NITROGEN
BEST MANAGEMENT PRACTICES
INTRODUCTION

Nitrogen management has major impacts on the productivity of almond orchards, the profitability of growers statewide and the effect of nitrogen on the environment. With the implementation of the Irrigated Lands Regulatory Program (ILRP), every grower is required to implement a plan that allows for the efficient use of nitrogen fertilizer and reduces nitrogen leaching into groundwater.

Efficient, environmentally sound and profitable nitrogen fertilization can be achieved when growers abide by the 4 Rs of Nutrient Management, which state that nitrogen must be applied at the Right Rate, at the Right Time and in the Right Place, using the Right Source of nutrients. The ultimate goal of nitrogen management is to apply adequate, but not excessive, amounts of nitrogen so that productivity is optimized and loss to the environment (and waste of the input) is minimized.

The Almond Board of California’s Nitrogen Best Management Practices provide almond growers with an understanding of nitrogen’s role in almond production and guidance on how to achieve efficient, profitable nitrogen management. These best management practices should serve as a guide to growers — individual management plans should be devised in conjunction with PCAs and other field experts to adequately meet individual orchard’s needs.

KEY PRINCIPLE

You cannot enhance orchard productivity by providing more nitrogen than is needed by the crop. However, you can harm productivity by applying too much nitrogen.

With proper management, optimal productivity and minimized nitrogen loss can be achieved simultaneously.

Every individual orchard must have a specific nitrogen management plan that considers the 4 Rs of Nutrient Management — there is no “one-size-fits-all” approach.

- Right Rate
- Right Time
- Right Place
- Right Source
NITROGEN LOST FROM THE ORCHARD SYSTEM

If nitrogen supply is not well managed, nitrogen will be lost from the orchard system, nitrogen use efficiency (NUE) will be reduced, money will be wasted, and tree productivity will be compromised.

The single most significant cause of nitrogen loss can occur when nitrogen moves below the active root zone through a process called leaching. A small amount of nitrogen can also be lost via gaseous losses and surface runoff, which may occur if excess irrigation or rainfall washes fertilizer and sediment from the orchard surface.

How Does Leaching Occur?

Leaching occurs when nitrogen in the soil is rapidly converted to nitrate ($\text{NO}_3^-$), a negatively charged form of nitrogen that is not held by soil particles and moves with water down into the soil. Any soil water that moves outside the active root zone may carry nitrate with it, effectively moving the nitrogen out of the trees’ root zone where it can no longer support tree and kernel demand.

While nitrogen can be applied in many fertilizer forms (urea, nitrate, ammonium, and organic nitrogen forms, among others) in California’s warm and neutral soils during periods of peak nitrogen demand (March to September), all forms of nitrogen, regardless of how they were applied, can be converted to nitrate in a matter of days (see Fig. 2).

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### PRINCIPLES OF SOUND FERTILIZATION: THE 4 Rs PRINCIPLE

#### Right Rate

To determine the right rate of nitrogen to apply to maintain productivity, a grower must first estimate their tree nitrogen demand and then determine their orchard’s total nitrogen supply from all sources. From there, the grower should subtract their total supply from tree demand to arrive at their right rate of application.

\[
\text{Right Rate} = \text{Tree Demand} - \text{Nitrogen Supply}
\]

#### Estimating Nitrogen Supply

Prior to determining the right application rate, growers must first estimate their availability of total nitrogen from all sources.

Three sources of nitrogen are most commonly present in California almond orchards:
- nitrogen in irrigation water,
- residual nitrogen in the soil from the prior crop year, and
- nitrogen released from added soil organic matter (discussed in greater detail in the Right Source section on page 13).

Nitrogen in irrigation water acts as an excellent, free nitrogen “fertilizer” and should be included in a grower’s total annual nitrogen budget, as illustrated in Table 1.

#### Estimating Nitrogen Demand

Nitrogen is required for the optimal growth of all annual systems (flowers, new shoots and roots, kernel growth) and perennial organs (branches, the trunk and root system, etc.).

For almond trees four years and older, kernel yield in the current crop year is the primary factor impacting nitrogen demand, while in young trees tree growth is the major factor to consider when determining nitrogen demand.

