Pistachio 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 three years of research at multiple sites and were validated in additional trials in 2012.

Right Rate:
For mature pistachio (> 10 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 28-30 lbs N per 1,000 lbs CPC yield, depending on the N status of the tree. In three years of experimentation at multiple sites, the ideal N removal rate averaged 28 lbs N per 1,000 lbs of CPC yield. This removal rate corresponds to maximal yield and optimal use of N resources, and coincides with a whole-fruit N% of 2.3%. (Note: The estimated removal of 28 lbs of N per 1000 CPC yield also includes in the N removed with shells and hulls). The amount of N required for vegetative growth in a yielding tree is small in contrast to that required by the fruit, and averages 25 lbs per acre per year in orchards (trees > 10 years old).

The amount of N required (from fertilizer or other amendments) is determined by crop size (yield x 28 lbs N per 1,000 lbs CPC yield) 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 May 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. May 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 May 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. On average an orchard removes approximately 28 (lbs) of N, 3 (lbs) of P and 24 (lbs) of K in the harvested fruit producing 1000 (lbs) of CPC yield in the field (Fig. 1).

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 pistachio fruits and leaves were determined in our observational trials over three years and across four geographical locations in California from 2009–2011. 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. In pistachio, results indicate that fertilizer use can be optimized and considerable nitrogen losses can be reduced if nitrogen applications are synchronized with the actual tree demand (Fig.1).

N use efficiency (% measured as N removed/N supplied x 100) is illustrated in figure 2. In this pistachio site, an annual application of 1.54 lb per tree (200 lb N per acre) was applied while the average N removal (fruit plus tree growth) over that three year period was 0.96 lb per tree (125 lbs per acre). Evidence from prior research suggests that an average of 25 (lbs) N and 22 (lbs) of K is utilized to support tree growth requirements. In the estimate of NUE we have included nutrient demand for growth. Variability in yield while fertilization was held constant did result in NUE varying from a high of 93% to a low of 43% (Fig. 2). In 2009 and 2011 NUE was less than 51% which would have resulted in substantial residual N in the soil profile at the completion of the season. The presence of residual N in the soil over winter and during preseason leaching events exposes residual N to loss below the root zone.

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 hull split, tree N demand is satisfied entirely by soil N uptake. Following fruit maturity (hull split), 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 (>10 years old) is small in comparison to the demand of the fruit. Evidence from prior research suggests that an average of 25 (lbs) N and 22 (lbs) of K per acre per year is utilized to support tree growth requirements in a mature tree (> 10 years old). Therefore, the fertilization program should not only replace the nutrients removed in the fruits, but also supply the nutrients for annual growth of the trees as well. 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. Annual dynamics of NPK removal is provided in Figure 1.

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 hull split. 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 hulls split 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 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.
Since yield estimates will not be available before mid- to late May, the primary opportunity for in-season fertilization rate adjustment is the period from early May through postharvest. A May yield estimate coincident with receipt of a May 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 pistachio, 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 May 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 10 leaves from non-fruiting, well-exposed branches per tree at approximately 40+/-6 days after full bloom when the majority of leaves on non-fruiting branches have reached full size. In the majority of California pistachio orchards, this corresponds to mid-May. Note the date of sample collection on the sample bag.

- Collect leaves from 18–20 trees per orchard. Combine all leaves in a single bag for submission to a reputable laboratory. EACH SAMPLED TREE MUST BE AT LEAST 25 YARDS APART. A minimum of 180 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 Kerman variety in orchards that are at least10 years old. If other cultivars are used, please note which cultivar was sampled on the sample bag.
- 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 May 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 web-based pistachio prediction model utilized as a tool for these calculations can be downloaded at http://ucanr.edu/sites/scri/Crop_Nutrient_Status_and_Demand__Patrick_Brown/ (labeled "Pistachio prediction model"). 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. These steps should be repeated for each orchard block.

1) Conduct a preseason (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 (Mid-May).
4) Collect and analyze May leaf samples according to preceding instructions.
5) Conduct in-season yield estimation (April – May).
6) Adjust fertilization strategy for remainder of year to reflect May leaf and yield estimates.

