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

Project No: **09-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 yield 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:

Results of a survey of almond growers and consultants in California, suggested that leaf sampling and comparison with established standards does not provide sufficient guidance for nutrient management. Two explanations for this observation are possible. 1) The current Critical Values (CVs) are incorrect or not useful for the decision-making process due to lack of sensitivity or inappropriate timing, 2) There are systematic errors in the manner in which critical values are used. One of the goals of this research is thus to conduct a systematic examination of leaf sampling protocols and their use in decision making. A second goal of the project is to determine the response of Almond to various rates and sources of N and K fertilizer, and to develop nutrient demand curves in order to developed 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 are taken at various times throughout the season to determine the degree of variability in tissue nutrient concentrations over time, space and withing tree canopies. While this assessment requires data collection over several seasons (3-5 years), some preliminary data will be presented. These data indicate that leaves from spurs with local fruit load are more indicative of critical tree nutrient status than leaves from spurs without local fruit load. In addition, there is consistent evidence to postulate that the death of fruit bearing spurs can be attributable to a local nutrient deficit of N, P, K, Zn, S, and Cu throughout the season. Data also demonstrate that early season leaf sampling can be used effectively to monitor tree nutrient status.

The second project goal is addressed in a fertigation trial at Belridge, CA. This experiment will be used 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 used to develop integrated nutrient best management practices for almond. Treatments in the fertigation trial consist of four rates of nitrogen (125 lb/ac, 200 lb/ac, 275 lb/ac and 350 lb/ac), supplied by two commercially important sources of nitrogen, UAN 32 and CAN 17. 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). Leaf and nut samples were collected from 768 individual trees in April, May, June, July and August and analyzed for essential plant nutrients. The results indicate that there is a significant effect of nitrogen rates on yield in year 2 of this experiment. Fruit nitrogen accumulation was directly correlated with N application rate while potassium rates and sources had no significant effect on the yield in the first and second year of the trial. N and K rates had a significant effect on fruit and leaf nutrient concentration while differences between N and K sources have not been established yet. Knowledge of tree yield and nut nutrient concentration can be used to calculate orchard nitrogen removal and to plan fertilization replacement strategies. Results are based on two years data and must be repeated for at least two additional years to be fully validated.

Materials and Methods:

Variability trial

At each site samples were collected from 8 to 10 year-old microsprinkler irrigated (one drip irrigated) almond orchards of good to excellent productivity planted to Nonpareil (50%). At experiment completion, trees will have reached 11 to 14 years of age (after 3 or 5 years) representing their most productive years.

For each of 4 almond sites (Arbuckle, Belridge, Madera and Modesto), plots are 10-15 acre contiguous blocks. Leaf and nut samples from 114 trees are collected at 5 times during the season for a period of 3-5 years. Sample collection is spaced evenly over time from full leaf expansion to one month post-harvest. As a phenological marker, days past full bloom and stage of nut development are noted. Light interception, trunk diameter, and individual yields of these trees are 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. To establish seasonal nutrient accumulation, composite nut samples were collected from each site. Both leaf and nut samples were dried and ground prior to sending them to the DANR Analytical Laboratory located on the UC Davis campus.

Fertigation trial

The 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) 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 neighbouring 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. Four pound samples were collected from two data trees each in each replicate to determine crack out percentage 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

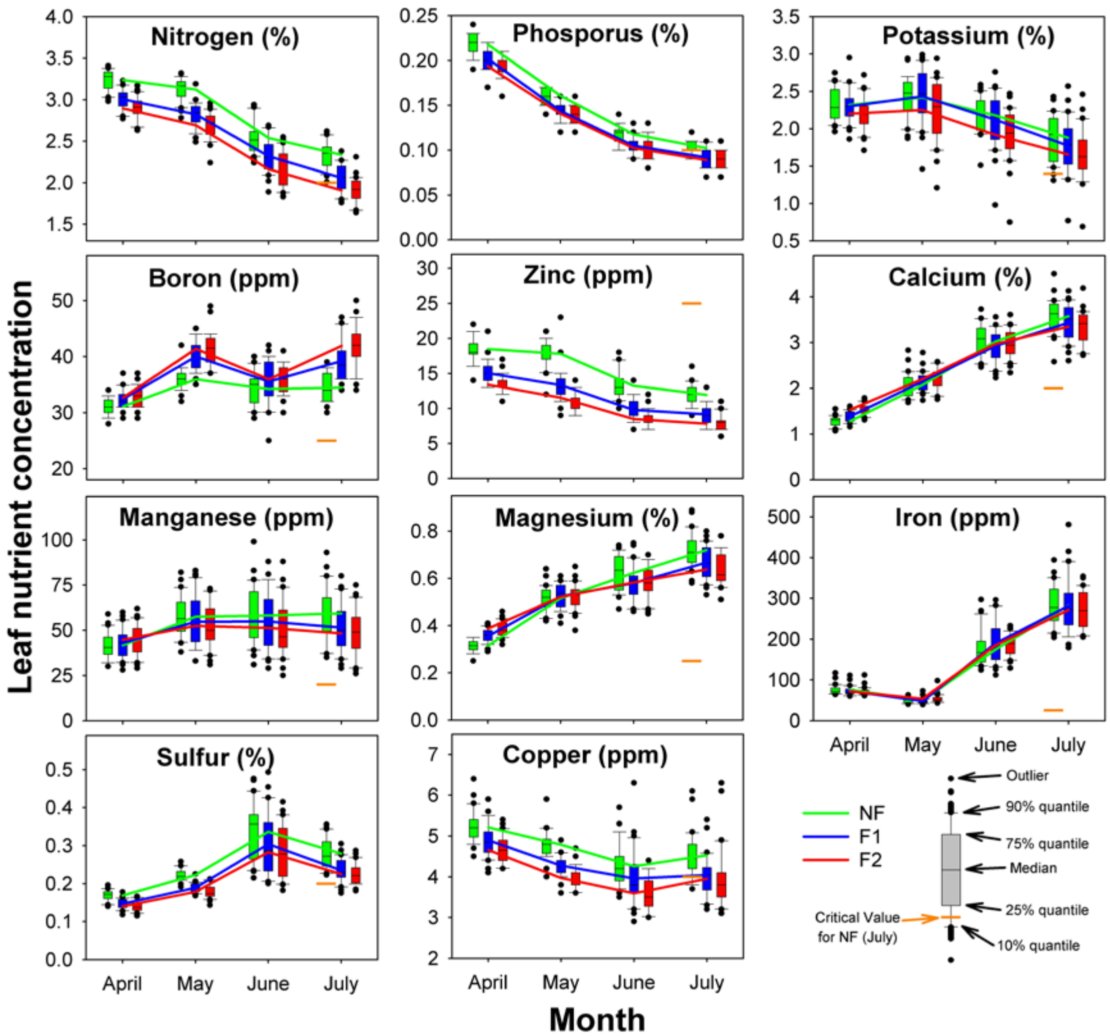
Results and Discussion:

<u>Variability trial</u>

This observational study illustrates nutrient dynamics throughout the season. Data from the first two years of sample collection (2008 and 2009 field season; **Figure 1**) suggest that nutrient concentrations and their variability depend on the nutrient sampled, sample type and sampling time: Patterns consistently found during the season, between locations, and during the two years of study.

The preliminary information obtained in this project adds considerably to current understanding of the factors that determine spur longevity and potential to re-bear. Preliminary data from this project confirms that fruit presence alters spur level N and K dynamics resulting in local deficits that may negatively impact yield. Further, there is a consistent and highly repeatable depletion of P, K, S, Zn, and Cu in fruiting spurs as crops develop. This observation, which needs confirmation, suggests that that 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. We are currently testing the hypothesis that local deficit of these 6 elements are important for spur longevity, and yield sustainability.

2008 Season



Nitrogen (%)
Phosporus (%)
Potassium (%)
Boron (ppm)
Zinc (ppm)
Calcium (%)
Manganese (ppm)
Magnesium (%)
Iron (ppm)
Sulfur (%)
Copper (ppm)
Leaf nutrient concentration
Month
April
May
June
July
NF
F1
F2
Outlier
90% quantile
75% quantile
Median
25% quantile
10% quantile
Critical Value for NF (July)

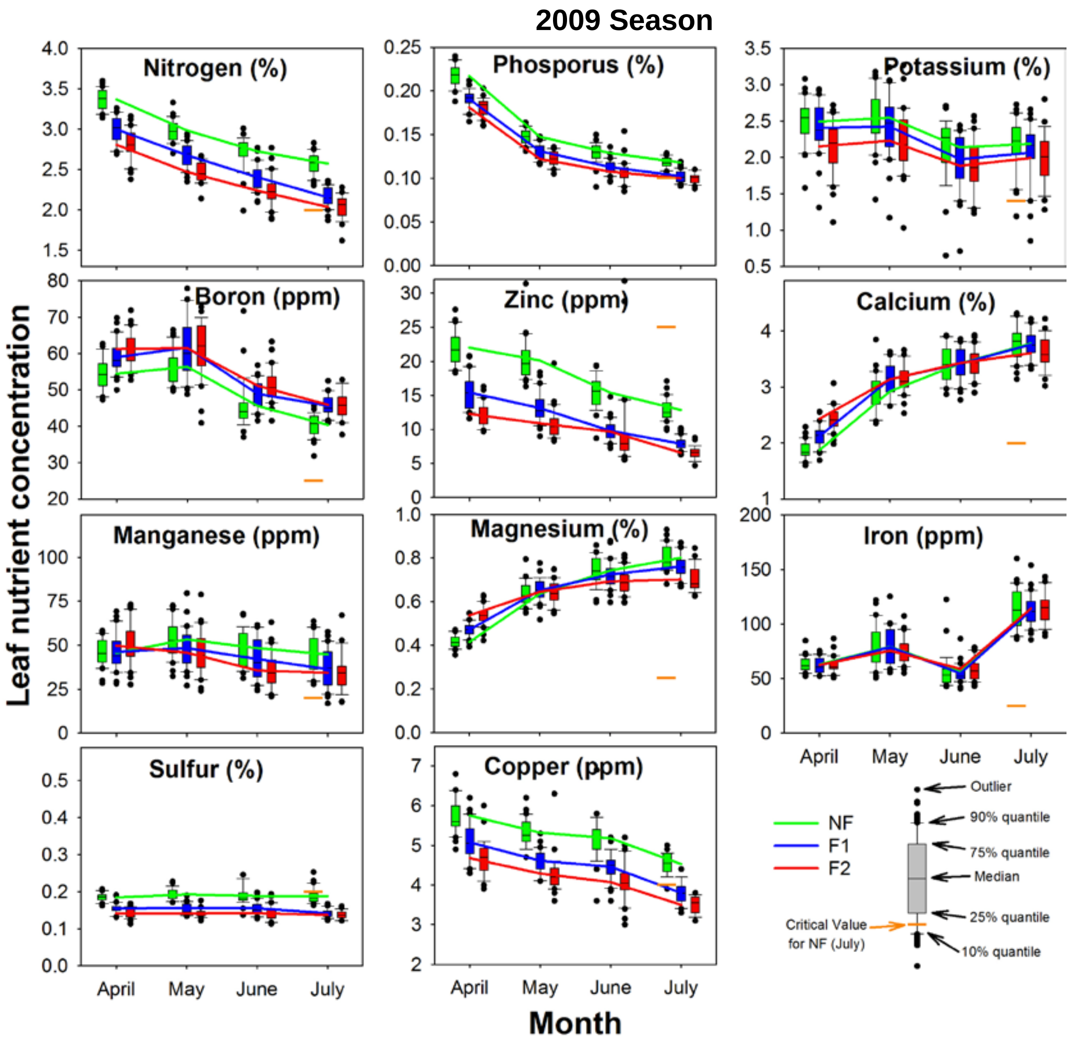


Figure 1. Nutrient behavior throughout two seasons in leaves from non-fruiting spurs (NF), spurs with 1 fruit (F1), and spurs with 2 fruits (F2). The graphs show data collected from the Arbuckle orchard during the 2008 and 2009 season.

Results suggest that the current standard sampling protocol, which only includes leaf samples from non-fruiting spurs, may not reflect critical local tree nutrient status. The difference in response of NF and F1/F2 samples, clearly visible for N and Zn, may be of particular relevance as F1 and F2 leaves were below established leaf critical values in July.

Leaf samples are characterisitically collected in July in Almond. Collection of leaves earlier in the season appears to provide important information on orchard nutrient status and preliminary studies suggest early season samples are better predictors of yield and tree health than July samples. Early nutrient deficit reflects late season patterns and is spatially correlated with yield. (**Figure 2**).

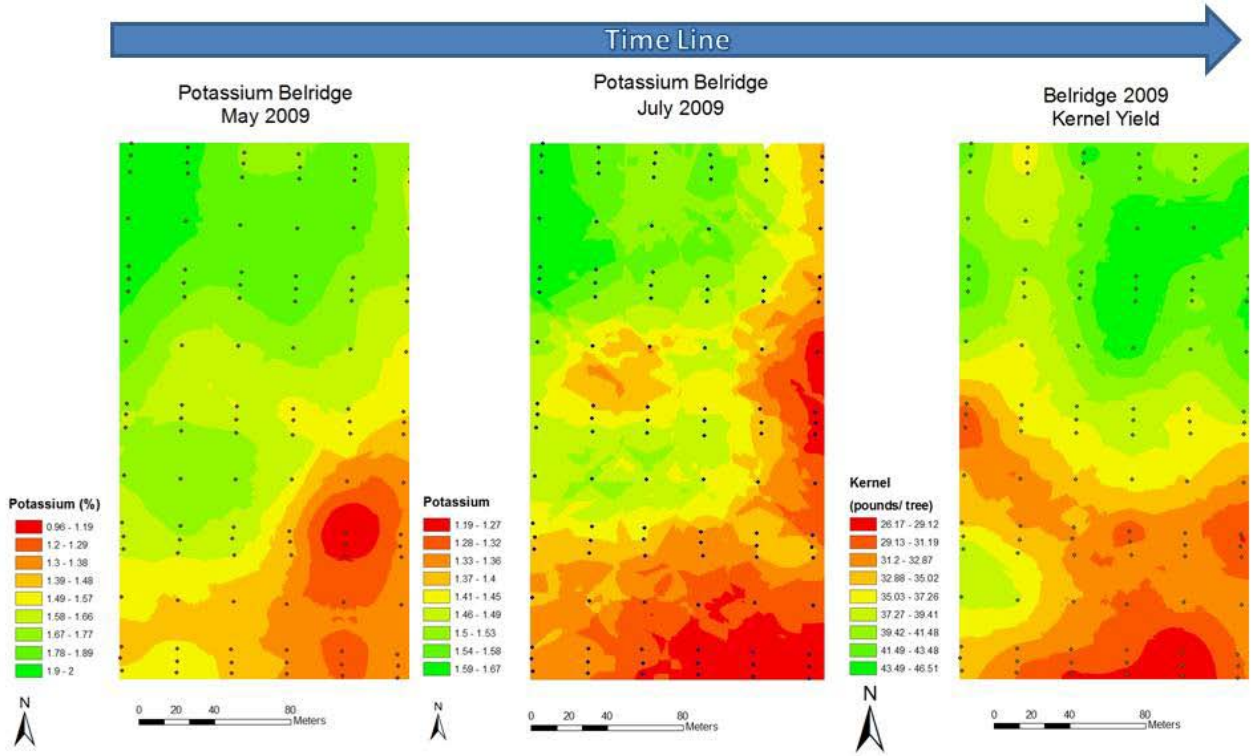


Figure 2. Spatial Variability of Potassium found during the months of May and July 2009 that is directly correlated with the Spatial Variability of the Yield recorded in the same season. Data was generated from the Belridge site using kriging interpolation method.

