2011-2012 Final Report CDFA Fertilizer Research and Education Program

10-0015-SA

Development of leaf sampling and interpretation methods for Almond and Pistachio

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B: Objectives

The integrated objectives of these research projects were to:

1 Determine the degree to which leaf nutrient status varies across a range of representative orchards and environments.
2 Determine the degree to which nutrient status varies within the canopy and within the year.

3 Validate early season leaf analysis protocols and relationship with yield, validate current CV's and determine if nutrient ratio analysis provides useful information to optimize fertility management.
4 Test utility of use of fruiting spur leaf analysis under variable N and K treatments, validate as an indicator of tree nutrient status, monitor role of fruiting spur leaves in yield, monitor relationship between spur nutrient status and spur survival in almond.
Develop and extend an integrated nutrient BMP for almond and pistachio

C: Abstract

The overall goal of this research project was to develop integrated nutrient management practices for almond and pistachio trees across different ranges of environments to provide growers with tissue sampling protocols and interpretation tools to better manage their crops. Previous results of a survey of almond and pistachio growers, and consultants in California, suggested that the existing leaf sampling protocol and comparison of the tissue results with the established standards does not provide sufficient guidance for nutrient management. Concerns with leaf tissue testing are a poor correlation between tissue nutrient concentration and soil nutrient availability and a high degree of variability in tissue nutrient concentration in adequately fertilized crops within a single tree and within the same field. Further, growers typically collect one composite sample per management unit or orchard zone, which hardly represents the mean of the nutrients in the orchard. Also the current practice of sampling late in the summer limits the grower's ability to make in season fertilizer adjustments.

Under the current projects we have developed improved leaf sampling protocols and have developed nutrient budget models for pistachio, in a separate report (10-0039-SA) a nutrient budget approach for almond has been provided. The nutrient budget model as a management tool helps growers optimize the time and rate of fertilizer application to coincide with the tree demand. Extensive leaf and fruit samples and yield data were collected at multiple times across four growing seasons to determine the degree of variability in tissue nutrient concentrations over time, space, and within tree canopies. Variations in leaf nutrient status of the trees over the growing seasons, between sites and years were used to refine field-sampling methodologies and to develop an early season sampling protocol. This early season sampling protocol offers management advantages to growers by providing information on which to base decisions about in-season fertilizer adjustments. Additionally, the large data set were used to estimate the validity of current critical values. The implementation of the improved sampling strategies combine with the nutrient budget models is expected to help growers to better monitor and manage the nutrient status of their orchards and increase their profitability and environmental stewardship.

D: Introduction

At present, growers primarily use leaf tissue analysis to determine tree nutrient status and make fertilizer management decisions. This is often followed by uniform fertilizer application across the entire orchard and across years. An inherent problem with this approach is that some trees may be over fertilized, and others may be under fertilized. Comparing the results of the leaf samples with the established critical values is the standard for nutrient management decisions in California. Results of a survey of almond and pistachio growers, and consultants in California, suggested that the existing leaf sampling protocol and comparison of the tissue results with the established standards does not provide sufficient guidance for nutrient management. Two explanations for this observation are possible a) The current critical values (CVs) are incorrect or not useful for the decision-making process due to lack of sensitivity or inappropriate timing or b) Leaf tissue analysis alone is not adequate to provide nutrient management recommendations.

Concerns with current leaf tissue testing are a poor correlation between tissue nutrient concentration and soil nutrient availability and a high degree of variability in tissue nutrient concentration in adequately fertilized crops within a single tree and within the same field. Earlier studies on leaf analysis have also recognized the problem of variability which makes effective leaf sampling extremely difficult. Currently, growers typically collect one tissue sample per management unit or orchard zone however no study has been conducted to date, to determine how this sample should be collected to adequately represent the spatial variability of the orchard so that a true mean of the nutrients in the orchard can be determined. In general, midsummer is the recommended period of leaf sampling for nutrient analysis in fruit and nut trees including in California, this corresponds to the period from July through early August in the central valleys of California. The midsummer timing has been established because the concentration of most nutrients remains fairly stable during this time. This practice of sampling late in the summer however, limits the grower's ability to make in season fertilizer adjustments for the current crop load.

The aim of the current projects was to develop new approaches and interpretation tools that better quantify field and temporal variability and are sensitive to yield and provide for in-season monitoring and fertilizer optimization in almond and pistachio across different locations. These projects also offered the unique opportunity to verify the current critical values of major nutrients for almond and pistachio. Parallel to the leaf sampling projects, we have collected fruit nutrient and yield data of all the experimental trees at each of the four pistachio orchards over the growing seasons from 2009-2011 and have developed and validated yield and phenology based nutrient budget curves for pistachio across a range of environmental conditions for major nutrients including nitrogen, phosphorus and potassium. Similar work has been recently completed in almonds (see 2012 FREP report 10-0039-SA). Results from our large and multi-year project indicates that fertilizer use can be optimized and considerable nitrogen losses can be reduced if nitrogen applications are synchronized with the actual tree demand.

E: Work Description

A large-scale and long term survey of within-field, between-field, within-tree and between-organ nutrient concentration and variance was conducted in mature almond and pistachio orchards. The interaction between yield and nutrient status was determined at 4 almond orchards (on >600 individual trees), and at 4 pistachio orchards (on >400 individual trees). All almond and pistachio trials were initiated in 8 or 9 years old almond orchards and 10-15 year old pistachio orchards of good to excellent productivity planted to nonpareil (50%) and Kerman (97%) respectively. Both, almond and pistachio orchards were in soils representative of the major production regions.

The 4 experimental sites for almond project were located in Arbuckle, Modesto and Madera (2) and the 4 pistachio sites were located at Fresno, Madera, Kern and Kings County sites. At 54 grid points uniformly distributed across a 10 acre block of trees, leaf nutrient status throughout the year (May through August) (N, P, K, S, Ca, Mg, B, Zn, Fe, Mn, Cu),and tree yield were determined in each tree. Further, in almond trees, three different kinds of leaves and nut samples were collected at 5 times during the growing season to explore different sampling methods. Similarly, in pistachio trees, leaf and nut samples were collected at various times throughout the season (2009-2012) to determine the degree of variability in tissue nutrient concentrations over time, space and within tree canopies to validate the established standards and develop nutrient budget models for important major nutrients. To validate project results, sample collection was continued over the growing season in 2012 in six different orchards for the case of almond and in the same orchards for the case of pistachio. Additionally, in pistachio leaf samples were collected in 8 new orchards over the season in 2012. To validate our protocols against expected grower practice leaf sampling in the last year of the pistachio project (2012) utilized pooled leaf samples. All plant tissues were analyzed for nutrient concentration of N, P, K, Ca, S, Mg, B, Zn, Cu, Mn and Fe by standard methods at the Agriculture and Natural Resources (ANR) Laboratory at the University of California Davis.

This current grant is an extension of 06-671 and as such the following tasks and outcomes represent the combined project duration.

Objective 1/Task 1: Determine the degree to which leaf nutrient status varies within and across a range of representative orchards and environments.

Task 1.1 Continue trials commenced in 2008, harvest will be conducted in 2010 and results used to determine if additional years are required.

Initiated August 2007: Complete November, 2010 for almond and in 2011 for pistachio

All trials were initiated in microsprinkler irrigated almond and pistachio orchards of good to excellent productivity. Almond trials were initiated in 8 or 9 year old commercial orchards and were planted to Non-Pareil (50%) on Nemaguard rootstock in soils representative of the region and a large percentage of Almond acreage. At experiment completion, trees have reached 14 years of their age (after 5 years) representing their most productive years. In addition, observational trials were established in 4 pistachio orchards located at Madera, Fresno, Kings and Kern County sites on 9-15 year old micro-sprinkler irrigated pistachio orchards of good to excellent productivity planted to Kerman (female cultivar) on pioneer gold rootstock in soils representative of the region and a large percentage of pistachio acreage. The results of Nonpareil are likely to be highly relevant to other almond cultivars.

Task 1.2 Initiate and conduct sample collection:

Initiate Jan, 2008: Complete November, 2010/11

In four, 8-9 year old mature Nonpareil (NP) orchards growing under excellent management conditions in four major growing regions, and four Pistachio orchards (9-15 year old) we established an extensive Grid-Sampling protocol using techniques developed for GIS (with Richard Plant, a leading agronomic statistician). At 54 grid points uniformly distributed across a 10 acre block of trees, May and July leaf nutrient status, light interception, trunk diameter and tree yield were determined in each Nonpareil tree. At 25 of these grid points, the nutrient status and yield of 2 neighboring trees were also collected as independent data points. Initially, non-fruiting spur leaves (and sub-terminal leaves in pistachio) in exposed positions were selected for these samples, however, depending on the early results of Task 2 below, sampling protocols were adjusted. In pistachio, starting from leaf expansion in May, leaf and fruit samples were collected at 114 sample locations in each orchard over a period of six months from May to October (2009). At 54 sample locations leaf and fruit samples were also collected during the growing seasons in 2010, 2011 and 2012. For nutrient analysis and biomass accumulation purposes fruit is comprised of (hull+shell+kernel) and includes the split/non-split and blank nuts. Two statistical techniques 'nugget sampling' and 'modified Mantel' statistics were used, this approach allows for partitioning of variance in nutrient status due to environment, due to genetic variability and 'random' variability and allows for determination of the interactions and dependencies between nutrition and yield and the nature of spatial variability within an orchard .

Task 1.3 Tissue analysis

Initiated March 2008, ongoing through 2011/12.

Tissue determination for the major elements (N, P, K, S, Ca, Mg, B, Zn, Fe, Mn, Cu) in all leaf samples were processed by the DANR analytical laboratory at UC Davis. The results of tissue analysis were interpreted with reference to individual tree yield and environmental variability. This approach is unique as previously researchers have not considered the strong interactions that occur between yield and leaf nutrient concentrations. Not only does enhanced nutrition potentially enhance yield (positive correlation), but high yields clearly decrease leaf nutrient status through competition (negative correlation). This iterative interaction has undoubtedly confused previous research in this area and was addressed here.

Task 1.4 Determine tree yield

Initiated August, 2008 Completed 2010/11

In all experiments described here, individual tree harvest was performed three days prior to commercial field harvest by selectively shaking individual experimental trees then raking and weighing by hand. To facilitate this we used multiple supervised teams of 3-4 laborers and UC personnel at each site. A total of eight orchards and in excess of 1000 trees were managed in this way. Pistachio fruits were harvested in September through

October and individual tree yields (>1000 trees) were recorded for all experimental trees over three years (2009-2011) at four locations.

Task 1.5 Statistical Analysis

Initiated July 2008, completed 2011/12.

In this experiment and in the second project submitted to this program (CDFA-FREP Brown et al: Development of a Nutrient Budget Approach To Fertilizer Management In Almond 10-0039-SA) we used 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.

Where spatial data was involved, data was geostatistically interpolated to develop maps of nutrient status for each element. These maps were used to estimate the distribution of nutrient concentration in the field. Based on these distributions and spatial relationships a sampling plan was developed that permits growers to determine with a high level of probability that an acceptable percentage of their trees meets or exceeds the UC CV. While this initial experiment involves complex statistics and extensive sampling the expectation is that this basic information will allow us to develop a practical grower-friendly protocol. Basically, once the mean and variance of nutrients in a typical almond orchard is known, then a single composite sample of adequate size can provide all required information to select a target mean leaf nutrient value.

Task 2/Objective 2: Determine the degree to which nutrient status varies within the canopy and within the year and develop tissue-sampling protocols that provide early season measures of nutrient status.