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### TABLE 1

This demonstrates nitrogen from irrigation water that is available for tree use (measured in acre-inches of tree evapotranspiration (ETc)).

<table>
<thead>
<tr>
<th>Acres-Inches</th>
<th>Reported as NO₃ (Nitrate) (ppm or mg/L)</th>
<th>Pounds of Nitrogen in Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 ppm</td>
<td>5 ppm</td>
</tr>
<tr>
<td>1</td>
<td>0.05</td>
<td>0.3</td>
</tr>
<tr>
<td>6</td>
<td>0.3</td>
<td>1.5</td>
</tr>
<tr>
<td>12</td>
<td>0.6</td>
<td>3.1</td>
</tr>
<tr>
<td>36</td>
<td>1.8</td>
<td>9.2</td>
</tr>
<tr>
<td>48</td>
<td>2.4</td>
<td>12.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acres-Inches</th>
<th>Reported as NO₃-Nitrogen (Nitrate Nitrogen) (ppm or mg/L)</th>
<th>Pounds of Nitrogen in Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>1.4</td>
<td>6.8</td>
</tr>
<tr>
<td>12</td>
<td>2.7</td>
<td>13.5</td>
</tr>
<tr>
<td>36</td>
<td>8.2</td>
<td>40.8</td>
</tr>
<tr>
<td>48</td>
<td>10.9</td>
<td>54.4</td>
</tr>
</tbody>
</table>
Breakdown of Nitrogen Demand Based on Tree Age

Years 1 – 2: A study performed in Modesto (during which Whole Orchard Recycling was not conducted) showed that applying three ounces of nitrogen per tree during the first growing season and four ounces per tree in the second growing season resulted in optimum growth, a conclusion that took trunk diameter and tissue samples into account. Total nitrogen applications were divided into six applications over the course of the season and all fertilizer was applied to the active root zone. These findings are in line with previous research conducted at Nickels Soil Lab near Arbuckle.

In orchards where the old orchard was chipped and incorporated back into the soil prior to replanting (via Whole Orchard Recycling), higher rates of nitrogen application may be required in the first year of the newly planted almond orchard.

Smaller, more frequent doses of nitrogen fertilizer are more efficient in young trees with small root zones. Since the root systems of one and two-year-old trees are very small, special care must be taken to ensure that the applied fertilizer is placed within the root zone. If the irrigation system delivers significant amounts of water outside the root zone, then the fertigation taking place will not efficiently deliver nitrogen to the tree. To ensure nitrogen is delivered appropriately, growers should look to hand fertilization, removing or moving emitters, or using low-throw microjets or drip emitters placed close to the trunk (without wetting it).

Years 3 – 6: During this period nitrogen demand for tree growth (leaf and woody biomass) is significant as overall canopy growth to cover orchard space is rapid. In orchards with significant bare ground, nitrogen in fallen leaves and other plant debris is not fully recycled, slightly increasing nitrogen demand. As the trees enter their first years of productivity and commercial harvest takes place, yield will begin to represent significant nitrogen demand and should be estimated.

Years 7 – on: As the trees grow to fill the orchard space and as yields exceed 1,000 lbs./acre, nit production becomes – by far – the largest determinant of nitrogen demand. Then, as certain trees reach the end of their productive lifespan and individual trees die, the orchard’s nitrogen demand decreases.

The 1,000 lbs. of kernel weight includes all the nitrogen removed in hulls, shell, kernels, and debris to yield 1,000 lbs. of kernel weight. This removal rate was observed in high-yielding, well-managed orchards and corresponds with a whole fruit nitrogen percentage of 1.8%.

