A: Cover Page: CDFA Fertilizer Research and Education Program 2010

Development of a Nutrient Budget Approach To Fertilizer Management In Almond (Request for three year funded continuation to 07-670)

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Project location: Paramount Belridge Orchard and selected representative Almond Orchards

Project duration: Three years.

Description of target audience: Growers of >1 million acres of Almonds. Farm Advisors, Consultants, Fertilizer Industry.

Supporter: Paramount Farming Company

CDFA Funding Request: Year 1: $48,443 Year 2: $49,270 Year 3: $49,533

Other Funding for Related Research not directly funding this proposal**: Almond Board of California**: Yr 1: $34,000, Yr 2: $34,000. Contact: Robert "Bob" Curtis - Senior Manager, Production Research, 1150 9th Street, Suite 1500 - Modesto, CA 95354 USA - 209 343.3216 - Cell 209.604.0385. **Yara Fertilizers**: Yr 1: $25,000, Yr 2:$25,000 Contact: Sebastian Braum, PhD, Manager, Marketing Support & Agronomic Services, Yara North America, Inc. 3840 Ginger Court, Auburn CA 95602, 530-878-3934, sebastian.braum@yara.com

B. Executive Summary: Evidence from the recent CDFA-FREP nutrition focus group and survey of industry leading consultants, growers and Farm Advisors (Brown et al 2007) suggests that our current approach to managing nutrition in Almond is inadequate to meet production goals. Ninety % of growers and consultants felt that UC Critical Values (CVs), especially for N and K, were not appropriate for current yield levels and that the link between the results of leaf and soil sampling and specific fertilizer recommendations is poor. Sound nutrient management will require 1) knowledge of the scale and timing of nutrient demand by the crop, 2) an understanding of the relationship between fertilization type, fertilizer rate and crop response, and 3) optimization of nutrient delivery. This project aims to advance our approach to nutrient management with a primary focus on nitrogen and potassium and secondary focus on P, S, Mg, Ca, Zn, B. These goals will be achieved through the following objectives:

1. **Develop a phenology and yield based nutrient model for Almond.**
2. **Develop fertilizer response curves to relate nutrient demand with fertilizer rate and nutrient use efficiency.**
3. **Determine nutrient use efficiency of various commercially important N and K fertilizer sources.**
4. **Determine the role of harvest date on N remobilization, spur survival, tree productivity and NUE.**
5. **Validate current CVs and determine if nutrient ratio analysis provides useful information to optimize fertility management.**
6. **Develop and extend an integrated nutrient BMP for Almond.**

Progress: Differential treatments were initiated in 2008. In 2008 statistical differences in leaf N status were observed, by 2009 these differences had increased and differences in tissue K were seen. Yield differences were observed in 2009 in the N rate trials and trends were seen in the K rate trial. Source of fertilizer (UAN, CAN17, KCL, SOP, KTS) and irrigation method (drip / fan jet) had clear statistical effects on tissue nutrient concentrations in 2009 and clear trends in yield. With full establishment of treatment effects, continuation of this experiment through years 2010-13 will provide exceptionally valuable data.

Several important goals have been achieved: Nitrogen use efficiencies have been calculated and suggest that well managed Almond can be very efficient (80% and 72% NUE in 2008 and 2009 respectively at 275 lb N application). Supplemental funding has been acquired to measure gaseous N loss, soil N accumulation and N leaching to create a whole system N budget. Seasonal patterns of uptake accumulation and demand have been established, and will be used to establish new CV's, nutrient budgets and rate response dynamics. We have observed that harvest date significantly influences N cycling in the plant and tree N demand, this will be examined further.

This is the largest, most detailed and best monitored N and K rate trial every conducted in trees, treatments have been established and responses are clear. We have leveraged this experiment by adding separate funded remote sensing, modeling, soil and air N flux projects. Field research with mature trees requires at least five years of data to establish treatments and compensate for unusual seasons (such as 2010). Continuation of this trial for two additional harvests (three years total) is required to determine the long-term effect of the treatments on tree productivity, provide critical information on nutrient cycles and tree response and thus provide the means to optimize nutrient management in Almonds.

C: Justification: *This is a request for continuation for three years of CDFA-FREP project 07-670. Justification goals and objectives of the original grant are provided here. New activities that are derived from early results will be highlighted.*

Growers of tree crops apply a range of different nutrient management strategies, ranging from simple to very sophisticated (Westerman, 1990). One of the simplest forms of nutrient management bases fertilization decisions on the 'Critical Value' concept, where fertilizers are applied to ensure that leaf nutrient concentrations exceed what has previously been determined as the critical concentration for good yield levels. In this approach, which is currently the industry standard for most tree crops in California, leaf nutrient analysis only provides an indication of adequacy or deficiency, rather than specific information on appropriate fertilizer rates or timing of applications. In more sophisticated approaches, such as 'crop logging' (Bowen, 1990), nutrient decisions are made in direct response to models of plant growth potential, current climatic factors, nutrient status measured at numerous points in time, historic and predicted yield. Generally, the higher the value of a crop, the greater the benefit that can be derived from optimizing nutrient management (Ullrich and Hills, 1990). Surprisingly, Almond, a high value, long lived species, is typically managed using relatively unsophisticated approaches. This paradox is a direct result of the difficulty in conducting research in tree crops and the relatively low number of investigations that have been conducted.

Previous research and nutrient management recommendations in Almond (and in most other tree nut species) have mostly been based on the Critical Value concept (Brown and Uriu, 1996). Ideally, critical values are established by carefully controlled experiments in which the relationship between yield and nutrient concentration is closely followed. The majority of critical values relating to almond, however, have been determined on the basis of visual symptoms, not from yield reduction (Beutel et al., 1978; Brown and Uriu, 1996). Yield based determination of critical values in Almond, for example, are only available for N (Uriu, 1976; Meyer, 1996; and Weinbaum et al, 1980, 1990), K (Meyer, 1996; Reidel et al, 2004) and B (Nyomora et al, 1999), and to our knowledge no yield-based CVs have been established for the essential elements P, Mg, Ca, S, Cu, Zn, Fe, Mn, Mo, Ni, or Cl.

