NITROGEN

BEST MANAGEMENT PRACTICES

California Almonds
Almond Board of California

University of California
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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.

4Rs of Nutrient Management

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

THE BASICS OF NITROGEN IN ORCHARDS

Nitrogen is essential for a wide range of processes in plant production, including tree growth, leaf photosynthesis, and the production of protein, which is a major component of the almond kernel. With every 1,000 lbs. of almond kernels produced, 68 lbs. of nitrogen are exported from the field and an additional amount of nitrogen is required to satisfy the trees' annual growth demand. To maintain productivity and avoid losses, nitrogen must be replaced efficiently.

Managing nitrogen in almond orchards is a balancing act of supply and demand: growers need to consider the supply of nitrogen provided by fertilizers, organic matter, and irrigation water, as well as the demand for nitrogen due to tree growth and kernel production needs. An understanding of various nitrogen sources and how nitrogen can be "lost" in the system will help growers better make management decisions (see Fig. 1).

The Nitrogen Cycle: A Balancing Act

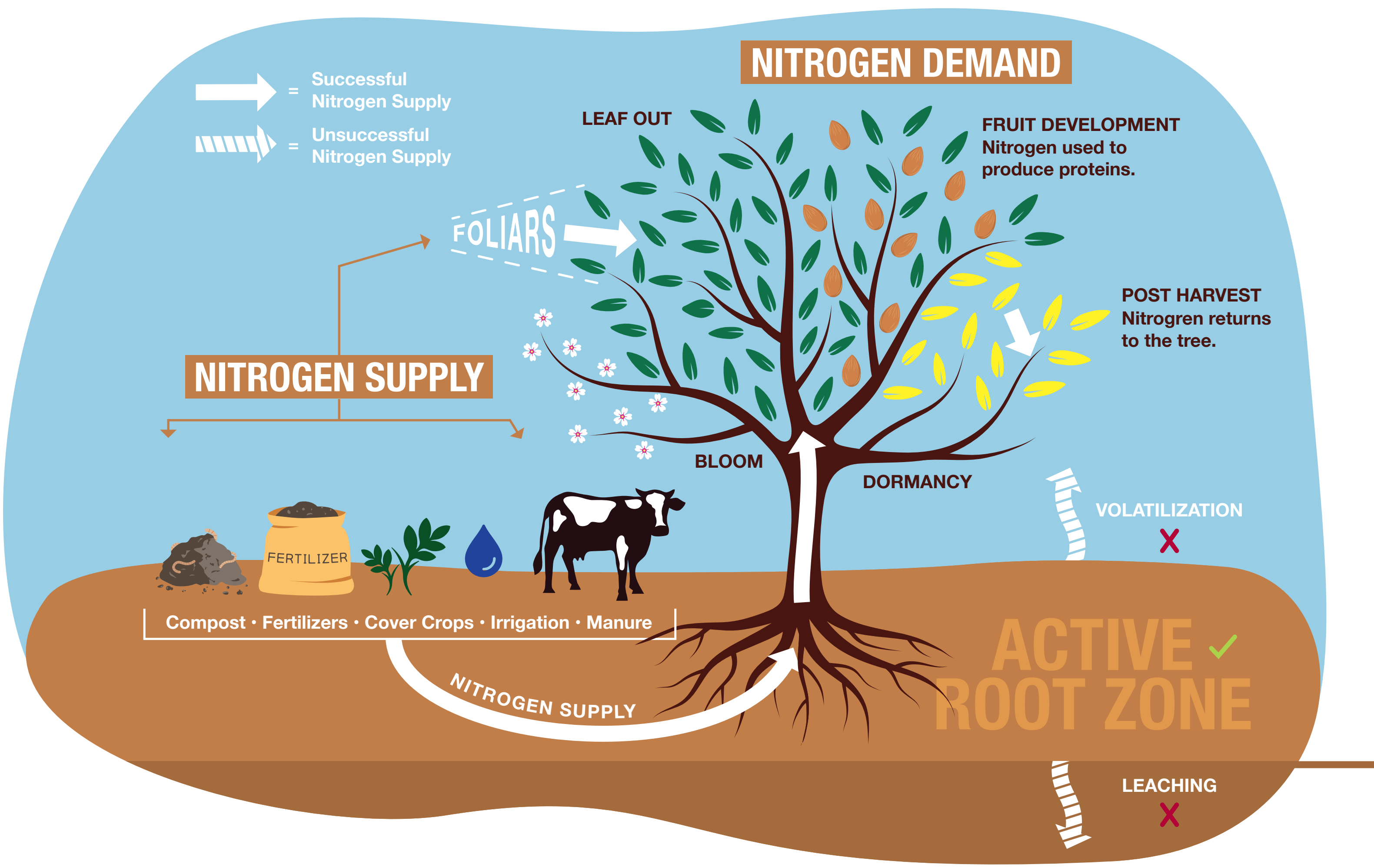
FIGURE 1

