

Almond Early-Season Sampling and In-Season Nitrogen Application Maximizes Productivity, Minimizes Loss

Protocol for Early-Season Sampling and In-Season Nitrogen Budgeting

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Background:

Efficient and profitable nitrogen (N) application demands that N be applied at the right rate, with the right timing and in the right location, so that productivity is maximized and the potential for N loss to the environment is minimized. The goal of N management is to apply adequate but not excessive amounts of N. You cannot enhance orchard productivity by providing N in greater amounts than is demanded by the crop. With proper management, optimal productivity and minimal N loss can be achieved simultaneously. To help growers achieve the goal of efficient and profitable nitrogen application, a new method of tissue testing and yield-driven fertilization has been developed. The following approaches are based on four years of research at multiple sites and were validated in additional trials in 2012.

Right Rate:

For mature almonds (> 7 years), nut yield in the current year is the primary determinant of N demand. The amount of N that will be removed from the orchard for a given yield ranges from 50 to 75 lbs N per 1,000 lbs of kernel yield, depending on the N status of the tree. In four years of experimentation at multiple sites, the ideal N removal rate averaged 68 lbs N per 1,000 lbs of kernel yield. This removal rate corresponds to maximal yield and optimal use of N resources, and coincides with a whole-fruit N% of 1.8%. (Note: This conversion stated as kernel pounds also factors in the N removed with shells and hulls to equal the “total fruit” N removal). Higher fruit N removal rates (>68 lbs N/1,000 lbs kernel) occur when trees have received N in excess of demand. The amount of N required for vegetative growth in a yielding tree is small in contrast to that required by the fruit, and averages 20 to 40 lbs per acre per year in orchards with 70% or greater orchard light interception.

The amount of N required (from fertilizer or other amendments) is determined by crop size (yield x 68 lbs N per 1,000 lbs kernel yield) less N supplied from water and other N sources including manures, composts, nitrogen-fixing cover crops, etc. Previous N applications in excess of crop N removal can also enhance soil and tree N reserves, thereby reducing current fertilizer N demand.

Nitrogen in irrigation water is an excellent and free N ‘fertilizer’ and should be included in your total annual N budget. The supply of N (lbs/acre) from water is calculated by multiplying nitrate concentration in water (ppm) x acre feet irrigation applied x 0.61. If the N concentration in irrigation water is reported as Nitrate-N, then the supply of N (lbs/acre) from water is calculated by multiplying Nitrate-N concentration in water (ppm) x acre feet irrigation applied x 2.73.

Our ability to estimate the contribution of soil N supply to orchard N demand is limited due to the extensive rooting depths of tree crops and complexities in determining the rate of N availability. A general guideline suggests that if soil nitrate exceeds 10–15 ppm, then N fertilization can be significantly reduced. Leaf tissue analysis in April provides information on the general availability of soil N and tree reserve N, and can be used to adjust in-season fertilization (described below).

In-season monitoring and N rate adjustments.

In the N management approach proposed here, growers establish a preseason N fertilization plan (rate and in-season distribution), based upon predicted yields and N contributions from water and other sources. April tissue sampling and early-season yield estimation are then used to optimize the annual N fertilization plan by adjusting the May-through-July and/or fruit maturity/postharvest fertilization rates accordingly. In years of lower-than-expected yield with adequate April tissue N analysis, a reduction in mid-season N fertilization is suggested, while higher-than-expected yields might require an increase in N applications. The goal of this approach is to ensure N fertilization rates are more closely matched to individual orchard productivity in the current year.

Right Timing:

Efficient fertilization and N management require that crop nitrogen demand is satisfied, and N is applied coincident with root uptake. The dynamics of N accumulation in annual tree structures (leaves and fruit) and perennial tree structures (roots, trunk and branches) were determined in a series of experiments conducted in high-yielding orchards throughout California from 2008–2012 (Fig. 1). The pattern and rate of N uptake from the soil can be derived from analysis of N accumulation in fruits (hulls, shells and kernels) and leaves, and N depletion and accumulation in perennial organs (trunk, branches and woody roots) (Fig. 2).