The reason for the minimalist approach to nutrient management in Almond is clear. Research is very difficult to conduct, management at a scale smaller than a whole orchard is difficult, and for the most part there has been little financial or clear environmental impetus. Clearly, however, this is not a sustainable strategy, as fertilizer prices and consumer demands for responsible management increase, and as the environmental consequence of over fertilization becomes evident. Moreover, excess N has been shown to increase disease pressure in Almond, impacting crop quality and raising production costs, indicating that the full economic effects of overfertilization might not have been adequately assessed. With more than 1 million acres of Almond in California and a crop value exceeding $1 billion, there is clearly justification for a modernization and optimization of nutrient management in Almond.

Nutrient Budget Alternative to Fertilizer Management in Tree Crops:

In the production of many field crops and most food animals, fertilization/feeding recommendations are not based on Critical Values, but on a process-based assessment of the physiological needs of the plant/animal. This approach is very common in high-value products produced in highly controlled environments, such as poultry, pork, beef, dairy, fish and greenhouse vegetables and flowers. While more difficult under the variable environmental conditions in field and orchard crops, physiology-driven nutrient demand models are becoming increasingly common in many field crops. These models derive nutrient demands from estimates of nutrient levels in soil and plant, as well as from crop nutrient requirements specific to the environmental conditions of the site and tree-specific parameters, such as tree age, variety and phenology. In tree crops, this approach has already been applied to the production of avocado and macadamia in Australia.

Almond production in California is well suited to the adoption of a nutrient budget driven approach to fertilization, since the high value of the crop justifies the adoption of such a precision agriculture approach. Crop values are at an all time high and there is an increasing interest in 'sustainable' production techniques to address customer desires and product image. Management techniques are increasingly amenable to 'on-demand' fertilization through increased adoption of fertigation systems and the use of fluid fertilizer formulations. Production techniques increasingly demand rapid growth and high productivity in early years, and consistent high yields demand that nutrient supply is non-limiting. Fertilizing trees only when deficiencies are detected by leaf analysis is too-little, too-late. The mature almond tree is well suited to a budget approach to fertility management, as it is relatively determinant in its growth patterns, almonds show limited vegetative re-growth after fruits reach full size, and the majority of whole tree macronutrient demand is partitioned to nuts. Once the spur leaves are fully mature, the N and K requirements for vegetation are largely satisfied. Fruits, on the other hand, continue to accumulate N and K until harvest (Almond Board of California, 1972-2003, Brown et al., 1995). The development of the nut and the tree yield are therefore excellent measures of whole tree nutrient uptake, which are not significantly compromised by vegetative competition.

In the first objective of this project, we will develop an improved phenology, cultivar and yield linked nutrient demand curve derived largely from the rate of nutrient acquisition by the developing fruit at multiple locations. By providing many more data points with specific relationship to environment, phenology and cultivar, we will greatly strengthen, validate and qualify the key assumptions of the model and hence improve its utility. Knowledge of tree nutrient demand derived in the first objective, provides no information on efficiency of fertilizer use and represents merely a baseline nutrient requirement for a given yield level. Currently, we have essentially no information describing the specific relationship between fertilizer rate, fertilizer type, crop nutrient status, yield, and tree nutrient response in Almond. Our ability to satisfy the nutrient demand of a growing almond crop clearly requires knowledge of the scale and timing of that demand, as well as an understanding of how fertilizer form and rate can be used to satisfy that demand while minimizing wastage.

Knowledge of the relative efficacy (cost and productivity) of different fertilizer materials and rates is critical to guide fertility management. This will be addressed in Objective 2 and 3.

Objective 4 is new for this project submission and is based upon results observed in 2008 and 2009 that suggest that significant remobilization of N from mature fruit to spurs occurs (Figure 4). We hypothesize that this N remobilization will influence spur survival and return yield, and that harvest date influences the extent of N remobilization, total N demand and N use efficiency. A more complete description is provided below.

Based on all information obtained from the preceding objectives, currently applied CVs will be validated, and the applicability of a nutrient ratio approach, as opposed to the currently common single-nutrient approach, will be tested (Objective 5). Finally, all project results will be integrated to develop a new *Best Management Practice for Nutrient Management in Almonds in California* (Objective 6).

This experiment has now been leveraged with funding from USDA and Almond Board of California. Additional experimentation to develop remote sensing, to model yield response to climate, to measure and quantify gaseous and leaching N losses are underway and will be integrated with the current proposal to provide the first truly holistic analysis of nutrient dynamics in Almond. The sum of all activities will allow us to simultaneously answer many questions and develop new management tools.

CDFA/FREP Goals: This project specifically addresses two areas of special emphasis for the 2007 call: 1) Nutrient uptake by tree crops and 2) Guidelines for orchard fertilization patterns. This project also aims to develop improved diagnostic tools and site specific management technologies. In combination with the partner project submitted to this call (Brown et al: Development of Leaf Sampling In Almond and Pistachio), these combined projects will determine crop nutrient requirements, critical values and efficiency of several fertilization practices.

Impact: In the absence of a reliable nutrient monitoring system and integrated fertilization program, growers of >700,000 acres of Almond have inadequate scientifically validated tools on which to make sound fertilizer decisions. The development of tools and approaches that can be effectively used to monitor plant nutrient status, construct nutrient demand budgets, create a full system evaluation of N losses, analyze effect of rate and N source and design efficient fertilizer strategies is a crucial step toward responsible and profitable fertilizer use. Efficient and responsive fertilizer strategies are essential if we are to protect the Californian environment from non-point fertilizer pollution and is an economic imperative as consumers increasingly demand sustainability and responsible production techniques.

