and fix it, then the next most limiting, etc. Applying more nutrients may not be the first best answer to a crop production problem.
Generalized Dynamic Nutrient Cycle: Fate of Nutrients

**Keep records**
- harvest
- irrigation
- soil fertility
- fertilizers
- leaf analysis

**Storage in tree**

- Lost or gained to/from atmosphere
- Naturally occurring in irrigation water
- Released or tied-up through organic decay or soil chemical reaction
- Lost in hulls and nuts at harvest
- Supplied by grower in fertilizers

**Lost in hulls and nuts at harvest**
The tree has the ability to store nutrients. Total stored nutrients at the end of the season in lbs/acre from Weinbaum, Brown and Rosecrance

<table>
<thead>
<tr>
<th>Cropping Status</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>ON</td>
<td>13</td>
<td>0</td>
<td>47</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>OFF</td>
<td>101</td>
<td>12</td>
<td>82</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Spoon feeding the orchard is not necessary, however it can result in higher fertilizer-use efficiencies – especially in sandy soils.
Many factors limit nutrient availability and/or utilization.

- poor irrigation system design, scheduling
- competition with weeds
- presence of hardpans, poor water infiltration, perched water tables, alkali spots
- salinity (soil or water), pH, nutrient fixation
- low soil temperature (microbial activity, root activity)
- weather/climate, limitations of tree uptake and transport
- low or high native soil fertility for one or more nutrients
- Root disease (i.e. Verticillium wilt affects K uptake)
Soil Series, texture, pH and irrigation water all affect nutrient availability

- Soil pH affects nutrient availability
  - pH > 7.5   Zn, Cu, Mn, Fe - fixed
  - pH < 6.0   P, Ca, B - leached
- Sandy soils have less native fertility
- Irrigation waters differ in nutrient content
Soils differ in their ability to provide macro and secondary nutrients. For example:

In general, in the San Joaquin Valley of California, a high variability exists in a soil’s ability to naturally provide or not to provide copper, boron, potassium and magnesium.

Typically many soils on the west side of the San Joaquin Valley are able to provide sufficient boron and calcium to pistachio trees with no or little supplemental fertilization (leaf tissue analysis over time can help track this).
Choice of soil amendment can influence nutrient availability

Examples,
- dolomite vs limestone
- limestone vs pit gypsum
- pit gypsum vs pure gypsum
- Manures vs gypsum, limestone
What the Grower Can Do

Knowledge is Power

• Know your trees, your soil and your water.

• Leaf, soil and water testing allows the grower to be proactive not just reactive.
The Basic Premise of Leaf Tissue Sampling

The fraction by weight of nutrients in non-terminal, non-fruiting leaflets in late July and August is correlated to orchard nutritional status.

Soil chemistry is complex. The leaves can give us a net result.
Nutrient Curves through Season

Typical nutrient concentration in leaves

- N, P, Zn
- Cu
- Mn
- K, Mg, Cl, B
- Ca

MONTH

A M J J A S O N
Leaf tissue sampling:

• is extremely useful and reflects how successfully the tree in obtaining nutrition from the soil.

• in conjunction with soil samples and good fertilization and irrigation records, will provide valuable information to conduct, improve or correct farming practices.

• should be conducted on an annual basis
Foliar tissue analysis is a ‘snapshot’ of the plant nutrient cycle.

Foliar tissue analyses should be interpreted with caution in consideration with soil chemistry, fertilization practices and irrigation water quality.
Example: Value of historical leaf-sampling/fertilization record for block of mature pistachios, planted 1983, east side.