In the period from dormancy (January) through early leaf-out, the tree depends almost entirely upon N that is remobilized from perennial organs, and essentially no N uptake occurs from the soil. Following flowering, during the period of leaf and fruit expansion, uptake from the soil commences while remobilization of N from perennial tissues continues. During the period from full leaf expansion until early hullsplit, tree N demand is satisfied entirely by soil N uptake. Following fruit maturity (hullsplit), tree N demand and root uptake decline rapidly, and stop completely as soon as leaves commence senescence. While fruit is developing, the rate of soil N uptake (lbs per acre per day) is directly determined by the yield of the tree. The demand for N to supply new tree growth in a mature orchard (>7 years old) is small in comparison to the demand of the fruit, and current estimates suggest it does not exceed 40 lbs per acre per year in a mature orchard. Nitrogen in flowers, leaves and perennial storage N is predominantly provided from internal and soil N recycling and, hence, does not contribute to annual fertilizer N demand.

A detailed description of the annual dynamics of N accumulation and uptake is provided in Figure 1 and Figure 2 in their accompanying captions.

Theoretically, N fertilizer should be applied at a rate and timing that are coincident with the demand curve by using very frequent or even continuous fertigation. Frequent fertigation with smaller amounts of N ensures soil N concentrations are always adequate for plant uptake while reducing the periods of high N concentration that may be subject to leaching loss in subsequent irrigation or rainfall events. Continuous fertigation, however, is often not practical as most growers do not currently have the facilities, water delivery schedules or engineering control to implement such a program. Furthermore, continuous fertigation may not be necessary, as the majority of mature orchards have relatively extensive root systems, which combined with low rainfall in season and careful irrigation strategies, means that N can be stored in the soil for subsequent root uptake. Therefore, short-term N excess will not substantially increase the potential for N loss by leaching below the root zone. Thus, less-frequent fertilizations can be used effectively if irrigation and fertigation are well managed.

The challenge of retaining N in the root zone is greatest in orchards grown in light-textured soils, particularly where water moves below the root zone due to rainfall or irrigation management, or under conditions that develop a restricted root distribution. In these situations, it is very important to minimize the amount of residual N in the profile prior to leaching events (water application or rain greater than root zone soil-water holding capacity).

Irrespective of the irrigation or fertigation system available, at least 80% of nutrients should be applied during the active tree growth period commencing in early spring (after leaf-out begins) and continuing through early hullsplit. A minimum of two fertilization events and, ideally, four or more should be initiated during this period, with the amount of each application proportional to the demand of the crop. An additional 20% of annual fertilization can be provided during the period after hullsplit through early postharvest while leaves are still healthy. However, this decision should be made based upon the current-year yields, prior N fertilization rates and July leaf N values.

All decisions of fertilization will be influenced by local environment and must be adjusted accordingly. For example, in regions with rainfall that may persist well into leaf-out, application to the soil may be problematic. Similarly, in areas with substantial rainfall soon postharvest, growers must adopt practices that minimize the amount of N that resides in the soil at that time. Pre- and postharvest foliar applications of N, as a substitute for soil applications, could be used to provide N to trees if yield and tissue sampling indicates a need. However, the implications of immediate pre-harvest foliar N on disease and vegetative regrowth in well-managed trees are not well studied. An online spreadsheet has been developed to provide orchard-specific fertilization guidelines (see below for the link), and a smartphone/tablet application is under development.

Since yield estimates will not be available before mid- to late April, the primary opportunity for in-season fertilization rate adjustment is the period from late April – May through postharvest. An April – May yield estimate coincident with receipt of an April leaf analysis can be used to adjust fertilization rates for the remainder of the year to ensure efficient fertilization strategies.

Maximizing Efficiency:

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

Leaf Sampling:

The current practice of sampling leaves in July is too late to allow for current-season adjustment of fertilization practice, and leaf sampling alone does not provide sufficient information to make fertilizer recommendations. An improved method of leaf sampling and fertilization management has been developed that utilizes April leaf sampling and yield estimations to predict N demand and to allow for in-season fertilizer adjustments.