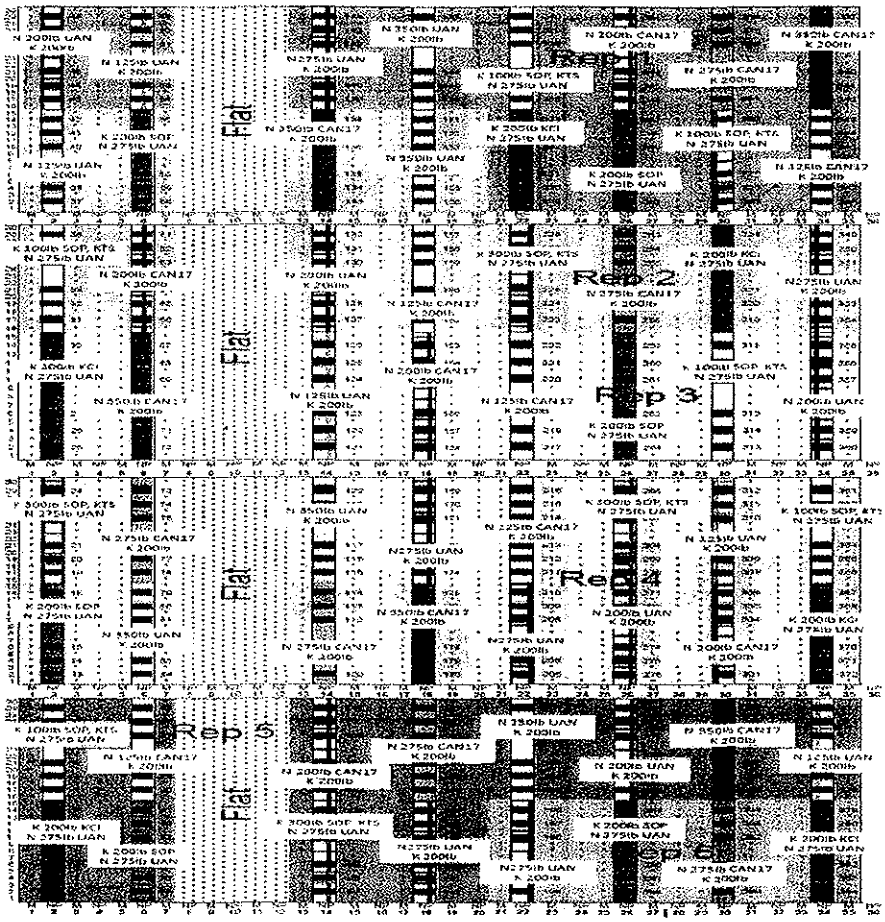
Long Term Solutions: This project will provide a robust new approach to fertilization strategies and integration with yield dependent variability. The **target audience** for this work is the Almond industry. **Success** will be measured by the reliability of new sampling and analytical protocols and subsequent field-testing, by the nature and effectiveness of outreach activities and by the adoption of new practices by the industry. This project has been developed collaboratively with all major stakeholders (growers, consultants, fertilizer companies, farm advisors, industry, regulatory agencies and analytical laboratories), through this and effective dissemination of our results, we expect excellent buy-in and adoption. This project is well supported by Almond Board and Yara NA who are funding related research on this topic.

Related Research, Justification for Continuation (see 07-670 annual report for more details) : *The first two years of this experiment have been highly successful. A very large, well replicated and highly effective field trial has been established and treatment effects have been established (Fig 1). Tissue responses (Fig. 2) to N treatments were observed starting 2008 and yield responses were seen in 2009 (Table 1). Tissue responses to K treatments were observed starting 2009 (Fig. 3). Since K affects productivity through its effect on spur growth (Reidel et al 2004) yield responses are not expected until 3 years after trial establishment. Nutrient acquisition by fruit throughout the growing season has been measured for all nutrients and is shown here for N (Fig 4.) and K (Fig 5).*

Nitrogen accumulation in fruits (Fig 4) increases linearly from immediately post bloom until day 136 after full bloom and then declines significantly from day 36 through harvest (day 166). This decline in fruit N represents movement of up to 35 lbs of N from hulls to tree. This dynamic has never previously been documented. We hypothesize that this N represents a critical N source for spur survival and early season growth. Further we hypothesize that earlier harvest dates will result in less of this remobilized N reaching the tree, this in turn diminishes N use efficiency, transports greater N out of the field and potentially compromises early season flowering and fruit set. The N status of the tree greatly influences whole tree nutrient balance. These observations will be directly tested in a new objective and experiment for 2011-13.

Potassium accumulation in fruit is essentially linear throughout the season and does not show net K movement from fruit to tree after fruit maturity (Fig 5).

Effects of treatments on nutrient dynamics, yield and interactions are expected to increase as soil and tree nutrient reserves become depleted. A more detailed analysis of this trial is provided in the annual report for 07-670.



Treatment	N source	N amount (lbs/ac)	K source	K amount (lbs/ac)
A	UAN32	125	60% SOP / 40% KTS	200
B	UAN32	200	60% SOP / 40% KTS	200
C	UAN32	275	60% SOP / 40% KTS	200
D	UAN32	350	60% SOP / 40% KTS	200
E	CAN17	125	60% SOP / 40% KTS	200
F	CAN17	200	60% SOP / 40% KTS	200
G	CAN17	275	60% SOP / 40% KTS	200
H	CAN17	350	60% SOP / 40% KTS	200
I	UAN32	275	60% SOP / 40% KTS	100
J	UAN32	275	60% SOP / 40% KTS	300
K	UAN32	275	100% SOP	200
L	UAN32	275	100% KCl	200

Figure 1. Layout of the experimental plot at Bakersfield (Fan Jet block only). Different background colors indicate different experimental units. Black rectangles mark trees that are intensively sampled in this experiment. This trial is replicated in drip irrigation. Total experimental trees 850.