The current leaf sampling standard of collecting non-fruiting exposed spur leaves in the July was chosen because it was necessary to combat the extreme variability in nutrient status that exists spatially and temporally in trees (see Righetti et al. 1990). It was never rigorously verified that this was a highly reproducible, sensitive or effective approach, only that it limited variability. Indeed it is possible that the current sampling strategy is highly reproducible but also highly insensitive to nutrient status. Several researchers have observed that once an almond leaf exceeds 2.2% N that additional fertilizer has only a slight effect on leaf N concentration (Uriu, 1976; Meyer, 1996; and Weinbaum et al, 1980, 1990). Indeed, Weinbaum observed in several experiments that a doubling of fertilizer application from 250 to 500 lbs per tree had no significant effect on leaf N concentration (Weinbaum, 1990). This observation has generally been interpreted as evidence that little of this additional N was acquired by the tree. This assertion might be incorrect, however, and an alternative explanation is simply that non-fruiting, exposed spur leaves sampled in late July are a poor indicator of tree N status.

Observation tells us that spur leaves associated directly with fruit are the first to show deficiencies, and as such may be the most sensitive indicators of a whole tree nutrient

stress. Reidel et al, 2004; demonstrated that spur leaf nutrient status correlates with current yield and influences future yield. Hereema (2005), contrasted leaves collected from fruiting and non-fruiting spurs and demonstrated that fruiting greatly decreases leaf nitrogen status, but he did not conclude that there is clear benefit to using these leaves. Hereema (2005) did not however, examine leaves early in the season when growers would be interested in an early indicator.
Ultimately, our goal was to develop a method of sampling trees that best reflects the current nutrient status of the tree, predicts possible shortfall and guides in-season fertilizer practice. Attempts to use dormant tissue sampling as a measure of tree nutrient storage is not likely to be useful for high yielding Almond since total stored N appear to account for less than 10% of annual tree N demand. Overall, there has been inadequate rigorous research to determine if there is a meaningful or interpretable relationship between the various leaf types and either whole tree nutrient status or yield.

Twenty trees, on which yield was determined in the approach above, were selected at each site for multiple within-year and within-canopy tissue sampling (80 trees in 4 almond orchards and 80 trees in one Pistachio Orchard.). Yield was determined on all individual trees. Leaves were collected from central leaves on 1-3 year old well exposed spurs at 5 dates during the year from March till 1-month post harvest. Leaves from three spur types in almond were collected and analyzed separately. In Almond, non-fruiting spur leaves, and fruiting spur leaves from spurs with either 1 or 3 fruits will be sampled. The specific phenological stage of the tree at each sample date was determined by noting the stage of fruit development characteristics and days past full flowering. A total of 1500 (100 trees x 5 dates x 3 spur types) leaf samples were collected. Yield on each of these trees was determined in 1.4 above along with an analysis of local nutrient variability determined in 1.2 above. Leaves were analyzed for the full suite of important elements.

Task 3: Objective 3: Validate early season leaf analysis protocols and relationship with yield, validate current CV's and determine if nutrient ratio analysis provides useful information to optimize fertility management.

Task 3.1 Collect yield x leaf nutrient data for all essential elements and at multiple times through growing season. Relate to yield and nutrient ratios.

Initiate August 2010: Complete Dec, 2012
Validate at new field site with wider range of tissue N and K status (see Objective 4 below).
Initiated June 2010, complete Dec 2012

Results from year 1 and 2 data clearly suggested that early season leaf analysis is a strong predictor of both late season nutrient status and yield. Indeed the relationship between early season analysis and yield appears to be stronger than is evident from traditional sampling. Initial regression analyses suggests, however that prior year yield also interacts with this relationship in a complex fashion. Results obtained in objective 2 above were analyzed using a variety of statistical techniques with the goal of developing models that effectively predict July/August tissue values from March/April samples for almond and samples taken in May for pistachio.

In the combination of experiments described here, >500 individual trees were monitored for yield and nutrient status each year over a 4 year period at 8 sites. This represents by far the largest data base of yield x nutrition ever collected and was used to help redefine or validate existing Critical Values. 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 and pistachio. 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, Mitscherlic response fitting etc).

Results from the first three years of experimentation were analyzed and targeted re-sampling was conducted to validate models and refine the process.

Task 4: Objective 4: Test utility of use of fruiting spur leaf analysis as an indicator of tree nutrient status, monitor the relationship between spur nutrient status and spur survival in Almond.

Data from this experiment in 2008 and 2009 suggest that fruiting spurs are more sensitive indicators of nutrient status than non-fruiting spur leaves. Further, 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. In shaded canopy positions, leaf abscission rates on single-fruited spurs from May 31 to Sept. 28 were much lower on ‘high N’ (57%) than ‘low N’ (75%) trees.

Like N, potassium nutrition has been suggested as a critical factor for spur viability (Basile et al., 2003). Basile et al., (2003) observed that K deficiency resulted in premature leaf senescence and abscission. Potassium deficiency negatively affected the yield of almond trees by increasing the mortality of fruit-bearing spurs and reducing flowering of K-deficient spurs. Late in the season, tree light interception declined in non-fertilized trees compares with the high K trees. This effect could clearly be a consequence of premature leaf abscission, which was observed on fruiting spurs as the season progressed, and was exacerbated by the harvest process. Almond leaves located close to developing fruits had lower K concentration than leaves located on vegetative spurs suggesting that fruits draw K nutrition from nearby leaves.

In almond trees, spurs behave as semi-autonomous units (behaving independently of each other and the tree as a whole) with the autonomy of the spur unit increasing as yield increases. Survival of the individual spur is largely dependent upon local exposure, age of the spur and local fruit load. The semi-autonomous nature of individual spurs on a tree offers an opportunity for within-tree replication thereby reducing experimental error and tree-tree variability. To adequately conduct research in this system, however, it is essential that very careful attention be paid to the selection and replication of the experimental unit (spurs) on the tree.

To further validate our observation that spur nutrient status reflects tree nutrient stress and predicts future yield we utilized the N rate trial experiment underway at Belridge under the direction of Dr Brown (CDFA project 10-0039-SA). In this trial a large number of trees with clearly divergent N and K status have been established.

One hundred forty-four commercial almond trees variety “Nonpareil” exhibiting significant differences in yield and tree nitrogen status as a consequence of differential rates of nitrogen fertilization for three prior years (140, 224, 392 kg/ha) were selected (48 trees per nitrogen rate). Yield and leaf N analysis suggest that these fertilizer rates provided deficient, just adequate and excessive N supply respectively. In each tree, eleven spurs per category (non-fruiting spurs (F0); spurs with one fruit (F1); spurs with two fruit (F2)) were carefully chosen for uniform light exposure at the east most outer side of the canopy and tracked for one complete season (2011-2012). In pistachio, to assess the variation in leaf nutrient status, leaf samples were also collected from different positions within a single-tree canopy as well as from the fruiting and non-fruiting branches. In this study, three canopy heights were used to assess the effect of position within a canopy on the leaf nutrient concentrations. Rachises were also collected over the season in 2010. In all cases, each leaf sample was comprised of 10 fully expanded mature leaves collected from exposed branches from around the tree canopy and each leaf sample was analyzed separately.
Yield data were collected on all trees at harvest (September-October).

Task 5. Develop fertilizer response curves and nutrient use efficiency to relate nutrient demand and fertilizer source with fertilizer rate.

Initiate January 2009, final harvest and sampling Sept 2012.
Analysis complete Dec 2012

The current use of leaf sampling to manage N applications does not provide any specific information on the right rate and time of the fertilizer applications. As a result, over-fertilization is currently the only tool growers have to ensure optimal field productivity, which is neither efficient nor environmentally sustainable. To complement the leaf tissue analysis and provide guidance for fertilization, we have developed and validated yield and phenology based seasonal nutrient removal curves that quantify the time course of nutrient uptake and total plant demand across different environmental conditions for major nutrients-including nitrogen (N), phosphorus (P) and potassium (K).

Knowledge of seasonal patterns of N, P and K uptake in mature pistachio tree is an important component of fertilizer management and can be used to increase nutrient use efficiency by synchronizing fertilizer applications with the periods of high uptake capacity.

The current report describes this work in pistachio while a partner report (10-0039-39) has developed rate driven nutrient budget curves for major nutrients in almonds. This parallel work on nutrient budget models in almond is an integral part of the present leaf sampling project and complements the improved sampling protocols developed under this project.

Task 5.1 Sample Collection (Pistachio)

Leaf and fruit samples were collected at 114 sample locations in each orchard over a period of six months from May to October (2009). At 54 sample locations leaf and fruit samples were also collected during the growing seasons in 2010, 2011 and 2012. The intensity of this sampling was reduced to three months over the season in 2012 and samples were collected in May, July and at harvest. Every fruit sample was comprised of 25 fruits collected from exposed branches from around the tree canopy and a total of approximately 4000 fruit samples were collected by the end of the experiment. Finally, the data on nutrient content of fruits and their biomass at each sample date stage was related to final tree yield and nut weight to develop a curve of seasonal nutrient and biomass accumulation.

Task 5.2 Nutrient Use Efficiency

To calculate N fertilizer demand (pistachio) 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 effective monitoring (optimized sampling), and applying the right rate of N (yield based) at the right time (according to uptake curves) in the right place (the active root zone) while avoiding the movement of N below the root zone.

Task 6. Develop new sampling and interpretation approaches that provide growers with a rational, and timely sampling protocol to optimize yield and return. Develop and extend an integrated nutrient BMP for Almond.

Initiate Jan 2012: Complete Dec, 2012

Ultimately, our specific goal in this current project is to provide growers with information needed to determine what their target mean nutrient concentration should be to guarantee that 90%, 95% or 99% of their orchard is above a prescribed value. We have also developed the means to sample leaves early in the season to allow for more effective in-season nutrient management. We have also provided critical information on the role of fruiting spur leaf nutrition on spur survival and yield sustainability. We have utilized this information to develop more rigorous critical values and if indicated develop approaches to use of nutrient ratios and site specific critical values. Collaboratively, a new nutrient BMP has been developed from an integration of this project and the parallel project (see 10-0039-SA Brown et al: Development of a Nutrient Budget Approach To Fertilizer Management In Almond). The combination of nutrient budget determination, nutrient response information, improved sampling and monitoring strategies and yield determination 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 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. In the coming year in collaboration with the not yet completed partner grant 10-0039-SA, we expect to also refine current leaf CV's, investigate the utility of nutrient ratios and define the optimal rate of N application and effect of nutrient source. To date research has emphasized N and K but will include an analysis of all essential elements commonly applied in California.

Given the very large amount of data to be collected in this project a substantial amount of time will be devoted to a well-integrated and highly accessible summary of activities and recommendations. Data and presentations will be posted to a website and an easy to use interactive decisions support system will be developed. A number of industry and science focused publications have been produced and more are expected.

F:Data/Results

Task Objective 1.1 to 1.5

In these well managed and visually uniform orchards there is substantial variability in nutrient concentration between orchards (Fig. 1a and 1b) and within orchards (Fig. 2b) that needs to be captured to correctly obtain the true mean of the nutrient being sampled and allow correct interpretation of them. This detailed analysis of data from eight well-managed and visibly uniform sites over four years has allowed us to estimate 'typical' field variability in Californian orchards of this type and to use that data to determine best sampling strategies. Thus, data from these field sites has been used to calculate the number of pooled leaf samples that is required to accurately determine the true field nutrient mean. Table 1a for the case of Almonds and Table 1b for the case of Pistachio represent the result of this analysis, accepting that growers usually collect one pooled sampled per orchard.