Thus, to correctly fertilize, meeting the tree’s needs without over-supplying nutrients, growers must estimate yield potential and then include an amount of nitrogen as shown in Table 2 to provide for the growth of the tree. In four years of experimentation at multiple sites, researchers determined that the nitrogen removal rate averaged 68 lbs. of nitrogen per 1,000 lbs. kernel yield.


table 2

<table>
<thead>
<tr>
<th>Age</th>
<th>Total Non-Yield Nitrogen Demand (lbs/acre)</th>
<th>Nitrogen Demand for Kernel Yield (lbs/acre)</th>
<th>Representative Yield Capacity by Year for Nonpareil</th>
<th>Representative Total Nitrogen Demand (lbs/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>30** (3 oz/tree)</td>
</tr>
<tr>
<td>2***</td>
<td>55</td>
<td>0</td>
<td>0</td>
<td>55 (4 oz/tree)</td>
</tr>
<tr>
<td>3</td>
<td>65</td>
<td>Expected yield x 0.068</td>
<td>750</td>
<td>116</td>
</tr>
<tr>
<td>4</td>
<td>55</td>
<td>Expected yield x 0.068</td>
<td>1,750</td>
<td>174</td>
</tr>
<tr>
<td>5</td>
<td>45</td>
<td>Expected yield x 0.068</td>
<td>2,750</td>
<td>232</td>
</tr>
<tr>
<td>6</td>
<td>40</td>
<td>Expected yield x 0.068</td>
<td>2,900</td>
<td>237</td>
</tr>
<tr>
<td>7 – 15</td>
<td>40</td>
<td>Expected yield x 0.068</td>
<td>2,500 – 3,100</td>
<td>210 – 255</td>
</tr>
<tr>
<td>16 – 25</td>
<td>30</td>
<td>Expected yield x 0.068</td>
<td>1,800 – 2,800</td>
<td>152 – 220</td>
</tr>
</tbody>
</table>

Estimating Yield

Since nitrogen demand is driven by yield in mature trees, and fertilizer decisions must be made prior to the current year’s orchard yield being known, growers must estimate their orchard’s yield and use that estimate to develop an annual fertilization plan. Growers can generally make these estimates based on their trees’ productivity over the past two years, paired with the expected productivity of similar orchards in their region, environmental conditions of the prior year, winter chill and spring flowering conditions.

Yield estimates made early in the season are valuable to orient fertilization management even if they are not precise (±500 lbs.), as these estimates can be adjusted throughout the growing season as the crop develops and a more accurate picture of that year’s yield begins to form. Using frequent, small fertilizer applications through the growing season provides growers with greater ability to adjust the amount applied based on changes in anticipated yield.

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**If large amounts of woody biomass were incorporated at planting (such as following Whole Orchard Recycling) then nitrogen demand will be higher in the first year as those materials decay and microbes immobilize the available nitrogen. Nitrogen will be released slowly from these materials over the following 2-3 years.

***If substantial yield occurs in year 2, then the nitrogen rate could be increased to meet that demand by applying nitrogen in proportion to estimated crop load.

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Table 2

This table shows representative tree and yield progression, with age, under good growing conditions and planted at 145 trees per acre. Orchards with less favorable growing conditions, or wider spacing, will develop canopies more slowly and will generally yield lower amounts, requiring less nitrogen. Some conditions may result in faster development and higher yields.

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After four years of experimentation at multiple sites, which involved whole tree excavation, researchers determined the nitrogen removal rate for almonds averaged 68 lbs. of nitrogen per 1,000 lbs. kernel yield.

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4 For more information on Whole Orchard Recycling, visit https://orchardrecycling.ucanr.edu/.

Efficient fertilization and nitrogen management requires that the application of nitrogen coincide with demand after the commencement of root growth and prior to leaf senescence.\(^5\)

- Nitrogen uptake requires healthy and transpiring leaves.
- In spring, uptake does not occur until the tree has depleted the nitrogen stored within the tree – this typically occurs at 70% leaf out.
- Once leaves begin senescence (around October), almond trees no longer take up significant nitrogen from the soil.

Nitrogen uptake from the soil closely follows the development of fruits and shoots, increasing in March after stored tree nitrogen is depleted (70% leaf out) and slowing dramatically after hull split. The industry’s understanding of the pattern and rate of nitrogen uptake from the soil is derived from a series of experiments conducted in high yielding orchards throughout California from 2008-2012 (Table 3 and Fig. 3).

