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CALIFORNIA ALMOND BOARD

Project No. 2C1: Optimization of Fertilizer N Usage in Almond Orchards

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Statement of Objective:

This study is being conducted in two mature almond orchards in the nitrate-sensitive region of the Northern San Joaquin Valley in Stanislaus County. The objectives of this project include:

1) Determination of the relationship between leaf N concentration and the rate of applied fertilizer N. Assess the sensitivity of leaf N concentration to overfertilization and reassess the validity of the currently accepted leaf N critical value (i.e., the relationship between leaf N concentration and tree productivity).

2) Assess the relationship between the rate of applied fertilizer N and the recovery of isotopically labeled (^{15}N-depleted) ammonium sulfate.

3) Assess the magnitude of nitrate leaching below the root zone and its relationship to fertilizer N application rate, efficiency of fertilizer N recovery, and tree N status.

4) Estimate N usage by almond trees.

5) Refine current management guidelines for N usage which will help to maintain productivity while reducing the amount of fertilizer N leached below the root zone.

Executive Summary:

Research plots were established in two mature orchards located in nitrate-sensitive areas of Stanislaus County.

The timeline of project activities included the following: (1990) Pretreatment collection of baseline data including soil nitrate levels, leaf N concentrations, tree yields, nitrate concentration of the irrigation water and the calculation of N application in the irrigation water; (1990-1993) Establish tree and soil N differentials as a result of differential rates of applied fertilizer N (0, 125, 250, and 500 lbs N/A/Yr) and monitor tree yields, and leaf N concentrations; (1993) Apply labeled fertilizer to all treatments; (1993-1995), and monitor labeled N recovery in crop and perennial tree parts (following tree excavation) to calculate the effect of prior fertilizer N application rates on the efficiency of fertilizer N recovery.

Evidence consistent with overfertilization included the following: leaf N concentrations greater than 2.5%, lack of yield response to applied fertilizer N, lack of increase in leaf N concentration at high fertilizer N application rates and a 50% reduction in the recovery of labeled fertilizer N by trees fertilized previously at the highest (500 lbs N/A/Yr) rate.

Several management parameters can be used to increase recovery of applied fertilizer N. Reduce application of fertilizer N to the extent that high nitrate irrigation water supplies significant amounts of N.

Leaf N concentrations >2.5% are associated with high residual levels of nitrate in the soil and fertilization should either be omitted for a season or significantly reduced in these orchards. Apply fertilizer during periods of significant N utilization of trees. Currently, available data suggest that multiple or at least split applications should be made between April and the last preharvest irrigation in July or August. Post-harvest applications of fertilizer N appear inconsistent with efficient recovery of fertilizer N and are likely to contribute to groundwater pollution.

Materials and Methods

Measurement of Soil Hydraulic Conductivity, and Water Fluxes Below the Root Zone of Almond Trees.

The purpose of this task is to estimate fluxes of nitrogen below the root zone of almond trees.

Measurement of soil hydraulic conductivity and hydraulic gradient at test site.

This approach assumes that water flow in the profile is one-dimensional and uses Darcy's Law over specific periods of time during the season to estimate the flux of water below a selected depth increment in the soil.

Darcy's Law is represented by the following equation:

$$q = -K\ (dH/dx)$$

where q is the flux of water (cm^3/cm^2/time), K is the soil hydraulic conductivity (cm/time) and dH/dx is the hydraulic gradient where H is the potential head and x is the distance across the slice being considered. Since H is the sum of the matrix potential (h) and gravitational potential (z), the equation can be expanded to:

$$1 = -K\ [dH/dx + 1]$$

To use this equation to estimate water fluxes, it is necessary to know the h and K for each time period being considered. The frequency of sampling varied seasonally and with the frequency of rainfall during the dormant season. Since both H and K are functions of the soil water content, they varied with time over the season as the water content of the soil varies.

Tensiometers were used to measure h. The set up is to position one instrument at the upper boundary of the slice being considered and the other at the bottom of the slice. Again, tensiometer measurements were taken periodically to determine dH/dx. These values can be +, -, or 0 indication downward, upward or no flow, respectively. While the sign indicates the direction of flow, the magnitude of dH/dx is used to quantify the flux. This is conducted when there is no water use by the trees or evaporation of water from the soil surface; normally in the winter.

The procedure is to thoroughly wet the area surrounding a neutron probe access tube and associated pair of tensiometers. This was done by setting up a berm around the area (say one tree spacing) and flooding the soil until it was wet to at least the slice that had been established as below the root zone. The soil was then covered with plastic sheeting to prevent surface evaporation and neutron probe readings were taken immediately to determine the soil moisture profile. Tensiometer readings were also taken. Drainage was rapid at first so readings were taken daily for three to four days and then the frequency of readings decreased. Changes in the soil moisture profile are due to only one mechanism -- water movement downward. Thus, the difference in soil water contents above the slice being considered between readings is the flux of water. The tensiometer readings were used to determine dH/dx. Simple arithmetic is used to calculate K for each set of readings. Since it has been found that K is directly related to soil moisture content, K was plotted vs. the average soil water content across the slice in question. The relationship between K and soil water content is assumed to be a straight line, so a first order equation is developed from the data. This equation is then used during the season to estimate K from the actual soil water content for any given period. General estimates of hydraulic conductivity in the Salida orchard were made between December 1992 and January 1993.