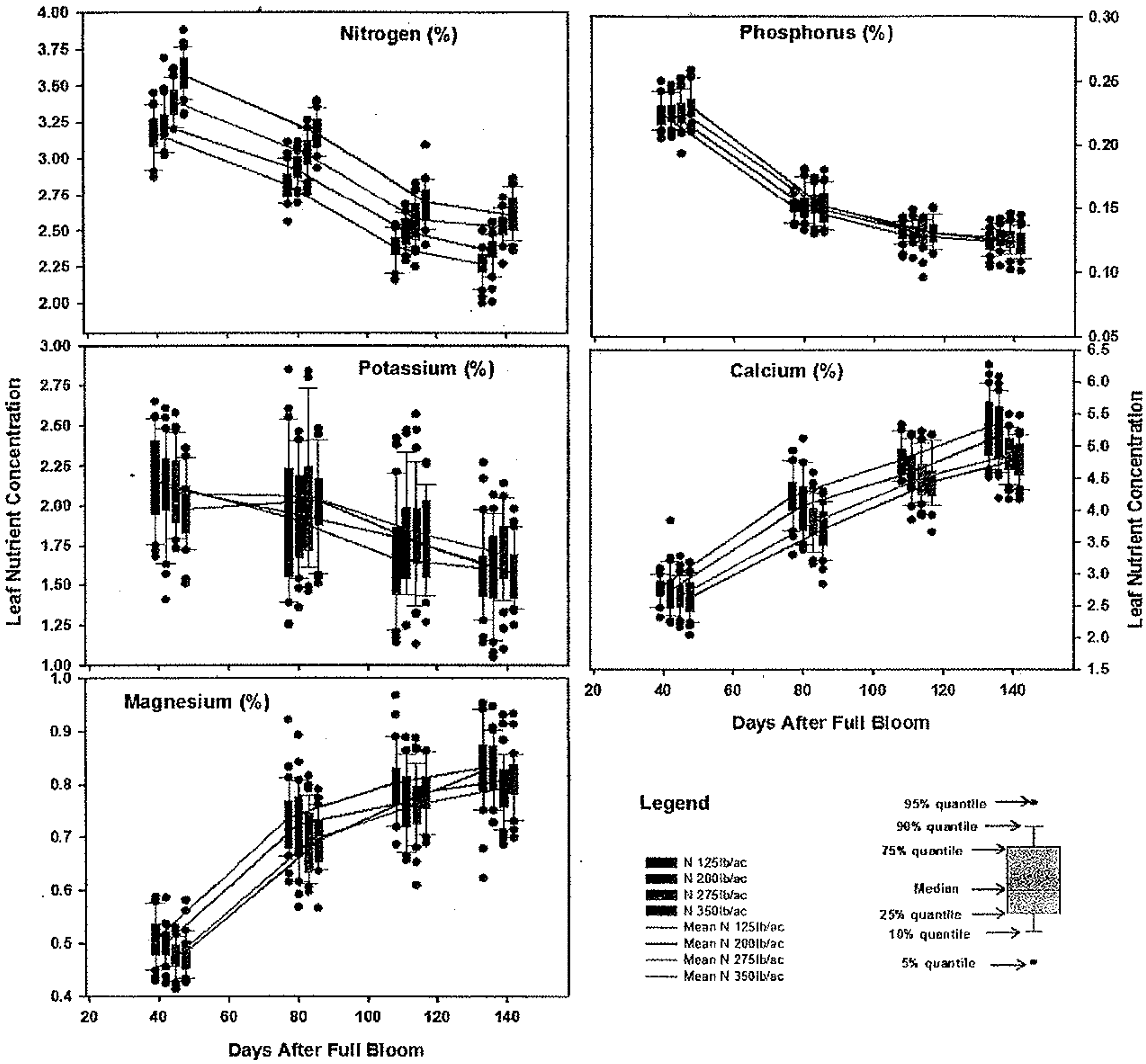


Figure 2. Effect of different nitrogen rates (N UAN 32) on leaf nutrient concentration in 2009 (for Fan Jet Irrigation). In box plots, the central line is the median of the distribution, the edges of the boxes are the 25% and 75% quantiles, error bars, represent the 10% and 90% quantiles, and all points are outliers

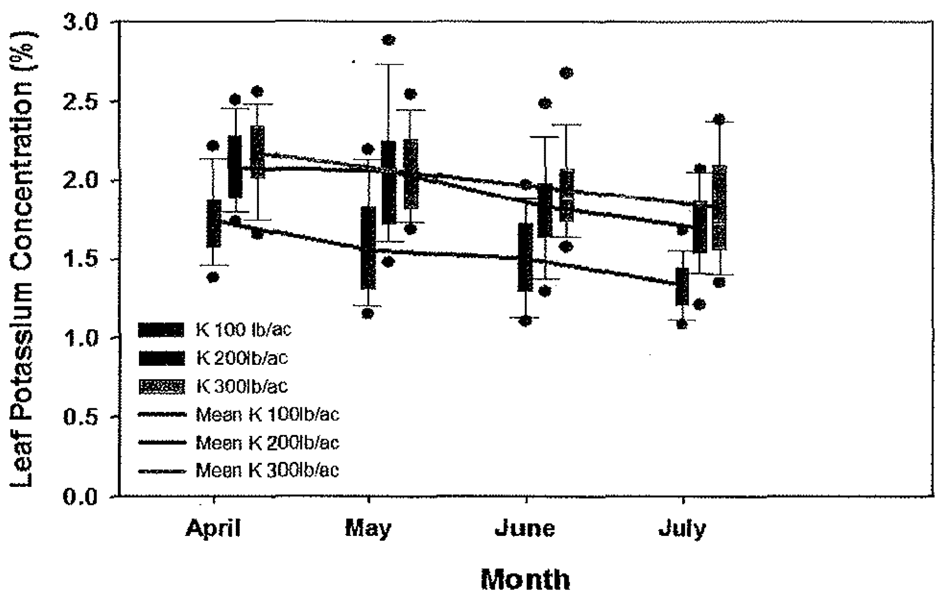


Figure 3. Effect of different Potassium rates (SOP+KTS) on leaf Potassium concentration in 2009. In box plots, the central line is the median of the distribution, the edges of the boxes are the 25% and 75% quantiles, error bars, represent the 10% and 90% quantiles, and all points are outliers

Table 1. Mean kernel yield (lb/ac) for different treatment in 2009; treatments not represented by same letter within irrigation are significantly different. (refer to table 1 for the description of letters).