Nitrogen Supply: Nitrogen can be sourced from added organic matter such as composted manure, green waste or cover crops. Additionally, irrigation water in many parts of California contains nitrates that can contribute to satisfying trees' nitrogen demand. Finally, nitrogen fertilizer provides any additional nitrogen not supplied by irrigation water, organic matter, nitrogen stored in the tree, or residual soil nitrogen (nitrogen left over and pooled due to excess application).

Nitrogen Uses: In the fall, nitrogen in trees' leaves remobilizes to the branches, trunk and permanent roots, where it is stored for use in the subsequent year. Then, from bud break to leaf out, is used to help meet tree demand and grow the kernel. During that time, additional nitrogen is taken up from the soil to further meet demand.

Nitrogen Demand: The demand for nitrogen is driven by crop yield, tree growth, and prunings or debris removed from the orchard.

Nitrogen Loss: There are three primary causes of nitrogen loss: rainfall or irrigation that leads to leaching of nitrogen (as nitrate) below the active root zone, sediment runoff, and volatilization to the air.



Good fertigation starts with a strong, well-maintained irrigation system.

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.

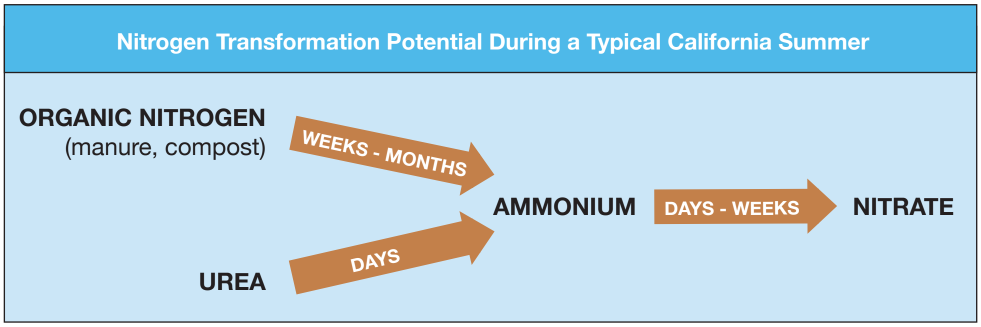
How Does Leaching Occur?

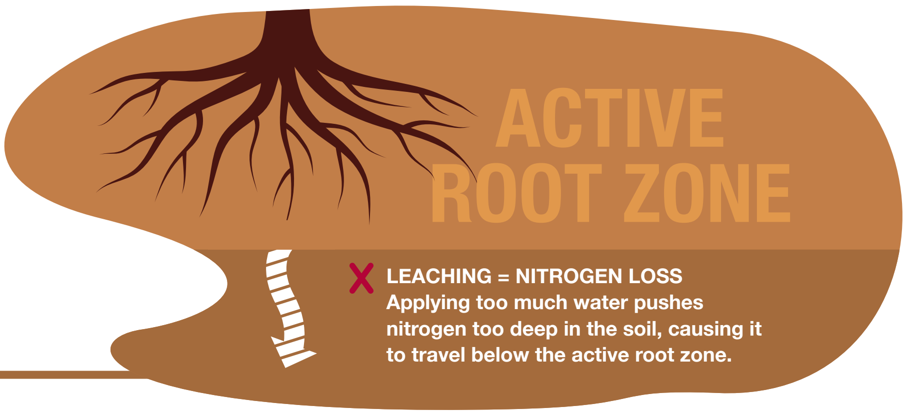
Leaching occurs when nitrogen in the soil is rapidly converted to nitrate (NO_3^-), a negatively charged form of nitrogen that is not held by soil particles and moves with water down into the soil. Any soil water that moves outside the active root zone may carry nitrate with it, effectively moving the 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).