<table>
<thead>
<tr>
<th>Year</th>
<th>fertilization</th>
<th>leaf boron</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>boron, lbs/acre</td>
<td>ppm</td>
</tr>
<tr>
<td>1994</td>
<td>0</td>
<td>1300</td>
</tr>
<tr>
<td>1995</td>
<td>0</td>
<td>56</td>
</tr>
<tr>
<td>1996</td>
<td>0</td>
<td>52</td>
</tr>
<tr>
<td>1997</td>
<td>5 + 20</td>
<td>75</td>
</tr>
<tr>
<td>1998</td>
<td>5 + 20</td>
<td>78</td>
</tr>
<tr>
<td>1999</td>
<td>5 + 20</td>
<td>80</td>
</tr>
<tr>
<td>2000</td>
<td>5 + 20</td>
<td>150</td>
</tr>
<tr>
<td>2001</td>
<td>20</td>
<td>243</td>
</tr>
</tbody>
</table>
## Critical and Suggested Levels for Mature Tree in late July/August Leaf Samples

<table>
<thead>
<tr>
<th>Element</th>
<th>Suggested Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>nitrogen</td>
<td>2.5 - 2.8 %</td>
</tr>
<tr>
<td>phosphorous (P)</td>
<td>0.14 - 0.17%</td>
</tr>
<tr>
<td>potassium (K)</td>
<td>1.5 - 2.2%</td>
</tr>
<tr>
<td>calcium (Ca)</td>
<td>1.3 - 4.0%</td>
</tr>
<tr>
<td>magnesium (Mg)</td>
<td>0.6 - 1.2%</td>
</tr>
<tr>
<td>boron (Bo)</td>
<td>120 - 250 ppm</td>
</tr>
<tr>
<td>zinc (Zn)</td>
<td>10 - 15 ppm</td>
</tr>
<tr>
<td>copper (Cu)</td>
<td>6-10 ppm (???)</td>
</tr>
</tbody>
</table>
Critical and Suggested Levels for Mature Tree in August Leaf Samples

<table>
<thead>
<tr>
<th>element</th>
<th>suggested range</th>
</tr>
</thead>
<tbody>
<tr>
<td>sodium</td>
<td>not established</td>
</tr>
<tr>
<td>chlorine</td>
<td>&lt;0.1 %</td>
</tr>
</tbody>
</table>

Sodium concentration in the leaf appears to be a poor indicator of salinity (exclusion by tree?). Chlorine concentration is better.
Leaf Sampling Procedure for Pistachios

• sample female trees in late July or August

• collect fully expanded sub-terminal leaflets from non-fruited branches

• collect one or two average-looking leaflets per tree from 60 – 75 trees in the area of interest. Sample tree quadrants equally.

• foliar nutrient sprays cloud results

• best to submit samples for testing within 24 hours
Initial soil/water investigation:

- Soil survey maps are available for most ag land in California.
- Backhoe pits and deep augering (bedrock, hardpans, perched water tables, layering, etc.
- Irrigation water testing available.

If you start with a fertile, deep, well-drained soil, and good irrigation water that is efficiently applied, considerably less time will be spent diagnosing and correcting nutrient problems.
Understanding the soil - importance of soil sampling

• soils commonly change with depth (pistachio is deep rooted).

• different soil type can occur within a single orchard (e.g. old river beds, differences in elevation, sand deposits, old oil wells, cuts or fills, old corals, alkali patches, etc.)
Suggested Soil Sampling Protocol

- sample to three feet in one foot increments (knowing that pistachio roots can go much deeper than that!)

- take three to ten sub samples from a given area and composite them by depth into single samples.

- replicate samples across the orchard.

- soil samples do not generally need to be taken annually.
THE MACRONUTRIENT
NITROGEN
(N)

‘Macro’ means big. Macronutrients are required in large quantities by the plant.

‘Micro’ means small. Micronutrients are required in comparatively smaller quantities by the plant.
Nitrogen is used by plants to make proteins and nucleic acids.

Nitrogen, then, is a necessary component of plant enzymes, chlorophyll, growth regulators, genetic material, and plant structural components.
Nitrogen Deficiency Symptoms:

- young leaves pale
- old leaves drop
- reddish petioles and midribs
- reddish bark in severe deficiency
Not a Problem
Estimate of Soil N Demand over the Alternate Bearing Cycle from Weinbaum, Brown and Rosecrance