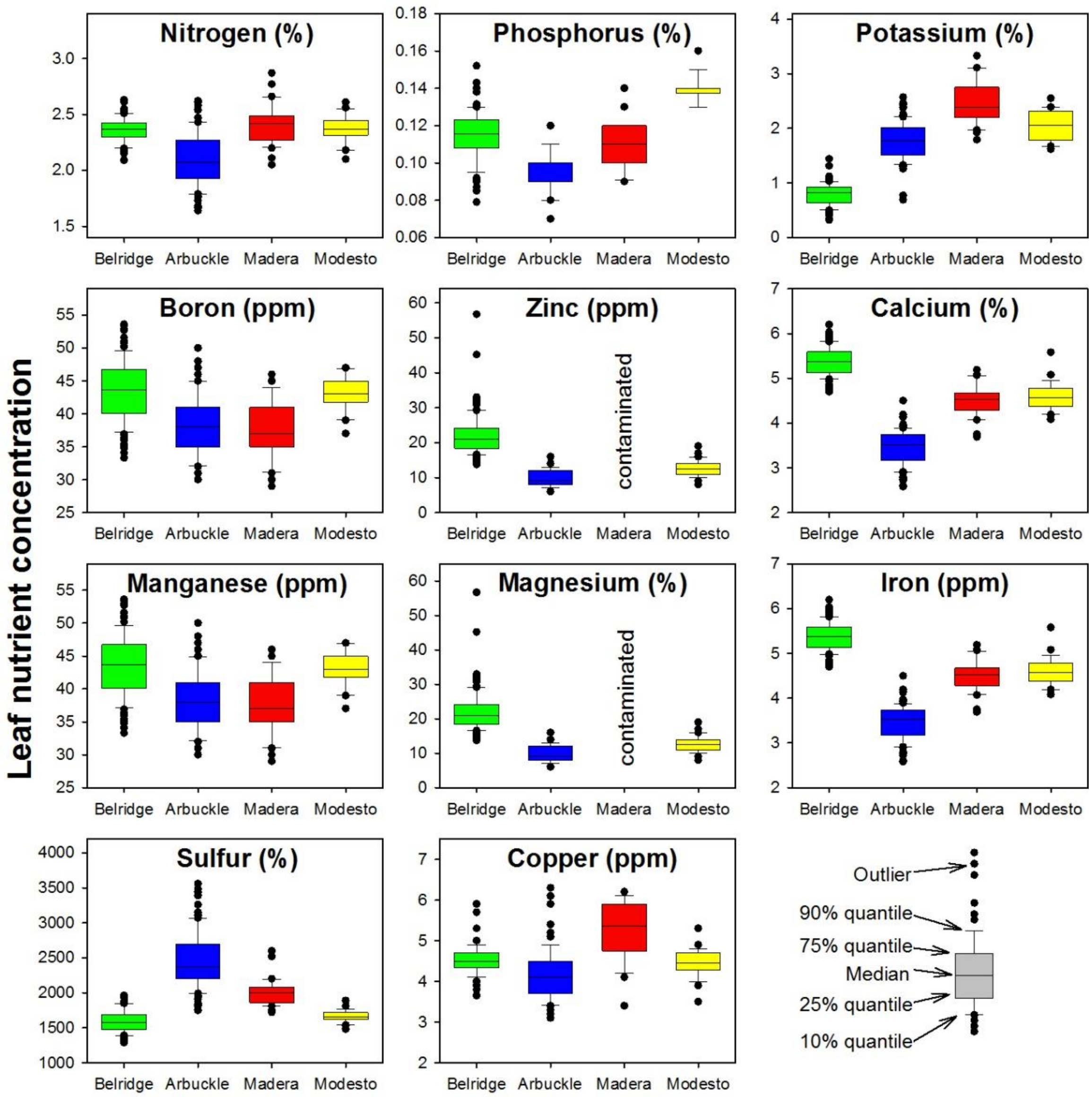

Figure: 1a. Variability in leaf nutrient concentrations within and among almond orchards sampled in July. Non-fruiting spur leaf samples collected from 114 individually sampled trees at 4 sites.

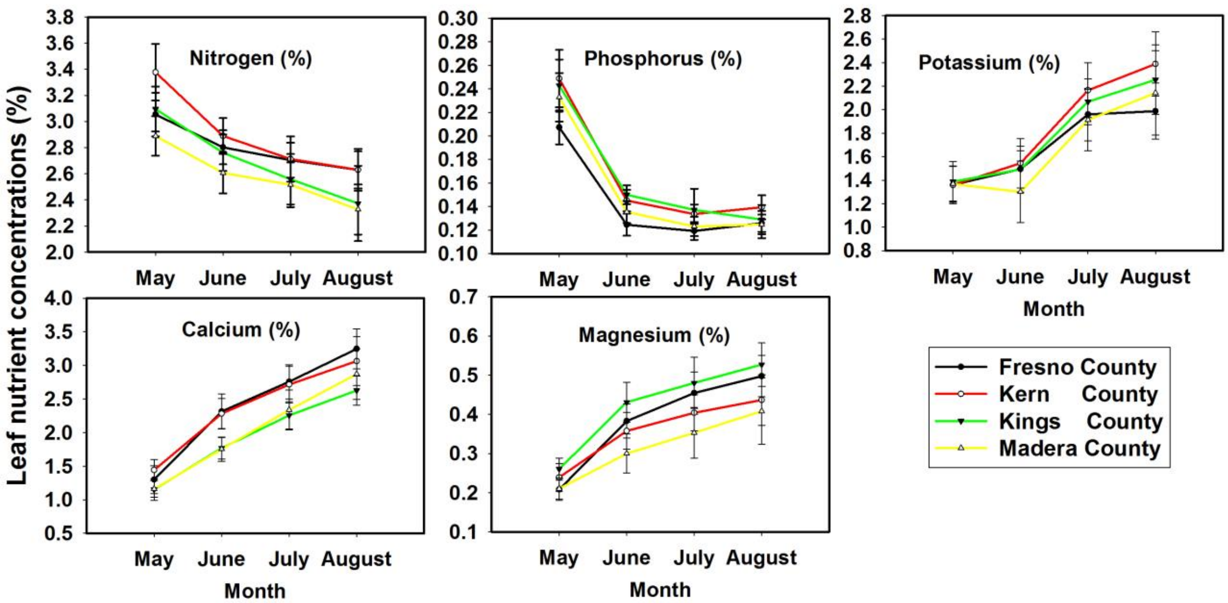

Figure: 1b. Changes in leaf (non-fruiting branches) nutrients over the season. Data represents values from 54 individual trees at each site and year and is the average nutrient concentration of each tree over two seasons.

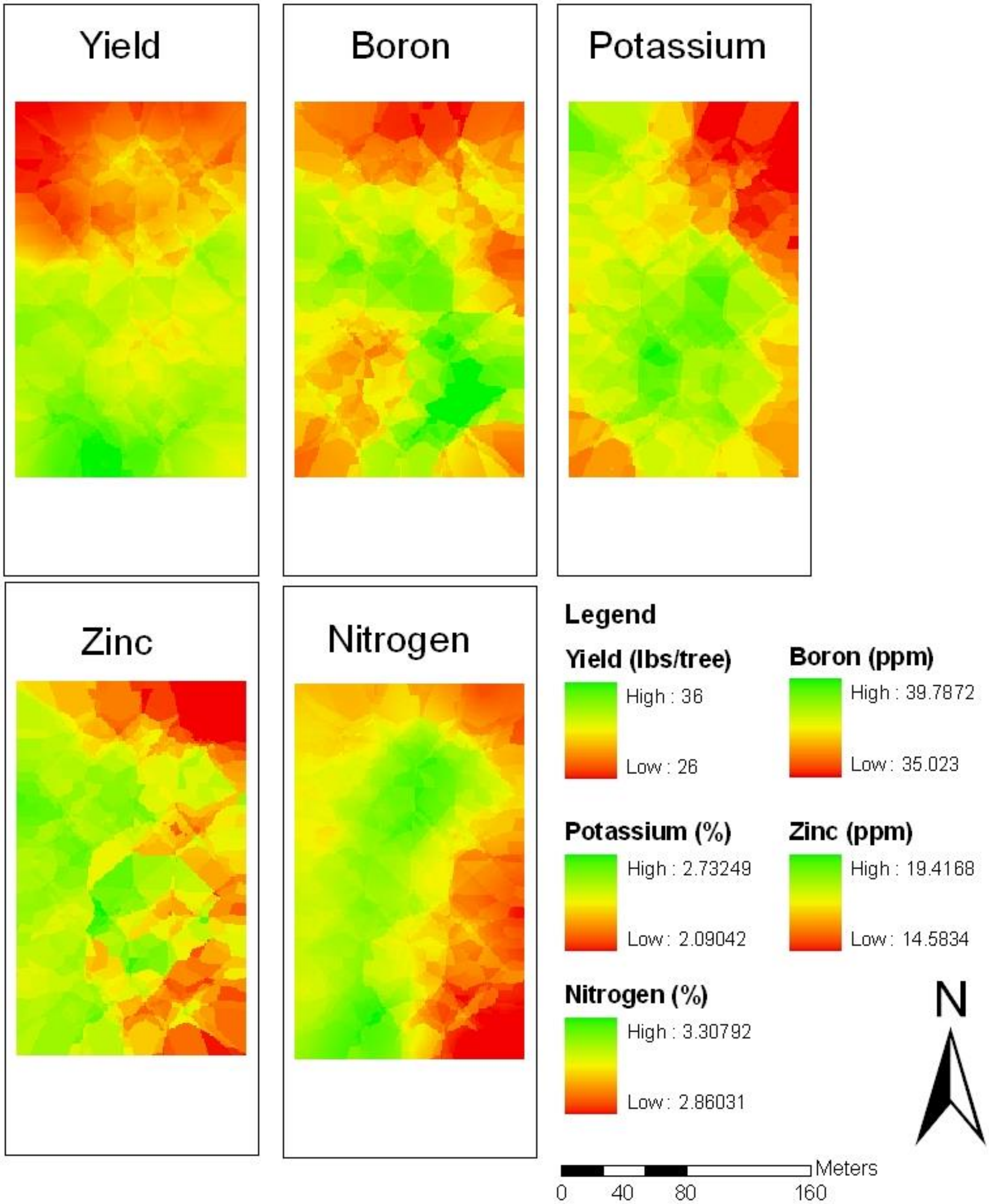

Figure: 2. spatial leaf nutrient content recorded in May and the current season yield in a representative California Almond Orchard.

Table: 1a. Number of trees that should be sampled and pooled to effectively estimate the true nitrogen mean in almond orchards. One acre is assumed to be 100 trees. Details on specific sampling strategy are provided below.

Number of Acres	Trees needed at 95% Confidence	Trees needed at 90% Confidence
2	25	18
5	27	19
10	28	19
50	28	20
100	28	20

In pistachio we have determined the number of trees needed to be sampled to estimate the true mean of nutrients to within 5% of the overall mean with 90% confidence as shown in table 1b. This was performed for a suite of nutrients across four locations for the month of July (2009- 2011). The variability in nutrients from tree to tree differs with N typically being the least variable and Mg the most variable. This is directly proportional to the increase in the coefficient of variation for magnesium. Three orchards utilized here were deemed representative and generally uniform, the 4th orchard located at Madera County site was less uniform and suffered from Mg deficiency and K imbalance.

Table: 1b. Number of trees needed to be sampled to effectively estimate the overall mean of nutrients to within 5% of the true mean with 90% confidence level for July leaf samples at four research sites. The calculation is based on observations from 54 individual trees at each site and year.

