Development of Leaf Sampling and Interpretation Methods for Almond and Development of a Nutrient Budget Approach to Fertilizer Management in Almond

Project No: **11-PREC2-Brown**

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Objectives:

- Determine the degree to which leaf nutrient status varies across a range of representative orchards and environments.
- Determine the degree to which nutrient status varies within the canopy and within the year.
- Validate current CVs and determine if nutrient ratio analysis provides useful information to optimize fertility management.
- Develop a phenology and yield based nutrient model for Almond.
- Develop fertilizer response curves to relate nutrient demand with fertilizer rate and nutrient use efficiency.
- Determine nutrient use efficiency of various commercially important N and K fertilizer sources.
- Develop and extend an integrated nutrient BMP for Almond.

Interpretive Summary:

The primary goals of this research are to 1) conduct a systematic examination of leaf sampling protocols, their use in decision making, and to develop early season sampling protocols, and 2) to determine the response of Almond to various rates and sources of nitrogen (N) and potassium (K) fertilizers, to develop nutrient demand curves, to conduct a long term assessment of nutrient use efficiency and to develop more refined fertilization recommendations.

The first goal is being addressed in almond orchards in four locations in California (Arbuckle, Belridge, Madera and Modesto). Leaf and nut samples were taken at various times throughout the season to determine the degree of variability in tissue nutrient concentrations over time, space, and within tree canopies. This has been used to establish sound leaf sampling protocols. Results demonstrate that there is a high degree of consistency in patterns of change in tissue nutrients over time and that early season sampling can be used to diagnose deficiencies and nutrient demands. July leaf nitrogen content (and likely other nutrients) can be well predicted with an early season (April) sampling.

The second project goal is addressed in a fertigation trial at Belridge, Kern County, CA with data also drawn from the four sites used above. This experiment aims to develop a phenology and yield based nutrient model for Almond, to develop fertilizer response curves to relate nutrient demand with fertilizer rate and nutrient use efficiency, and to determine nutrient use efficiency of various commercially important N and K fertilizer sources. Findings from both project components will be integrated to develop nutrient best management practices for almond. Treatments in the fertigation trial consist of five rates of nitrogen (0, 125, 200, 275 and 350 lb/ac), supplied by two commercially important sources of nitrogen, UAN 32 and CAN 17. The zero N control was introduced in fall 2011 as a split plot in the previously 125 lb treatment. There are three treatments for potassium rates (100 lb/ac, 200 lb/ac and 300 lb/ac) and three sources of potassium (SOP, SOP+KTS and KCl).

The results from the four years of data indicate a significant effect of nitrogen rates on yield. Fruit nitrogen accumulation was directly correlated with N application rate while potassium rates had no effect on yield or fruit K concentrations at this site. K sources had an effect on yield only in the 3rd year under drip irrigation only. Knowledge of tree yield and nut nutrient concentration can be used to calculate orchard nitrogen removal and to plan fertilization replacement strategies. Results show that 80% of N and 70% of K is accumulated in the almond fruit by mid June. A 1000 pound Nonpareil kernel yield removes between 55 and 75lb of N at the 125 and 275lb/ac N rate respectively. Averaged across years and locations, the N removal per 1000 lb yield (all fruit parts) is a remarkably consistent 61.7 +/- 3[i] lb N and 85 +/- 3.2 lb K. Nitrogen removal per 1000 lb of Monterey yield in 2011 at Belridge site was 62 +/- 2.8 N and 71 +/- 2.7 lb K. Increasing nitrogen rates above 275lbs had no consistent effect on crop yield, however nutrient use efficiency declined significantly and nitrate accumulated in the deepest soil profile sampled. The optimal rates defined here are relevant at this individual site and should not be applied elsewhere without an assessment of local yield potential.

Ongoing activities including long term productivity trends, nutrient accumulation in perennial tissues, effects on tree size, effects on soil N reserves, effects on disease incidence, validation of early tissue sampling strategies and construction of a whole system budget for all nutrients.

Materials and Methods:

Sampling Methodology and Field Variability trial

At each site samples were collected for a period of 3 years from 8 to 10 year old micro sprinkler irrigated (one drip irrigated) almond orchards of good to excellent productivity planted to Nonpareil (50%). For each of the 4 almond sites (Arbuckle, Belridge, Madera and Modesto), plots were 10-15 acre contiguous blocks. Leaf and nut samples from 114 trees were collected at 5 times during the season. Sample collection was spaced evenly over time from full leaf expansion to harvest. As a phenological marker, days past full bloom and stage of nut development were noted. Light interception, tree water status, and individual yields of these trees were also measured.

A standard leaf sampling protocol was used to determine nutrient concentrations in samples of exposed, non-fruiting spurs (NF), as well as leaves from fruiting spurs with 1 and 2 fruit (F1 and F2, respectively) to explore the sensitivity of different sampling methods as indicators of tree nutrient demand. In 2010, the use of F1 samples was discontinued as it did not provide additional useful data. In 2011 and 2012 tissue samples were collected from NF and F2. To establish seasonal nutrient accumulation and nutrient export, composite nut samples were collected from each site at various dates through the year. Both leaf and nut samples were dried and ground prior to sending them to the DANR Analytical Laboratory located on the UC Davis campus.

In 2011 the spatial and temporal variability of the leaf nutrient content collected at all sites and years was used to develop statistical models to answer the following questions:

1) Can we sample in April and predict July Nitrogen content?
2) What is the best sampling method?
3) Can we predict from either April or July samples the proportion of trees that will be below certain critical value in July?

In 2012 we have been validating the models developed in 2011 by selecting 6 new orchards representative of the major production areas of the California valley. In addition to this, we will use data from the Belridge fertigation trial to further validate and calibrate the models under different fertilizer management regimes.

Fertigation trial

The original fertigation rate and source experiment was established in a Paramount Farms almond orchard at Belridge, Kern County, California under Fan jet and Drip irrigation systems. Each of the 12 treatments (**Table 1**) was replicated in five or six blocks with 15 trees per block. Treatments consisted of four rates of nitrogen (125, 200, 275 and 350 lb/ac), supplied as two commercially important sources of nitrogen (Urea Ammonium Nitrate 32% [UAN 32] and Calcium Ammonium Nitrate 17% [CAN 17]). Potassium was applied at three rates (100, 200 and 300 lb/ac as K) and supplied by three sources of potassium (Sulfate of Potash [SOP], SOP + Potassium Thiosulfate [KTS] and Potassium Chloride [KCl]). 60% of the potassium in K rate treatments was applied as SOP in early February, while the remaining 40% was applied as KTS in four fertigation cycles. Nitrogen was applied in four fertigation cycles with 20%, 30%, 30% and 20% of total nitrogen supplied in February, April, June and October, respectively. Fifteen trees and their immediate 30 neighbors, in two neighboring orchard rows were treated as one experimental unit. All data were collected from six trees in the middle row. A total of 768 experimental trees were selected for this experiment. Leaf and nut samples were collected from individual trees in April, May, June, July and August. A total of 5400 leaf and nut samples were collected and analyzed for N, P, K, Ca, S, Mg, B, Zn, Cu, Mn and Fe at the Agriculture and Natural Resources (ANR) Lab at the University of California Davis. The crop was harvested in August and individual tree yields were determined for all data trees. Yield of the remaining nine non-data trees in the data trees row was also determined to get average plot yield of fifteen trees. Four-pound samples were collected from two data trees each in each replicate to determine crack out percentage (turn over) and oven dry weight. Twenty nuts were collected at harvest from each experimental tree to determine the ratio of kernel to shell/hull and the partitioning of nutrients.