<u>Fertigation trial</u>

The accumulation of Nitrogen, Phosphorus, Potassium, Sulfur, Calcium and Magnesium in the fruit at different rates of N increased over the season as shown in **Figure 3**.

<u>Nitrogen</u>

Nitrogen accumulation in the fruit was positively correlated with nitrogen supply at all sampling dates. At 42 days-after-full-bloom (DAFB) 82 lb/ac N was accumulated for N rate 125 lb/ac, 100 lb/ac for N rate 200 lb/ac, 112 lb/ac for N rate 275 lb/ac, while 117 lb/ac N was accumulated for N rate 350 lb/ac. Nitrogen accumulation increased in all treatments and was maximal at 136 DAFB. At 165 DAFB (harvest), however, total fruit N accumulation declined for all N rate treatments suggesting that N in fruit had been remobilized back to the tree. This trend of nitrogen remobilization in 2009 was consistant with the observations in 2008.

Phosphorus

Phosphorus exhibited an annual trend that resembled nitrogen and increasing nitrogen supply also increased phosphorus uptake. All treatments also exhibited a small but significant decline in P concentrations between 136 and 165 DAFB (harvest). This pattern of pre-harvest decline was observed with N, P and Sulfur but not with any other element and hence reflects protein degradation in the 'senscing' hulls.

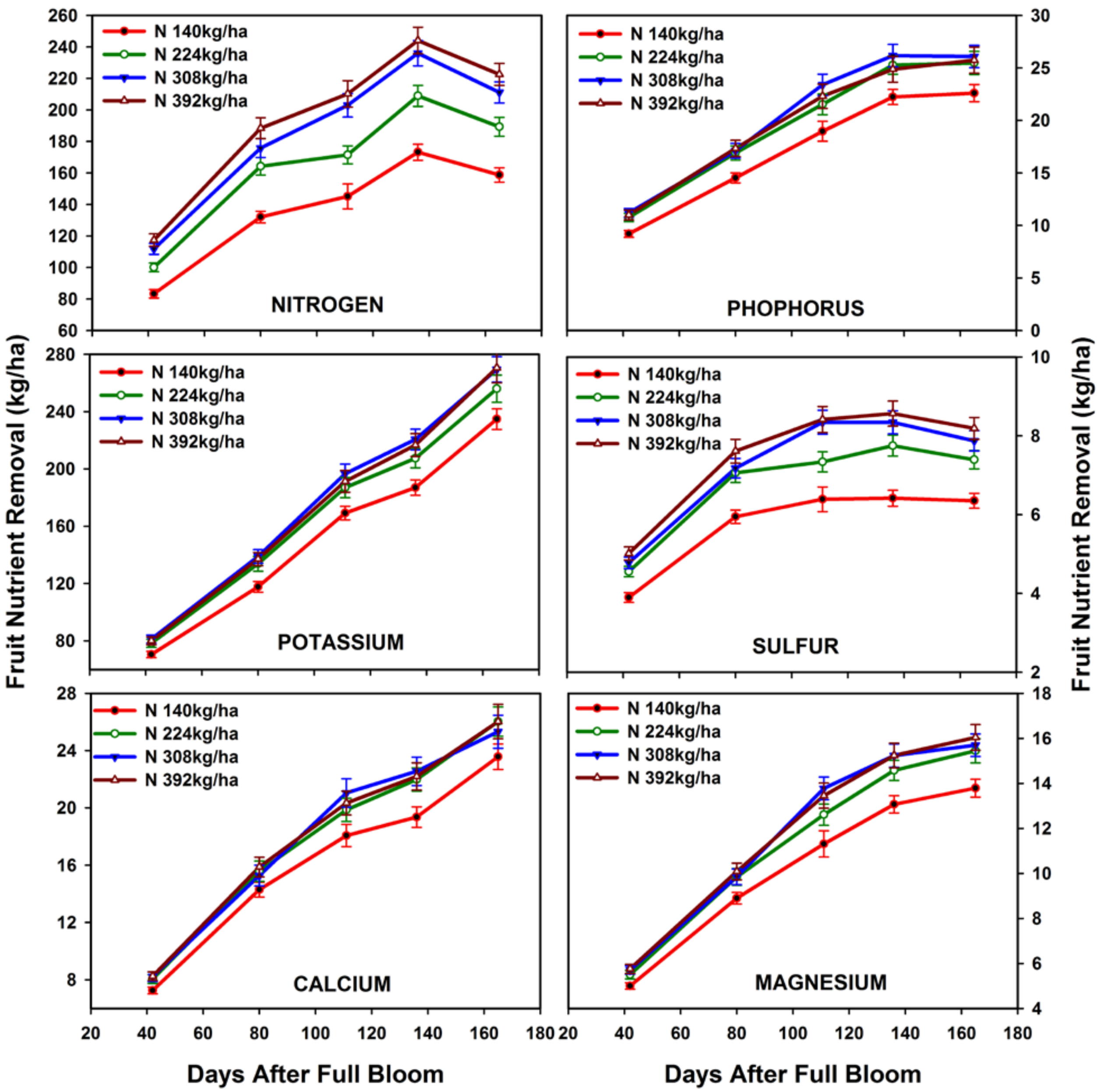


Figure 3. Nitrogen, Phosphorus, Potassium, Sulfur, Calcium and Magnesium uptake by almond fruit from nitrogen rate treatments in 2009