Paramount (Kings County)				
Year	N	P	K	Mg
2009	8	9	11	13
2010	5	6	11	15
2011	6	10	13	14
Buttonwillow (Kern County)				
Year	N	P	K	Mg
2009	9	8	15	21
2010	3	5	13	15
2011	7	5	12	19
KammAvenue (Fresno County)				
Year	N	P	K	Mg
2009	5	5	15	15
2010	3	3	18	21
2011	5	2	11	17
Madera (Madera County)				
Year	N	P	K	Mg
2009	8	6	21	40
2010	8	8	23	37
2011	7	8	38	40

In addition to determining optimum field sampling strategies, the detailed analysis of data from eight well-managed and visibly uniform sites over four years also allows us to extrapolate from a well collected leaf sample to estimate the percentage of the field that will be above a particular established critical value. For example the established critical value is 2.2% N in July for almonds (Table 2a), using this knowledge and the sampling strategies we have established, it is possible to better understand the distribution of tree nutrient status in the orchard.

Table: 2a. Relationship between July leaf tissue N concentrations in almond samples collected according to previously described sampling methods (this report) and percentage of trees in the orchard that will exceed the specified critical value of 2.2%.

Relationship between July leaf tissue N concentration and percentage of the trees exceeding the critical value of 2.2%										
July N (%)	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
% of Trees Above 2.2%	6.6	22.6	50.0	77.4	93.4	98.8	99.9	100.0	100.0	100.0

Task 2

In almond analysis of nutrient dynamics in the three different leaf types sampled (non-fruiting, single fruited and double fruited) collected over the full season suggests that leaves on fruiting spurs may exhibit nutrient deficiencies even when non-fruiting leaves on the same tree may have “adequate” leaf concentrations in excess of existing critical values (results presented in task 4). Using the data collected in the almond experiment we developed five unique statistical models that allow for the prediction of July leaf N values from April sample collection dates. One of these models used leaves from fruiting spurs with the premise that it could be a more sensitive indicator of tree nutrient status. However, the results showed that the most sensitive model consisted in a model fitted with non-fruiting leaves (results presented in Task 3).

For the case of pistachio three years of sampling data was used to develop an approach to use May (spring-early season) collected samples to predict July (late summer) leaf nutrient (N/K) status using stepwise multiple linear regression models (results presented in Task 3). This was performed for all sites and for three seasons (2009, 2010 and 2011). The goal was to produce a model that works reasonably well for all sites and years, rather than one that needs to be calibrated to the characteristic of a particular site and year. Prediction results suggest that these models can be used as components in decision support system to guide crop management, such as for nitrogen fertilizer management.

To test whether the leaves from the fruiting or non-fruiting branches in pistachio have a better relationship with yield, we regressed yield on the difference between the fruiting and non-fruiting leaf nitrogen values (since they were observed on the same trees). The difference was not statistically significant with the sample size we used (15) ($p = .14$). Overall, no particular leaf type or tree position provided greater information than any other. It is recommended, therefore, that the existing sampling strategy of collecting leaf samples from non-fruiting branches be maintained.

Task 3

Almond models received two types of validation. The first validation consisted in creating the model while holding out one site/year information and then compare the predicted outputs on that site*year combination (process known as cross validation). The second validation consisted in sampling a new set of Californian orchards in 2012 and applies the models previously developed. Six CA almond orchards were sampled and the results of this second validation are presented on Figure 3. Overall, there was a good fit between predicted and observed and the best model was submitted to the fruit and nut website for its general use.

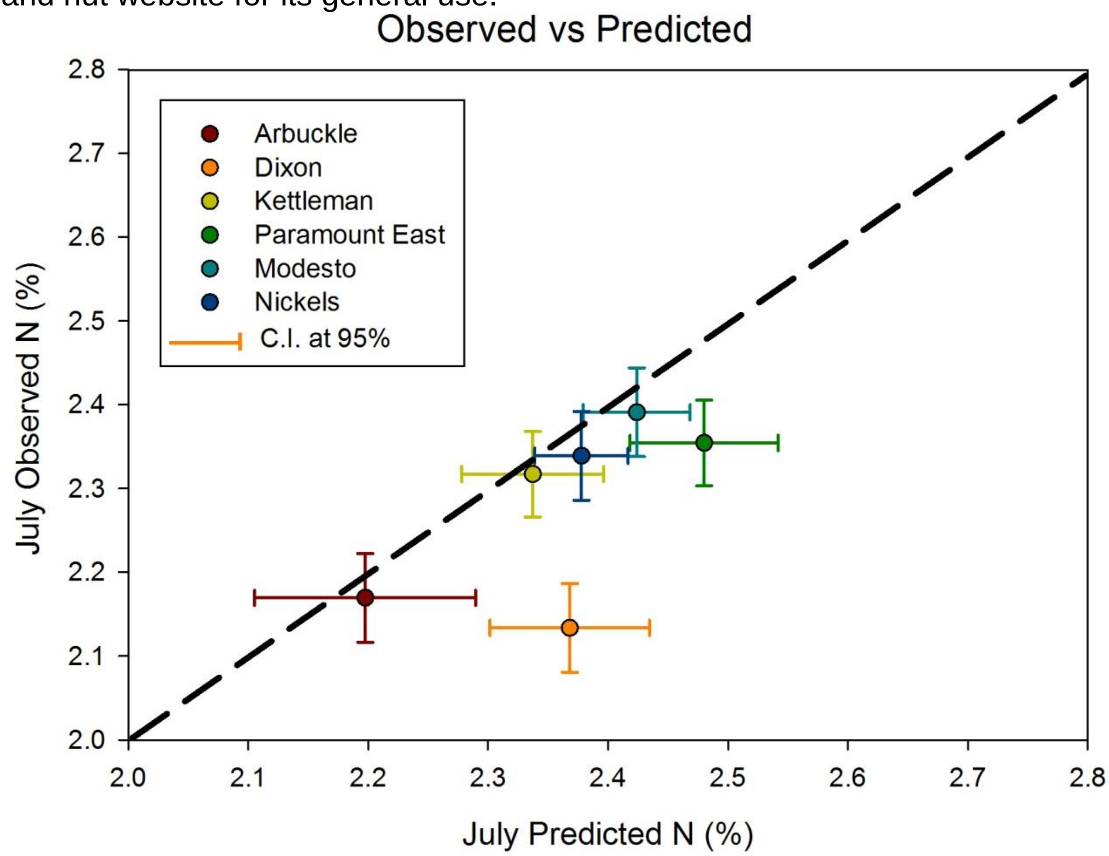

Figure: 3. Model Validation outcomes. Dash line represent perfect fit between observed and predicted.

The pistachio prediction model (PPM) which predicts late summer nutrient values was validated extensively with data from several well managed commercial pistachio orchards located in different geographical locations (broader spatial scale) in California (USA). In addition to validations conducted for orchard sites in California (Table 3a and

4a) we have applied the pistachio prediction model to the data that had been collected from various pistachio orchards located in Australia (Table 3b). The data used for the validation of the models were completely independent of model development and a wide range of conditions and seasons were tested. The validation outcomes support the apparent validity and reproducibility of our regression models. The web-based model is available for general us at UCDAVIS website.

Table: 3a. Observed Leaf N (%) in summer (July) contrasted with summer predicted values derived from May samples. Leaf samples represent values from orchards located in California. B1-B3 represents composite leaf samples from 18 individual trees from existing sites. NO1 and NO2 represent composite leaf samples from18 individual trees from the new orchards.

N_7: (b_0 + b_1DAFB_5+b_2N_5+b_3Ca:Mg_5+b_4P_5+b_5Cu_5+b_6Ca_5).

Site	County	Year	Summer Observed leaf N	Summer predicted leaf N (from spring samples)
Buttonwillow (B1)	Kern	2012	2.9	2.8
Buttonwillow (B2)	Kern	2012	3.0	2.8
Buttonwillow (B3)	Kern	2012	2.9	2.8
Buttonwillow (NO1)	Kern	2012	2.8	2.8
Buttonwillow (NO2)	Kern	2012	3.0	2.8
KammAvenue (B1)	Fresno	2012	2.7	2.6
KammAvenue (B2)	Fresno	2012	2.7	2.6
KammAvenue (B3)	Fresno	2012	2.6	2.6
KammAvenue(NO1)	Fresno	2012	2.7	2.5
KammAvenue (NO2)	Fresno	2012	3.0	2.6
Madera (B1)	Madera	2012	2.5	2.6
Madera (B2)	Madera	2012	2.5	2.6
Madera (NO1)	Madera	2012	2.6	2.5
Madera (NO2)	Madera	2012	2.7	2.6
Paramount (B1)	Kings	2012	2.6	2.6
Paramount (B2)	Kings	2012	2.7	2.7
Paramount (B3)	Kings	2012	2.5	2.7
Paramount (NO1)	Kings	2012	2.9	2.7
Paramount (NO2)	Kings	2012	2.7	2.7

Table: 3b. Observed Leaf N (%) in summer (July) contrasted with summer predicted values derived from May samples. Leaf samples represent values from orchards located in Australia. The table also shows the confidence intervals for the mean nitrogen values for the late summer nitrogen values.

N_7: (b_0 + b_1DAFB_5+b_2N_5+b_3Ca:Mg_5+b_4P_5+b_5Cu_5+b_6Ca_5).

Site	Year	Rootstock	Summer Observed leaf N	Summer predicted leaf N (from spring samples)	Lower N (Mean, 95%)	Upper N (Mean, 95%)
1	2001	Pioneer Gold	2.6	2.8	2.7	3.0
2	2001	Terebinthus	2.9	2.7	2.5	2.8
3	2002	Terebinthus	2.9	2.5	2.4	2.5
4	2002	Terebinthus	2.4	2.5	2.4	2.6
5	2003	Pioneer Gold	2.8	2.6	2.5	2.7
6	2003	Terebinthus	2.9	2.7	2.6	2.8
7	2004	Pioneer Gold	2.7	2.6	2.6	2.7
8	2005	Pioneer Gold	2.6	2.6	2.5	2.7
9	2005	Terebinthus	2.8	2.5	2.4	2.5
10	2005	Terebinthus	2.7	2.6	2.4	2.7

Table: 4a. Observed Leaf K% in summer (July) contrasted with summer predicted values derived from May samples. Leaf samples represent values from orchards located in California. B1-B3 represents composite leaf samples from 18 individual trees from existing sites. NO1 and NO2 represent composite leaf samples from18 individual trees from the new orchards.

K_7: ($b_0 + b_1DAFB_5+b_2N_5+b_3P_5+b_4K_5+b_5Ca+b_6Mg_5+b_7Cu_5+b_8Ca{:}Mg_5$).

Site	County	Year	Summer Observed leaf K	Summer predicted leaf K (from spring samples)
Buttonwillow (B1)	Kern	2012	2.3	2.3
Buttonwillow (B2)	Kern	2012	2.2	2.3
Buttonwillow (B3)	Kern	2012	2.2	2.2
Buttonwillow (NO1)	Kern	2012	2.1	2.3
Buttonwillow (NO2)	Kern	2012	2.4	2.4
KammAvenue (B1)	Fresno	2012	2.0	2.1
KammAvenue (B2)	Fresno	2012	2.1	2.2
KammAvenue (B3)	Fresno	2012	2.2	2.2
KammAvenue(NO1)	Fresno	2012	2.1	2.0
KammAvenue (NO2)	Fresno	2012	2.2	2.1
Madera (B1)	Madera	2012	2.1	2.1
Madera (B2)	Madera	2012	2.1	2.1
Madera (NO1)	Madera	2012	1.9	1.9
Madera (NO2)	Madera	2012	2.1	2.1
Paramount (B1)	Kings	2012	2.4	2.4
Paramount (B2)	Kings	2012	2.6	2.5
Paramount (B3)	Kings	2012	2.4	2.4
Paramount (NO1)	Kings	2012	2.5	2.7
Paramount (NO2)	Kings	2012	2.4	2.4

In Pistachio, extensive correlation and regression analysis between yield and tissue nutrient concentrations were performed on all data sets to determine critical values and determine if nutrient ratio analysis was a viable alternative to traditional critical value analysis. Because all orchards were well managed we found no evidence of nutrient deficiencies for any element except Mg at one site. Nutrient ratio analysis showed significant relationships at only one site (Madera).

