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

Project Nos.: **08-HORT8-Brown**
08-WATER3-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 Best Management Practices for almond.

Interpretive Summary:

Results of a survey of almond growers and consultants in California, suggested that leaf sampling and comparison with established standards do not provide sufficient guidance for nutrient management. Two explanations for this observation are possible. 1) The current 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 within 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 preliminary evidence to postulate that the death of loaded spurs may be attributable to a local nutrient deficit throughout the season.

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, August and October and analyzed for essential plant nutrients. The results indicate that there is a significant effect of nitrogen rates on yield in year 1 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 year of the trial.

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 to 15 acre contiguous blocks. Leaf and nut samples from 114 trees are collected at 5 times during the season for a period of 3 to 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 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 neighboring orchard rows were treated as one experimental unit. All data was 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, August and October. 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. Two kilogram samples were collected from 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.

Results and Discussion:

Variability Trial

This observational study illustrates nutrient dynamics throughout the season. Data from the first year of sample collection (2008 field season; **Figure 1**) suggest that nutrient concentrations and their variability depend on the nutrient sampled, sample type and sampling time.

Local fruit load, for example, appeared to significantly affect concentrations of N, P, K, B, Zn, S, and Cu. Other nutrients, such as Ca, Mg, Mn and Fe were much less affected by local fruit load. A clear effect of local competition between fruit and leaf can be observed for some nutrients. This competition may be critical for explaining nutrient mobilization from leaves to local nut load.