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

In fall of 2011 a zero N treatment (A1) was added as a split plot utilizing 50% of the trees previously receiving 125 lbs N acre.

Results and Discussion:

Sampling Methodology and Field Variability trial

The key questions addressed in this research trial are:

1) Can we sample in April and predict July Nitrogen content?
2) What is the best sampling method?
3) Can we predict from either April or July samples the proportion of trees that will be below certain critical value in July?

1) Predict July Nitrogen content sampling in April: Leaf samples are characteristically collected in July in Almond. Collection of leaves earlier in the season would be useful for management by providing important information on current orchard nutrient status and providing adequate time to correct deficiencies if any. A major perceived constraint with the use of early season samples is attributed to rapid leaf growth early in the season which was thought to make timing of sample collection difficult. As leaves mature, nitrogen concentration decreases rapidly while other elements such as Ca increase. The standard July leaf nutrient sampling was historically selected because leaf growth has been completed at this time and nutrient concentrations have stabilized. Evidence from this current trial suggests that this premise is not correct and that early season leaf analysis can be used for nutrient management purposes. To overcome perceived problems with early season sample collection and to correct for the rapid changes that occur throughout the year we have incorporated the measurement of leaf-Ca into our models. Leaf Ca has now been shown to be an excellent method to estimate phenological leaf age (**Figure 1**).

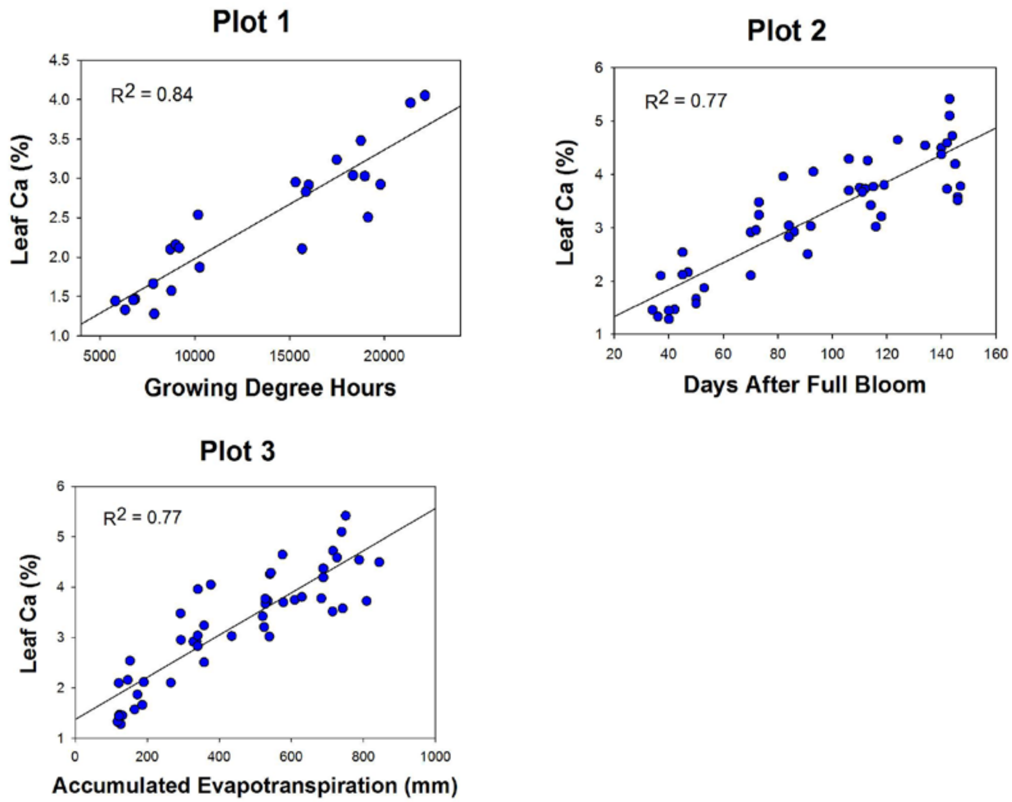

Figure 1: Regression plots validate the use of calcium (Ca) as an indicator of leaf physiological age. Leaf Ca concentration is correlated with growing degree hours, (Plot 1), days after full bloom, (Plot 2) and accumulated evapotranspiration (Plot 3).

Using the data collected in this experiment we have developed five unique statistical models that allow for the prediction of July leaf N values from April sample collection dates. These models are currently being tested in six CA almond orchards and a validation is also being conducted by prominent soil testing labs in California. In addition to this, we will use data from the Belridge fertigation trial to further validate and calibrate the models under different fertilizer management regimes.

2) Developing Ideal Sampling Methods: Leaf sampling is only of value if enough samples are collected so that they adequately represent the nutrient status of the orchard as a whole. Based upon the three years of data analyses of moderately uniform and good producing orchards, we have derived a standard protocol required to effectively estimate orchard nutrient status. This protocol is based upon grower standard practice of collecting only one sample per orchard and has been validated for Nonpareil trees of greater than 8 years of age. The following sampling strategy should be conducted independently in all orchard blocks. Based upon the analysis of the orchards used in this experiment, the following sampling protocol is valid when applied to a generally uniform orchard of any size, however if the orchard is known

to be non uniform then independent samples should be collected in each productivity 'zone'.

This is a minimum sampling strategy and improved management can be attained by taking additional samples, especially in areas of lower productivity. This methodology is valid for both April or July collected samples. In the following strategy all leaves for each 'sample' will be collected into a single bag to be submitted for analysis. Separate 'samples' should be collected for each orchard, or for each zone within an orchard:

- Leaf sample(s) should be collected 6 weeks after full bloom for April sampling, or at standard late July sampling time.
- Collect one sample if your orchard is uniform in terms of yield and avoid trees with obvious problems (i.e. sick trees).
- Collect multiple samples (separate bags) if zones of varied productivity are present.