Over the course of four year at four sites we have monitored the relationship between leaf nutrient levels in July with the pistachio yield in a total of 1100 trees. The individual orchards in this trial were selected for their yield and excellent management and as a consequence very few deficient trees were observed. While the absence of deficient trees prevents the determination of the exact critical value, data from all trees in each year can be used to determine the nutrient concentration above which yield is optimized. This approach may therefore overestimate the CV but will not underestimate it. Here we take the approach that the lack of a yield response across a range of sites and years is an indication that the CV is at least lower than the lowest recorded values. With the exception of Mg, we find no evidence that CV's for nutrients in pistachio need to be adjusted.

Data on the establishment of critical values and nutrient ratios in Almond has illustrated the great complexity in this type of statistical process. Full analysis is still underway utilizing additional data sets from the ongoing FREP project 10-0039SA. As an example leaf tissue values and yield relationships are provided in Fig. 4 below for Ca in non-fruiting July leaves over 4 sites and 3 years. It can be seen in this data set that clear statistically significant relationships between Ca and yield were seen in Belridge 2009, Modesto 2010 but no significant relationships were observed in any other site/year. On the basis of this data alone one would conclude that 5.5% leaf Ca was inadequate to obtain optimal yield in Belridge 2009, Modesto 2010. In contrast, the lack of response at all other site years would suggest that 3.5% Ca is adequate for full productivity.The implication from this analysis is that site/year/nutrients/yield are all interacting to determine plant response to Ca. This represents a very substantial statistical challenge that we are still grappling with.

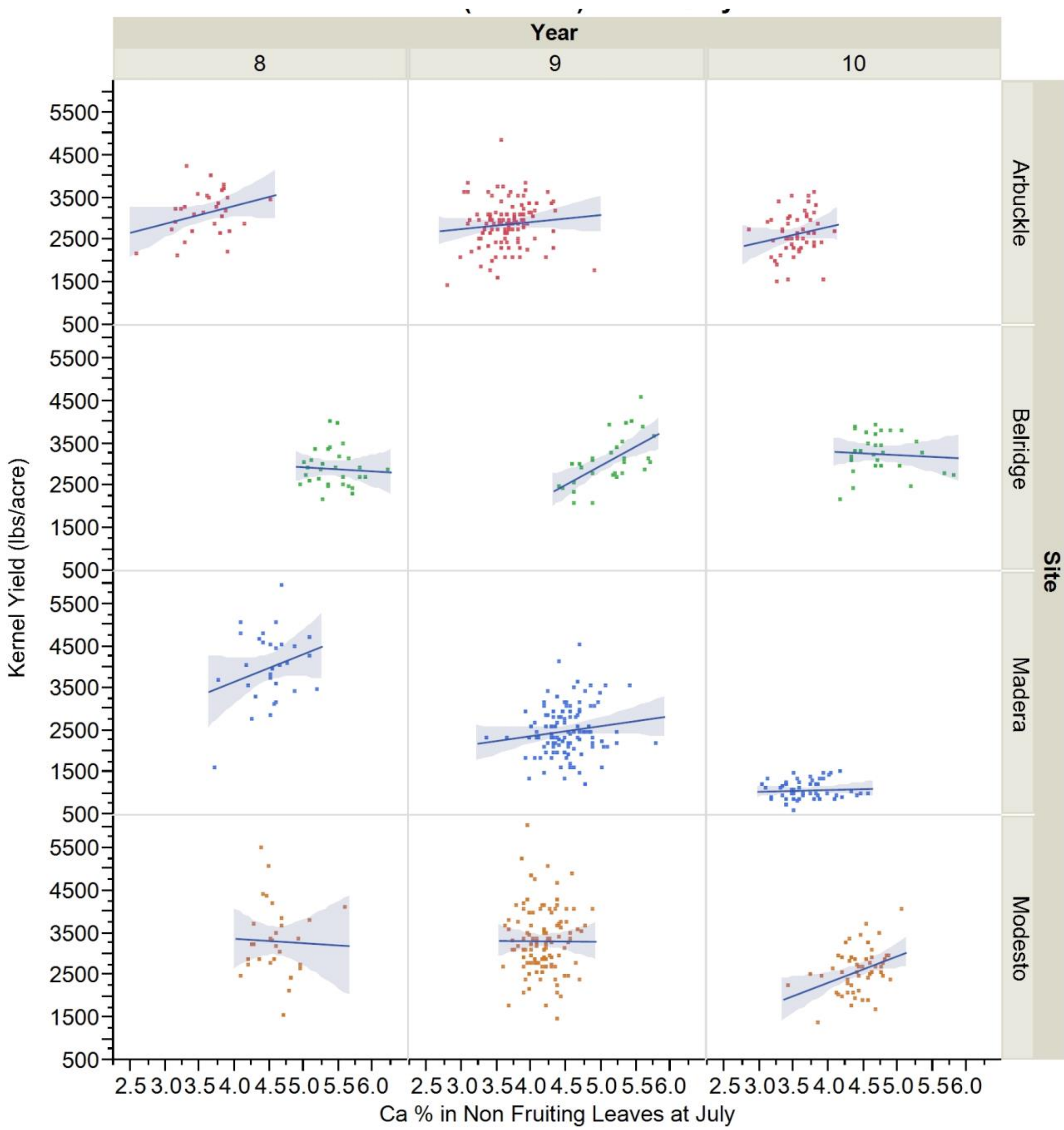

Figure: 4. Relationship between leaf Ca (%) and yield at four locations over three years. Best fit linear relationship with 90% error bars is shown.

Nutrient ratio analysis

In Pistachio, analysis of nutrient ratios and their relationship with yield have been conducted. Though all of the many hundreds of possible ratios and relationships with yield have not yet been analyzed, it is clear that K and Mg interacts strongly at least in one site (Madera) and has a profound influence on crop yield (Fig. 5).

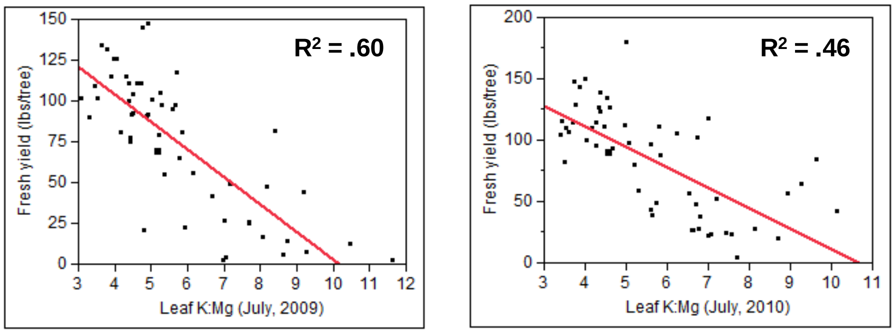

Figure: 5. Relationship of K: Mg ratio with the pistachio yield in July, 2009 and 2010 (Madera County). Values represent data from 54 individual trees.

Interestingly the negative correlation between K: Mg ratio and yield is only observed when tissue Mg values are below 0.4% which occurred only at the Madera site and in one year at the Kern county site (Fig. 6). These results potentially suggest that low Mg levels in leaf are compromising yield and that high tissue K levels can exacerbate this deficiency.

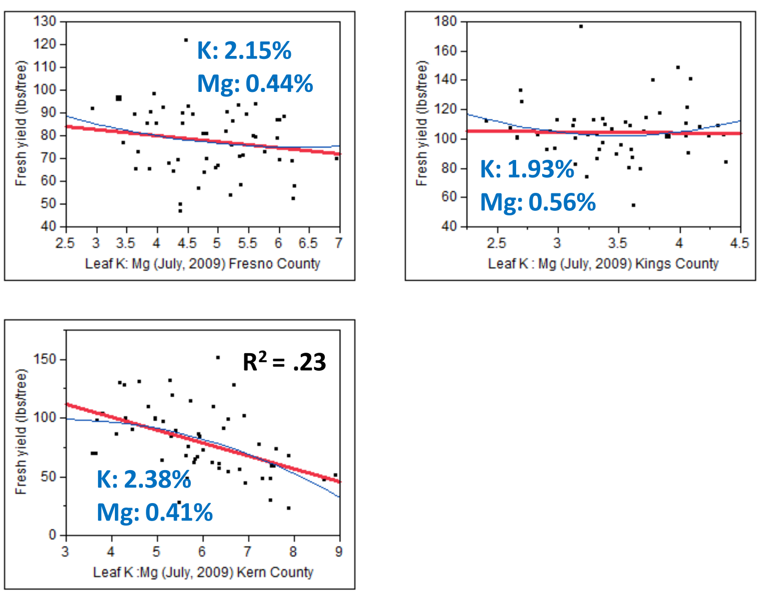

Figure: 6. Relationship between leaf potassium to magnesium ratio and fresh yield across three locations in California, July, 2009. Data represent 54 individual trees and the analysis was done using linear (red lines) and quadratic (blue lines). R^2 values on the graphs are for the linear models.

Task 4 Test utility of use of fruiting spur leaf analysis as an indicator of tree nutrient status, monitor the relationship between spur nutrient status and spur survival in Almond.

Leaf N concentrations recorded at 91 days after full bloom (DAFB) in almond from non-fruiting spurs on trees receiving low soil N applications (140 kg N) averaged 2.37% N while fruiting spurs averaged 2.05 % N. For trees receiving high soil nitrogen application rates (392 kg N), non-fruiting spurs averaged 2.95% N while fruiting spurs averaged 2.67 % N (Fig. 7). Higher soil N applications significantly increased leaf nitrogen concentration in all spur categories and fruiting spurs had significantly lower nitrogen concentrations than non-fruiting spurs (though this difference tended to be less under the high nitrogen rate treatment). Fruiting spurs had significantly lower survival rates than non-fruiting spurs. F2 spurs had survival rates that averaged 15 % while F1 spurs and F0 spurs had survival rates of 38 and 62%, respectively, across all treatments. The survival rates of all spurs were significantly decreased under the high nitrogen application rates when compared to medium and low soil N rates with overall survival values of 33% under high N and 42% under low N.

In pistachio, results indicate that leaf nitrogen concentration was highest in the upper canopy branches of the trees and that nitrogen and potassium distribution between the leaves of a single tree canopy is not uniform (Fig. 8). To test whether the leaves from the fruiting or non-fruiting branches have a better relationship with yield, we regressed yield on the difference between the fruiting and non-fruiting leaf nitrogen values (since they were observed on the same trees). The difference was not statistically significant with the sample size we used (15) ($p = .14$). Overall, no particular leaf type or tree position provided greater information than any other. It is recommended, therefore, that the existing sampling strategy of collecting leaf samples from non-fruiting branches be maintained.