### Table 3: Key Nitrogen Dynamics

<table>
<thead>
<tr>
<th>Nitrogen Phenology (Stage)</th>
<th>Key Nitrogen Dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dormancy</td>
<td>Nitrogen remains stored in the perennial wood</td>
</tr>
<tr>
<td>Bloom Time</td>
<td>Nitrogen demand is supported by remobilization of stored nitrogen</td>
</tr>
<tr>
<td>70% Leaf Out</td>
<td>Nitrogen uptake from the soil begins and stored nitrogen is depleted</td>
</tr>
<tr>
<td>100% Hull Growth</td>
<td>30% nitrogen uptake from soil has taken place by 100% hull growth</td>
</tr>
<tr>
<td>Kernel Fill</td>
<td>55% nitrogen uptake from soil has taken place by the end of kernel filling</td>
</tr>
<tr>
<td>Kernel Weight Accumulation Complete</td>
<td>85% nitrogen uptake from soil has taken place by the end of kernel weight accumulation</td>
</tr>
<tr>
<td>Hull Split to 3 Weeks Post-Shake</td>
<td>100% nitrogen uptake from soil has taken place*</td>
</tr>
<tr>
<td>Early Leaf Senescence to Leaf Fall</td>
<td>No nitrogen uptake from the soil</td>
</tr>
</tbody>
</table>

* For late-harvest cultivars, cold temperatures or harvest stress can limit post-shaking nitrogen uptake.

\(^5\) A physiological process where the tree breaks down the proteins in the leaves and transports nitrogen from the leaves to storage areas in the tree.
Further, a nitrogen application will only be effective if the irrigation system was not damaged during harvest operations, and if trees remain healthy and active. Applications to trees excessively stressed during harvest or in trees beginning to remodelize leaf nitrogen (commonly in October or later) will not be effective.

Continuous fertigation, in which the appropriate amount of nitrogen is provided in every irrigation event, is highly effective, particularly in sandy soils with low nutrient holding capacity. The amount of nitrogen applied should be made according to the trends illustrated in Fig. 3 and Table 3 on page 10. Continuous fertigation, however, is often not practical as many growers do not currently have the equipment, water delivery schedules, or engineering control to implement such a program. In the absence of the capacity to spoon-feed the tree, careful irrigation strategies and well-timed fertilizer injections can limit the possibility of loss of nitrogen through leaching; this will be further discussed in the “Right Place” section.

Hull Rot, Nutrient Storage and Shaking Efficiency

Overfertilized trees can be susceptible to hull rot and difficulty in shaking. High levels of tree nitrogen result in prolonged greening of hulls, extends the period during which hull rot infection can occur, and may reduce shaking efficiency. Applying more nitrogen than is required in May and June, then withholding nitrogen fertilizer until after harvest, is not recommended. This practice exposes the early excess nitrogen application to leaching loss in subsequent irrigations and may “over-feed” trees in the period immediately preceding hull split. Cessing to apply nitrogen fertilizer in May or June may also deprive trees of nitrogen during the critical bud formation period as well as the time when trees begin to stock up on nitrogen supply to prepare for harvest, which occurs from hull split to early post-harvest.

To avoid these problems and minimize hull rot attack, growers should fertilize continuously at the right rate and right time in as many small applications as possible, according to the information found in Fig. 3 and Table 3 on page 10.

In-Season Monitoring and Nitrogen Rate Adjustments

Growers should establish a pre-season nitrogen fertilization plan (rate and in-season distribution) based on predicted yields and nitrogen contributions from water and other sources. April tissue sampling and early season yield estimation may then be used to optimize the annual nitrogen fertilization plan by adjusting May through July and/or fruit maturity/post-harvest fertilization rates accordingly. In years of lower-than-expected yield with adequate April tissue nitrogen analysis, a reduction in mid-season nitrogen fertilization is suggested. The goal of this approach is to ensure nitrogen fertilization rates are more closely matched to individual orchard productivity in the current year. For more information on monitoring, see page 14.

Right Place

Our understanding of the Right Place and Right Source principles is derived from knowledge of the timing and location of root growth, the principles of soil science and irrigation practice, and research conducted in both growers’ fields and university and industry research trials.

The challenge of retaining nitrogen in the root zone is greatest in orchards grown in light textured soils as water from rainfall or irrigation moves quickly below the root zone, or under conditions that lead to restricted root distribution. Minimizing the amount of residual nitrogen in the soil profile prior to leaching events can reduce nitrogen loss.