Each Sample should be collected as follows:

- Collect leaves from 18 to 28 trees (90 and 95 % confidence intervals respectively.
- Sampled trees must be at least 30 yards apart from each other
- From each tree, collect leaves from all sides of the tree from leaves on at least 6 to 8 well-exposed spurs located between 5-7 feet from the ground.
- Send the samples to the lab and ask for a FULL NUTRIENT ANALYSIS (N, P, K, B, Ca, Zn, Cu, Fe, Mg, Mn, S)

3) Interpretation of the July Nitrogen content (either from a July leaf sampling or from the models' output): A detailed analysis of July leaf sample data from four well-managed and visibly uniform sites over four years has allowed us to estimate 'typical' field variability in Californian orchards of this type. Using these data from a well collected leaf sample (see above), the percentage of the field that will be above the established critical value of 2.2% N in July can be estimated.

The data provided here allows growers to better interpret the results of their leaf sampling procedures. For example if a collected leaf sample (either collected in July or collected in April and used to predict July) shows a field N concentration of 2.3% then this will typically imply that 78% of all trees in that orchard have a N concentration above 2.2% which is the established critival value for N. (**Table 2**.)

Table 2: Relationship between July leaf tissue N concentrations in 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

Fertigation Trial

Interpretation of the following experimental results requires that readers consider the yields achieved in these experiments and adjust fertilization rates to match the normally achieved yields in their individual circumstance. Fertilization rates should be selected to satisfy the demands of the potential crop which is a function of tree age, size and current year fruit set.

Yield

Nitrogen treatments had a significant effect on crop yields in all the four years of the experiment. The effect of nitrogen and potassium rate and source on kernel yield in 2010 and 2011 is presented in **Tables 3 and 4**. Maximum kernel yield was obtained from the N rate treatment of 275 lb ac^{-1} and significant yield reduction was obtained with lower nitrogen rate treatments (125 and 200lb ac^{-1}). Increasing nitrogen supply above 275 lbs acre did not increase yield but did result in reduced nitrogen use efficiency, defined here as N removed in harvested fruit divided by N supplied in fertilizers and water (NUE) (**Table. 5**). In these experiments, we report a NUE from N rate 275lb/ac of over 85% which is remarkably high and reflects the precision with which N is managed in this setting. To address issues of the contribution of soil reserves to total plant N uptake, we implemented a zero N treatment in 2011 and have been collecting intensive soil samples (data to be presented in 2013). Preliminary analysis suggests that trees treated with 125 and 200 lbs N are suffering from N deficiency (decreased tree size, leaf N). Trees receiving 125 lb N fertilizer treatments and 200 lb N are depleting soil N reserves as indicated by diminishing soil N and organic matter in the surface layers.

Despite significant decreases in tissue K concentrations (<1.8% in the 100 lb K rate) no significant differences in yield have been observed for K rate treatments. K sources had shown a slight significant effect on yield under drip irrigation in 2010, however no significant effect was observed in 2011. No significant effect of N sources has been observed on kernel yield.

Table 3. Mean yield (lb/tree) for different N/K treatments in 2010; treatments with same letter within irrigation are not significantly different. (Refer to **Table 1** for the description of treatments).

Mean Kernel Yield 2010 (lb/ac)

Treatment	N UAN 32				N CAN 17				K Rate			K Source		
	A	B	C	D	E	F	G	H	I	C	J	C	K	L
	125	200	275	350	125	200	275	350	100	200	300	200	200	200
Drip Irrigation	2,859	3,426	3,909	4,332	2,624	3,191	3,967	3,995	3,860	3,922	3,734	3,922	3,459	3,703
	C	BC	AB	A	C	BC	AB	A	AB	AB	AB	AB	B	AB
Fan Jet Irrigation	2,872	3,581	3,810	3,776	3,030	3,410	3,993	3,898	3,873	3,810	3,751	3,810	3,605	3,359
	B	A	A	A	B	AB	A	A	AB	AB	AB	AB	AB	B

Table 4. Mean yield (lb/tree) for different N/K treatments in 2011; treatments with same letter within irrigation are not significantly different. (Refer to **Table 1** for the description of treatments).

Mean Kernel yield 2011 (lb/ac)

Treatment	N UAN 32				N CAN 17				K Rate			K Source		
	A	B	C	D	E	F	G	H	I	C	J	C	K	L
	125	200	275	350	125	200	275	350	100	200	300	200	200	200
Drip Irrigation	3,811	4,274	4,643	4,735	3,640	4,336	4,864	4,852	4,700	4,643	4,774	4,723	4,791	4,804
	C	B	A	A	C	B	A	A						
Fan Jet Irrigation	3,870	4,014	4,480	4,425	3,803	4,159	4,452	4,398	4,382	4,480	4,498	4,471	4,362	4,348
	B	B	A	A	C	B	A	A						

Table 5: Cumulative Nitrogen Use Efficiency 2008-2011. Calculated as total N outputs in all fruit divided by total N inputs (fertilizer and irrigation water).

N Rate (lb/ac)	Drip	Fan Jet
125	1.43	1.30
200	1.03	1.03
275	0.93	0.88
350	0.82	0.70

Nutrient Removal in Crop and Changes in Nutrient Concentrations and Accumulation through the Season:

Nitrogen

Nitrogen accumulation in the fruit was influenced by nitrogen supply at all sampling dates. Trees suffering from an N limitation (125 and 200 lb/acre in this experiment) had reduced N concentration in leaves, kernels, shells and hulls. In all treatments and years about 80% of the total N accumulation in fruit had occurred by mid June (126 DAFB in 2010 and 119 DAFB in 2011) as shown in **Figures 2** and **3**. At harvest 52lb and 54lb nitrogen was removed in 2010 and 2011 respectively for each 1000lb kernel in the 125lb/ac nitrogen rate while 73 lb nitrogen was removed in fruit in 2010 and 2011 from N rate 275 lb/ac. The corresponding July leaf N concentration was 2.05% and 2.3% for 125lb/ac N rate in 2010 and 2011, and 2.4% and 2.8% for N rate 350lb/ac in 2010 and 2011. The cooler spring and early summer in 2011 delayed fruit maturity and when the samples were collected in July there was no hull split, while in the other years there was about 10% hull split when samples were collected in July. This may account for the higher N concentrations in leaves sampled in July these years. The nitrogen removal by 1000lb kernel yield slightly increased over the past three years 2009 (data not shown) to 2011 for the N rates 275lb/ac and 350lb/ac due to a slight increase in the fruit nutrient concentration in 2010 (data not shown) and 2011 (**Figure 9**).

Table 6 presents data on averaged nitrogen and potassium removal per 1000 lbs kernel from different years and sites in the Central Valley. Averaged across years and locations, the N removal per 1000 lb yield (all fruit parts) is 61.7 +/- 3[ii] lb N and 85 +/- 3.2 lb K. Nitrogen removal per 1000 lb of Monterey yield in 2011 at Belridge site was 62 +/- 2.8 N and 71 +/- 2.7 lb K. (**Table 7**).