Potassium

Fruit potassium accumulation increased overt time but was not significantly influenced by K treatment suggesting that K availability at this site was not rate limiting. (**Figure. 4**).

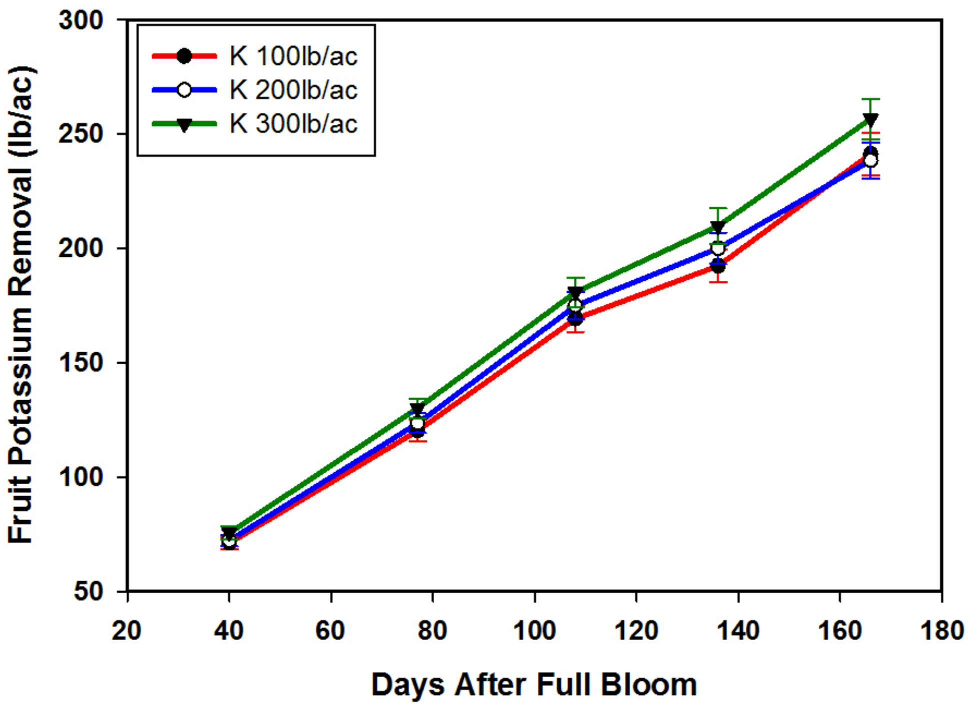


Figure 4. Potassium uptake by almond fruit from potassium rate treatments in 2009

Leaf Nutrient Concentration

Leaf nitrogen, phosphorus and potassium concentrations were high in the beginning of the season and then declined though the season, while leaf calcium and magnesium concentrations were low at the beginning of the season and then increased later on (**Figure 5**). Significant differences in leaf nitrogen concentration were observed between N rate treatments throughout the season. Significant differences in leaf potassium concentration were observed between K rate treatments (**Figure 6**). Data illustrate the extreme degree of variability that exisits in tree K concentrations and suggests that tissue sampling for K is extremely limited in its utility.

The very consistent pattern of leaf nutrient accumulation suggests that samples of most nutrients could be effectively collected at any time of the year and be used to define tree nutrient status if compared with standards developed for the same time period. For example, if a leaf exhibited a tissue N concentration of 3.25 on the 40th day after full bloom, then there is a 95% likelihood that an equivalent leaf would have a leaf N concentration of 2.35 on 140 days after full bloom.