Efficient Irrigation is Essential for Efficient Fertilization

To optimize the use of nitrogen fertilizer in almonds, fertilizers must be present in the root zone when they are most likely to be used by the tree. Nitrogen in the soil moves easily with irrigation water. As such, the application of nitrogen in a large single dose during times of limited plant growth exposes that nitrogen application to movement below the root zone. Smaller applications applied frequently and timed in alignment with periods of tree demand limit the potential for nitrogen loss. The uniformity of your irrigation system will define the uniformity of your nitrogen application. If portions of an orchard differ significantly in soil characteristics or productivity, it may be necessary to sub-divide the fertilization system to meet site-specific water and fertilizer demands, or to consider applying a portion of the annual nitrogen needed in a site-specific ground or foliar application.

All decisions around fertilization will be influenced by and must be adjusted according to the local environment. For example, in regions with rainfall that may persist well into leaf out, application to the soil prior to the completion of likely rain events may be problematic. Similarly, in areas with substantial rainfall soon after harvest, growers must adopt practices that minimize the amount of nitrogen that is resident in the soil at that time. The use of pre- and post-harvest foliar nitrogen applications can be used to provide nitrogen to trees if yield and tissue sampling indicate a need. However, the implications of immediate pre-harvest foliar nitrogen applications to address disease and vegetative regrowth in well-managed trees is not well studied.

Impact of Fertilization Timing on Nitrate Uptake by the Tree

Nitrogen in the soil moves easily with irrigation water, hence the application of nitrogen in a large single dose during times of limited plant growth exposes that nitrogen application to movement below the root zone. Smaller applications applied frequently and timed with periods of plant demand limit the potential for nitrogen loss.

Not shown: Structural roots reaching below 18 inches that anchor the tree but do not uptake nitrogen.
Almonds can effectively utilize different fertilizer and organic nitrogen sources to meet the annual nitrogen demand for fruit and tree growth. Different fertilizer formulations including urea ammonium nitrate (UAN32), calcium ammonium nitrate (CAN17), potassium nitrate (KNO₃) and ammonium sulfate ([NH₄]₂SO₄) are widely and effectively used. Urea and ammonium-based fertilizers tend to be more cost-effective, are initially less mobile in soil, and can lead to soil acidification over time. The conversion of urea and ammonium to plant-available nitrogen is dependent on soil temperature and occurs very rapidly (within days). Nitrate-based fertilizers are immediately at risk for leaching due to nitrate mobility, especially in sandy soils. Selection of nitrogen fertilizer formulations may also depend on the need for other essential nutrients like potassium, sulfur and calcium. Early research has shown that nitrogen stabilizers used with urea and ammonium-based fertilizers may slow the formation of nitrate, leading to less nitrogen immobilization. Only organic nitrogen sources with a C:N equal to or less than 13 become available during the season of application.

Application of compost on the wetted berm helps facilitate decomposition and nitrogen release within the tree root zone. Typical application rates of compost in orchards range from 4 to 7 tons per acre with a C:N of 11 to 13. A common practice in orchards is to apply compost as a mulch on the soil surface. Post-harvest application of compost during October maximizes the amount of time for breakdown before the subsequent year’s harvest. This time reduces residual compost on soil surface at harvest, which lowers potential food safety risk and interference with harvest equipment. Use of compost over time may result in buildup of soil organic matter and slow nitrogen release over time. Planting cover crops in the orchard adds organic matter and organic nitrogen to the soil. The amount of cover crop biomass depends on the crop’s establishment and winter rainfall. Cover crops may include a combination of lower C:N legumes, and grasses with a higher C:N. A hairy vetch cover crop with a C:N of 11 can add substantial nitrogen to an orchard. A vetch cover crop at the vegetative stage with a C:N of 25 adds important organic matter to the soil, but would supply limited plant-available nitrogen. Nitrogen availability from cover crops also depends on active tree roots growing in the orchard. In addition to organic matter addition, cover crops provide other benefits to orchards such as improving water infiltration, soil microbial diversity and habitat for pollinators and other beneficial insects. Different nitrogen sources offer growers options to balance nutrition for almond trees. Compost and cover crops are valuable nitrogen sources that add organic matter and help retain nitrogen in orchard soil. The Nitrogen Budgeting Tool as part of the California Almond Sustainability Program (CASP) provides up-to-date coefficients to calculate nitrogen availability. In combination with the right rate, time and placement, the right nitrogen sources optimize productivity and minimize nitrogen losses.