FIGURE 2

This diagram demonstrates the process and timing behind how different forms of nitrogen can transform to nitrate in warm, moist conditions typical of an irrigated orchard during a California summer.[1]





[1] Jarvis-Shean, Katherine, et al. Young Orchard Handbook. UC Cooperative Extension Capitol Corridor, 2018.

PRINCIPLES OF SOUND FERTILIZATION: THE 4 Rs PRINCIPLE

4 Rs of Nutrient Management

The 4 Rs of Nitrogen Management (Right Rate, Right Time, Right Place, Right Source) provide a framework to help growers understand and manage nitrogen optimally.

Right Rate: apply nitrogen in proportion to tree demand.

Right Time: align nitrogen application timing with tree uptake, which begins at 70% leaf out and is complete soon after harvest.

Right Place: apply nitrogen to the tree's active root zone or on foliage, irrigating effectively, and, if possible, vary nitrogen application to address in-orchard variability in soils and yields.

Right Source: use the form of fertilizer best suited to the crop and the environment, optimizing other nutrients, as needed.

Research shows there are significant opportunities to increase NUE through approaches encompassed by the 4 Rs Principle, including improved methods of application, better integration with irrigation practices, strategic choice of nitrogen sources, optimization of soil organic matter (to further improve soil health), and the adoption of precision field management.

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.

Right Rate = Tree Demand — 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.

Reported as NO_3 (Nitrate) (ppm or mg/L)					
Acres-Inches	Pounds of Nitrogen in Water				
	1 ppm	5 ppm	10 ppm	15 ppm	20 ppm
1	0.05	0.3	0.5	0.8	1
6	0.3	1.5	3.1	4.6	6.1
12	0.6	3.1	6.1	9.2	12.2
36	1.8	9.2	18.3	27.5	36.6
48	2.4	12.2	24.4	36.6	48.8
Reported as NO_3-Nitrogen (Nitrate Nitrogen) (ppm or mg/L)					
Acres-Inches	Pounds of Nitrogen in Water				
	1 ppm	5 ppm	10 ppm	15 ppm	20 ppm
1	0.2	1.1	2.3	3.4	4.6
6	1.4	6.8	13.5	20.3	27.0
12	2.7	13.5	27.0	40.5	54.0
36	8.2	40.8	81.6	122.4	163.2
48	10.9	54.4	108.8	163.2	217.6

TABLE 1

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

Nitrogen in irrigation water should be accounted for in a grower's total annual nitrogen budget.

Soil samples collected prior to growers' first fertilization can provide an estimate of how much available nitrogen and other nutrients are present within the soil. This analysis can then be used to determine the amount (in pounds) of nitrogen available to the trees. Because tree roots are not stretched across the whole soil area (particularly in early years), growers must get an estimate of the percent of an acre that tree roots are exploring, as well as a determination of nitrogen available via a residual pool, in order to calculate how much nitrogen can be made available for trees to use through the soil.

Nitrogen Supply = Nitrogen in irrigation water + Nitrogen present in the soil at the start of the crop year

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.

Breakdown of Nitrogen Demand Based on Tree Age

Years 1 – 2: A study[2] 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.[3]

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, nut 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.

NITROGEN REMOVAL RATE
68 lbs. of nitrogen/1,000 lbs. kernel yield

In four years of experimentation at multiple sites,[4] researchers determined that the nitrogen removal rate averaged 68 lbs. of nitrogen per 1,000 lbs. kernel yield.