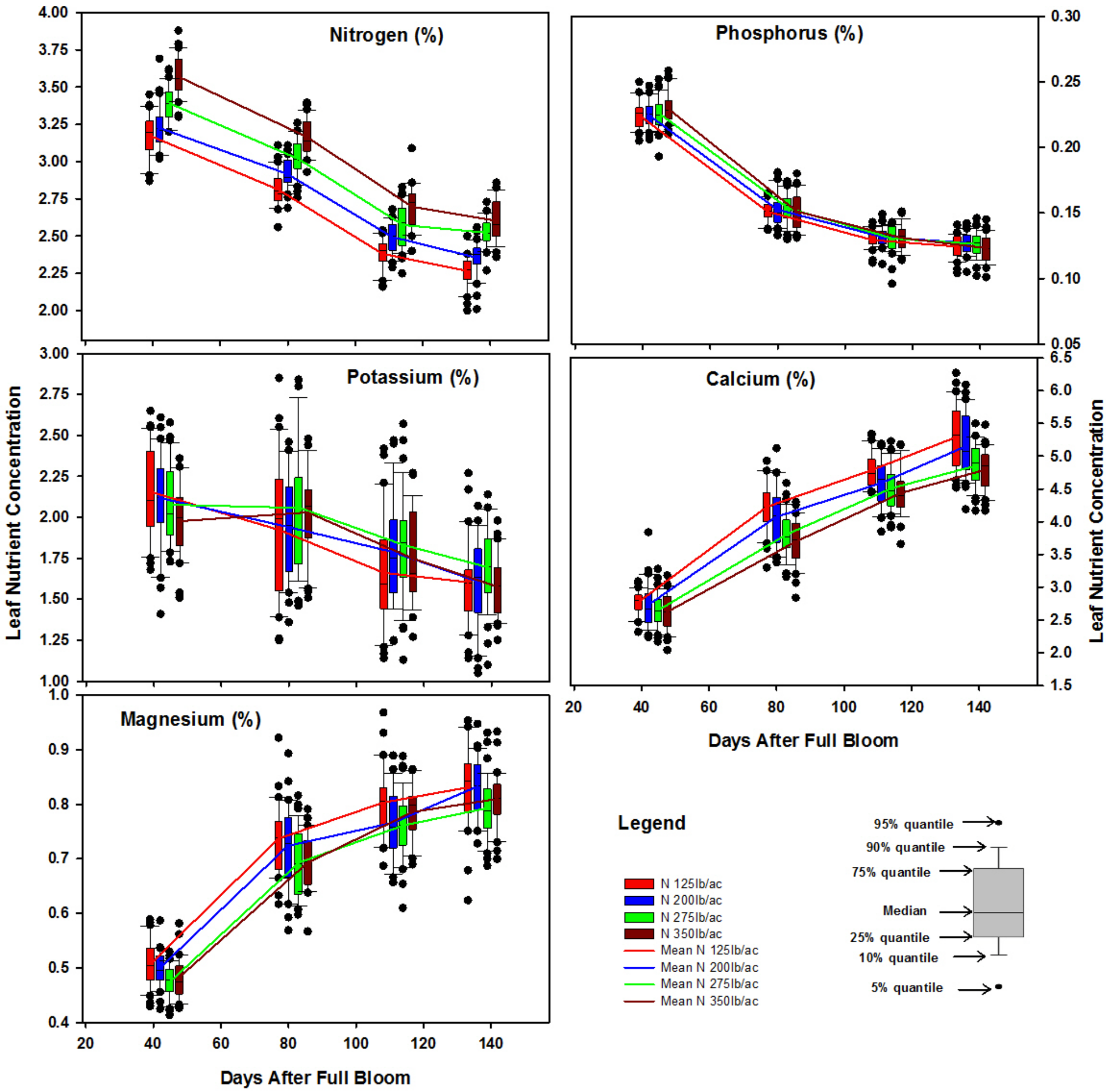


Figure 5. Effect of different nitrogen rates (N UAN 32) on leaf nutrient concentration in 2009 (for Fan Jet Irrigation). In box plots, the central line is the median of the distribution, the edges of the boxes are the 25% and 75% quantiles, error bars, represent the 10% and 90% quantiles, and all points are outliers

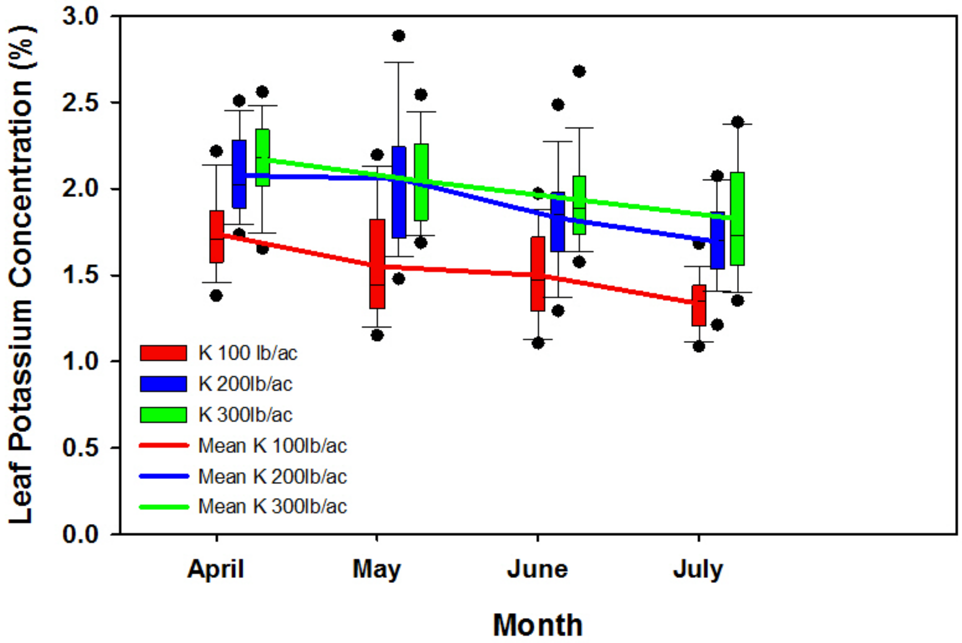


Figure 6. Effect of different Potassium rates (SOP+KTS) on leaf Potassium concentration in 2009. In box plots, the central line is the median of the distribution, the edges of the boxes are the 25% and 75% quantiles, error bars, represent the 10% and 90% quantiles, and all points are outliers

Fruit Nitrogen Concentration

Fruit nitrogen and phosphorus concentrations declined over time in all N rate treatments; fruit potassium showed a variable trend while there was slight decline in fruit calcium and magnesium concentration (**Figure. 7**).