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

Sampling Method (UC Davis Early-Sampling Protocol, or 'UCD-ESP')

For each orchard/block or sub-block that you wish to have individual information on, do the following:

- Sample all the leaves of 5–8 non-fruiting, well-exposed spurs per tree at approximately 43+/-6 days after full bloom when the majority of leaves on non-fruiting spurs have reached full size. In the majority of California orchards, this corresponds to mid-April. Should sampling at this date not be possible, then please note the date of sample collection on the sample bag.
- Collect leaves from 18–28 trees per orchard. Combine all leaves in a single bag for submission to a reputable laboratory. EACH SAMPLED TREE MUST BE AT LEAST 30 YARDS APART. A minimum of 100 leaves per sample bag is required.
- Send the samples to the lab and ask for a FULL NUTRIENT ANALYSIS (N, P, K, B, Ca, Zn, Cu, Fe, Mg, Mn, S) and application of the UCD-ESP program.

Summary:

- These techniques have been validated only for the Nonpareil variety in orchards that are at least 8 years old. If other cultivars are used, please note which cultivar was sampled on the sample bag. Method development for other cultivars is under way. However, this current approach will result in valuable information for any cultivar, as cultivar-specific nutritional requirements likely do not vary significantly.
- Repeat for all orchards and orchard regions that differ in productivity, age or soil type. Identify your areas of low performance, and collect samples from them independently.
- Label all samples well with collection date, field number, cultivar and within field location if needed. Please note if foliar fertilizers have been applied.

Data Interpretation and Integration:

All California testing laboratories will be provided with UCD-ESP guidelines for interpreting April tissue values. If your testing lab does not currently offer this service, please request it and refer the testing lab to Patrick Brown (phbrown@ucdavis.edu).

This information can then be integrated with expected yield to determine annual N application, as illustrated in the scenarios below. A spreadsheet utilized as a tool for these calculations can be downloaded at the web page Crop Nutrient Status and Demand: Patrick Brown in the upper right corner (labeled “N Prediction Model for Almond”). (http://ucanr.edu/sites/scr/Crop_Nutrient_Status_and_Demand_Patrick_Brown/) Growers are encouraged to test these new methods and contrast results with existing practices. Your feedback will help refine the methodology for all growers.

Integrated Guidelines for Tissue Sampling, N Budget Determination and Nitrogen Fertilization Scheduling:

The recommended approach to N fertilization scheduling consists of the following six steps, which have been incorporated into the worksheet noted above. These steps should be repeated for each orchard block.

- 1) Conduct a pre-season (January) estimate of expected yield, based upon historic yield trends for each orchard, last year's yield, and grower experience.
- 2) Estimate annual inputs of N in irrigation water, manures, composts, etc.
- 3) Calculate preliminary fertilization rates and timings, and make first application of fertilizer in early- to mid-spring (March – April).
- 4) Collect and analyze April leaf samples according to preceding instructions.
- 5) Conduct in-season yield estimation (April – May).
- 6) Adjust fertilization strategy for remainder of year to reflect April leaf and yield estimates.

The fertilization recommendations of the worksheet are based upon 70% efficiency of N use. While 70% or greater efficiency of N use is possible in well-managed orchards and is a viable goal, your particular conditions may result in a lower efficiency of N use. Should you observe that your orchards appear to require greater amounts of N than recommended by the worksheet, this is an indication that N may be being lost to the environment. An assessment of the possible sources and causes of this N loss should be conducted.

The following recommendation assumes that fertilizers can be applied at four intervals:

- Early-Spring Application (end of bloom through full leaf expansion). 20% of total annual demand.
- Fruit Growth Application (from full leaf expansion through shell hardening). 30% of total annual demand.
- Kernel Fill Application (shell hardening through early hullsplit). 30% of total annual demand.
- Fruit Maturity/Early Postharvest Application (hullsplit through early postharvest). 20% of total annual demand.

If more than four applications can be made, then amounts should be distributed accordingly.

Examples and Scenarios: These scenarios should be adjusted based upon local environment.