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.

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.

Tree and Yield Progression with Orchard Age				
Age years	**Total Non-Yield Nitrogen Demand** leaf + woody biomass	**Nitrogen Demand for Yield** kernel lbs.	**Representative Yield Capacity by Year for Nonpareil** 14 x 22 planting	**Representative* Total Nitrogen Demand** lbs. per acre
1	30	0	0	30** (3 oz/tree)
2***	55	0	0	55 (4 oz/tree)
3	65	Expected yield x 0.068	750	116
4	55	Expected yield x 0.068	1,750	174
5	45	Expected yield x 0.068	2,750	232
6	40	Expected yield x 0.068	2,900	237
7 – 15	40	Expected yield x 0.068	2,500 – 3,100	210 – 255
16 – 25	30	Expected yield x 0.068	1,800 – 2,800	152 – 220

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.

*Estimated demand for nitrogen for leaf and woody biomass production from Muhammad et al., Europ. J. Agronomy 65 (2015), Muhammad et al., Front. Plant Sci., 2020, and Jarvis-Shean, Katherine, et al. Young Orchard Handbook. UC Cooperative Extension Capitol Corridor, 2018.

**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.

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.

Tree Nitrogen Demand
=
Growth Demand +
Yield Demand (Table 2)

When determining tree nitrogen demand, calculate the total nitrogen that needs to be provided as either organic or inorganic nitrogen fertilizer.

[2] Jarvis-Shean, Katherine, et al. Young Orchard Handbook. UC Cooperative Extension Capitol Corridor, 2018.

[3] For more information on Whole Orchard Recycling, visit https://orchardrecycling.ucdavis.edu/.

[4] Muhammad et al. Europ. J. Agronomy 65, 2015.

Time nitrogen applications according to tree phenology. These almonds, for example, have reached 100% hull growth and are about to start shell hardening and kernel fill.

Right Time

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).

Timeline of Tree Nitrogen Uptake

From dormancy through 70% leaf out, the tree depends entirely on nitrogen that is remobilized from perennial organs – branches, trunk and roots – and essentially no nitrogen uptake occurs from the soil.

During the period from full leaf out until early post-harvest, tree nitrogen demand for fruit and growth is satisfied entirely by soil nitrogen uptake, with the vast majority of the nitrogen being utilized by fruit (illustrating the importance of yield estimation to determine nitrogen application).

Tree nitrogen that will be stored in buds and wood for the subsequent year's flowering and fruit set begins to accumulate once kernel fill is complete and continues to accumulate up until early leaf senescence. Once leaf senescence commences nitrogen from the leaves is used to fill the tree's nitrogen storage, and soil uptake ceases.

Nitrogen fertilizer should be applied at a rate and time that coincides with the demand curve described in Table 3 and shown in Fig. 3, using very frequent or even continuous fertigation with the goal of matching the tree's demand pattern with nitrogen applications. Uptake from the soil commences once leaves approach 70% leaf out – fertilization should be commenced just prior to this stage in a manner that ensures the applied nitrogen is present in the active root zone. Applications made too early risk loss due to spring rain or irrigation, as there is no transpiration to drive uptake by the roots.

Frequent fertigation during the growing season ensures soil nitrogen concentrations are always adequate for tree uptake. The traditional three-to-four nitrogen applications in a growing season result in temporary high soil nitrogen that is prone to leaching in subsequent irrigation or rainfall events. Nitrogen applications made more frequently and in smaller amounts, however, reduce instances of high nitrogen concentration, thus reducing the potential for leaching.

Nutrient demand decreases as plants approach fruit maturity and diminishes completely once trees' leaves begin to turn yellow, starting the process of leaf senescence. This typically occurs four-to-six weeks post-harvest but can occur earlier in water-stressed trees. In most orchards, nitrogen fertilization can be halted at or just before harvest. If yields were greater than anticipated or if leaf tissue analysis shows low or marginal nitrogen, additional soil or foliar nitrogen applications may be required.