<table>
<thead>
<tr>
<th></th>
<th>(Apr,May)</th>
<th>(June – Aug)</th>
<th>(Sept – Dec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropping Status</td>
<td>Spring</td>
<td>Nut Fill</td>
<td>Post</td>
</tr>
<tr>
<td></td>
<td>Flush</td>
<td>Period</td>
<td>Harvest</td>
</tr>
<tr>
<td>Total Status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>-----------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>ON</td>
<td>46</td>
<td>103</td>
<td>*</td>
</tr>
<tr>
<td>OFF</td>
<td>60</td>
<td>76</td>
<td>*</td>
</tr>
</tbody>
</table>
Weinbaum, Brown and Rosecrance

• In an On-year 85% of the total nitrogen uptake went to the nuts, while on the Off-year 67% of the nitrogen went to the canopy.
• Data were taken from 20-year old Kerman pistachio trees budded on *P. atlantica* rootstock.
Considerable Nitrogen Exits the Orchard in the Nuts

- Approximately 12 pounds of nitrogen are removed for every 500 pounds of hulled and dried nuts.
- Additional nitrogen must be present to grow the tree and to offset losses due to denitrification, tie-up, leaching, etc.
- Some nitrogen comes back in leaf decomposition, and from the atmosphere.
FACTORS AFFECTING THE NITROGEN FERTILIZATION REQUIREMENT

- Chemical form of fertilizer (pH, etc)
- Tree density (at least initially)
- Tree age
- Orchard health and productivity
- Fertilizer application methods
- Nitrogen in irrigation water
- Nitrogen stored in soil as nitrate or in organic matter
- Nitrogen available in organic amendments
- Presence of cover crops
- Irrigation efficiency
- Nitrogen deposited with rain water
Supplemental nitrogen requirement per acre for mature pistachio

At good irrigation efficiency levels, the amount of N in the soil and water, and depending upon the productivity of the orchard, approximately 150 – 200 pounds of nitrogen should be applied per acre per year.
Immature Tree Nitrogen Requirements

- First Leaf: 0 - 0.1 pounds/tree
- 2nd Leaf: 0.15 - 0.2 pounds/tree
- 3rd Leaf: 0.25 - 0.35 pounds/tree
- 4th Leaf: 0.5 - 0.6 pounds/tree
- 5th Leaf: 100 – 120 pounds/acre
- 6th Leaf: 120 – 130 pounds/acre
- 7th Leaf: 135 – 150 pounds/acre

Leaf tissue sampling can help adjust these annual supplemental nitrogen fertilizations.
Leaf Tissue Sampling

• The major tool available to the grower and PCA for monitoring the nitrogen status of the orchard is leaf-tissue sampling.

• The percent by weight of nitrogen in the non-terminal, non-fruiting leaflets in August has been correlated to the orchard nitrogen status.
Optimal Levels of Leaf Nitrogen

• 2.6 - 2.9% for young rapidly growing immature trees.
• greater than 2.3% for mature trees with no or little advantage seen for levels greater than 2.5%.
The percentage of N in the dry matter of leaves is an indication of how much N is stored in the tree.

Think of the leaf tissue sampling report as a speedometer.

If leaf N levels are above 3.0 %, the speedometer is ‘pegged’.
SOME NITROGEN IS ALREADY PRESENT IN THE TREE

Excessively high leaf nitrogen concentrations in the leaves suggests that N fertilization rates can be reduced from previous season levels.
REMEMBER,

Annual nitrogen applications may be adjusted to fit the grower’s own conditions based on leaf-tissue sampling.
Apply Nitrogen in the Spring and Early Summer

- Make a limited application during the spring flush (late March to mid-May)
- Apply the remainder during June through the end of July so that it will be available for fruit growth and nut fill (which in Kerman occurs through August on-year) or tree storage (off-year).
Pistachios appear to be slow to respond to changes in levels of nitrogen fertilizers.

In 1984, 1985 and 1986, Drs. Wolpert and Ferguson found no difference in yield in mature trees in two different orchards over ranges of annual N fertilization of 0 to 500 lbs per acre.

Leaf N levels did appear to decrease with time in trees receiving less than 100 lbs of N per acre. Soil residual N levels were not measured.
Avoid Late Nitrogen Applications

Nitrogen applications after July may encourage excessive vegetative growth and delay dormancy, especially with Kerman on *P. integerrima* rootstocks. Delaying dormancy may result in freeze damage, especially to younger trees, from late October and early November freezes.