In the following examples, recommendations are provided as lbs (units) of N. The conversion of lbs of N required into lbs of fertilizer is determined by the concentration of N in the fertilizer. For example, UAN 32 is 32% N by weight, and hence 100 lbs (units) of N will be delivered in 312 lbs of UAN.

Preseason Predicted Crop Demand in lbs N (A): Predicted yield, as estimated in January or February (Y_{pred}), divided by 1,000 and multiplied by 68. (Example: 3,000 lbs = 204 lbs N)

Nitrogen in Irrigation Water in lbs N (B): Nitrate concentration (ppm) x acre feet irrigation applied x 0.61 or: Nitrate-N concentration (ppm) x acre feet irrigation applied x 2.73. (Example: 4 acre feet at 10 ppm Nitrate = 24 lbs N)

Nitrogen from Other Inputs (Manures, Composts, Cover Crops) in lbs N (C): See worksheet for calculation. (Example = 0)

Early-Spring Application Rate (D): Early-spring N application rate equals (A) minus (B+C) times 0.28 (20% of annual demand at 70% efficiency). This is the lbs. N per acre that can be applied in the spring period (Early-Spring Application). $D = (204 - 24) \times 0.28 = 50$ lbs N

In-Season Adjustment Factor (E): Conduct leaf sampling and analysis according to methods described above for "Leaf Sampling." The testing lab will provide a prediction of your July leaf tissue adequacy. Using your best judgment or that of an expert consultant, visually estimate the yield of the orchard in late April or May (Y_{est}). Please note that yield estimations need only be 'as good as possible,' since it is recognized that this is a difficult skill and that subsequent fruit drop can occur. The intent is to be flexible in management and respond to current-season demands with adjustments in fertilization strategy.

Four scenarios are described here to serve as an illustration of this process:

- 1) If April leaf tissue analysis predicts that your July tissue concentrations will be adequate or excessive, and if estimated yields (Y_{est}) are approximately equal to predicted yields (Y_{pred}) as determined in (A) above, then the following N fertilization can be used:
 - a. Fruit Growth Application and Kernel Fill Applications = $1.5 \times$ Early-Spring Application Rate (**$50 \times 1.5 = 75$ lbs N**)
 - b. Fruit Maturity and Early Postharvest Applications = Early-Spring Application Rate (**50 lbs**). Note: In regions where significant rainfall may occur during this period, growers should consider use of a foliar application of N or supply N in a manner that minimizes loss potential.

- 2) If April tissue analysis predicts that your July tissue concentrations will be adequate or excessive, and if estimated yields (Y_{est}) differ substantially from preliminary predicted yields (Y_{pred}) as determined in (A) above, then **reduce or increase** N fertilization in subsequent fertilizations accordingly:
 - a. Divide field estimated yields (Y_{est}) by preliminary predicted yields (Y_{pred}) = **Z**. (**Example: $2000/3000 = 0.66$**)
 - b. Fruit Growth Application and Kernel Fill Applications = $(1.5 \times Z) \times$ Early-Spring Application Rate. (**Example: $50 \times 1.5 \times 0.66 = 49.5$**)
 - c. Fruit Maturity and Early Postharvest Applications = Early-Spring Application Rate $\times Z$. (**Example: $50 \times 0.66 = 33$**). Note: In regions where significant rainfall may occur during this period, growers should consider use of a foliar application of N or supply N in a manner that is minimizes loss potential.

- 3) If April tissue analysis predicts that your July tissue concentrations will be less than adequate, and if estimated yields (Y_{est}) differ substantially from preliminary predicted yields (Y_{pred}) as determined in (A) above, then **reduce or increase** N fertilization in subsequent fertilizations accordingly:
 - a. Divide field estimated yields (Y_{est}) by preliminary predicted yields (Y_{pred}) = **Z**.
 - b. Fruit Growth Application and Kernel Fill Application = $(1.7 \times Z) \times$ Early-Spring Application Rate
 - c. Fruit Maturity and Early Post-Harvest Applications = $(1.2 \times Z) \times$ Early-Spring Application Rate. Note: In regions where significant rainfall may occur during this period, growers should consider use of a foliar application of N or supply N in a manner that minimizes loss potential.