However, later nitrogen applications can also be inefficient and unhelpful, especially in the following situations:

- A July/August leaf analysis shows the trees are already adequate in their nitrogen levels. Leaf analysis is one of the best indicators to determine nitrogen status. If in July your leaf nitrogen value is higher than 2.5%, a fall nitrogen application is likely not necessary.
- There is sufficient nitrogen still available in the soil to supply tree demand. Soil sampling can be conducted to determine if sufficient nitrogen is still present in the active root zone.
- Tree health is suboptimal when you plan to apply nitrogen. This may be the case if, for instance, your trees are too stressed during harvest or will be too stressed post-harvest due to dry down, water limitations, salinity, etc. Trees in suboptimal conditions will have greatly reduced nitrogen uptake since active green leaves are needed to drive nitrogen uptake from the roots.

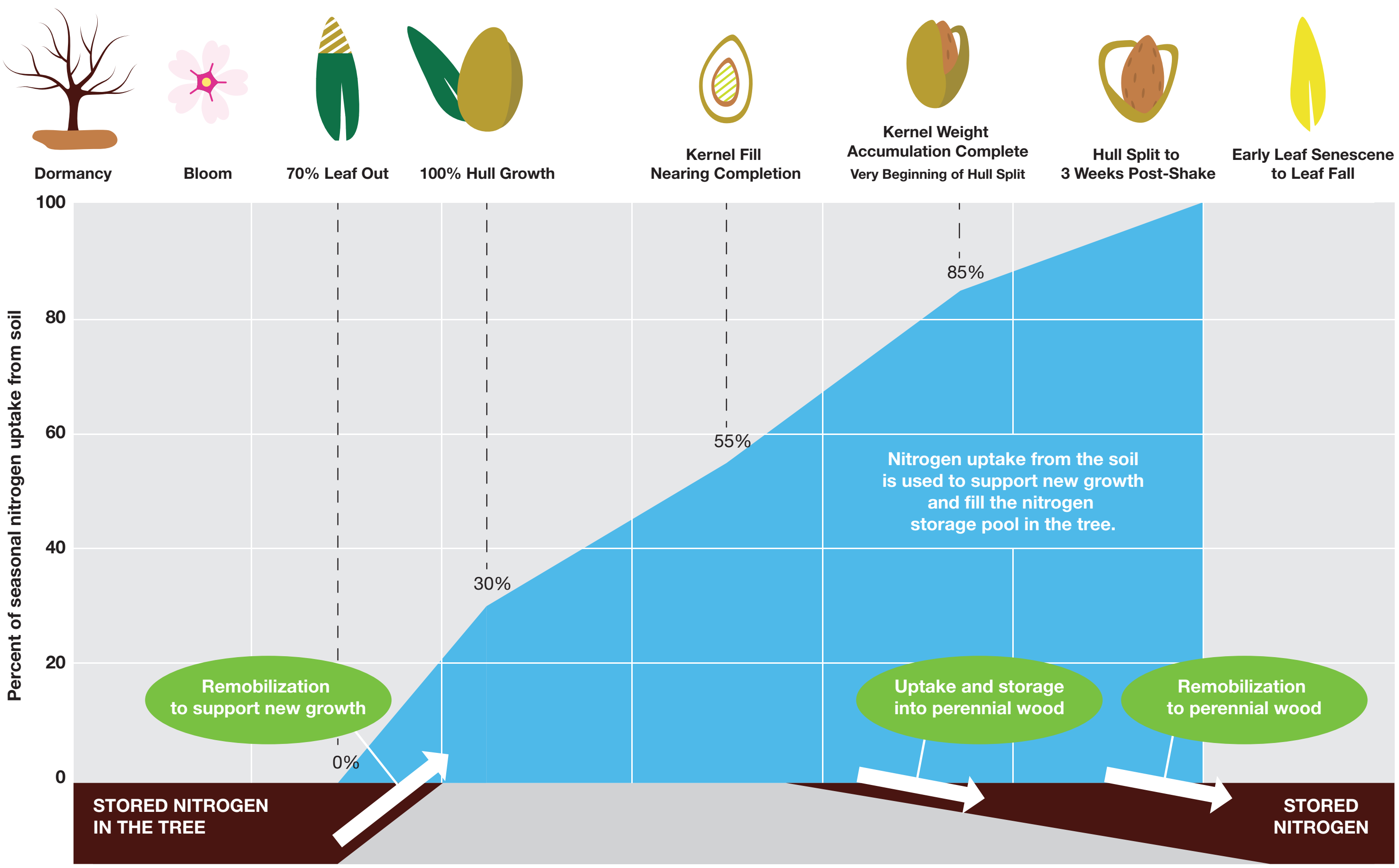


FIGURE 3

Nitrogen dynamics (tree nitrogen remobilization, demand and uptake patterns) over the growing season. Data shown is from 11-12-year-old Nonpareil trees yielding 4,800 lbs. per acre.

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

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

TABLE 3

Key nitrogen dynamics (tree nitrogen remobilization, and demand and uptake patterns) at each stage of the growing season. The percent of nitrogen uptake prescribed in this table provides guidance on the right time to apply nitrogen.

[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.

Timeline of Tree Nitrogen Uptake

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 remobilize leaf nitrogen (commonly in October or later) will not be effective.

Applying nitrogen when your trees have poor health conditions or when your trees and soils already have sufficient levels of nitrogen will likely result in nitrogen loss through leaching or gaseous losses.

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.

Using a specialized camera, researchers identified the location of the active roots most responsible for nitrogen uptake.

Failure to follow the 4 Rs of Nutrient Management can make trees more susceptible to hull rot, one type of which – *Rhizopus,* shown above – can be identified by black fungal growth.

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. Ceasing 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.

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.

Here are key factors to keep in mind when determining the Right Place to make a nitrogen application:

- Ensure that nitrogen is placed and retained close to active roots during periods of tree demand (Fig. 4).
- During the growing season, roots will be most active where water is abundant (usually the top 0-18 inches in the wetted irrigation zone).
- Non-uniform irrigation will result in non-uniform nitrogen application.
- Frequent small nitrogen applications matched in time and rate to tree nitrogen demand (Fig. 4) will result in maximum efficiency.
- Developing fertigation systems for each cultivar and management zone will lead to increased efficiency.

Efficient Irrigation is Essential for Efficient Fertilization

To optimize the use of nitrogen fertilizer in almonds, fertilizers must be present in the root system 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.