Table 6. Averaged nitrogen and potassium removal per 1000 lbs crop from different years and sites in the Central Valley

N and K export ito fruits by 1000lb kernel yield (lb)																		
Site			BELRIDGE								MODESTO		MADERA		BELRIDGE (plot 2)		ARBUCKLE	
N rate			N 125lb/ac		N 200lb/ac		N 275lb/ac		N 350lb/ac		N 185 lb/ac**		N 250 lb/ac**		N 275 lb/ac**		N 190 lb/ac**	
Variety	Year	Nutrient	Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
Nonpareil	2008	N	56	1.3	59	1	61	1.7	63	1	*	*	*	*	*	*	*	*
		K	53	1.6	54	1.8	53	1.9	52	2.1	*	*	*	*	*	*	*	*
	2009	N	53	0.9	56	0.9	59	1	60	1.1	62	1.4	69	1.7	62	1	*	0.8
		K	74	1.6	72	1.1	73	1.2	72	1.7	94	2	*	3.5	80	2.3	81	1.1
	2010	N	55	1.3	61	1	73	1.7	70	1	58	1.8	76	4.8	62	1	51	1.4
		K	88	1.6	81	1.8	79	1.9	82	2.1	98	3.3	*	5.8	81	2.7	94	3.2
	2011	N	54	1.4	65	1.3	73	1.8	75	1.6	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
		K	77	1.4	76	1.5	77	1.8	75	1.8	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Monterey	2011	N	55	2.7	60	1.5	67	1.5	66	1.9	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
		K	78	5.7	70	2.5	71	1.7	65	2.5	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

* = Data is still under examination

** = Average rate used by the grower during the years of sampling

N.A. = Data was not collected

Table 7. Averaged leaf nitrogen values from different years and sites in the Central Valley.

Mean leaf N concentration at July (%)								
Site	BELRIDGE				MODESTO	MADERA	BELRIDGE (plot 2)	ARBUCKLE
Year	N 125lb/ac	N 200lb/ac	N 275lb/ac	N 350lb/ac	N 185 lb/ac**	N 250 lb/ac**	N 275lb/ac**	N 190 lb/ac**
2008	2.31	2.41	2.49	2.53	2.36	2.39	2.43	2.34
2009	2.26	2.35	2.52	2.60	2.75	2.41	2.39	2.6
2010	2.05	2.19	2.44	2.41	2.47	2.36	2.62	2.59
2011	2.29	2.54	2.74	2.82	N.A.	N.A.	N.A.	N.A.

** = Average rate used by the grower during the years of sampling.
Experiment was commenced in 2008 and treatment effects were not clearly seen until the 2009/10 season.

N.A. = Data was not collected

Phosphorus

Phosphorus exhibited an annual trend that resembled nitrogen. By increasing nitrogen supply, fruit phosphorus removal declined slightly but not significantly. The N rate 125lb/ac removed 9lb and 8.7lb phosphorus for a 1000lb kernel yield in 2010 and 2011 respectively (**Figures 2** and **3**). The N rate 350lb/ac removed 7.8lb and 8.3lb phosphorus in 2010 and 2011 to yield a 1000lb kernel.

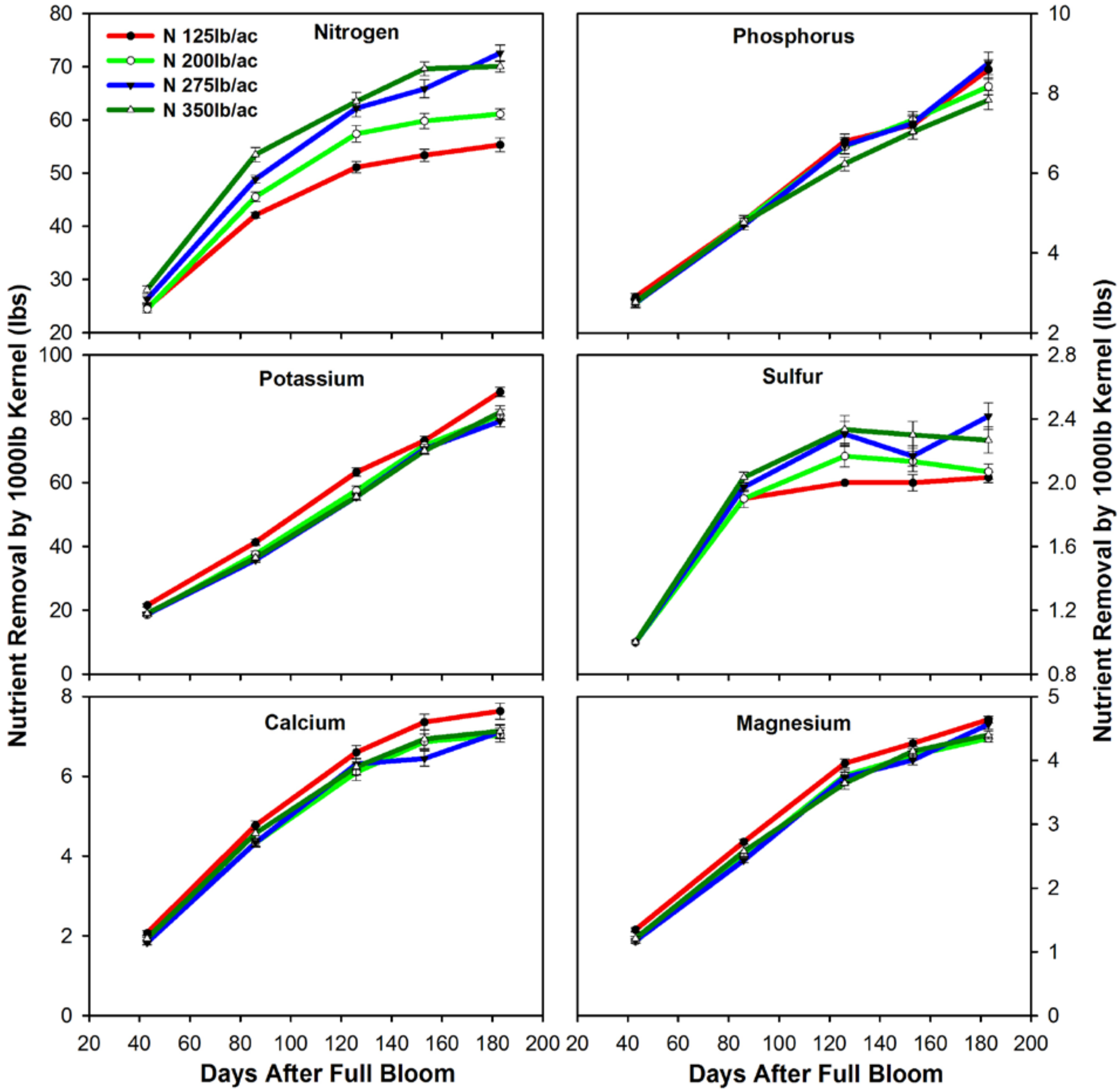

Figure 2. Nitrogen, Phosphorus, Potassium, Sulfur, Calcium and Magnesium removal by almond fruit to produce 1000lb kernel yield from nitrogen rate treatments in 2010. Each point represents mean and std error.