Cuyama Valley, Buttonwillow
Avoid Excessive Nitrogen Applications

Excessive N applications;
- encourage excessive vegetative (branch and leaf) growth at the expense of reproductive (nut) growth
- may result in pollution of the ground or surface water.
The Macronutrient Potassium (K)
### Estimate of K Uptake over the Alternate Bearing Cycle

<table>
<thead>
<tr>
<th>Cropping Status</th>
<th>Spring</th>
<th>Nut</th>
<th>Post</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>Flush</td>
<td>Fill</td>
<td>Harvest</td>
<td></td>
</tr>
<tr>
<td>ON</td>
<td>0</td>
<td>192</td>
<td>18</td>
<td>210</td>
</tr>
<tr>
<td>OFF</td>
<td>1</td>
<td>91</td>
<td>0</td>
<td>92</td>
</tr>
</tbody>
</table>

_______________ lbs K/acre ________________

based on differences in tree K content.
Potassium (K) removal in nuts

Data from Rosecrance, Weinbaum and Brown showed that harvested pistachios (on-year) nuts contained about 200 lbs/acre $\text{K}_2\text{O}$ (166 lbs of K).
Potassium (K) Deficiency Symptoms

Suggested leaf tissue concentration: 1.7 – 2.0 %
Potassium deficiency symptoms:

• symptoms appear in early to mid-summer

• symptoms worst on older leaves of current shoots

• trees show slow growth and smaller leaves

• trees may look normal but produce yields below potential
In a study by Brown et al., fertigating or soil banding potassium in neutral, K-deficient loam soils at the rate of 100-200 lbs/acre increased:

- soil and leaf K concentrations
- individual nut weight and total yield/acre
- split percentage
- percentage of filled nuts (i.e. reduced blanking)
- suggest leaf tissue should be 1.7 – 2.0 % K
Source of potassium was not important.

- Potassium chloride (KCl)
- Potassium sulfate (K$_2$SO$_4$)
- Potassium nitrate (KNO$_3$)

All produced similar results
In a 1984-1985 study by Dr. Wolpert on Kern County west-side soils that have high native potassium fertility:

Potassium applied in the range of 0 to 12 lbs of K per tree, did not increase nut yield, and split percentage was only increased if potassium chloride (KCl) was the source of potassium.

Leaf potassium content ranged from 1.45 % (0 lbs/tree) to 1.75 % (12 lbs/tree).
THE MACRONUTRIENT
PHOSPHOROUS
(P)
Phosphorous Deficiency in Pistachio

Optimal Range: 0.14 – 0.17 %
Data from Rosecrance, Weinbaum and Brown showed that harvested pistachios (on-year) nuts contained about 50 lbs/acre of $\text{P}_2\text{O}_5$. May be a good idea to add that yearly.
Magnesium (Mg)

Deficient magnesium (Mg) concentrations in leaves is a greater concern in soils:

• that are sandy, acidic and well leached.
• or with high native calcium and potassium fertility.
• or where calcium (i.e. gypsum) and sulfur are added in large quantities to offset saline soils.

Magnesium sulfate (epsom salt) may be sprayed at the rate of 2-3 lbs per acre per 100 gallons of water in early May to maintain leaf Mg concentrations.
CRITICAL MICRONUTRIENTS
Zinc (Zn), Copper (Cu), Boron (B)
In the Central Valley of California, deficiencies of the following elements are most likely to occur:

- zinc (more likely in alkaline soils)
- copper (more likely in alkaline soils)
- boron (more likely on east side soils, (acidic soils, pure irrigation water))
Pistachio trees on P. atlantica rootstocks are less likely to show boron, copper or zinc deficiency symptoms. However, atlantica rootstocks are much more susceptible to verticillium wilt disease. Plant rootstock with P. integerrima heritage where Verticillium wilt is a problem.
Pistachio Cultivars Appear To Vary in Boron Uptake