The above technique yielded water flux estimates which varied with the frequency of monitoring. The N concentration in the soil solution at the selected slice was determined with the same frequency, multiplying the water flux (cm^3/cm^2/time) by the N concentration (ug/ml) gave us the N flux in ug/cm^2/time.

Irrigation water balance. Total seasonal net irrigation (spray evaporation loss taken into account) is compared with estimated potential seasonal orchard water use (ETc). The latter value is generated with reference crop (ETo) data from the nearest reliable CIMIS weather station and published crop coefficient (Kc) values.

Use of bromide as a nitrate tracer. Bromide (Br) moves through the soil profile with the water front like nitrate. Since Br is much less abundant in the soil than nitrate, Br movement is easier to resolve than nitrate movement and can be used e.g., to trace the extent of nitrate movement through the soil profile. A pulse of Br was sprayed uniformly within a 15 foot radius surrounding each of 8 trees at different sites throughout the orchard. Bromide was applied on 28 September, 1992 and irrigated into the soil profile immediately thereafter. Soil cores were sampled to a depth of 10 feet on 12 November 1992 (i.e. 45 days) and 4 March 1993 (157 days) after bromide application. Br distribution within the soil profile at each of the two sampling dates was determined by compositing the soil within each 6" increment i.e., 0-6", 6-12", 12-18", etc.) and analyzing for bromide.

Soil Solution Sampling and Analysis of Nitrate at One-foot Increments between 2 feet and 5 feet Below the Soil Surface.

The purpose of this task was to complement Task 1, i.e., multiplying the water flux by the nitrate concentrations to give us the flux of nitrate below the root zone.

We equipped 6 sites with the instruments necessary to calculate N flux through the profile. Tensiometers placed at 2, 3, 4, and 5 feet, were used to calculate hydraulic gradients. Neutron probe access tubes were used to calculate soil water content at one foot increments. An experiment conducted during the winter allowed us to establish the relationship between soil water content and soil hydraulic conductivity. Thus, with the tensiometer and neutron probe data our intent was to estimate the flux of water periodically during the seasons (cm^3 H_2O/cm^2 soil/time). Soil water solution samplers were placed at the same depths as the tensiometers. These are essentially empty tensiometers with small tubes placed in the bottom of the cup. A vacuum of about 80 cb is drawn on the samplers via evacuated cylinders for about 6 hrs, resulting in soil water moving into the cups. The small tube is then used to transfer this sample into the collection vials for later N analysis. These data (μg N/cm^3 H_2O) are multiplied by the water flux to give the flux of N. The soil solution was sampled at 2 week intervals throughout the season. Data were collected between June 1993 and June 1994. Nitrate analysis of soil solution samples was completed using the rapid diffusion conductivity method developed by Dr. R.M. Carlson.

Establish and Maintain Differential Tree N Status, Assess Tree N Status, Measure Individual Tree Productivity, and Analyze the Relationship Between Leaf N Conc and Tree Productivity; Monitor Soil N Differentials.

The purpose of this task was to establish and maintain differential tree N status by applying different rates of fertilizer N. Leaf analysis to monitor tree N status, and yield determinations were made to assess tree performance. This was the foundation of continuing experimentation to assess the relationship between tree N status (and accompanying soil nitrate levels) with nitrate leaching and the efficiency of fertilizer N recovery by the tree.

Four treatments each with four two-tree replicates were randomized within the orchard with adequate tree buffers. Treatments were begun in October, 1990 and continued until October 1994 in the Ceres Orchard. Treatments were continued until October 1993 in the Salida orchard when the labeled N was applied.

Treatments:

1. No fertilizer N applied.
2. N applied in a split application at the rate of 125 lbs N/A/Yr.
3. N applied in a split application at the rate of 250 lbs N/A/Yr.
4. N applied in a split application at the rate of 500 lbs N/A/Yr.

Note: All treatments receive the N applied in the irrigation water. The N rates in treatments 2, 3, and 4 are exclusive of the N supplied in the irrigation water. To assess, the leaf nitrogen concentration below which tree productivity is reduced, our intent was to allow some trees to go N deficient (Treatment 1). Our analyses indicate that 72 and 98 lbs N/A/Yr are applied with the irrigation water in the Salida and Ceres orchards, respectively, as a result of the nitrate concentrations of the irrigation water.

Trees were fertilized each April (1/3) and Oct. (2/3 of annual application) in keeping with typical grower practice in that area.

Leaf sampling from each individual tree (96 individual trees in both the Salida and Ceres orchards) each July was followed by tissue drying; grinding, weighing, Kjeldahl digestion and N analyses to assess tree N status.

Soil cores were augured to a depth of 10 feet, and soil from one- or two-foot increments was composited to determine soil nitrate concentrations and the association between differential application rates of fertilizer N and the levels and distribution of nitrate in the soil profile. The purpose of soil core sampling and processing for nitrate determinations in the fall was to determine the levels of residual nitrate in the soil as winter approached and tree capacity for N uptake declined. The purpose of the post-dormant sampling in March was to assess the loss of nitrate and ammonium during the dormant period when N absorption by trees is known to be very low.