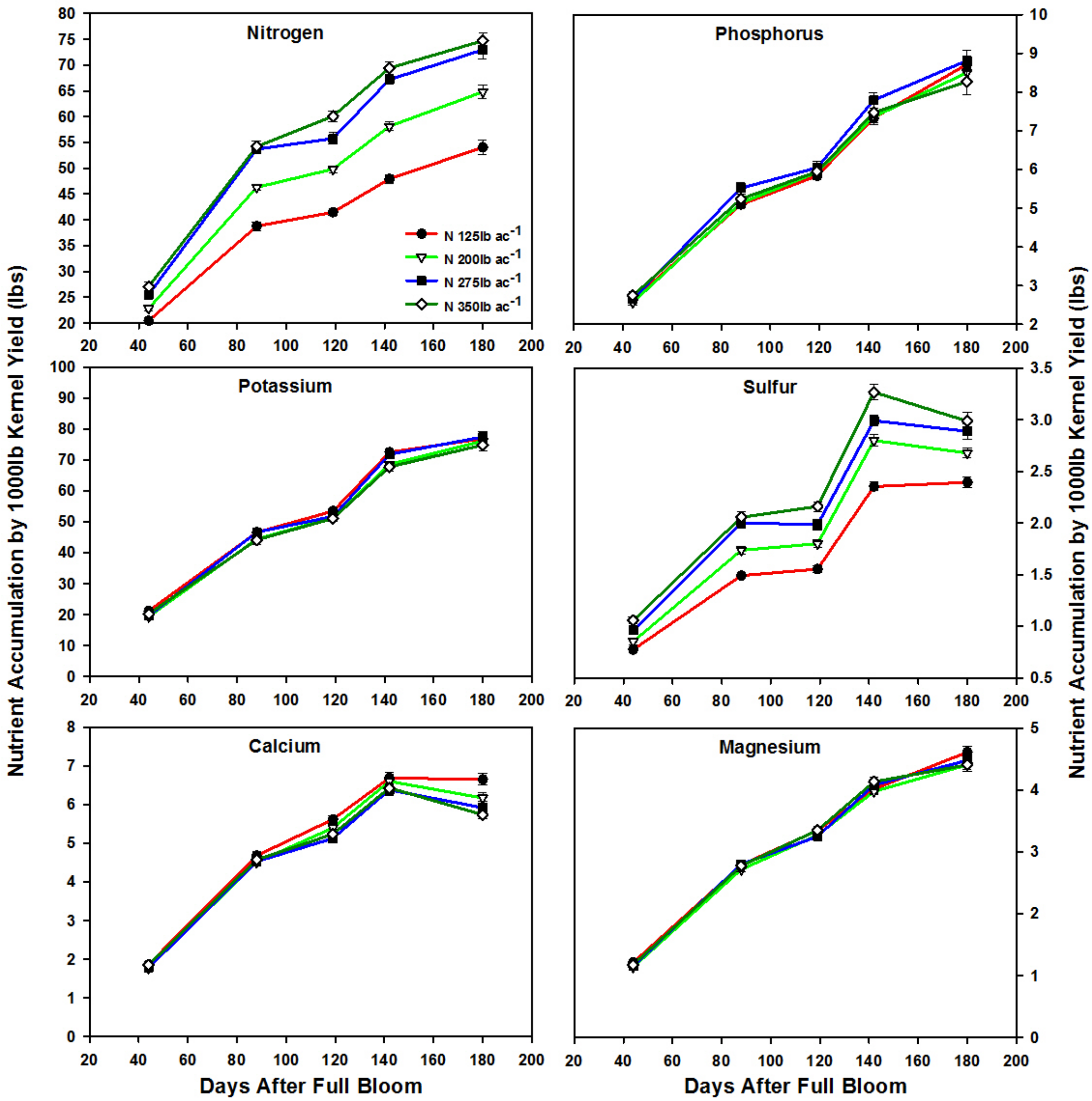

Figure 3. Nitrogen, Phosphorus, Potassium, Sulfur, Calcium and Magnesium removal by almond fruit to produce 1000lb kernel yield from nitrogen rate treatments in 2011. Each point represents mean and std error.

Potassium

Fruit potassium accumulation by 1000lb kernel increased linearly through the season. The effect of K rate on K accumulation is shown in **Figures 4** and **5**. Averaged over two years, 1000lb kernel yield accumulated 70 lb K per 1000 lb kernel at the 100lb K/ac rate and 80 lbs per 1000 lb kernel at the 300lb K/ac rate. About 70% of the K was accumulated in the fruit by mid June (126 DAFB in 2010 and 119 DAFB in 2011).

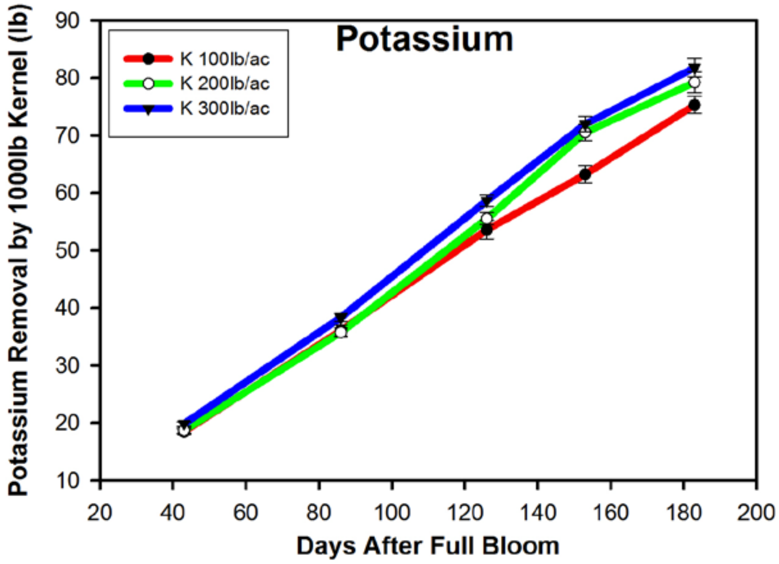

Figure 4. Potassium removal by almond fruit to produce a 1000lb kernel yield from potassium rate treatments in 2010. Each point represents mean and std error.