Kernel Yield 2009

Treatment	UAN 32				CAN 17				K Rate			K Source		
	A	B	C	D	E	F	G	H	I	C	J	C	K	L
Drip Irrigation	2689 b	2977 b	3327 ab	3507 a	2512 b	2634 b	3064 b	3605 a	3304	3327	3534	3327	3246	3480
Fan Jet Irrigation	2776 b	3111 ab	3263 ab	3380 a	3143	3130	3248	3216	3457	3263	3489	3263	3308	3404

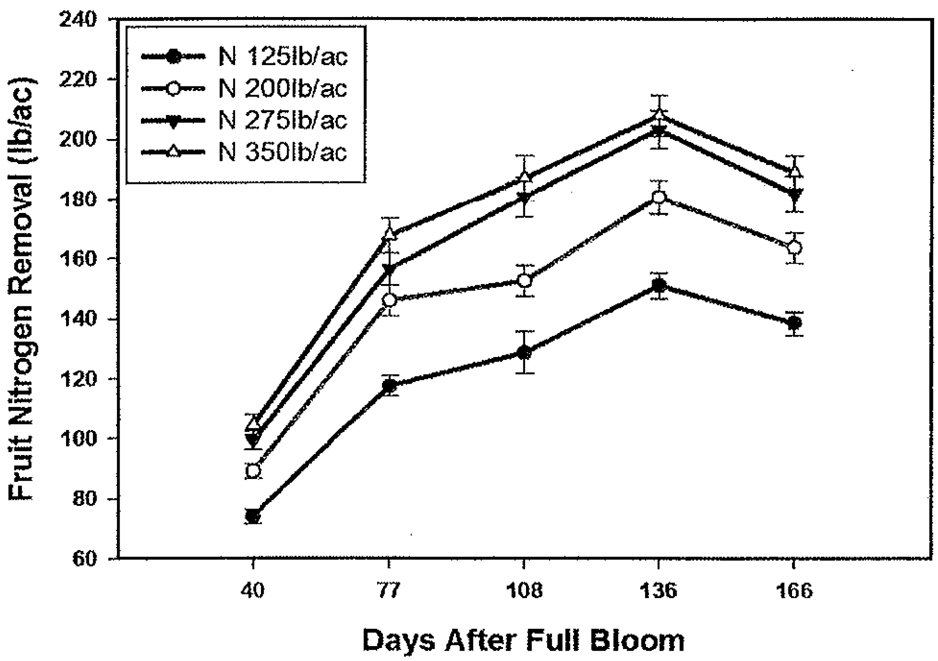


Fig 4. Fruit nitrogen removal from nitrogen rate treatment UAN 32 (fan jet irrigation) in 2009. Each point represents mean and standard error.

Fruit Potassium Removal 2009

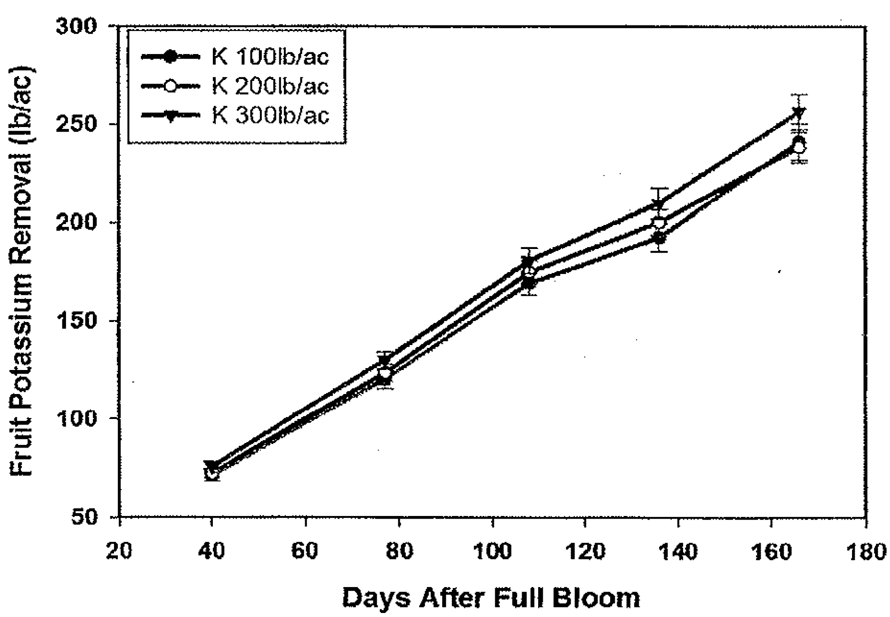


Figure 5. Fruit potassium removal from K rate treatment SOP + KTS (fan jet irrigation) 2009. Each point represents mean and standard error.

OBJECTIVES

1. **Develop a phenology and yield based nutrient model for Almond.**
2. **Develop fertilizer response curves to relate nutrient demand with fertilizer rate and nutrient use efficiency.**
3. **Determine nutrient use efficiency and contrast various commercially important N and K fertilizer sources.**
4. **Determine the role of harvest date on N remobilization, spur survival, tree productivity and NUE.**
5. **Validate current CVs and determine if nutrient ratio analysis provides useful information to optimize fertility management.**
6. **Develop and extend an integrated nutrient BMP for Almond.**

PLANS AND PROCEDURES

The following includes ongoing objectives and tasks submitted under the first three year project (07-670) of which this is a request for continuation. Status of ongoing tasks and proposed new activities and timelines are highlighted.