Test trees were harvested individually to assess the relationship between tree N status and tree productivity (meat weight and nut number per tree). Data were used to assess the validity of the currently accepted leaf N guidelines.

Effect of Tree N Status on Recovery of Isotopically Labelled Fertilizer N

The use of isotopically labelled fertilizer N permits direct measurement of tree recovery of fertilizer N. Eighteen trees differing in tree N status were identified on the basis of leaf N concentration (July) in the Salida orchard in 1993 and were fertilized with ^{15}N-depleted $(NH_4)_2SO_4$ on October 2, 1993. Trees fertilized with labelled N were sampled on March 1, 1994 (blossom sample) and mature fruit were sampled in August, 1994. Tissue samples were oven-dried at 60°, and ground before N analysis. Total N was determined by a Kjeldahl procedure, and the ammonium salts were sent to Isotope Services, Los Alamos, N.M. where the ammonia was oxidized to N_2 gas before the isotopic composition was determined by mass spectrometry. Atomic percent values were expressed as percentage of N derived from fertilizer (% N DFF) using standard conversions. The product of tissue dry weight and % N DFF represents the amount of labelled fertilizer N present in the tissue. Isotopic composition of mature fruit samples coupled with the yield data enabled us to calculate total (labelled) fertilizer N recovery in the crop. In early February, 1995, selected trees fertilized 15 months earlier with labelled N, were excavated. Isotopic analyses of these similarly-yielding trees differing in tree N status (as of October, 1993) permitted determination of the effect of previous fertilization rate and tree N status on total tree recovery of isotopically labelled fertilizer N.

<u>**Data Summarization, Statistical Analysis, and Publication**</u>

The culmination of this project involves the analysis, summarization and interpretation of the data accumulated between 1990-1995. We anticipate developing specific recommendations for refining N management practices for almond especially in "Nitrate-Sensitive" areas. This information will be (and has been) dispersed in a variety of ways; scientific publications, popular trade journals, grower meetings, Almond Board annual reports, and short course presentations.

RESULTS AND DISCUSSION

Evidence for Overfertilization. Current fertilization practices in many almond orchards favor overfertilization - the application of fertilizer nitrogen in excess of tree capacity to utilize it. Evidence consistent with that interpretation include; high residual levels of nitrate in the soil, lack of yield response to the fertilizer applied and lack of response of leaf N concentration to high fertilizer N application rates.

The presence of high residual levels of nitrate in the soil. These may result from the combined use of high nitrate - containing irrigation water (33 ppm nitrate in Salida and 44 ppm nitrate in Ceres) as well as excessive application rates of fertilizer N. High application rates of fertilizer nitrogen were associated with increased residual levels of nitrate in the soil going into the winter rainy period (discussed later).

Lack of a yield response to the fertilizer. In the 4 years following establishment of the fertilizer rate trial, a significant yield reduction in unfertilized trees occurred only in 1993, which was 3 1/2 years after the last fertilization (Table 1). The lack of significant yield reduction in unfertilized trees in 3 out of 4 years (Table 1) indicates that fertilization was not required annually to maintain productivity under the given orchard conditions. We must conclude that sufficient N was available from other sources (e.g. high nitrate irrigation water, etc.) to maintain productivity without supplemental fertilization.

High leaf N concentrations. Pretreatment (1990) leaf N concentrations averaged above 2.6% in both orchards (Table 2). There is no evidence that almond yields respond to fertilizer N when leaf N concentrations exceed 2.5%. Leaf N concentration appears to be insensitive to overfertilization, thus there is virtually no difference in leaf N concentrations between trees receiving 250 lbs N/A/Yr and those receiving 500 lbs N/A/Yr (Table 2). This probably means that at higher levels of available soil N, tree capacity for N uptake is saturated, and additional fertilizer N accumulates in the soil and becomes vulnerable to loss - probably leaching- in coarse-textured, sandy soils.

Preliminary analyses indicate not only that almond tree productivity is N-limited when mid-summer leaf N concentration is below 2.2%, but yield may even be reduced when leaf N concentrations are between 2.2 and 2.3%. This is a higher threshold than is currently accepted. A major determinant of yield is fruit number. As flower differentiation occurs in the summer soon after diagnostic leaf sampling in July, our data suggest that leaf analysis is more predictive of the subsequent year's crop than the current year's crop. Thus, a leaf N concentration below 2.3% in July 1993 may be predictive of a reduced crop in 1994. On the basis of our data, the ideal range of leaf N concentration to both maintain yield and minimize subsequent leaching appears to be between 2.3% and 2.5% N.

Tree N status and recovery of isotopically labeled fertilizer N. Following three years (1990-1993) of differential rates of N fertilization, we selected trees (Salida orchard) varying in leaf N concentration (Table 3). Labelled ammonium sulfate was applied post-harvest (October 2, 1993) at the rate of 166 lbs N/A/Yr. Trees also received 84 lbs N/A/Yr (non-labeled) in April 1994 for a combined total of 250 lbs N/A/Yr. We determined total recovery of labeled N in fruit at harvest (August, 1994). Four of the trees were also excavated in February, 1995 and analyzed for labeled N content to compute total recovery of the labelled N and the influence of N fertilization rate on the percentage recovery (recovery efficiency) of the labelled N.