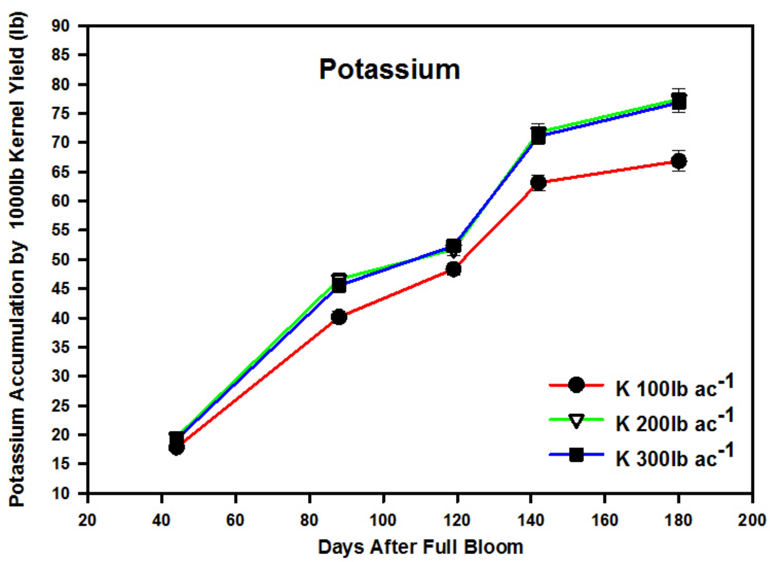

Figure 5. Potassium removal by almond fruit to produce 1000lb kernel yield from potassium rate treatments in 2011. Each point represents mean and std error.

Leaf Nutrient Concentration

Leaf nutrient concentration for the nitrogen rate treatments for 2010 and 2011 are shown in **Figures 6** and **7**. Significant differences in leaf nitrogen concentration were observed between N rate treatments throughout the season in both 2010 and 2011. The cooler spring and early summer in 2011 delayed leaf and fruit development, and likely altered tissue nutrient concentrations at sampling date. Differences in leaf N concentration have not been observed in the N source treatments (data not shown). Significant differences in leaf potassium concentration were observed between K rate treatments in both 2010 (data not shown) and 2011 (**Figure 8**). No significant differences have been observed between the K source treatments. The extensive tissue analysis conducted throughout this experiment demonstrates that leaf K is highly variable and only poorly responsive to K fertilization rates. Data illustrate the extreme degree of variability that exists in tree K concentrations and suggests that tissue sampling for K is limited in its utility.

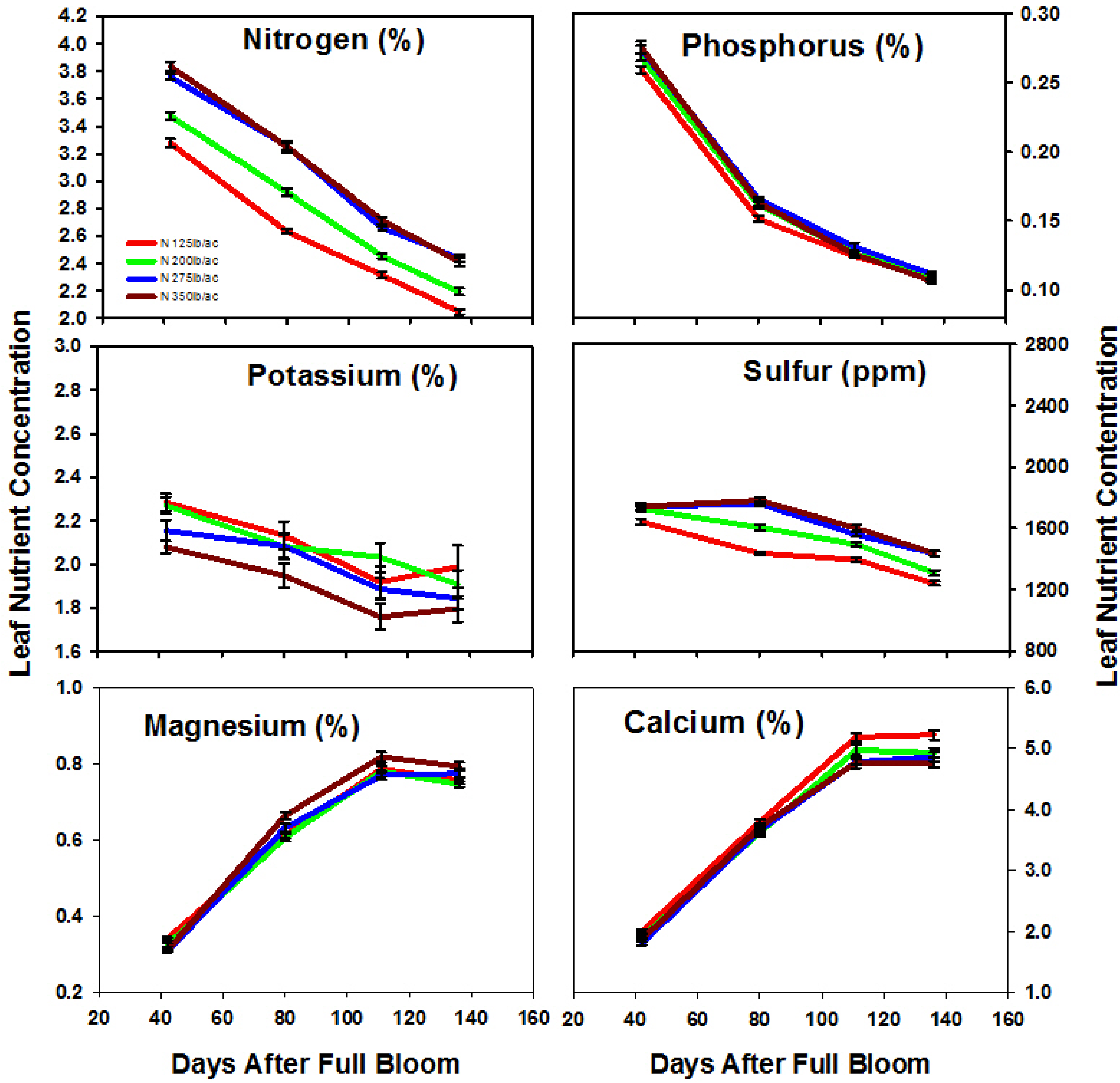

Figure 6. Effect of different nitrogen rates (N UAN 32) on leaf nutrient concentration in 2010. Each point represents mean and std error.