Task 1 (Objective 1): Develop a phenology and yield based nutrient model for Almond.

Initiated Jan 2008, final harvest 2012 unless indicated.
Analysis complete Dec 2013

1.1 Identify field locations, pre-scout and receive grower compliance commitment.

This task is being conducted in collaboration with fields utilized in project 07-671 and in the major experiment (Task 2) established at Belridge, Ca. All trials have been initiated in 8 or 9 year old microsprinkler irrigated Almond Orchards of good to excellent productivity planted to Non-Pareil (50%) on uniform rootstock in soils representative of the region and a large percentage of Almond acreage. At experiment completion, trees will have reached 13 year old (after 5 years) representing their most productive years. Two full years of production, nutrient budget and sampling have now been completed, three additional years of sampling and harvest are requested.

1.2 Sample collection:

Composite nut samples and leaf samples are being collected from within the canopy of each of 6 replicate trees within each treatment block at the Belridge site. Nut and leaf samples are collected from 10 trees per orchard in exposed portions of the canopy for each tree in all other sites. The individual yield of these same trees, phenology (determined by fruit characteristics), local environmental and climatic conditions (CIMIS) are determined. The data on nutrient content of nuts and their biomass at each sample date stage is related to final tree yield and nut weight to develop a curve of seasonal nutrient and biomass accumulation. Any nut drop event will be monitored and estimated to allow for correction of biomass data.

1.3 Tissue analysis and tree yield determination

Tissue determination for the major elements (N, P, K, S, Ca, Mg, B, Zn, Fe, Mn, Cu) in all nut samples and leaf samples will be procçsses by the DANR analytical laboratory at UC Davis. All nutrient and biomass data will be cross-referenced to individual tree yield, phenology, environment and other variables to develop a phenology and yield based nutrient model for Almond.
In all experiments described here, individual tree harvest will be performed three days prior to commercial field harvest by selectively shaking individual experimental trees then raking and weighing by hand.

1.4 Statistical Analysis

We will use a combination of linear and non-linear statistical approaches utilizing both individual tree analysis and blocked treatments, replicated over several years in a mixed hierarchical model. Effects of climate, location in the field and environment on patterns of nutrient uptake, in-field variability and budget will be determined by cross site comparison, while the effect of nutrient status on nutrient uptake and budgets will be determined by within treatment comparisons at Belridge.
Where within field spatial data is involved, data will be geostatistically interpolated to develop maps of nutrient status for each element. These maps will be used to estimate the distribution of nutrient content.

Task 2 (Objectives 2/3): Develop fertilizer response curves and nutrient use efficiency to relate nutrient demand and fertilizer source with fertilizer rate.

Initiate January 2008, final harvest and sampling Dec 2012.
Analysis complete Dec 2013

2.1 Experimental setup

A fertilizer response trial is being conducted in an orchard operated by Paramount Farms Belridge. The establishment of the experiment was completed in 2008 and yield and nutrient data has been collected for 2008 and 2009. The trial consists of 128 experimental units, comprising 768 trees (Fig. 1). The layout and a preliminary analysis of samples already collected in 2008 and 2009 have been included in annual report for 07-670. Tissue analysis, determination of tree yields and statistical evaluation follow the same strategy as outlined above for task 1.

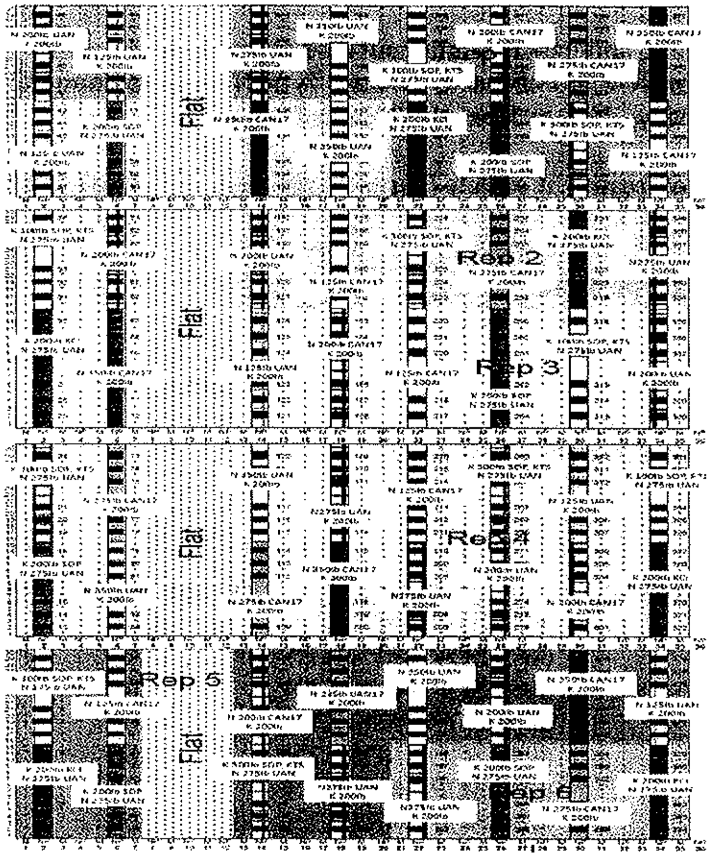


Figure 1. Layout of the experimental plot at Bakersfield (Fan Jet block only). Different background colors indicate different experimental units. Black rectangles mark trees that are intensively sampled in this experiment.

Statistical analysis of several large individual tree yield trials demonstrates that classic 'blocked' statistical designs are not ideal for tree-nut nutritional research. This is a consequence of the inherent difficulty in ensuring all trees in each fertilizer treatment actually 'receive' identical nutrient treatments and is a consequence of the inherent variability in yield that exists between trees and across years. A far more powerful, but logistically difficult approach is to conduct single tree (or small blocks of individual trees) experimentation with high degrees of replication and careful covariate determination of yield and other variables on each individual tree. In this approach the measured nutrient status of the individual can be contrasted with actual yield response in each year as well as repeated measures response across years.