Between 65% and 79% of the labeled N absorbed by the trees was localized in the fruit with the remainder present in the perennial tree parts (branches, trunk, roots, etc., Table 3).

Trees that were fertilized at the rate of 500 lbs N/A/Yr only recovered about 20.5% of the fertilizer N applied (Table 3). In contrast, trees that received 0, 125 or 250 lbs N/A/Yr recovered 30% of the labeled N applied - about 50% more. Thus, the high rates of N fertilizer application between 1990 and 1993 reduced recovery of fertilizer N in 1993-1994. The four trees which previously received labeled N (October, 1993) and were selected for detailed analysis of labeled N recovery satisfied two criteria. a) trees were similarly-yielding in 1994 and b) trees differed in tree N status as determined by leaf N concentration. We have found (in other studies) that N uptake is a function of tree N demand, and, in almond, fruit growth and nut fill are important determinants of tree N demand. Therefore, since tree N demand (yield) among the trees selected (Table 3) was similar, we believe that the reduced recovery of labeled N by trees previously fertilized at the high N application rate (500 lbs N/A/Yr) was a consequence of greater dilution of the labeled N in the soil. Soil nitrate concentrations (measured 10 days before application of labeled N) averaged 3 to more than 50 times higher beneath trees fertilized 5 months earlier at the highest N application rate vs. trees fertilized at the rate of 250 lbs N/A/Yr or less (Table 3).

During the post-harvest and dormant periods, growth nearly ceases, and dormant trees have a greatly limited capacity for N uptake. In years of heavy rainfall, significant leaching can occur between November and March. High residual levels of nitrate in the soil after harvest may be vulnerable to leaching as winter rainfall may be anticipated within several months. Thus, a) low N uptake by trees during the post-harvest and dormant periods coupled with b) vulnerability of nitrate to leaching with the winter rains should discourage heavy post-harvest applications of fertilizer N. The Winter of 1993-1994 was relatively dry, receiving only about 2/3 of the normal annual rainfall. Fertilizer recovery (Table 3) may have been even lower if we had conducted the study in 1994-1995 when rainfall was nearly double the long-term average. Our data do not allow us to determine how much of the labeled N recovery occurred between October, 1993 and March 1994 (bloom) and how much between bloom and harvest (August, 1994).

Relationship of nitrate leaching to fertilizer N application rate. Ponds were created at 6 different locations in the orchard during tree dormancy (when trees were leafless) to calculate soil hydraulic conductivity. Six additional sites throughout the orchard were equipped with tensiometers, soil solution samplers (at depths of 2, 3, 4, 5 and 6 feet), and neutron probe access tubes. Data were collected between June, 1993 and June, 1994. Our ultimate goal was to quantify N fluxes below the root zone as a function of N fertilization rate. Achievement of that objective was complicated by sources of orchard variability which included (but were not limited to) a hardpan in much of the orchard between three and five feet. Conditions required to calculate soil hydraulic conductivity are violated by a hardpan which precludes one-dimensional (i.e. vertical) water flow.

Realistic comparisons of soil nitrate flux as a function of fertilizer N application rate were also confounded by soil spatial variability and the lack of irrigation water distribution uniformity. The overall mean irrigation water application rate averaged 0.10 in/hr, however, the rate varied 4 fold (from 0.05 to 0.20 in/hr) among the 6 monitoring sites in the orchard. Based on the application rates measured and the hours of application, mean total applied water was 40.6 inches from June 3, 1993 to June 2, 1994 but varied from 20.3 to 81.1 inches at our six monitoring stations.

Data from only one of the six monitoring sites in the orchard will be discussed because that site was not underlain by a hardpan and, therefore, reflects undisturbed water flow. A summary of the principal findings are presented below.

1. Cumulative water flux between June 1993 and June 1994 declined with depth i.e., 397 mm water passed the 2 foot depth, 133 mm passed the 3 foot depth, 42 mm passed the 4 foot depth and 7 and 8 mm of water passed the 5 and 6 foot depths, respectively.

2. The temporal patterns of water flux and nitrate flux appeared quite similar. This was anticipated because nitrate in the soil solution is known to move freely with the advancing water front.

3. In this specific orchard site and in this particular year of record, water and nitrate flux were consistently greater at the 3 foot vs. the 5 foot depth. The bulk of the almond root system is restricted to the top 3 feet of soil in this orchard, and nitrate leached beyond that depth may become inaccessible to the tree.

4. Nitrate flux was considerably greater during the irrigation season than during the winter (Nov.-Feb.). This pattern must be considered within the context of the below-average winter rainfall (8.9 inches) during the season of record. Thus, nitrate flux below the root zone in winter is likely to be greater during years of more typical rainfall.