- 4) If April tissue analysis predicts that your July tissue concentrations will be adequate or will exceed the critical value, and if harvested yields (Y) are significantly less than preliminary predicted yields (Y_{pred}), the final fertilizer application can be eliminated.

These guidelines are based upon extensive research conducted in four high-yielding orchards across California from 2008–2012, and as such are thought to be representative of good growing practices. The applicability under all growing circumstances, however, cannot be predicted with certainty, and grower judgment remains critical.

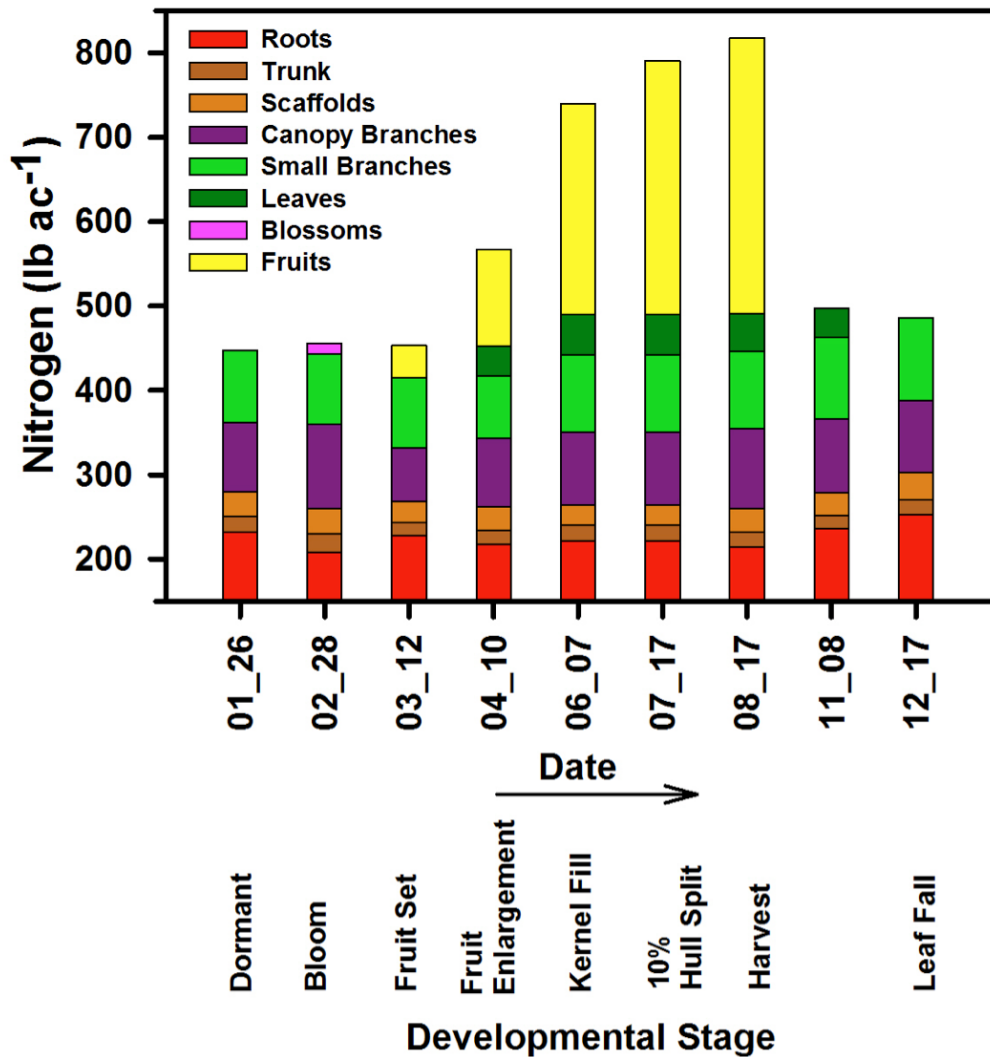


Figure 1: Changes in whole-orchard N balance in annual and perennial organs as determined by sequential tree excavation and serial sampling of all organs scaled to a whole-orchard basis. The orchard is 85% canopy closure, with a 13-year-old Nonpareil-Monterey 50:50 mix. Yield in the year shown was 4,800 kernel lbs. representing 305 lbs. of N in fruit (hulls, shells and kernels). Total increment in perennial tissue N from January to December is 34 lbs. N acre. Data are scaled with the assumption that Nonpareil and Monterey do not differ substantially in N distributions.