To calculate N fertilizer demand on the basis of N removal it is necessary to have an estimate of the efficiency of the nutrient delivery system and the losses that may be unavoidable. While a 100% efficiency of use would result in maximum profitability and minimal losses, this is impossible given limitations caused by soil variability, engineering limitations and losses that cannot be controlled. In almond it has been demonstrated that carefully managed fertigation of N can result in efficiencies of at least 70% and that is a feasible goal for pistachio given the high prevalence of micro irrigated and fertigated orchards. Ultimately efficiency is achieved by avoiding the movement of N below the root zone by implementing application of the right rate of N (yield based) at the right time (according to uptake curves) in the right place (the active root zone) and by monitoring effectively (optimized sampling).

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 28. (Example: 4,000 lbs = 112 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 2.7. (Example: 4 acre feet at 2.26 ppm Nitrate = 24.4 lbs N).

Nitrogen from Other Inputs (Manures, Composts, Cover Crops) in lbs N (C): Should be considered as part of the nitrogen budget for pistachio. This will further reduce the amount of the nitrogen fertilizer application.

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 = (112 – 24) x 0.28 = 25 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 May 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 x Early-Spring Application Rate **(25 x 1.5 = 38 lbs N)**
   b. Fruit Maturity and Early Postharvest Applications = Early-Spring Application Rate **(25 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 May 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: 3000/4000 = 0.75)**
   b. Fruit Growth Application and Kernel Fill Applications = (1.5 x Z) x Early-Spring Application Rate. **(Example: 25 x 1.5 x 0.75 = 28.12)**
   c. Fruit Maturity and Early Postharvest Applications = Early-Spring Application Rate x Z. **(Example: 25 x 0.75 = 19).** Note: In regions were 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 May 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 x Z) x Early-Spring Application Rate
   c. Fruit Maturity and Early Post-Harvest Applications = (1.2 x Z) x 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 May 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 2009–2012, 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.

Average Nurient Removal (2009+2010+2011) Per 1000 (lbs) Dry yield (CPC)