   (The rainfall during the winter of 1994-1995 exceeded the long term average rainfall by >50%.) We question the rationale of typical grower practice in that area. Currently, two-thirds of the annual N application is applied post-harvest in late September - early October. The accumulation of high amounts of nitrate in the soil at a time when a) tree demand for N is low and b) tree capacity for N uptake is decreasing places that nitrate in position to be leached beyond the root zone if significant winter rainfall occurs.

   Although we were not able to make definitive comparisons of nitrate flux among the four fertilizer N application rates, we can reasonably anticipate a heightened potential for leaching at the highest N application rate (500 lbs N/A/Yr), if we consider the higher levels of nitrate in the soil (Table 3) and assume that water flux remains constant across treatments.

Use of Bromide as an indicator of soil nitrate leaching over the dormant season. In two of the eight soil cores taken -row 10, trees 22-23 (R10, T22-23) and row 12, trees 13-14 (R12, T13-14) bromide was never detected in the soil profile (Table 4). It is not known whether the lack of resolution was due to deep percolation or whether sufficient dispersion occurred so that it was present in the soil profile at levels below the limits of chemical resolution. Among the remaining soil cores, bromide was detected at different depths between 6 and 36 inches on 12 Nov, 45 days after application. There was large variations among sites in the depth of bromide percolation after 45 days. Br measurements from soil cores obtained after the winter (4 March) also indicated large site to site variability in Br movement within the orchard. Where bromide was detected, however, it occurred at soil depths below 40 inches (Table 4). The bulk of the almond root system occurs within the top 3 feet of soil. Thus, movement of bromide (or nitrate) to soil depths below 40 inches is likely to indicate that it has leached beyond the root zone. We have shown previously that fruit trees have very limited capacity for N uptake during the winter i.e., between November and March. Thus, bromide movement below the root zone during dormancy would also be indicative of the movement of any nitrate present in the soil profile during that period and under those conditions. The winter of 1992-1993 was characterized by above-average rainfall. Since two-thirds of the annual application of fertilizer N is typically applied post-harvest (late Sept-early October) in Stanislaus County, there is reason to suspect that residual fertilizer N present within the root zone overwinter is vulnerable to leaching (if significant winter rainfall occurs) before trees absorb it the next spring. Again, the disappearance of bromide from the soil profile would be suggestive of nitrate leaching over this period in the coarse-textured soils of Stanislaus County.

Loss of extractable soil N over the dormant season. Typical examples of the relative concentrations of available N in the soil (i.e. nitrate and ammonium) profile as a function of the fertilizer N application rate and time of sampling are presented in Table 5. Tree roots primarily occupy the surface 3 feet of soil (data not shown). The following observations appear noteworthy (Table 5).

1) The amount of available N in the root zone prior to the September 28 fertilizer application was higher in the fertilized plots than the control plot even though sampling occurred 5 months after the last (April) fertilization.

2) As anticipated, the available N in the top 2-3 feet of the soil profile increased dramatically within 6 weeks after fertilization (see Table 5, 11-12-93). Differences in root zone soil N between the 125 and 250 lbs N/A/Yr treatments were less noteworthy than the spectacular increases detected at the highest (500 lbs N/A/Yr) application rate.

3) The levels of available N in the top 3 feet of soil decreased substantially over the winter dormant season. Both the amounts and percentage decreases in available root zone N were lowest in the unfertilized control. The magnitude and percentage decrease in available N was greatest at the highest fertilizer N application rate - i.e., 90% of the available N in the root zone disappeared over the dormant period.

Although some denitrification may have occurred, the most likely explanation for the disappearance is leaching deeper in the soil profile, i.e., beyond the root zone. It would appear desirable to minimize residual nitrate in the soil over winter to limit nitrate leaching below the root zone -- ultimately to reach the groundwater.

Typical grower practice in this area involves a split application of fertilizer in April (1/3) and after harvest of the latest maturing cultivars in October (2/3). Our data indicate that high application rates of fertilizer N in October results in significant quantities of residual nitrate in the soil overwinter when tree capacity of N uptake is quite limited. This period (i.e., Nov.-March) is also coincident with the period of winter rainfall and the greatest likelihood of nitrate leaching.

Nitrogen usage by almond trees. Despite the importance and size of the almond industry in California, N usage by almond trees is poorly understood. Data accumulated a decade ago in a previous, longer-term

N isotope study (Weinbaum, et al, 1987. Proc. Amer. Soc. Hort. Sci. 112:526-529) indicated that about 50% of almond tree N content was replaced annually via soil N uptake. Unfortunately we didn't excavate trees and determine N content at that time and were, therefore, unable to calculate annual N uptake. In the present study we determined both crop N removal and the N content of dormant trees (Tables 6 and 7). These data indicate that fruit N removal (including hull, shell and kernel) is equivalent to 40%-50% of tree N content (average equals 46%). Our data probably underestimate tree N content because N carried to the orchard floor at leaf fall was not determined and the N content of fine roots, was underestimated because 100% recovery was undoubtedly not achieved. Also root senescence and turnover, blossom and immature fruit drop, prunings, etc. may increase tree N content by a value approaching 10%. Thus, fruit N removal represents an estimated 85-90% of annual N demand in almond trees. Limited data have indicated that N carried to the orchard floor in the leaf litter represents less than 10% of the amount of N removed in the crop (R. Zaososki, LAWR, UC Davis, personal communication). Crop N removal is often considered to be equivalent to N removal in the meats. Analyses of the various fruit components, however, indicates that N removal in the kernel (meat) underestimates fruit N removal by 25-27% (Table 8).