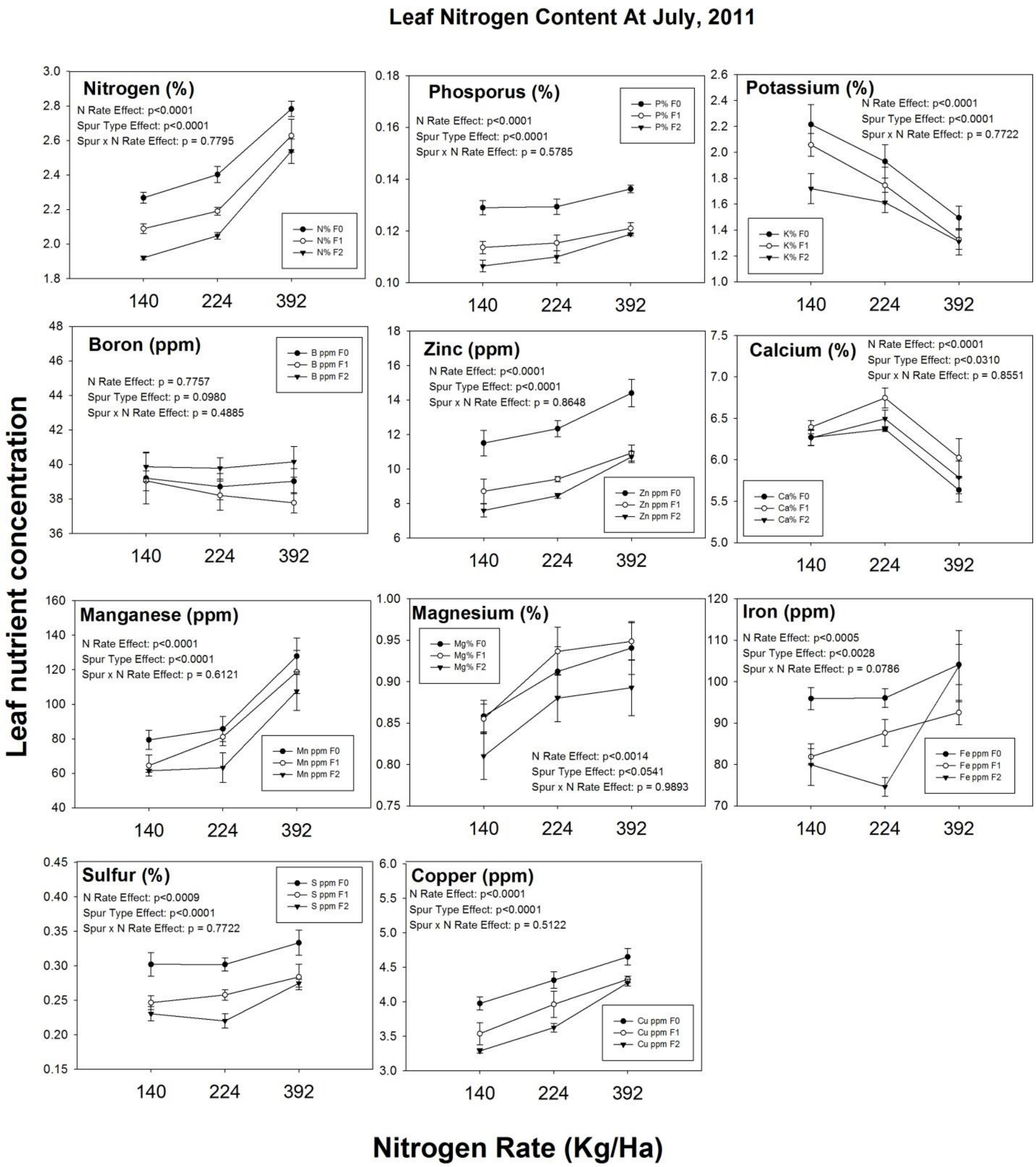

Figure: 7. Nutrient concentration of leaves collected from spurs without fruit (F0), one fruit (F1), and two fruit (F2) under three different nitrogen rates.

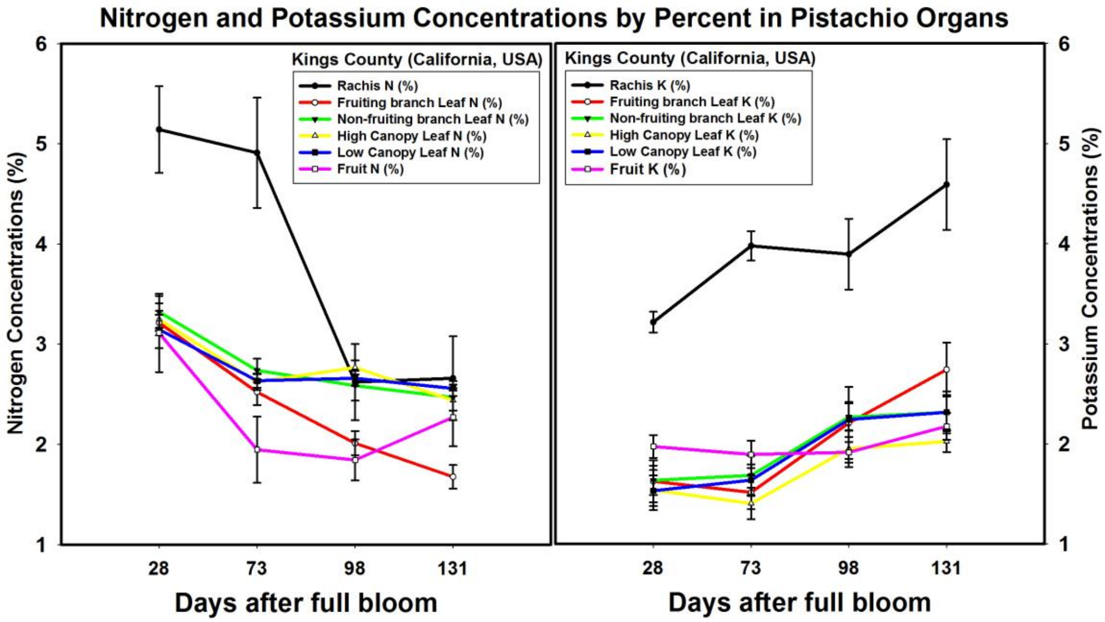

Figure: 8. Nitrogen and potassium variation within the tree canopy (Kings County). Lower canopy leaf samples were collected at about 4-5 feet height and leaves from higher canopy was collected at about 8-9 feet height from the ground. Leaves from non-fruiting branches and fruiting branches and fruit samples were collected from around the tree canopy at about 6-7 feet height from the ground. Data represents values for the leaf samples and rachis from 5 individual trees whereas data for fruit collection represents 54 individual trees (2010).

Task 5

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. To determine the average nutrient removal per 1000 lb of dry CPC yield, we have analyzed data on NPK removal from three seasons and across four locations. On average pistachio will remove 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. 9 and Table 4b). The pattern of yield accumulation in fruit over the year was determined by sequential fruit sampling and analysis (Fig. 9).

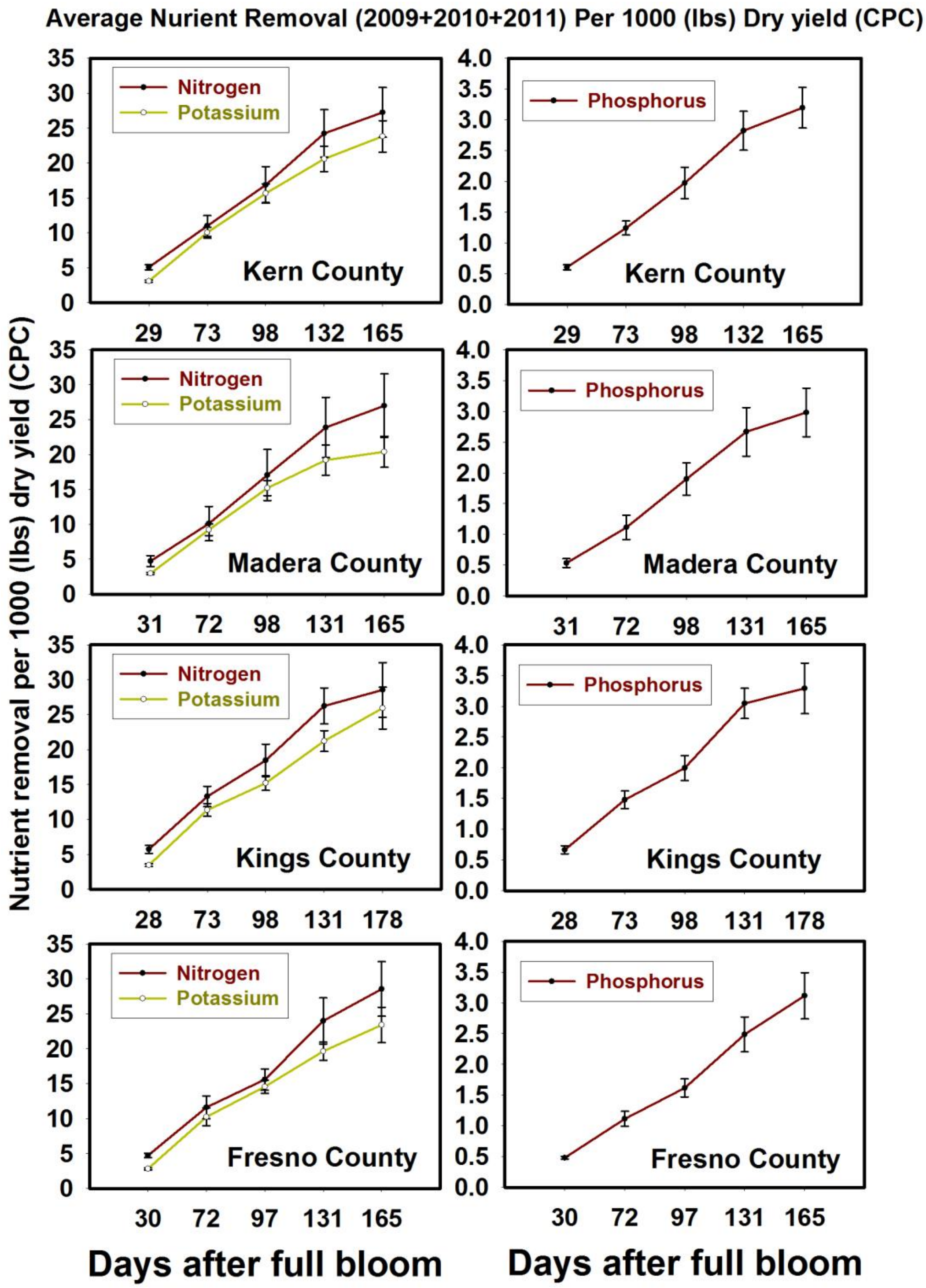

Figure: 9 . Average nutrient removals per 1000 (lbs) dry yield (CPC) at Kern, Kings and Fresno County sites over the years (2009+2010+2011). The data from Madera County site represents average of two years (2009+2010).

Table: 4b. Nitrogen and potassium removal in pistachio fruit, over a range of pistachio yield (CPC).

Dry Yield CPC (lbs)	Nitrogen removed (lbs)	Potassium removed (lbs)
1000	28	24
2000	56	48
3000	84	72
4000	112	96
5000	140	120
6000	168	144
7000	196	168
8000	224	192

N use efficiency (% measured as N removed/N supplied x 100) is illustrated in figure 10. 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 (Rosecrance et al., 1998). 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. 10). 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. Also, evidence from our research on the fertilizer N economy analysis suggests a potential savings of approximately US$ 40,000 per 1000 acres.

A critical finding from this data is the huge impact on overall efficiency that occurs in years of poor yield in which standard fertilization strategies are used. In this instance efficiencies of N use of >43% was observed in 2011. In the accompanying project description (10-0039-SA) low yields in 2012 in Almond resulted in NUE of less than 20%, while these same trees exhibited >85% NUE in the previous high cropping year. Matching applications with current yield is the single most important management tool growers have to reduce excessive N applications.