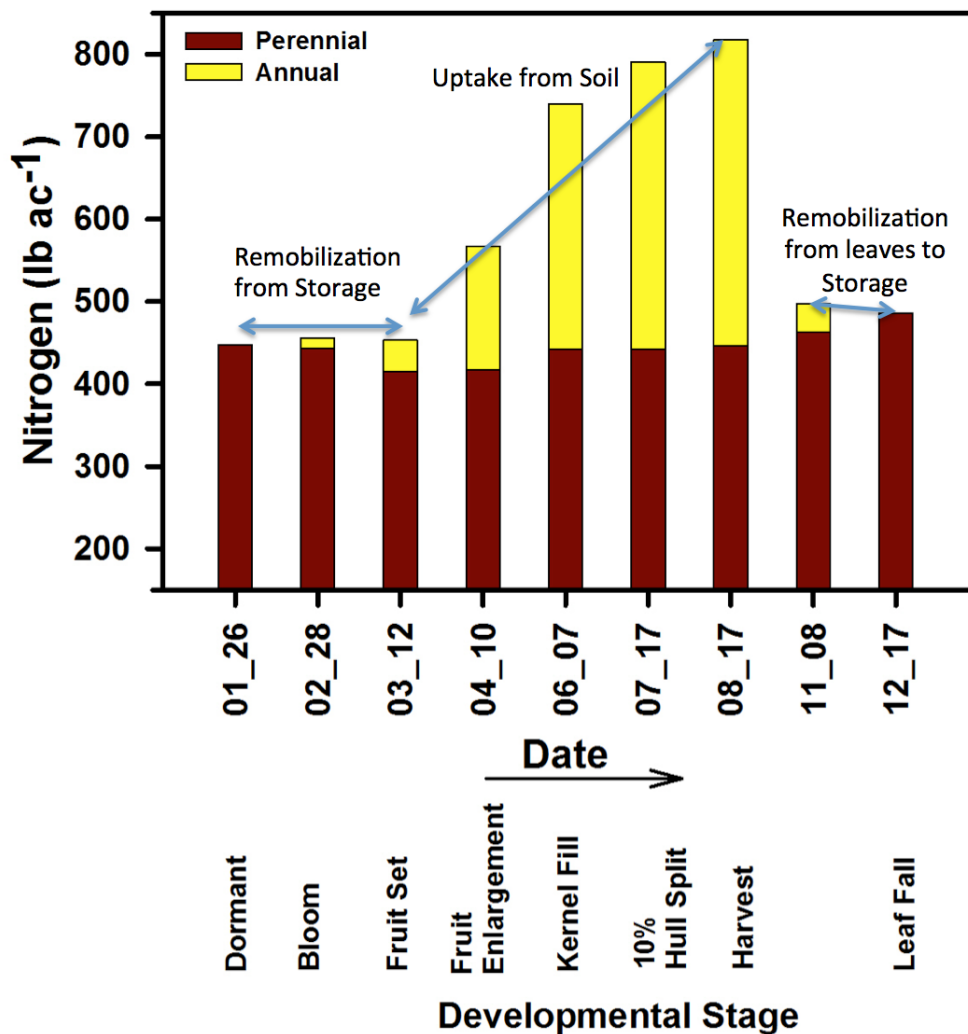


Figure 2: Data presented here are identical to that presented in Figure 1 with the exception that all annual and perennial tissues have been aggregated. The lack of increase in total tree N prior to the March 3 sample date is interpreted as evidence that very little net uptake of N from the soil occurred prior to this date. From fruit set through hull split, 90% of total annual N uptake occurred. A small amount of N uptake may also have occurred in the period immediately following fruit harvest.