CONCLUSION

Evidence was presented suggesting that overfertilization - the application of fertilizer N in excess of tree capacity to absorb it - occurred in our experimental orchards and, similarly, is likely to be widespread throughout the almond industry of California.

The question is how to reduce fertilizer N applications without sacrificing productivity. The answer is to focus in on strategies which (a) balance tree N utilization and availability, (b) withhold fertilizer N when tree N status exceeds 2.5% N (July standard leaf sampling), and (c) be aware of plant-available N other than currently - applied fertilizer N. Residual nitrate in the soil and the N contribution of high nitrate irrigation water (Table 9) are typical sources of plant-available N in the Central Valley of California. This alternative N supports tree growth and productivity just as effectively as fertilizer N and should be taken into consideration when developing a N budget. Thus, if 80 lbs of N is removed in the fruit and your calculations indicate that 80 lbs of N is applied with irrigation water as a result of it's high nitrate concentration, the amount of fertilizer N applied should be reduced by at least 80 lbs per acre. (d) Apply fertilizer N when almond trees are using it. Data suggest that almond trees use N primarily between the spring flush of growth (from late March) and nut fill (July). It's not clear how much N is absorbed by trees after nut-fill, and, at this time, we recommend withholding fertilizer N after harvest. If post-harvest fertilization is practiced, it should be very light. Data presented in this study indicated that heavy post-harvest applications of fertilizer N result in high levels of residual nitrate in the soil overwinter when (1) tree N uptake is low and (2) nitrate leaching is likely due to the combination of significant winter rainfall and highly permeable soils.

Table 1. Differential N Fertilization and Almond Yields in 2 Stanislaus County Orchards

Orchard	Treatments[z]	Meat Pounds Per Acre[zx]				
	(lbs N/A/Yr)	1990[y]	1991	1992	1993	1994
Salida	0	3508	3587 a	1470 a	1938 c	*
	125	3508	3554 a	1538 a	2735 ab	*
	250	3508	3421 a	1606 a	3120 ab	*
	500	3508	3610 a	1789 a	3710 a	*
Ceres	0	4444	1633 a	2512 a	2421 b	3967 a
	125	4444	2309 a	2542 a	2956 ab	3837 a
	250	4444	1807 a	2712 a	2913 ab	3786 a
	500	4444	1919 a	2879 a	3315 a	4008 a

[z] Treatments initiated post-harvest in 1990
[y] Pretreatment yields
[x]Values sharing a common letter within columns (years) in a given orchard do not vary statistically
* Plot treated with labeled N to assess effect of tree N status on fertilizer N recovery

Table 2. Changes in Leaf N Concentration With Rates of Applied Fertilizer N in 2 Stanislaus County Orchards

Orchard	Treatments[z] (lbs N/A/Yr)	Leaf N Concentration (% dry wt.)[x] 1990[y]	1991	1992	1993	1994
Salida	0	2.61	2.27c	2.13c	2.28c	*
	125	2.61	2.34bc	2.18c	2.40bc	*
	250	2.61	2.36bc	2.24b	2.52b	*
	500	2.61	2.42ab	2.37a	2.68a	*
Ceres	0	2.69	2.49a	2.29b	2.37c	2.51a
	125	2.69	2.48a	2.30b	2.51b	2.64ab
	250	2.69	2.49a	2.44a	2.68a	2.75bc
	500	2.69	2.53a	2.49a	2.74a	2.82c

[z]Treatments initiated post-harvest in 1990.
[y]Pretreatment values.
[x]Values sharing the same letter within a column did not differ statistically at $P<0.05$.
*Plot fertilized with labeled N to asses effect of tree N status on fertilizer N recovery.

Table 3. Effect of tree N status and previous fertilizer application rate on labelled N recovery following a uniform, post-harvest application of isotopically-labelled ammonium sulfate[z]

Tree I.D.	1994 Yield meat lbs/tree	Fertilization (1990-1993) (lbs N/A/Yr)	1993 Leaf N (% dry wt.)	Soil Nitrate-N[y] (ppm)	Labeled N recovery (%)		
					Fruit (Aug 1994)	Tree (Feb 1995)	Total
10-19	50.1	0	2.06	1.95	24	--	--
14-19	48.1	125	2.28	0.81	26	7	33
18-12	43.7	0	2.37	0.81	19	8	27
10-8	45.9	125	2.46	0.37	22	--	--
10-9	54.8	125	2.65	--	22	--	--
6-10	54.6	250	2.59	15.5	27	--	--
10-11	54.1	500	2.70	193.6	14	7	21
10-13	58.6	500	2.92	48.1	15	5	20

[z] 872 g labeled N per tree was applied on 2 October, 1993
[y] mg $N\text{-}NO_3^-$ per g of oven-dried soil. Analyses based on 4 soil cores per tree between 2 and 2.5 feet deep 10 days prior to application of labeled N.