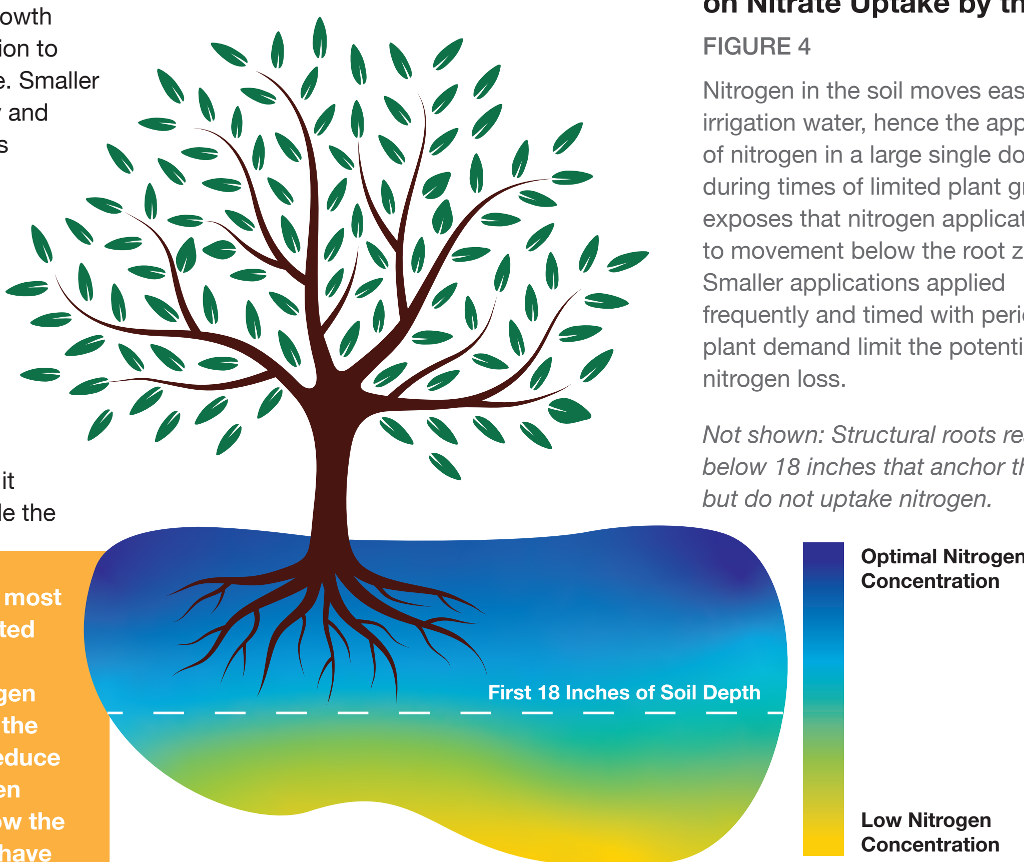
The uniformity of your irrigation system will define the uniformity of your nitrogen application.

If portions of an orchard differ significantly in soil characteristics or productivity, it may be necessary to sub-divide the fertigation 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.

Goal: Keep nitrogen where most of the active roots are located (0-18 inches). This can be achieved by injecting nitrogen fertilizer toward the end of the irrigation cycle (Fig. 4) to reduce the likelihood of the nitrogen moving with the water below the root zone before the roots have had a chance to take it up.

Impact of Fertigation Timing on Nitrate Uptake by the Tree

FIGURE 4



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.

Right Source

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 (KNO_3) and ammonium sulfate ($[NH_4]_2SO_4$) 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 nitrate 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 potential leaching.

Practices that add organic matter to the soil, often referred to as soil health practices, improve water holding capacity and maintain nitrogen in orchard top soil, thereby reducing the potential for leaching. Organic matter added to the soil contains nitrogen. However, the rate at which that nitrogen becomes plant-available varies dramatically depending on the carbon-to-nitrogen (C:N) ratio. Organic nitrogen sources with a C:N of 17 to 25 will have little-to-no nitrogen availability during the growing season while sources with a C:N greater than 30 may reduce nitrogen availability due to 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 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 rye 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.

MONITORING TREE NUTRIENT STATUS

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 supplement 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.

Leaf Sampling Protocol

The following leaf sampling protocol recognizes that growers generally collect one combined leaf sample per orchard. If the orchard to be sampled has substantial variability, then this sampling protocol should be repeated in each zone and nitrogen should be managed independently in each zone. Management of nitrogen in each zone can be achieved through separation of irrigation systems or by supplemental soil or foliar fertilization in high-demand areas. Efficient management of nitrogen requires that every orchard that differs in age, soil, environment or productivity should be sampled and managed independently.

For each orchard block or sub-block requiring individual information, growers should conduct the following in April and July/August:[6]

Collect leaves from 18-28 trees per orchard.

Combine all the leaves in a single bag.

Submit to a leaf nutrient analysis laboratory.

- Each sampled tree must be at least 30 yards apart. A minimum of 100 leaves per sample bag is required. Repeat this process for all orchards or orchard regions differing in productivity, age or soil type.
- Identify your areas with low yield performance and collect samples independently.
- Label all samples with collection date, field name, cultivar and location within the orchard, if possible. Note if foliar fertilizers have been applied. Retain records for year-to-year comparison.