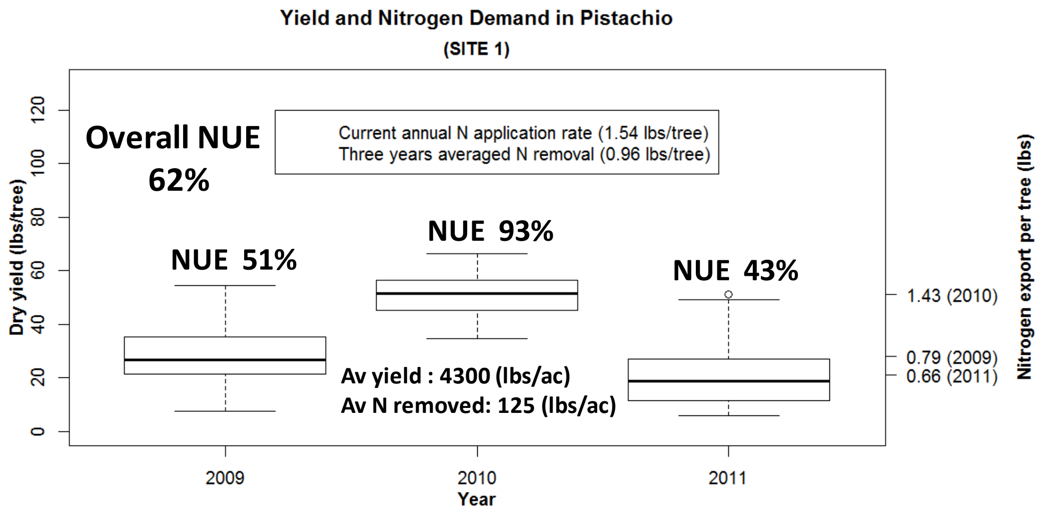

Figure: 10. Pistachio yield and nitrogen demand for the on plus off year trees at one of the experimental sites in California. Yield was measured in every individual tree over the three-year period. Box and whisker plots show median (25th and 75th percentiles) of yield in each year. The axis on the right 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.

Task 6

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

Almond 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.

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

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

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

Summary:

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

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

This information can then be integrated with expected yield to determine annual N application. A spreadsheet utilized as a tool for these calculations can be downloaded at http://ucanr.edu/sites/scri/Crop_Nutrient_Status_and_Demand__Patrick_Brown/ (at upper right, labeled “N prediction Model for Almond”). Growers are encouraged to test these new methods and contrast results with existing practices. Your feedback will help refine the methodology for all growers.

Integrated Guidelines for Tissue Sampling, N Budget Determination and Nitrogen Fertilization Scheduling:
The recommended approach to N fertilization scheduling consists of the following six steps, which have been incorporated into the worksheet noted above. These steps should be repeated for each orchard block.

1) Conduct a 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 (March – April).

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

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

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

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

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

Pistachio Protocol:

- To effectively obtain the average nutrient concentration (N, P and K) of a single production area or orchard growers must collect leaves from at least 18 trees in one bag each spaced at least 25 yards apart.
- If the growers goal is to only attain a representative sample of N in a field that is generally uniform, then a sample should be collected from 9 trees that are each 25 yards apart. The sample can then be pooled into a single bag for analysis or analyzed as 9 independent samples, the later approach would be chosen if the growers wanted information on variability in the field.
- The pooled sampling approach used here assumes 'typical' coefficient of variation (CoV), if growers wish to obtain their field specific CoV then samples collected from each tree should be analyzed independently and used to determine a site specific CoV to be used to adjust future sampling strategies.
- To identify and correct nutrient problems (if any) in the orchard, growers should collect leaf samples early in the season for in-season fertilizer adjustments. To utilize the spring sample nutrient prediction program growers must collect leaves from at least 18 trees in one bag each spaced at least 25 yards apart. Leaf samples for prediction purposes should be collected between 30-45 days after full bloom. Collection of samples from 18 trees each spaced 25 yards apart, followed by

analysis of full suite of plant nutrients in a reliable lab is required (N, P, K, S, Ca, Mg, Cu, Zn, Fe, Mn, B).

- These sampling protocols are for fully exposed non-fruiting sub-terminal leaves to be collected at 6-7 feet height from around the canopy of a healthy pistachio tree. This sampling protocol is valid for orchards of average variability.
- Evidence from three years results suggests that considerable improvement in N use efficiency of > 90% could occur with implementation of demand based fertilization programs. Therefore, fruit load must be considered before application of fertilizers. In the estimate of NUE we have included nutrient demand for growth.
- The average NPK removal from three season suggest that twenty-eight (28) (lbs) of N, 24 (lbs) of K and 3 (lbs) of P are removed per 1000 (lbs) of marketable yield (CPC). This value includes all nutrients removed in hulls, shells, kernels and blank nuts and other non-marketable yield per 1000 lbs. For example, a crop that results in 4000 lbs CPC yield would remove from the orchard 112 (lbs) N, 96 (lbs) K and 12 (lbs) P. Evidence from prior research suggests that an average of 25 (lbs) N and 22 (lbs) of K is utilized to support tree growth requirements. These values should be considered while recommending the fertilizer applications.

We recommend that the improved leaf sampling protocols developed by this project should be used in conjunction with the pistachio nutrient budget models to optimize fertilizer use and achieve optimum yield and thereby maximize economic return while reducing economic and environmental costs.

G: Discussion and Conclusions

Leaf samples have been characteristically collected in July in almond and pistachio. Growers have requested that methods be developed for collection of leaves earlier in the season thereby providing adequate time to correct deficiencies if any.

- The current project has developed new methods of early season leaf analysis that are effective and can be used, in combination with nutrient budget estimations, for effective nutrient management purposes.
- This was achieved through development of algorithms that utilize multiple elements to compensate for site specific variability and seasonal fluctuations.

Leaf sampling is only of value if enough samples are collected to adequately represent the nutrient status of the orchard as a whole. Prior to this project there had been no systematic evaluation of sampling strategies for orchards in California.

- We have derived a standard protocol required to effectively estimate orchard nutrient status.
- This is a minimum sampling strategy and improved management can be attained through the conduct of additional sample collections, especially in areas of lower productivity:

There is a consistent and highly repeatable depletion of N, P, K, S, Zn, and Cu in fruiting spurs as crops develop. It was hypothesized that these deficits influence spur survival and reblooming percentage:

- Soil and foliar N treatments effectively increased spur leaf area, fruit, and leaf nitrogen concentration. In the high N treatment the leaf nitrogen values exceeded the critical nitrogen concentration established for almond trees (Reuter and Robinson 1997) and the critical leaf area for spur survival and blooming thresholds established by Heerema et al. (2008) and Lampinen et al. (2011). However, none of these positive changes in leaf N or leaf area improved spur survival and/or return boom of any spur type. Indeed, there was a negative effect of increased soil N on spur survival, and hull + shell weight which coincided with a significant increase in whole tree yield as soil N increased.

High soil N in these experiments likely increased whole tree yield through increased tree size and fruiting positions (Lampinen 2012, Personal Communication, Muhammad et al. Unpublished) , but decreased spur level survival by inducing a carbon resource deficit thereby reducing per fruit hull + shell weight and reducing spur survival.

There has not been an extensive analysis of critical values or nutrient ratio analyses conducted in pistachio. The extensive data set on tissue nutrients and yield collected in this trial have been used in an attempt to validate current critical values and to determine the utility of nutrient ration analysis. The following data are for pistachio, almond data will not be available until completion of sister project 10-0039-SA.

- For all elements except Mg no evidence was found that the current critical values are incorrect.
- For Mg evidence suggests the current CV is too high and should be reduced to 0.45%
- With the exception of a single site, no evidence is provided to support the use of nutrient ratios of pistachio nutrient management.

The patterns of nutrient uptake by trees and the removal of nutrients in harvested fruit provide an estimate of the amount and timing of nutrient applications. We have derived these numbers for almond (see report 10-0039-SA) and pistachio. The outcomes for pistachio project are shown below:

- The average NPK removal from three season was twenty-eight (28) (lbs) of N, 24 (lbs) of K and 3 (lbs) of P per 1000 (lbs) of marketable yield (CPC). This value includes all nutrients removed in hulls, shells, kernels and blank nuts and other non-marketable yield per 1000 lbs.

- The seasonal pattern of nutrient accumulation has been determined and can be used to schedule fertilizer applications.

In pistachio, fruit load fluctuates between years and sites and hence N requirements also vary from year to year and this has important implications for fertilizer management.

- Analysis of the pistachio yield and nitrogen removal (fruit plus tree growth) clearly indicates that substantial improvements in nitrogen use efficiency can be achieved if annual nitrogen application rates are synchronized with the actual tree demand. The extent to which yield variability influences nutrient use efficiency is striking and adjustment of fertilization to meet current year demands is the single most effect means to improve efficiency of N use in orchards.

The growing environmental concerns related to N fertilizer imply that growers should improve nutrient management practices (especially for N) by adopting a combination of early season orchard monitoring and current season yield prediction to prescribe and adapt fertilization rates.

- Integrated best management strategies have been developed and disseminated by almond and pistachio industries.

H: Project Impacts

This research has been adopted by the Almond Board of California and the Pistachio industry as the new standards for nutrient management and is being widely publicized and distributed. This research project has been presented at grower, industry, extension, CDFA, ASA and university venues including keynote presentation at this year Almond and Pistachio Industry conferences. A webpage summarizing this work has been posted on the Almond Board's main grower information portal at http://www.almondboard.com/Growers/OrchardManagement/PlantNutrition/Pages/Default.aspx and on the University of California Fruit and Nuts Website http://ucanr.edu/sites/scri/Crop_Nutrient_Status_and_Demand__Patrick_Brown/ and is in process of being posted at the Almond Boards Sustainable Cropping Systems site. This work has been published in Pacific Nut Growers and other industry publications. A Google search for "Nutrient management in almond" yields 20 top ranked pages based upon this research.

I: Outreach Activities.

Publications:

Alsina, M.M., A.C Borges, and D.R. Smart. 2012. Spatiotemporal variation of event related N2O and CH4 emissions during fertigation in a California almond orchard. Ecosphere (in press).

Falk, M., R.D. Pyles, S. L. Ustin, B.L. Sanden and P.H. Brown. 2012 Long-term Estimates of Crop Evapotranspiration using the ACASA model at an irrigated Almond Orchard. Journal of Hydrometeorology (submitted).

Falk, M., R.D. Pyles, S.L.Ustin, K.T. Paw U, R.L. Snyder, L.Xu, Q. Hart, M.L. Whiting, and P.H. Brown. 2012 Regional water use over irrigated orchards with WRF-ACASA. Journal of Hydrometeorology (submitted).

Sanden, B, P.H. Brown, R. Snyder. 2012. New insights on water management in almonds. “Regulatory Issues Impacting California Agriculture” Visalia, California 7-8 Feb, 2012 Proceedings: Amer. Soc. Agron. Calif. Chap. pp. 88-93. Univ. Calf. Davis, http://calasa.ucdavis.edu

Schellenberg D.L., M.M. Alsina, S. Muhammad, C.M. Stockert, M.W. Wolff, B.L. Sanden, P.H. Brown and D.R. Smart. 2012. Yield-scaled global warming potential from N2O emissions and CH4 oxidation for almond irrigated with N fertilizers on arid land. Agriculture, Ecosystems and Environment 155: 7-15.

Shackel K.A., T.L. Prichard, L.J. Schwankl. 2012. Irrigation scheduling and tree stress. In: Prune production manual, University of California, ANR publication #3507.

Valdez Zarate, J.L., M.L. Whiting, B.D. Lampinen, S. Metcalf, S.L. Ustin, and P.H. Brown. 2012. Prediction of leaf area index in almonds by vegetation indexes. Computers and Electronics in Agriculture. 85:24-32.