Table 4. Use of bromide as a tracer for nitrate movement through the soil profile during dormancy when tree N uptake is very low.

	Tree site							
Soil depth (inches)	R4 T9-10	R8 T3-4	R8 T13-14	R10[z] T22-23	R12[z] T13-14	R17 T17-18	R20 T4-5	R22 T17-18
0								
6	7.7[x]	7.0[x]				12.8[x]	13.8[x]	8.7[x]
12	24.1[x]	11.2[x]	11.7[x]			11.4[x]	12.2[x]	7.6[x]
18	9.7[x]		5.6[x]			6.3[x]		7.3[x]
24						6.4[x]		6.1[x]
30						9.7[x]		
36	[y]					10.6[x]		
42							13.9[w]	
48		22.9[w]					45.5[w]	
54		21.2[w]						
60								
66			5.3[w]					
72			13.9[w]			8.2[w]		
78			7.6[w]					
84			5.9[w]					
90								
96								
102								
108								
114								
120								

[z]No bromide detected

[y]Vertical lines represent presence and depth of silt pan

[x]Tree sites and soil depths at which Br was detected on 12 Nov. 1992

[w]Tree sites and soil depths at which Br was detected on 4 March 1993

[v]Potassium bromide was applied on 28 September 1992 and its presence (ppm bromide) in the soil profile was monitored on 12 November 1992 (i.e. after 45 days) and 4 March 1993 (157 days after application)

Table 5. Representative examples of the relationship between rate of nitrogen (N) fertilization and apparent soil N losses during the dormant season. Two-thirds of annual application of fertilizer N was applied on September 28, 1992.

Treatment (lbs N/A/Yr)	Soil depth (ft)	Available N (ppm NO_3^- + NH_4^+) Pre-Fertilization (9-15-92)		Post-Fertilization (11-12-92)		Post-Dormancy (3-4-93)		Decreases in root zone (0-3 feet) Overwinter (%)
0 lbs N/A/Yr	0-1'	1.67	3.2	2.00	2.9	0.89	2.0	31%
	1-2'	1.03		0.35		0.58		
	2-3'	0.54		0.56		0.53		
	3-4'	0.38		0.46		0.51		
	4-5'	1.20		2.08		0.74		
	5-6'	40.65		87.54		12.56		
	6-7'	98.00		74.27		11.13		
	7-8'	127.58		48.10		21.03		
	8-9'	66.74		38.07		31.73		
	9-10'	37.08		56.92		30.93		
125 lbs N/A/Yr	0-1'	4.75	11.3	81.69	153.7	13.42	40.3	54%
	1-2'	3.88		66.40		13.33		
	2-3'	2.65		5.57		13.52		
	3-4'	74.51		2.08		33.80		
	4-5'	76.44		8.73		15.13		
	5-6'	56.63		36.86		16.28		
	6-7'	59.86		20.89		24.60		
	7-8'	29.14		71.78		35.70		
	8-9'	3.20		45.99		7.33		
	9-10'	2.92		22.30		5.45		
250 lbs N/A/Yr	0-1'	1.80	6.91	154.24	162.7	41.41	75.2	90%
	1-2'	1.31		6.91		5.92		
	2-3'	3.80		1.58		27.83		
	3-4'	33.45		13.60		70.24		
	4-5'	12.29		19.16		119.30		
	5-6'	29.55		26.13		102.20		
	6-7'	26.12		33.36		87.38		
	7-8'	26.51		74.76		63.66		
	8-9'	50.66		119.67		28.89		
	9-10'	55.34		15.35		14.91		
500 lbs N/A/Yr	0-1'	15.34	20.2	323.48	521.1	42.51	54.6	90%
	1-2'	1.15		166.45		8.39		
	2-3'	3.72		31.14		3.71		
	3-4'	4.95		11.00		5.53		
	4-5'	39.26		25.50		36.25		
	5-6'	18.35		41.75		93.65		
	6-7'	6.01		10.91		36.83		
	7-8'	1.71		7.77		54.66		
	8-9'	1.36		5.58		82.56		
	9-10'	2.09		5.55		31.80		

Table 6. Relationship between crop N removal and the N content of the perennial structure of dormant trees.

Tree I.D.	August 1994 Fruit N/Tree (lbs)	February 1995 Tree N Content (lbs)	Tree N Total[z] (lbs)	Fruit N as % of Tree N Total
10-13	3.30	3.04	6.34	52%
10-14	2.90	4.51	7.41	39%
18-12	2.46	3.39	5.85	42%
10-19	2.55	3.04	5.59	46%
14-19	2.66	2.79	5.45	49%
Mean	2.77 ±0.13	3.36 ±0.27	6.13 ±0.32	46% ±2.1

[z]Tree N total is considered to be the sum of Fruit N content and tree N content (i.e. the N content of the tree vegetative structure).