<table>
<thead>
<tr>
<th>Variety/selection</th>
<th>Leaf tissue boron, ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>B5-8</td>
<td>415 a</td>
</tr>
<tr>
<td>Lost Hills</td>
<td>606 b</td>
</tr>
<tr>
<td>Kerman</td>
<td>640 b (630, UCB1)</td>
</tr>
<tr>
<td>Golden Hills</td>
<td>864 c</td>
</tr>
</tbody>
</table>

Varieties on PG1 rootstock on west side of Kern County in 2005, 9th leaf.
Symptoms of zinc deficiency

Optimal leaf tissue concentration: 10 - 15 ppm
Symptoms of copper (Cu) deficiency
Zinc and Copper Deficiency:

Trees deficient in zinc and copper may need annual applications of these elements to maintain tree health and prevent yield loss.

Zinc and copper deficiency symptoms are typically most pronounced in trees just coming into bearing.
Zinc deficiency symptoms typically appear early in the season while copper deficiency symptoms appear in mid to late summer.
Correcting zinc and copper deficiencies

A single post-bloom foliar spray of zinc sulfate (2 lbs of ZnSO₄ (36%)/100 gal. water/acre) and copper (1/10 lb of Cu as chelated Cu) applied when the new leaf canopy is 50 to 90% fully expanded is effective in increasing leaf tissue Zn and Cu concentrations.
Correcting zinc and copper deficiency

Fertigating with non-chelated zinc and copper (e.g. zinc and copper sulfate) materials in alkaline soils is not effective.
Acidifying soils with sulfuric or phosphoric acids, or sulfur dust where lime is present, are often sufficient to correct some nutrient deficiency problems in alkaline soils:

- zinc, copper, iron, manganese
- magnesium
- (caution – sometimes this works too well, more later).
Boron is important in flowering, pollen viability and nut set in pistachio.

Optimal Leaf tissue B = 120 – 250 ppm
Boron deficiency symptoms:

- tip burning of growing points and young leaves
- shoot tips die back, terminal bud may remain dormant
- lateral buds sprout, short internodes
- leaves are yellow, tips curled upward and misshapen
- flower clusters often drop before fruit set.
Correcting boron deficiency

Borax (11%) broadcast in the fall or Solubor (20.5%) fertigated in the spring at the rate of 5.5 to 7.5 lbs/acre of actual B has given correction for several years.

Foliar sprays of Solubor at the rate of 2.5 – 5 lbs of product/100 gallons/acre at bud swell to green tip * (late dormant spray - late February to mid-March), or post-bloom at a rate of 2.5 lbs at 50 – 90% new leaf canopy expansion (late April to mid-May) usually provides an annual correction.

* some results by Dr. Brown, UC Davis show increased yield for this timing, if trees deficient in boron in the spring.
In the Central Valley of California, the elements that are more likely to be at toxic levels are:

- boron
- sodium (leaf analysis may not show as high)
- chlorine
Boron toxicity symptoms

leaf tissue  B > 400 ppm
Biologically-produced organic acids, acid-forming N fertilizers, phosphoric acids can all make boron that is normally unavailable temporarily too available.

Lesson: If you can’t leach excess boron from the soil, keep soils more alkaline and foliarly apply any deficient micro elements.
Salt Toxicity

July/August leaf tissue Chlorine (Cl) concentration > 0.3 percent i.e. 3000 ppm

Slide Courtesy of Louise Ferguson
Suspected manganese toxicity in (Ridgecrest - eastern Kern County) area

Acidifying soil appears to have increased available Mn (leaf Mn > 300 ppm, soil DTPA Mn > 40 ppm)
Preemergent herbicide damage may look similar to nutrient deficiencies.
Recovery from metam sodium damage
Goal and Roundup damaged leaves
With time, dedication, and a willingness to go the extra distance, even the toughest nutrition-related problem can be solved.
Don’t panic if all this seems a little complicated.

Assuming reasonable soil and water quality:

If you add enough nitrogen and get the irrigation uniformity and scheduling right, you are 75 % of the way toward growing a profitable crop of pistachios.

You’ll probably have time to pick up the other nutrition details later.

Ask questions first, apply nutrients later.