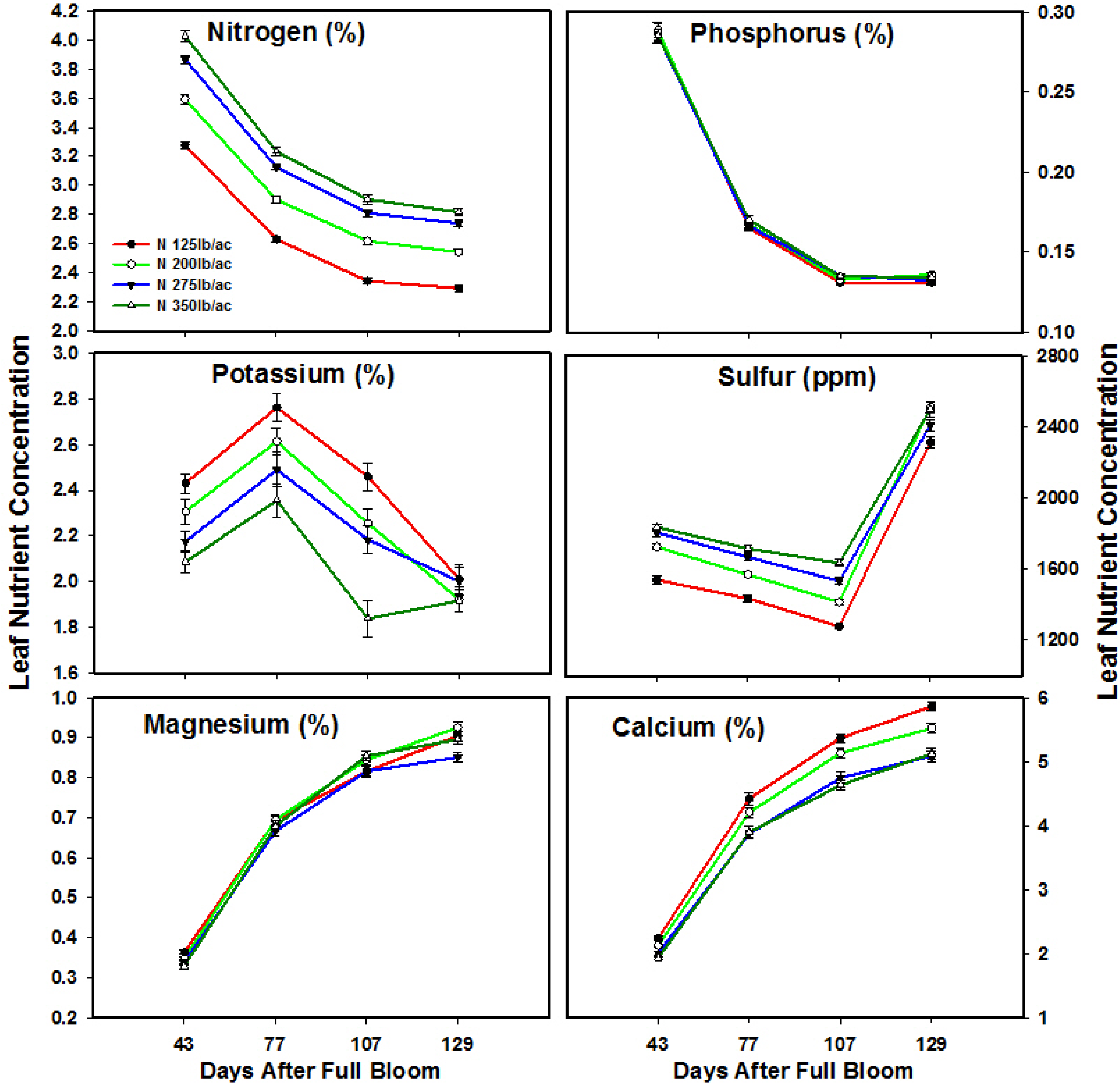

Figure 7. Effect of different nitrogen rates (N UAN 32) on leaf nutrient concentration in 2011. Each point represents mean and std error

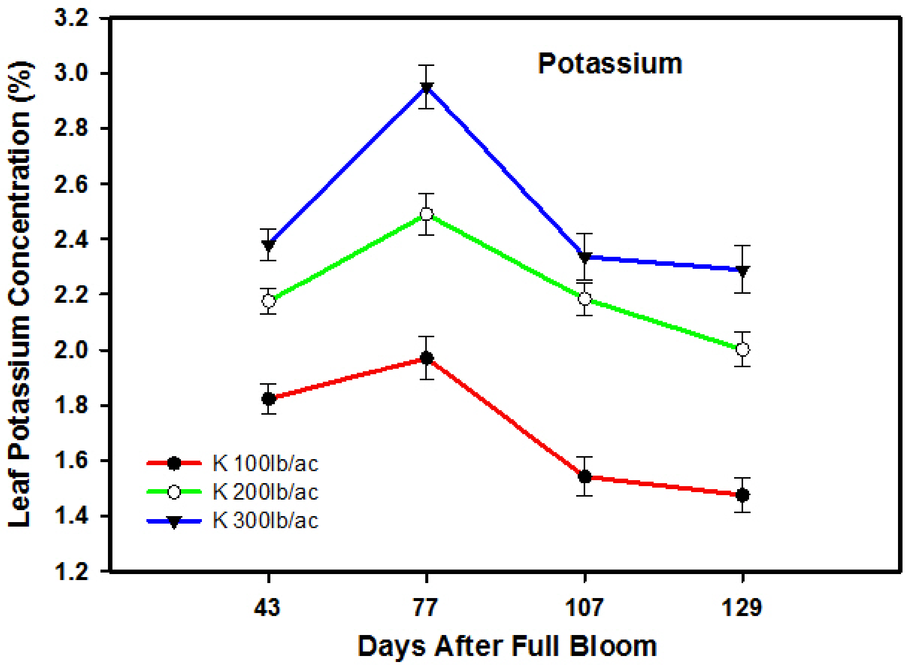

Figure 8. Effect of different Potassium rates (SOP+KTS) on leaf Potassium concentration in 2011. Each point represents mean and std error.

Fruit Nutrient Concentration

Fruit N, P, K, S, Ca and Mg concentration in 2011 are shown in **Figure 9**. Fruit N, P and S concentrations declined over time in all N rate treatments; fruit Ca and Mg concentrations also declined but the decline was less steep than N, P and K. The increase in S concentration in the mid season was due to contamination from a pesticide treatment. Potassium rate had a significant effect on fruit K concentration in 2010 (data not shown) and 2011 (**Figure 10**). The difference was bigger among the K rates in 2011 and that also influenced the K export by 1000lb kernel yield. A cycle of decline and increase was observed in fruit K concentration over the growing season.