Table 7. Dry weight, nitrogen concentration, nitrogen content and nitrogen distribution in 15 year old post-dormant[y] 'Nonpareil' almond trees excavated 3 February 1995

Tree Component	Dry Weight/Tree Lbs		Dry Weight/Tree % of Total	N Content/Tree Lbs		N Content/Tree % of Total	N Concentration (%)
Branches	676.2	± 31	68.3	2.32	± 0.17	69.0	0.34
Trunk	150.0	± 25	15.1	0.27	± 0.04	8.0	0.18
Rootstock	134.4	± 6	13.6	0.34	± 0.03	10.0	0.25
Roots	29.8	±30	3.0	0.43	± 0.10	12.8	1.44
Total	990.4	±49	100	3.36	± 27	100	

[z]Data are the means of 5 trees ± SE
[y]Budswell had commenced, thus data probably reflect some N transport from roots to above-ground plant parts.

Table 8. N content of almond fruit components at fruit maturity and N in the almond meat expressed as a percentage of fruit N content.

	Fruit Component			
	Meat	Hull	Shell	Meat as % of fruit N Content
Tree Row-No.		---- Lbs N/Tree ----		
10-19	1.93	0.53	0.10	75.4
11-09	1.97	0.61	0.09	73.8
18-12	1.80	0.58	0.09	72.9
10-8	1.80	0.51	0.08	75.3
10-9	2.12	0.77	0.09	71.1
6-10	2.08	0.72	0.09	72.0
10-14	2.14	0.69	0.08	73.5
10-13	2.30	0.87	0.11	70.0
Mean	2.02	0.66	.09	73.0

Table 9. Amount of nitrogen (pounds/acre) applied in irrigation water as a function of nitrate (or N) concentration[1] and the amount of irrigation water applied.

Concentration		Irrigation water (acre - ft per season)			
ppm NO_3^-	ppm NO_3^-	2.5	3.0	3.5	4.0
		Amount of N applied (pounds N/acre)			
2.26	10	15.4	18.4	21.5	24.6
4.52	20	30.8	36.8	43.0	49.2
6.78	30	46.1	55.2	64.5	73.8
9.04	40	61.5	73.6	86.0	98.4
11.30	50	76.9	92.0	107.5	123.0
13.56	60	92.2	110.4	129.0	147.6
15.82	70	107.6	128.8	150.5	172.2

[1]Agricultural laboratories may report their results of water analyses as either NO_3^-Nitrogen (ppm N) or ppm NO_3^-. The following conversion factors may be used to calculate the amount of N applied annually in the irrigation water for N concentrations or levels of applied irrigation water other than those listed above.

1 ppm NO_3^- N in the water = 2.72 lbs N/acre foot of water applied.

1 ppm of nitrate (NO_3^-) = 0.614 lbs N/acre foot of water applied.

Since the atomic weight of the N atom is 22.59% of the atomic weight of NO_3^-, then ppm NO_3^- x 0.2258 = ppm N.

Outreach Activities Summary

I. Talks

November 1992, "Nitrogen Fertilizer Management to Reduce Groundwater Degradation" First Annual Research and Education Program Conference, Davis, CA, 130 participants.

December 1, 1992, "Optimization of Fertilizer Nitrogen Usage in Almond Orchards" 20th Annual Almond Research Conference, 300 participants, Growers, PCA's, etc., Modesto.

December 1993, "Optimization of Fertilizer Nitrogen Usage in Almond Orchards", 21st Annual Almond Research Conference, 300 participant; Growers, PCA's, Modesto, CA.

December 1993, "Nitrogen Fertilizer Management to Reduce Groundwater Degradation", Davis, CA 150 participants, Second Annual Fertilizer Research and Education Program Conference.

August, 1994. "Effect of Nitrogen Status on Productivity and Recovery of Isotopically Labelled Fertilizer N by Mature Trees", presentation at American Society for Horticultural Science Mineral Nutrition Workshop, Corvallis, Oregon, 150 participants.

November, 1994, "Nitrogen Utilization in Almond Orchards", Almond Management Short Course, Davis, CA; 250 participants, growers, PCA's, etc.

December, 1994, "Optimization of Fertilizer Nitrogen Usage in Almond Orchards" 22nd Annual Almond Research Conference, 300 participants, Growers, PCA's Modesto, CA.

December 7, 1995, "Nitrogen Fertilizer Management to Reduce Ground Water Degradation", Proc. Third Annual Fertilizer and Education Program Conference, Parlier California, 150 participants, growers, PCA's and miscellaneous others.

January 18, 1996, "Nitrogen Fertilizer Use to Reduce Groundwater Degradation", California Chapter of the Amer. Soc. of Agronomy, Modesto, CA, 100 participants, growers, PCA's, etc.

II. Others

I was interviewed in preparation for a radio broadcast of a 5-part series dealing with the issue of nitrogen fertilization and groundwater quality. Broadcasts were carried on 15 statewide radio stations.

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DAVIS, CALIFORNIA 95616

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MAR 29 1996
ALMOND BOARD OF CALIFORNIA

March 28, 1996

Rodger Wasson
Almond Board of California
1104 12th Street
Modesto, CA 95354

Dear Mr. Wasson:

Per your request, enclosed is the Final Report, April 1, 1996 for Project No. 2C1: Optimization of Fertilizer N Usage in Almond Orchards.

Sincerely,

Steven A. Weinbaum
Professor of Pomology

SAW:mks