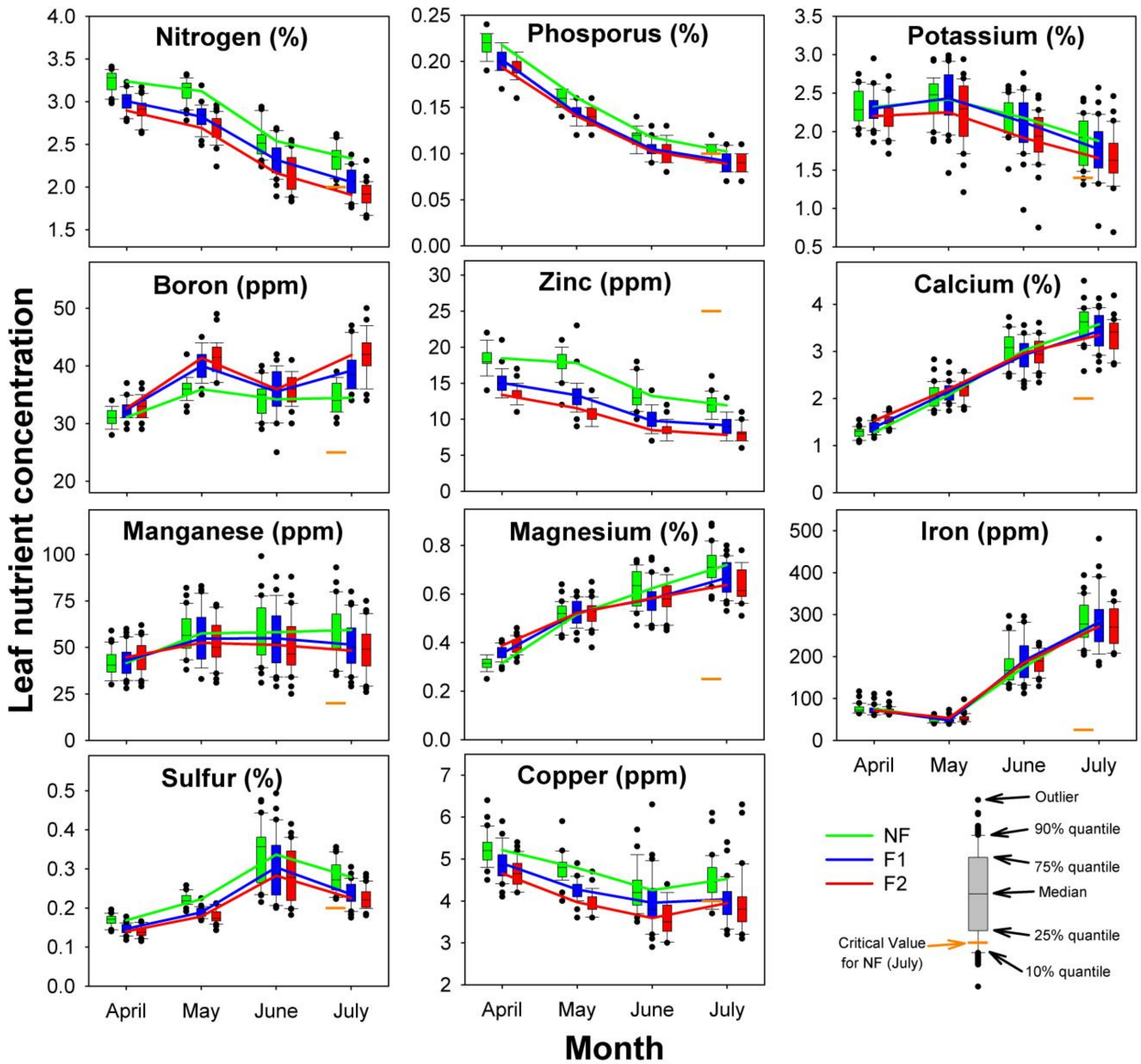

Figure 1. Nutrient behavior throughout the season in leaves from non-fruiting spurs (NF), spurs with 1 fruit (F1), and spurs with 2 fruits (F2). The graphs show data collected from the Arbuckle orchard during the 2008 season.

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 F/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.

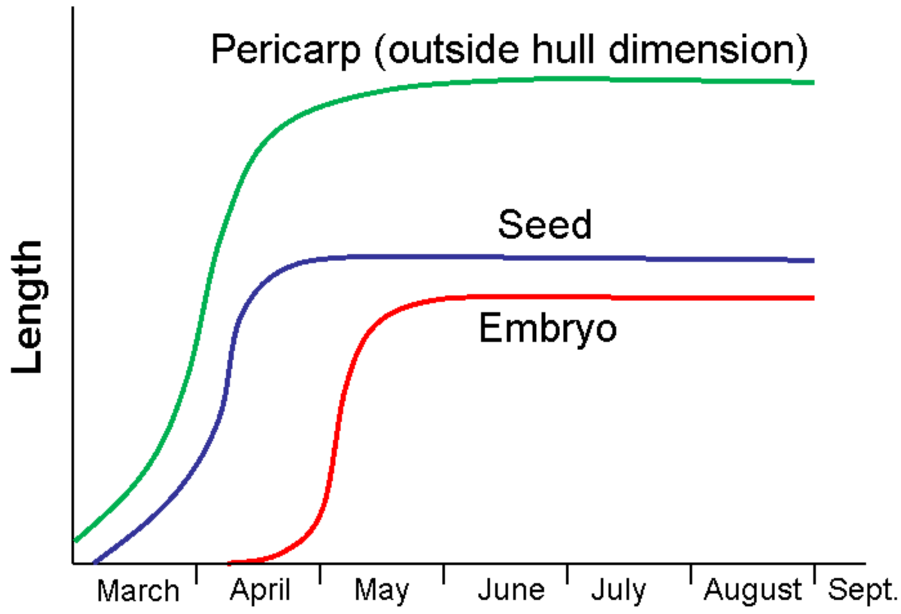

Figure 2. Conceptual representation of fruit development through out the season

The pattern of nutrient increase/decrease with time closely correlates with the pattern of total dry weight accumulation in fruit over time and suggest that fruit growth drives nutrient dynamics in almond (**Figure 2**).

Fertigation Trial

The accumulation of Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Zinc and Boron in the fruit for different rates of N increased over the season is shown in **Figure 3**.

Nitrogen

Nitrogen accumulation in the fruit was positively correlated with nitrogen supply at all sampling dates. At 30 DAFB 89 lb/ac N was accumulated for N rate 125 lb/ac, 97 lb/ac for N rate 200 lb/ac and 275 lb/ac, while 110 lb/ac N was accumulated for N rate 350 lb/ac. Nitrogen accumulation increased in all treatments and was maximal at 136DAFB. 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.

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 and P but not with any other element.