Fertigation treatments were performed by independently engineering an irrigation and fertigation scheme that replaces the grower system in each experimental block. This approach prevents the application of grower fertigation treatments to our blocks, while a computer controlled bypass valve allows experimental plots to receive normal grower irrigations. During periods when our fertigation treatments are applied (4 dates), valves to the non-treated portions of the field will be closed. We have strong support for this approach and a commitment for engineering and irrigation support. This scheme has been working exceptionally well over the first two years.

Specific treatments are as shown in Table 1, and experimental units are arranged as shown in Fig. 1. Sixty % of K is applied as granular SOP in February. Twenty % of N and remaining K fertilizers are applied in March, 30% in May, 30% in June and 20% in September.

Rates have been established and statistical treatment effects (tissue N, tissue K and yield) and clear trends have already been detected.

With this design the following contrasts are possible:
Effect of N rate on tree yield and nutrient response (Treatments A, B, C, D)
Effect of K rate on tree yield and nutrient response (Treatments C, I, J)
Interaction of N and K rate and source on yield and nutrient response (All Treatments)
Effect of N source on tree yield and nutrient response (Treatments A, B, C, D, E, F, G, H)
Effect of K source on tree yield and nutrient response (Treatment I, K, L)

Table 1. Fertilization treatments.

Treatment	N source	N amount (lbs/ac)	K source	K amount (lbs/ac)
A	UAN32	125	60% SOP / 40% KTS	200
B	UAN32	200	60% SOP / 40% KTS	200
C	UAN32	275	60% SOP / 40% KTS	200
D	UAN32	350	60% SOP / 40% KTS	200
E	CAN17	125	60% SOP / 40% KTS	200
F	CAN17	200	60% SOP / 40% KTS	200
G	CAN17	275	60% SOP / 40% KTS	200
H	CAN17	350	60% SOP / 40% KTS	200
I	UAN32	275	60% SOP / 40% KTS	100
J	UAN32	275	60% SOP / 40% KTS	300
K	UAN32	275	100% SOP	200
L	UAN32	275	100% KCl	200

2.2 Sample collection

Leaf and nut samples are collected from six individual trees from each replicate unit in all treatments at two dates (May and July), and from N and K rate treatments at three dates. The total number of annual samples for this part of the project for all five dates is 5,740 (2,676 leaf and 3,064 nut samples).

Task 3 (Objective 4). Determine the role of harvest date on N remobilization, spur survival, tree productivity and NUE. (NEW ACTIVITY)

Initiate Aug 2010, repeat 2011, 2012.

Complete Dec 2013

As this is a new activity a more detailed description and rationale is provided here. Prior work by Basile et al (2003) and Heerema et al (2008) suggest that the survival of fruiting spurs is a key determinant of return bloom and yield. Spurs serve as the fundamental bearing units in almond (Heerema et al., 2008), because mature almond trees bear a high percentage of fruit on these short shoots, with only a small percentage (fewer than 15%) of fruit born laterally on long 1-year-old shoots. Fourty five % of all productivity is carried on spurs with one fruit with 35% carried on spurs with two fruits. As a result, maintenance of the total number of living spurs per tree and ensuring their productivity is extremely important. Heerema et al. (2009) demonstrated that the interaction between tree N treatment and spur fruiting status was significant.

Deciduous trees cycle nitrogen by remobilizing nitrogen from the senescing leaves into woody tissue, and the stored nitrogen is used for growth in the spring (Tromp, 1983; Titus and Kang, 1982; Millard, 1989). As the conditions in the early spring are suboptimal for nitrogen uptake from the soil, the stored nitrogen is used for growth in the early season (Millard and Neilson, 1989). In almond nitrogen accumulated in the pericarp (hull and shell) contributes towards the nitrogen requirements of developing embryo (kernel). Weinbaum and Muraoka (1986) reported that under the conditions in California, the embryo of Nonpareil matures by 31 July and have determined that the pericarp contributed 46.8% to 55.7% of N content of the embryo with the remainder of the kernel N being derived from leaves and direct transport.

The current Belridge trial demonstrates for the first time that significant amounts of N are remobilized from pericarp to tree (the difference between fruit nitrogen removal between 136 DAFB and 165 DAFB) following fruit maturation and prior to harvest (fig 4). These results have several implications:

-N remobilization from fruit may be critical for flowering and yield in the subsequent spring

-Changing harvest date will change N export from the field, and N remobilization to spurs and ultimately NUE.

- In almond, flower initiation begins in mid July and continues until mid September (Lamp et al. (2001)). Remobilized nitrogen from fruit coincides with this time frame closely and hence may have role in flower bud development and return bloom and production in the subsequent year.

The experiment aims to quantify the amount of nitrogen remobilized from fruit to storage pools and determine the effect of this remobilization on return bloom strength. Our objectives are:

-To quantify the amount of nitrogen remobilization from almond fruit to storage organs at different times after kernel maturation and under different N application and yield regimes.
-To determine the effect of different harvest date on return bloom in the subsequent year and NUE.

Task 3.1 The experiment will be carried out in the Belridge almond orchard where the N/K/source experiment is in progress (Fig 1, table 1). Trials will be performed in the nitrogen rate replicated treatments in which discrete and well documented changes in N status have been established and monitored for 2 years.