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, cooper, magnesium, sulfur and manganese.
- Enter results of the April analysis into the CASP Nitrogen Calculator[7] to interpret the results under the framework of your whole fertilization 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 2.4% = 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 equal or more than 2.5%, 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.

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

[6] Adapted from Saa et al., Plant Soil (2014) 380:153–163

[7] For more information about the CASP Nitrogen Calculator, visit https://bit.ly/3dX2QS9

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 because tree roots are not exploring the whole soil area in their first year of growth. Therefore, an estimate of the percent of an acre that young tree roots are exploring needs to be made to estimate the nitrogen available in the soil that young tree roots can access and use. The analysis can then be used to determine pounds of nitrogen available to the trees. To find the amount of nitrogen in the first 18 inches of soil depth, simply multiply NO_3-N (in ppm) by 4 (NO_3-N x 4) and then adjust for percent of soil volume explored.

To ensure optimal management, it's important to regularly walk through your orchard/s and to implement proper irrigation and nutrient management year round.

NITROGEN EFFICIENCY

The fertilizer nitrogen demand calculated in the Right Rate section of this document is sufficient to meet all plant demands; however, it does not account for inefficiencies in nitrogen application. Inefficiencies exist in all systems due to natural soil microbial processes and as consequence of improper fertilizer and irrigation management. If not managed properly, inefficiencies will reduce the amount of nitrogen the tree receives, compromise productivity and increase the amount of nitrogen that escapes into the environment.

The efficiency with which applied nitrogen is utilized can be maximized by following the 4 Rs principles outlined in this document and can reach more than 80% under optimal conditions. Routine well-performed soil and plant testing can help the grower predict when trees may be approaching a deficiency and allow for careful supplementary applications.

Factors that affect nitrogen use efficiency and the approaches that can be adopted to minimize this risk include:

Application of the Right Rate of nitrogen to meet tree demand

- Accurately calculate tree demand.
- Independently estimate tree demand for each cultivar and manage fertilization.
- Frequently monitor soil, plant and irrigation water nitrogen.

Application at the Right Time

- Apply nitrogen according to tree uptake patterns shown in Fig. 4 on page 12 commencing at 70% leaf out and completing at or soon after tree shaking.

Application in the Right Place

- Time nitrogen application towards the end of an irrigation to ensure nitrogen remains in the active root zone.
- Do not apply nitrogen outside of the active root zone (especially important for young trees).
- Maintain the irrigation system to ensure uniformity of distribution and accuracy of nitrogen and water application rate.

Application of the Right Source

- The C:N ratio of organic nitrogen sources influences nitrogen availability with limited availability from 17 to 25, immobilization at greater than 30 and only in-season availability at a C:N ratio equal to or less than 13.
- Compost best practices include application as a surface mulch on the tree berm, and spreading post-harvest, before the first rainfall, to maximize breakdown prior to the subsequent harvest.
- Cover crops planted in the orchard may include a combination of legumes and grasses, and provide benefits such as improved water infiltration, soil microbial diversity and habitat for pollinators and other beneficial insects.

- Field variability in soil type and tree productivity.
  - Yield varies across all fields as a consequence of differences in soils, environment and irrigation uniformity, among others. The selection of a single uniform nitrogen rate to satisfy the average yield of the entire orchard will result in the under fertilization of many trees and overfertilization of the remainder.
    - Consider managing trees in zones of relative productivity by designing irrigation systems to provide cultivar and site (soil)-specific fertigation control and fertilizing at a rate to provide sufficient nitrogen for the majority of trees. Then supplement the highest performing trees with foliar or local surface applications.
- Deficiencies of other tree nutrients, areas of saline or sodic soils, soils with poor penetration of drainage or other local factors can reduce tree production and compromise nitrogen uptake. Optimizing management of all variables will increase the efficiency of nitrogen use.
- Avoid applications of nitrogen preceding a period of potential rain.

*These guidelines are based on extensive research conducted in four high-yielding orchards across California from 2008-2013, and as such are considered to be representative of good growing practices. The applicability under all growing circumstances, however, cannot be predicted with certainty — **grower judgment remains critical.***

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