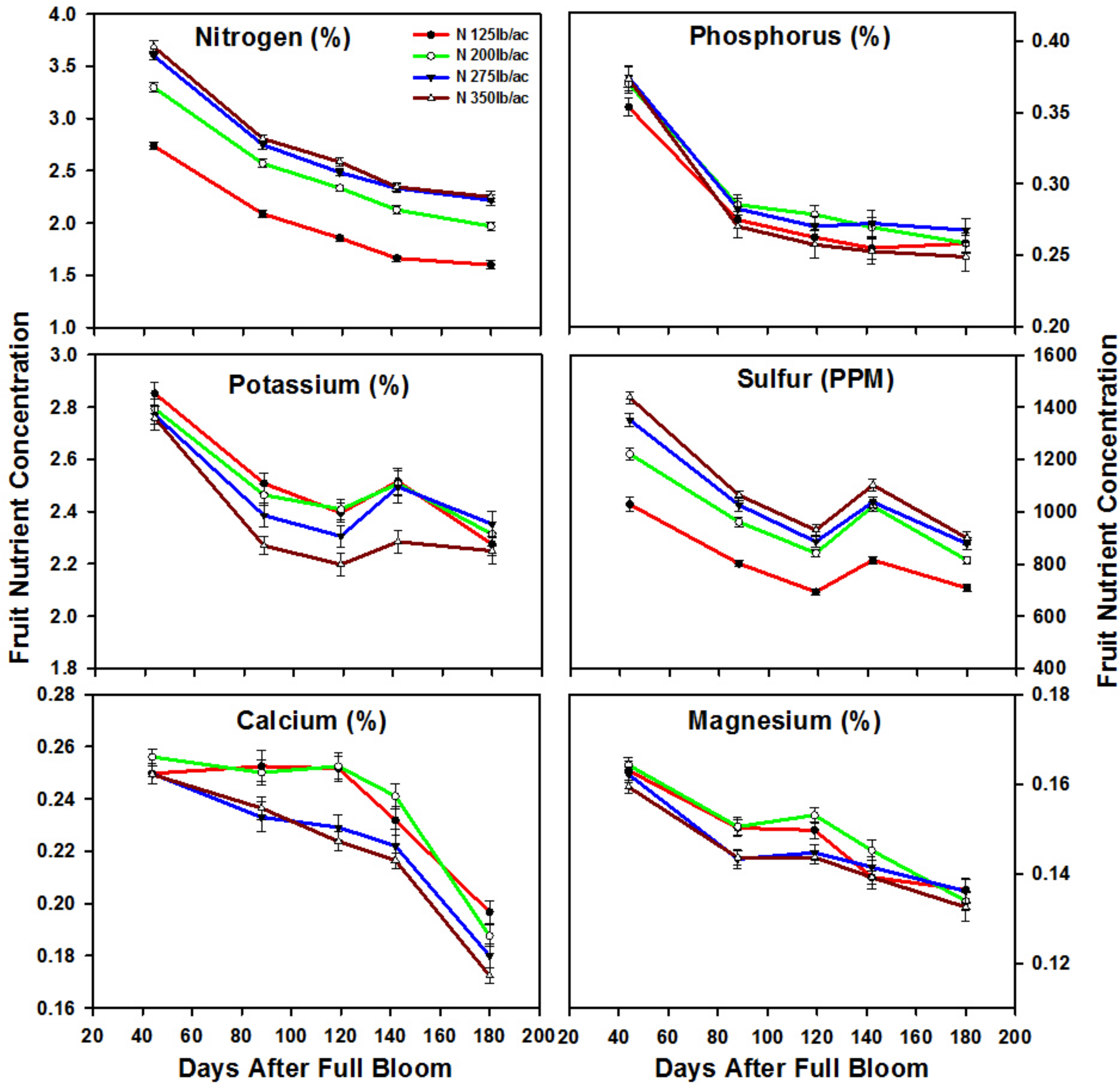

Figure 9. Nutrient concentration in Almond fruit over time for N rate treatments in 2011. Each point represents mean and std error.

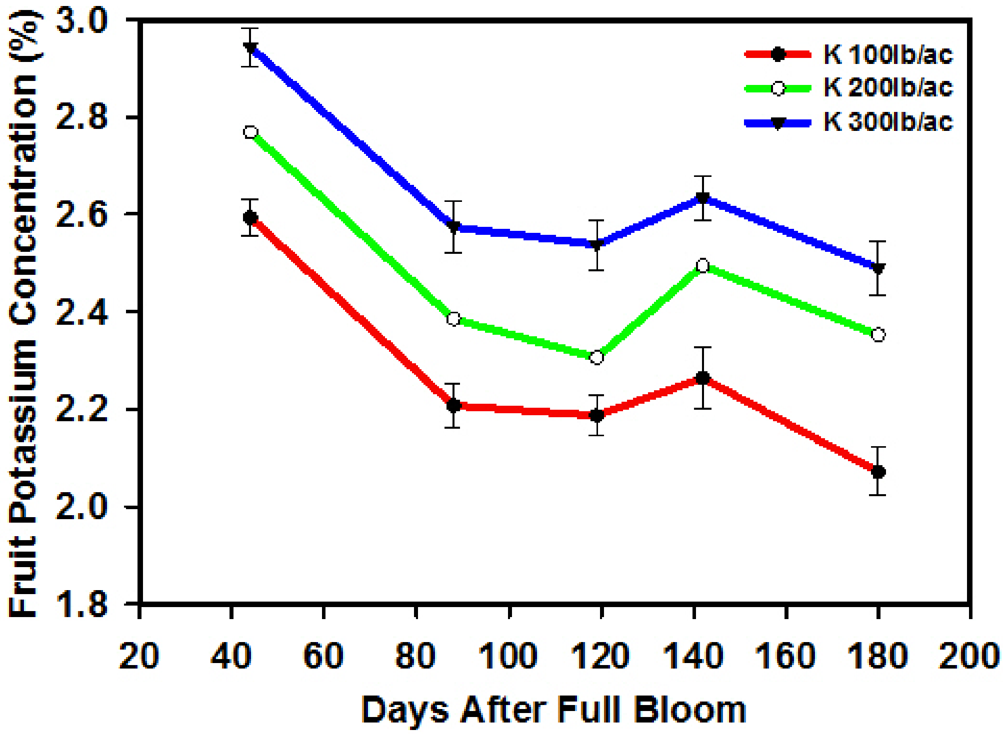

Figure 10. Potassium concentration in Almond fruit over time for K rate treatments in 2011. Each point represents mean and std error.

Recent Publications:

Two poster presentations and corresponding short papers were presented at the XVII International Plant Nutrition Colloquium in Sacramento, August 2009.

Two posters were presented in American Society for Horticulture Science conference in Palm Spring in August 2010.

A farmer's field day was conducted in Belridge Almond Fertility Trial (June 2011) and more than 150 farmers and industry people participated.

Posters were presented in the Almond Board conferences in 2010, 2011 in Modesto, CA.

A full listing of publications derived from the project can be found at http://ucanr.org/sites/scri/