Task 3.1.1 To determine the quantity and timing of N remobilization from fruit, fruit samples will be collected at 10 day intervals from mid July until complete fruit senescence (loss of green color); leaf samples will be collected at 20 days intervals to see the changes in the leaf N content. The grower has agreed to delay harvest on experimental trees as needed. Samples will be collected from 8 single fruited and 8 double fruited spurs in each of 3 trees in each of four replicate blocks in each of the 4 N rate treatments. All spurs will be labeled so that return bloom and spur nutrient status can be determined. Fruit will be dried, weighed and will be analyzed for nitrogen (P and K) contents in the fruit parts (hull, shell and kernel). Total 560 fruit and 240 leaf samples will be collected for this purpose each year. Trees will be harvested at full maturity (this is up to 1 month after normal harvest) and yield of individual data trees will be determined. The data from fruit nutrient concentration, biomass accumulation, dry yield, leaf and spur nitrogen contents will be used to determine nitrogen mobilization during different time and the amount of nitrogen remobilization from the fruit to storage organs. In 2011 and 2012 new spurs will be labeled and the experiment repeated.

To further evaluate the effect of remobilized N on return bloom strength, 8 trees will be selected each from high and low nitrogen rate treatments. Selected branches and spurs will be defruited at 15 day intervals starting mid July. Sixteen spurs bearing one fruit will be tagged on a 1.5 meter long branch and will be defruited at each date. A total of 1024 spurs will be labeled and monitored. Nitrogen status of the branches will be determined by taking leaf and spur samples and analyzing for nitrogen and carbohydrate contents.

Task 4 (Objective 5): Validate current CVs and determine if nutrient ratio analysis provides useful information to optimize fertility management.

Commenced December 2008, ongoing thereafter through Dec 2013

4.1 Statistical analysis and integration

In the combination of experiments described here, 891 individual trees will be monitored for yield and nutrient status over a 3-5 year period at 4 sites for a minimum of 2673 yield x nutrient data points for which all essential nutrients and numerous covariate factors will have been determined, every year. This large number of individual data points with yield, nutrition and covariate analysis represents by far the largest data base of yield x nutrition ever collected and will be used to help redefine or validate existing Critical Values. To fully interpret this data we are employing new multivariate statistical techniques (principal component analysis, canonic analysis, multilinear regressions, kriging, and variograms). Furthermore, this will allow us to analyze nutrient ratio x yield effects as a potential basis for application of the DRIS system of nutrient ratio analysis in Almond. This pool of data will be analyzed using a variety of statistical and graphical approaches to partition variance, identify and classify data clusters, identify and model data trends, and ultimately estimate nutrient optimums (Boundary Layers, DRIS analysis, Mitscherlich response fitting etc).

Task 5 (Objectives 6): Develop and extend an integrated nutrient BMP for Almond
Ongoing with major integration and publication Jan-Dec 2013.

5.1 Development of BMPs

Ultimately, our specific goal in this current project is to provide growers, consultants and regulators with information needed to optimize nutrient management of orchards.

Collaboratively, a new nutrient BMP will be developed from an integration of all parts of this project. The combination of nutrient budget determination, nutrient response information, nutrient cycling, nitrogen systems budgeting, improved sampling and monitoring strategies, yield responses, integration with irrigation provides a theoretically sound and flexible approach to ensure high productivity and good environmental stewardship. The output of this activity will be a new paper and computer based model and educational tool that will help growers define and optimize their fertilization strategies based upon a sound understanding of nutrient budget demands of the tree as influenced by environment, crop load, location and yield. We expect to also refine current leaf CVs, investigate the utility of nutrient ratios and define the optimal rate of N application, timing, placement and source on nutrient use efficiency. Research will emphasize N and K but will include an analysis of all essential elements commonly applied in California.

F: Project Management, Evaluation and Outreach

Dr. Patrick Brown will provide overall coordination of all activities working closely with the responsible farm Advisor in each county. Dr. Bruce Lampinen will be a key advisor in all activities and will play a significant role in light interception measurements, project design and coordination. Dr. Plant will supervise all statistical analyses.

A graduate student conducting his PhD in tree nutrition will be dedicated to this project. As a component of his thesis research this student will complete a thorough literature review of approaches to tree nutrient management and will in collaboration with Dr Brown write academic and 'farm press' summaries of these findings. Two additional Spanish speaking masters students will assist with all harvest activities.

Day laborers and student hourly help will be used extensively to assist with field harvest and avoid compromise with grower harvest schedule. Grower collaborators will be selected based upon their historical commitment to research, availability of harvest equipment and day labor pools.

Evaluation of project performance will be conducted on an ongoing basis. Conference calls are scheduled each 4 months among all participants to ensure progress is being maintained. Annual reports of activities will be submitted to CDFA and to the co-sponsors.

Outreach is a critical component of this project and will be actively pursued at all stages of project activity.

This project is derived in large part from the CDFA and industry sponsored focus groups and surveys currently underway by this project team. The involvement of >50 industry leading growers, consultants and farm advisors in the focus groups that helped initiate this project has helped raise the awareness of this activity. Further, the industry nutrition surveys recently mailed (>2,800) and the advertised web-based survey each contain specific explanations of our goals in new nutrient management in Almond and contain carefully phrased questions that will alert growers to the potential issues with current practices, thus whetting their appetites for new approaches.

We have found that involving stakeholders early in the process enhances buy-in in all projects, when stakeholders know what we are planning they tend to be more receptive to the results. The Almond Board and Yara fertilizers have pledged a significant commitment to associated projects. The involvement of these entities will encourage grower recognition and fertilizer industry attention.

Annually, Dr Brown and Farm Advisors will present this ongoing research and ultimately the outcomes of this project at numerous events. Dr. Brown for example, typically presents 3-5 large audience presentations annually to meetings of the Almond Research Conference, Western Plant Heath Association, Cal-ASA Plant and Soil conferences, Pistachio Conferences, almond industry events, FREP events, regional Almond Meetings (eg SJV Almond Day, Nickels Field Day), Chemical Industry Grower Days (Actagro, Tesenderlo Kerley, Yara), PCA/CCA events.
As specific project results are developed, they will be distributed widely to the primary audience through the meetings described above and through press releases and ultimately training courses. The FNRIC site at UC Davis will develop a project web page for this activity and ultimately will host any subsequent computer based product.

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