Zarate-Valdez, J.L., M.L. Whiting, B.D. Lampinen, S. Metcalf, S.L. Ustin, and P.H. Brown. 2012. Leaf area and Landsat vegetation indexes of fruit crops in California. Computers and Electronics in Agriculture (in press)

Presentations:
Brown, P. 2012. Nutrient Management of Almonds. Almond Board of California: Sacramento CA.1800 atten.
Brown, P. 2011. Update on Nutrient Management of Almonds. Almond Board of California: Modesto CA.1800 atten.
Brown, P. 2011. CDFA-FREP Annual Conference. Management of N in Tree Crops. Paso Robles CA. 300 atten.
Brown, P. 2011. Sampling strategies for Nutrient Management in Tree Crops. Fluid Fertilizer Foundation Meeting. Stockton CA. 55 atten.
Brown, P. 2011. Stakeholder Meeting Paramount Farming: Bakersfield CA. 18 atten.
Brown, P. 2012. Foliar fertilization of tree crops. ASHS. Miami FL. 60 Attendees.
Brown, P. 2012. Management of N in Almonds. CDFA-FREP and WPHA Annual Workshop. Modesto CA. 400 atten. Expert Panel Member presentation and discussion.
Brown, P. 2012. Managing large scale collaborative research projects. Pomology Extension Continuing Conference. Davis CA. 50 atten.

Brown, P. 2012. Nutrient Budget and development of new sampling strategies for N management. Northern San Joaquin Almond Day. Merced CA. 420 atten.
Brown, P. 2012. Nutrient Budget and development of new sampling strategies for N management. ISHS Meeting on Nutrition of Tree Crops, Chakrabourty Thailand. 250 atten.
Brown, P. 2012. Nutrient Budget and development of new sampling strategies for N management. Australian Almond Industry Annual Meeting, Nuriootpa, SA. 220 atten.
Brown, P. 2012. Nutrient Management in Pistachio. Pistachio Day. Visalia CA. 280 atten.
Brown, P. 2012. Plant Nutrition in a Changing Environment. German Soc. for Plant Nutrition. 200 atten.
Brown, P. USDA Grant Review SCRI CAP Project Panel, Washington DC.
Chabrillat, S. et al. 2012. Quantitative mapping of surface soil moisture with hyperspectral imagery using the HYSOMA interface. IEEE International Geoscience and Remote Sensing Symposium. Munich, Germany.
Sanden, B. 2012. "Irrigation Management to Maximize Almond Production in the SJV", Organic Almond Farming Workshop, Selma CA. 64 atten.
Sanden, B. 2012. Kern almond meeting, irrigation management and workshop. Kern Soil and Water Newsletter.
Sanden, B. et al. 2012. Almond Workgroup Tour, Kern County.
Sanden, B. et al. 2012. California's Effort to Improve Almond Orchard Kc. European Geosciences Union General Assembly. Vienna, Austria.
Schellenberg D. et al. 2012. Gross N transformations and 15N assimilation after arid land fertilization at the tree scale. ESA. Portland OR.
Shackel K., Sanden B. 2011. Fertigation: Interaction of Water and Nutrient Management in Almonds. Almond board of California annual report #09-HORT11.
Saa. S. 36th Annual Nickels Field Day Meeting. 2013. Speaker. 60 atten
The Seventh International Symposium on Mineral Nutrition of Fruit Crops. Thailand. 2012. Speaker. 400 atten

Saa, S. American Society of Agronomy: Plant & Soil Conference. 2012. Speaker. 250 atten.

Patrick Brown. Advances in pistachio production (A UCCE short course). 2012 Speaker. 200 atten.

Saa, S. Almond Board of California Conference. 2012. Speaker. 1800 atten.

Saa, S. 35th Annual Nickels Field Day Meeting. 2012. Speaker. 60 atten.
Field Meeting Almond Irrigation & Nutrient Management for High Yield. Year: 2011. Speaker. 150 atten

Saa, S. Laboratory Analysis Workshop. 2011. Speaker. 40 atten.

Saa Sebastian, Muhammad Saiful, Castro Sebastian, Brown Patrick; Effect of Spur Type, Foliar Sprays, and Differential Nitrogen Rates on Leaf Nutrient Content and Spur Leaf Area of Almond Trees. Thailand; International ISHS Symposium on Mineral Nutrition of Fruit Crops. 2012.

Siddiqui Muhammad. Annual pistachio board meeting: 2010. Speaker. 40 atten.

Siddiqui Muhammad. Seminar at UCDAVIS. 2011. Speaker.50 atten.

Posters:

Saa Sebastian, Muhammad Saiful, Brown Patrick; Development of leaf sampling methods and nutrient-budget fertilization; Almond Board of California, Modesto, USA. 2011. Poster.

Patrick Brown, Saiful Muhammad, Sebastian Saa Silva and Eike Luedeling; Development of Leaf Sampling Methods and Nutrient-budget fertilization; Almond Board of California, Modesto, USA. 2010. Poster.

Patrick Brown, Sebastian Saa Silva, Kenneth Shackel, Michael Whiting, Theodore Sammis, Bruce Lampinen, David Slaughter; Advanced Sensing and Management Technologies to Optimize Resource Use in Perennial Crops: Nutrient and Water Status ASHS Palm Springs, California, USA. 2010. Poster.

Saa Sebastian, Muhammad Saiful, Brown Patrick; Development of leaf sampling and interpretation methods Almond Board of California, Modesto, USA. 2010. Poster.

Brown Patrick, Eike Luedeling, Sebastian Saa, Jeremy Nunez; Development of leaf sampling and interpretation methods for Almond; International Plant Nutrition Conference, Sacramento, USA. 2009. Poster.

Patrick Brown, Saiful Muhammad, Sebastian Saa, Eike Luedeling; Development of Leaf Sampling Methods and Nutrient-Budget Fertilization. International Plant Nutrition Conference, Sacramento, USA. 2009. Poster.

J: Factsheet/Database Template:

Development of leaf sampling and interpretation methods for Almond and Pistachio

Grant Agreement Number: 10-0015-SA
Project Leaders (Patrick Brown, Professor, Department of Plant Sciences, One Shields Ave, University of California, Davis, CA 95616-8683, (530) 752-0929. phbrown@ucdavis.edu.
Start Year/End Year (2011-2012)
Location (Arbuckle, Modesto, Madera, Kettleman city, Buttonwillow, KammAvenue)
County (Colusa, Stanislaus, Madera, Kings, Kern and Fresno Counties)
Highlights

- The overall goal of this research project was to develop new approaches and interpretation tools that better quantify field and temporal variability are sensitive to yield and provide for in-season monitoring and fertilizer optimization in almond and pistachio orchards over a wide geographic scope. In this study, we have assessed new and improved ways to assess the nutrient status of the trees to help pistachio and almond growers manage their fertilizer applications with more precision.

- Predictive models to estimate leaf nutrient status from spring samples were developed. These computer based models are new monitoring tools in the management of nitrogen and potassium fertilizers. Use of these models allows the growers to make in-season fertilizer management decisions for the current crop load.
- Development and validation of yield and phenology based nutrient budget curves for major nutrients in almond and 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.

Introduction

Previous results of a survey of almond and pistachio growers, and consultants in California, suggested that the existing leaf sampling protocols and comparison of the tissue results with the established standards does not provide sufficient guidance for nutrient management. Thus, the overall goal of this research project was to develop new approaches and interpretation tools that better quantify field and temporal variability. These tools aim to be sensitive to yield and provide for in-season nutrient monitoring across different Californian orchards. To complement the leaf sampling protocols, yield and phenology based budget curves were developed for major nutrients, providing information about the right rate and right time of nutrient needs.

Methods

Almond trials were initiated in 8 or 9 years old orchards and pistachio trials were initiated in 10-15 year old orchards of good to excellent productivity planted to nonpareil (50%) and Kerman (97%) respectively. These orchards were in soils representative of the major production regions in California. Leaf and fruit samples were collected throughout the growing seasons to determine the degree of variability in tissue nutrient concentrations over time, space and within tree canopies and to develop nutrient budget curves for the major nutrients. Leaf and fruit samples, plus individual tree yield, were collected from all experimental sites covering all the growing season. All leaf and fruit samples were analyzed separately for nutrient composition by standard methods at ANR laboratory at University of California, Davis (UCDAVIS). Both linear and non-linear statistical approaches and GIS tools were used to analyze this large data set.

Findings (Results and Conclusions)

The integration of the objectives of this research project has allowed us to improve best management practices for almond and pistachio growers. Predictive models for nitrogen and potassium were developed to enable leaf sampling early in the growing season. To help growers apply these approaches in the field, detailed sampling protocols have been published. In pistachio, for all elements except Mg no evidence was found that the current critical values are incorrect. For Mg evidence suggests that the current CV is high and should be reduced to 0.45%. Also results in pistachio suggest that the magnesium status of the plants is important for achieving the positive impact of K on pistachio yield. With the exception of a single site, no evidence was provided to support the use of nutrient ratios in pistachio nutrient management. In almond, higher nitrogen in the soil resulted in increased tree growth and yield but decreased the percent spur survival.

In this project, budget curves were also developed for the major nutrients. These budget curves quantify the time course of nutrient uptake and total plant demand as determined by tree yield and nutrients required for growth. A critical finding from these data is the huge impact on overall efficiency that occurs in years of poor yield in which standard fertilization strategies are used. In this instance efficiencies of N use of >43% was observed in 2011. In the accompanying project (10-0039-SA) low yields in 2012 in almond resulted in NUE of less than 20%, while these same trees exhibited >85% NUE in the previous high cropping year. The most important conclusion is that N application rates based upon current yield in combination with in-season sampling and fertilizer rate adjustments are essential to maximize efficiency of N use while optimizing productivity. Findings of this research has been adopted by the Almond Board of California and the Pistachio industry as the new standards for nutrient management and is being widely publicized and distributed.

K: Copy of the Product/Results:

This research has been adopted by the Almond Board of California and the Pistachio industry as the new standards for nutrient management and is being widely publicized and distributed. This research project has been presented at grower, industry, extension, CDFA, ASA and university venues including keynote presentation at this year Almond and Pistachio Industry conferences. A webpage summarizing this work has been posted on the Almond Board's main grower information portal at http://www.almondboard.com/Growers/OrchardManagement/PlantNutrition/Pages/Default.aspx and on the University of California Fruit and Nuts Website http://ucanr.edu/sites/scri/Crop_Nutrient_Status_and_Demand__Patrick_Brown/ and is in process of being posted at the Almond Boards Sustainable Cropping Systems site. This work has been published in Pacific Nut Growers and other industry publications. A Google search for "Nutrient management in almond" yields 20 top ranked pages based upon this research.

References

Heerema, R.J., S.A. Weinbaum, F. Pernice and T.M. Dejong. 2008. Spur survival and return bloom in almond Prunus dulcis (Mill.) DAWebb varied with spur fruit load, specific leaf weight, and leaf area. Journal of Horticultural Science & Biotechnology. 83:274-281.

Lampinen, B.D., S. Tombesi, S.G. Metcalf and T.M. DeJong. 2011. Spur behaviour in almond trees: relationships between previous year spur leaf area, fruit bearing and mortality. Tree Physiology. 31:700-706.

Reuter, D.J. and J.B. Robinson. 1997. Plant Analysis: An Interpretation Manual 2nd Edition (CSIRO Land & Water Resources).

Rosecrance, R. C., S. A. Weinbaum and P. H. Brown 1998. Alternate bearing affects nitrogen, phosphorus, potassium and starch storage pools in mature pistachio trees. Annals of Botany 82: 463-470.