When conducting leaf sampling for non-fruiting spurs in April, growers must collect the entire cluster of leaves from each non-fruiting spur, ensuring they do not tear.

**Leaf Sampling**

Leaf sampling and analysis is a valuable monitoring method in determining the effectiveness of current practices and identifying problems. Determination of actual rates of nitrogen application must be made using the nitrogen balancing approach described in the Right Rate section of these best management practices.

Leaf sampling is a valuable supplemental to the 4 Rs and provides information on the current status of the tree and the effectiveness of grower’s management decisions. Sampling in conjunction with yield estimation can be conducted in April to help predict seasonal nitrogen demand, while sampling in July can be used to monitor plant nitrogen status and make end-of-year adjustments.

**MONITORING TREE NUTRIENT STATUS**

### APRIL SAMPLES:

- Sample the leaves of 5-8 non-fruiting, well-exposed spurs per tree approximately 35-50 days after full bloom, when the majority of leaves on non-fruiting spurs have reached full size (in most California orchards this takes place in mid-April).
- Request a nutrient analysis of nitrogen, phosphorus, potassium, boron, calcium, zinc, iron, copper, magnesium, sulfur and manganese.
- Enter results of the April analysis into the CASP-Nitrogen Calculator to interpret the results under the framework of your whole fertilizer plan. Note that all California testing laboratories have been provided with the model guidelines for interpreting April leaf tissue values.

### JULY/AUGUST SAMPLES:

- Sample all the leaves of 5-8 non-fruiting, well-exposed spurs per tree in late July through late August.

**Leaf samples between 2.4% and 2.8% = adequate nitrogen**

- If leaf samples show less than 2.4% nitrogen, there may be one of two problems:
  - Nitrogen fertilization was inadequate to meet tree demands.
  - Solution: Recheck your calculations of supply and demand.
  - The nitrogen applied was adequate but applied inefficiently.
  - Solution: Check for inefficiencies in placement, timing or irrigation practices.

- If leaf samples show more than 2.8% nitrogen, there may be one of two problems:
  - Overestimated tree demand.
  - Underestimated nitrogen supply from non-fertilizer sources (irrigation or organic amendments) led to over fertilization.

**FOR MORE INFORMATION:**

- For more information about the CASP Nitrogen Calculator, visit https://bit.ly/3dQ0Q69

**Note:** There is no clear relationship between leaf nitrogen percentage and the amount of nitrogen required or in excess.
Soil Sampling

Soil sampling can provide important information on the location and quantity of nitrogen available in the root zone. Soil samples prior to the first fertilization can provide an estimate of how much nitrogen and other nutrients are present within the soil and can be used to adjust spring fertilization. Soil samples as trees begin senescence can be used to estimate residual soil nitrogen as trees enter the dormant period with the goal to deplete soil nitrogen to low levels to minimize winter leaching. Soil samples should be collected from within the active root zone, which is generally the first 0-18 inches within the irrigated soil volume.

While soil sampling is a useful long-term monitoring strategy, soil nitrogen sampling is prone to significant challenges and thus the results should be interpreted carefully. Soil nitrogen is distributed very unevenly in the soil, particularly in microirrigated systems, making the collection of a representative sample difficult. Under low volume microirrigation systems, soil nitrogen may be highly concentrated and concentrated sampling is prone to significant challenges and thus the results should be interpreted carefully. Soil nitrogen is distributed very unevenly in the soil, particularly in microirrigated systems, making the collection of a representative sample difficult. Under low volume microirrigation systems, soil nitrogen may be highly concentrated and concentrated sampling is prone to significant challenges and thus the results should be interpreted carefully. 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Vision
California almonds make life better by what we grow and how we grow.

Mission
Expand global consumption of California almonds through leadership in strategic market development, innovative research and accelerated adoption of industry best practices.