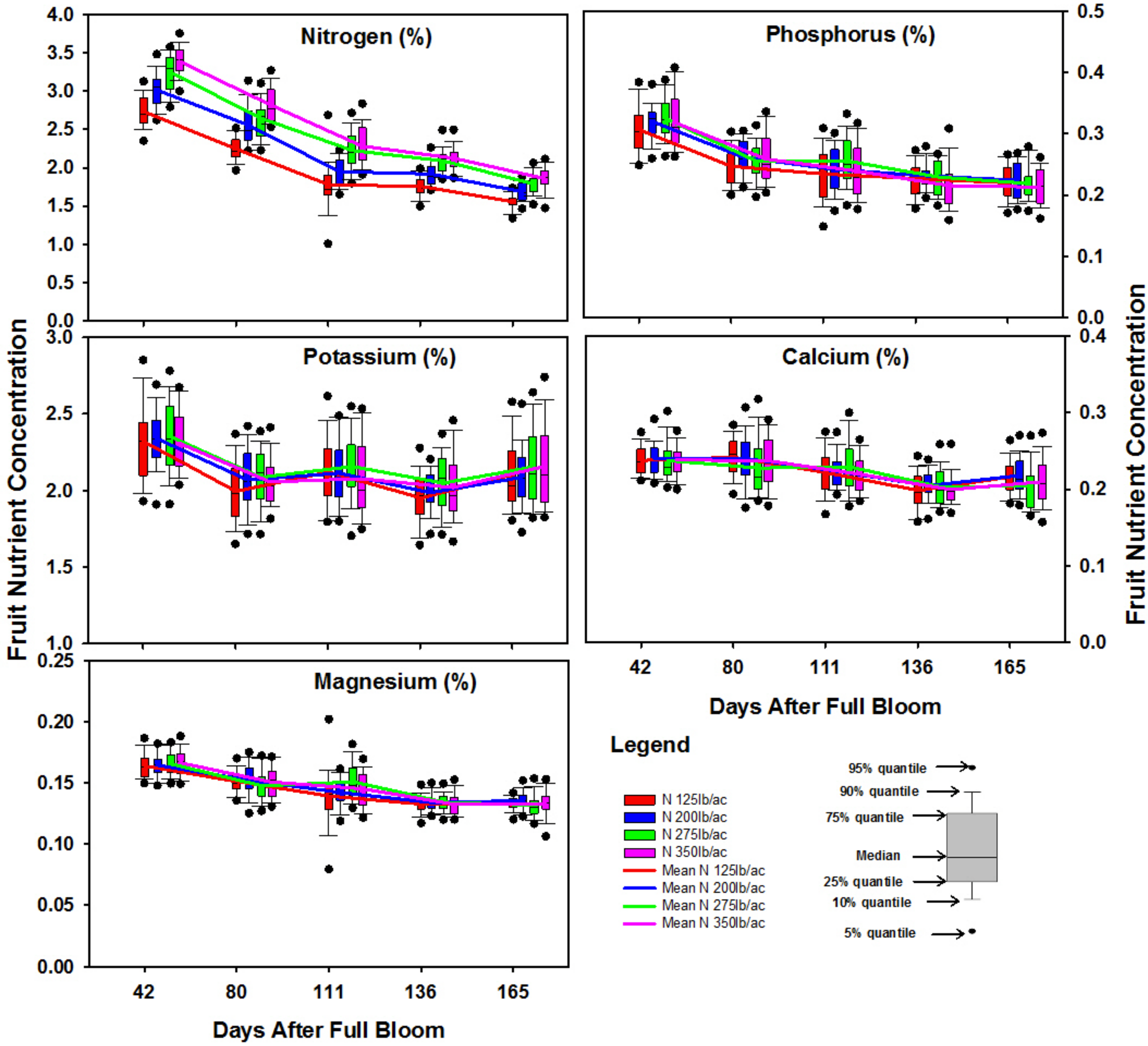


Figure 7. Nutrient concentration in Almond fruit over time for N rate treatments. Box plots illustrate the median of all samples (central line), the 25th and 75th quantiles (box edges), while error bars represent the 10% and 90% quantiles, outliers re shown as discrete points.

Yield

Crop yield varied substantially throughout the orchard even though the overall field performance was excellent and visible differences in tree vigor were not seen (**Figure 8**). Nitrogen treatments had a significant effect on crop yields in the second year of the experiment although differences were also observed in the first year. The effect of different treatments on kernel yield is presented in **Table 1**. Maximum kernel yield (3380 lb ac^{-1}) was obtained from the highest N rate treatment (350 lb ac^{-1}), while minimum yield was obtained from the lowest nitrogen rate treatment (125 lb ac^{-1}) under both drip and fan jet irrigation. The effect of the K rate and K source treatments on kernel yield was not statistically significant.