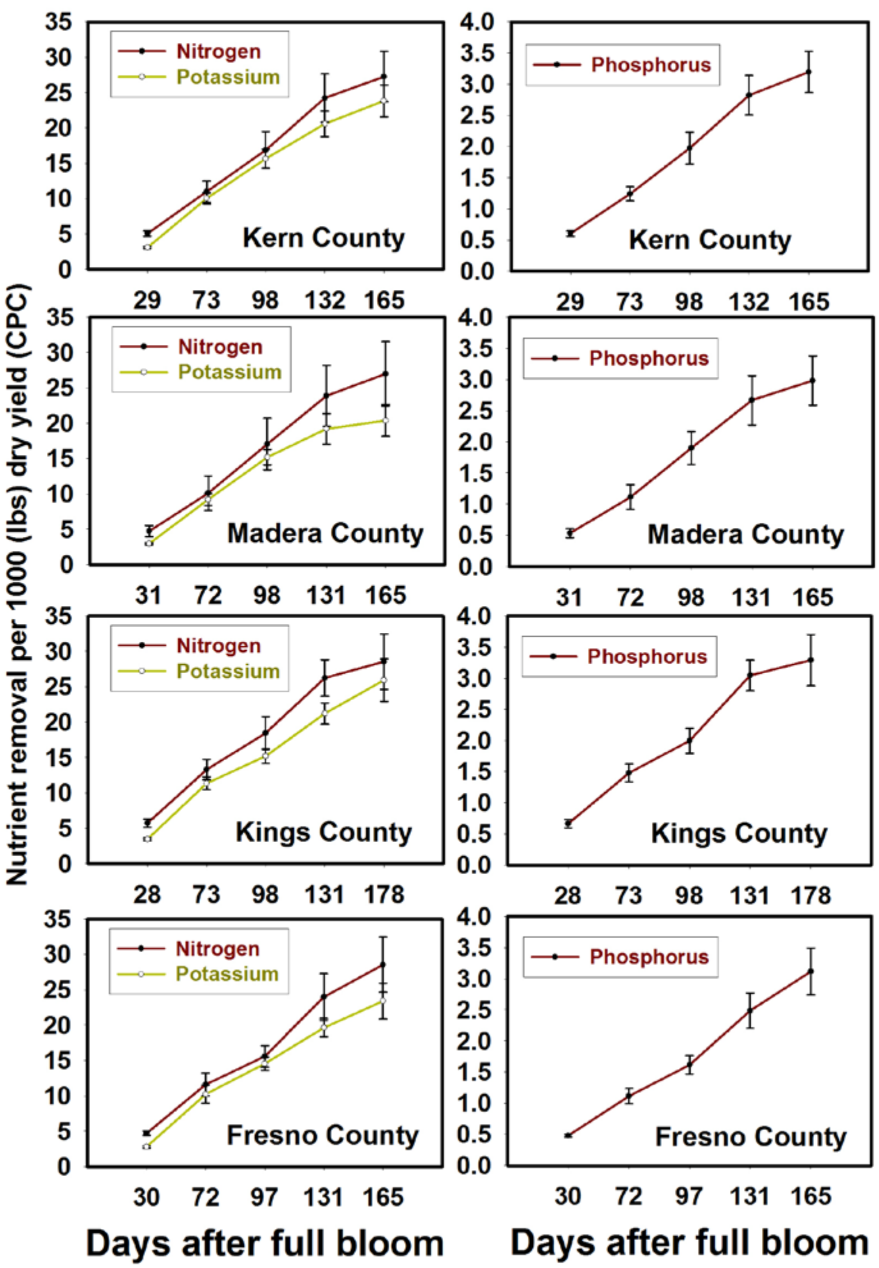

Figure 1: average nutrient removal per 1000 (lbs) dry yield (CPC) at Kern, Kings and Fresno County sites over the years (2009-2011). The data from the Madera County site represents the average of two years (2009+2010).

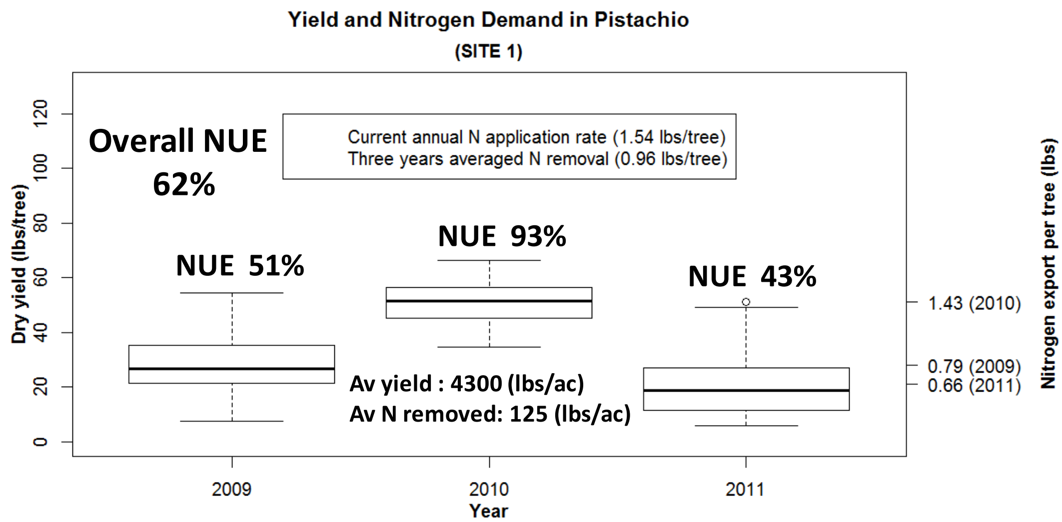

Figure 2: Pistachio yield and nitrogen demand for the on plus off year trees at one of the experimental sites in Kern County California. The graph provides a general guideline to adjust N applications to realistic yield expectations. Yield was measured in every individual tree over the three-year period. Box and whisker plots show median (25th and 75th percentiles) of yield in each year. The axis on the right hand site represents average annual N export per tree. Data represents values from 114 individual trees in 2009 and 54 trees each in 2010 and 2011.