Table 2. Mean kernel yield (lb/ac) for different treatment in 2009; treatments not represented by same letter within irrigation are significantly different. (refer to **Table 1** for the description of letters).

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

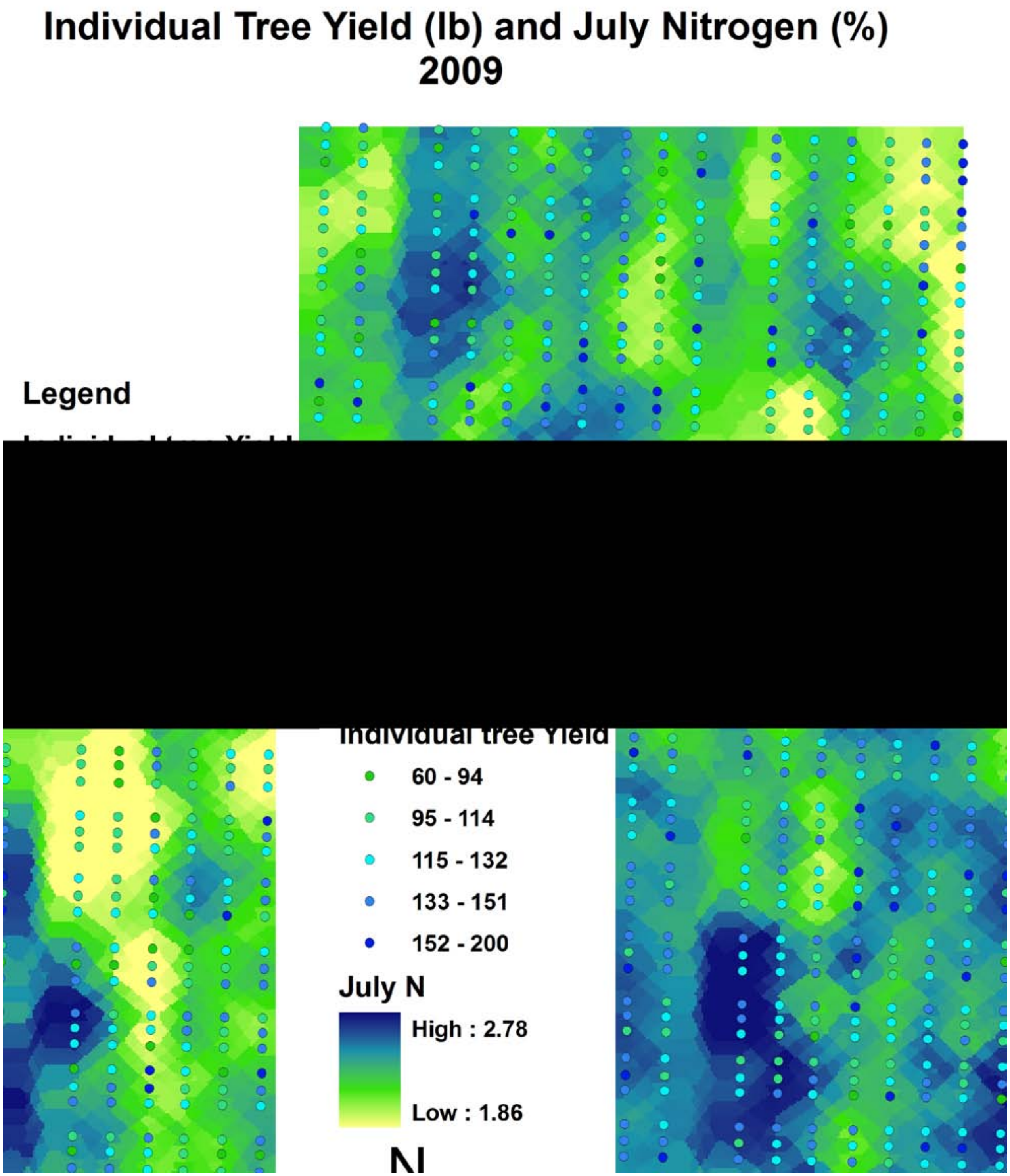


Figure 8. Yield map of the experimental trees and July nitrogen concentration

Discussion:

This is year two of a multi-year trial and hence results must be treated with caution. Increasing nitrogen supply significantly increased kernel yield and nitrogen concentration in the plant tissues. Trends in nutrient concentrations and fruit accumulation were evident early in the season and persisted throughout the year and may imply that early season sampling may be useful in monitoring of tree nitrogen demand. Nitrogen and phosphorus accumulation was highest at 136 DAFB and then decreased at harvest suggesting that N and P moved from the fruit to the shoot during nut maturation. Resoprtion of phloem mobile nutrients from fruit back toward tree woody structures has not, to our knowledge, been previously recorded. This effect was not seen with K, Ca, Mg, while small and statistically non significant resorption of sulfur also occurred. Results will be used to provide estimates of total nutrient demand and the timing of nutrient uptake from soils. Differences in tree response to N and K source have not yet been established.

Recent Publications:

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

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

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