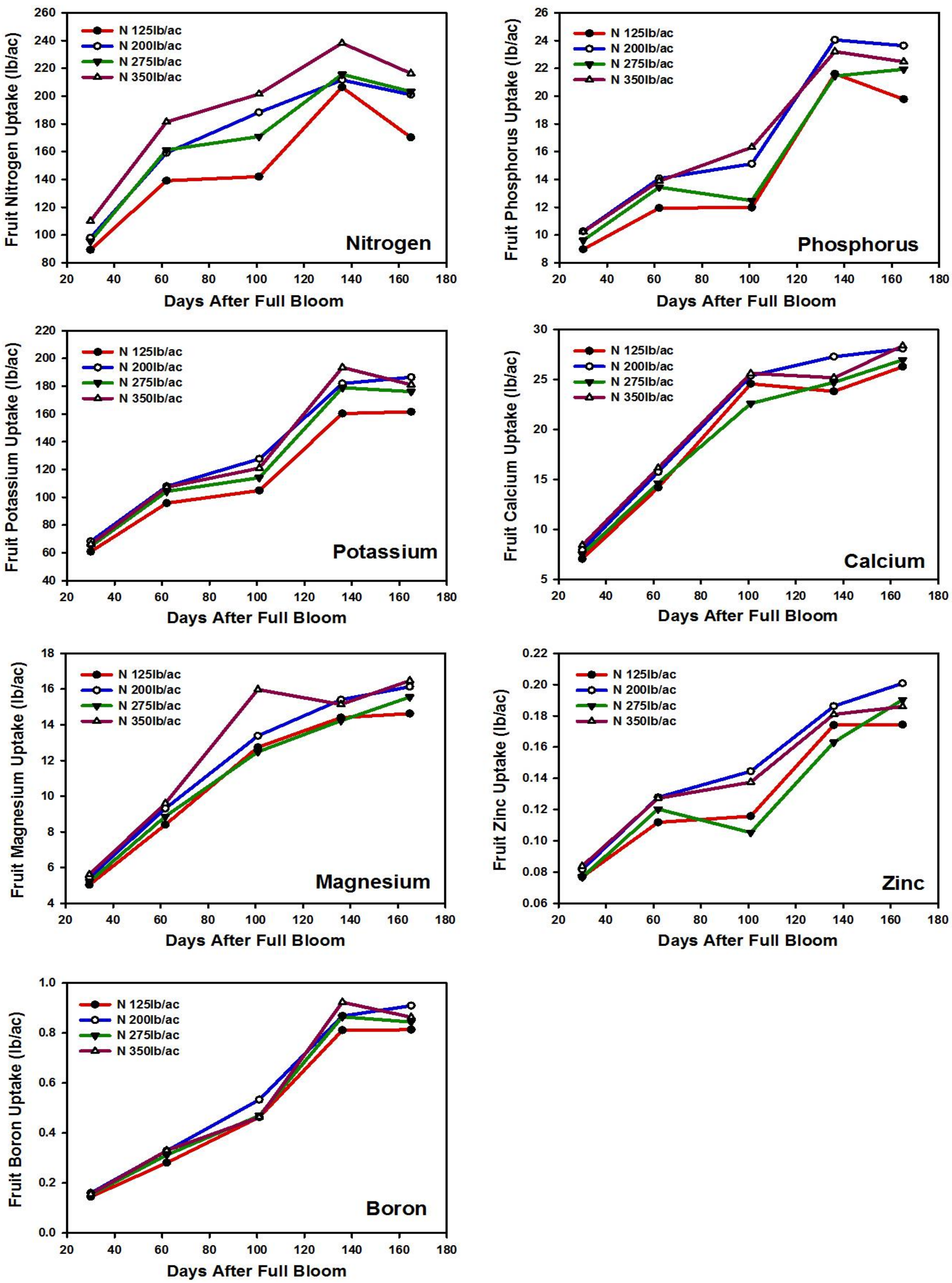

Figure 3. Nitrogen, Phosphorus, Potassium, Calcium, Magnesium Zinc and Boron uptake by almond fruit from nitrogen rate treatments

Potassium

Fruit potassium accumulation increased overtime but was not significantly influenced by K treatment (**Figure 4**).

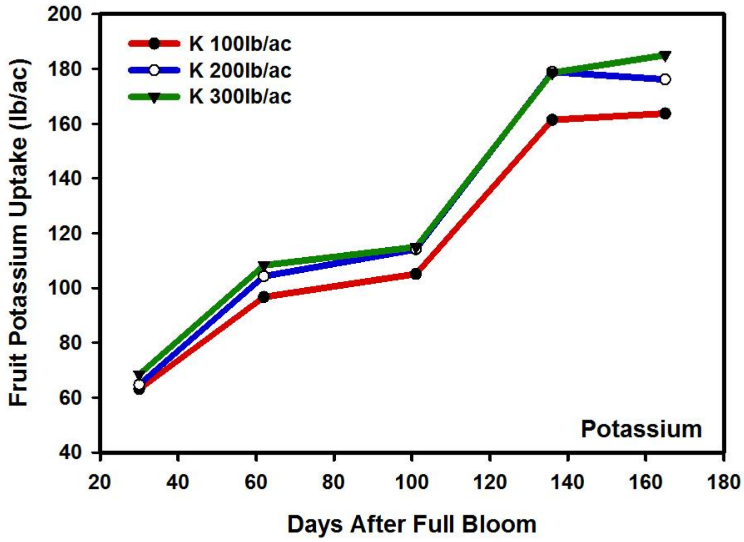

Figure 4. Potassium uptake by almond fruit from potassium rate treatments

Fruit Nitrogen Concentration

Fruit nitrogen concentration declined over time in all N rate treatments (**Figure 5**).

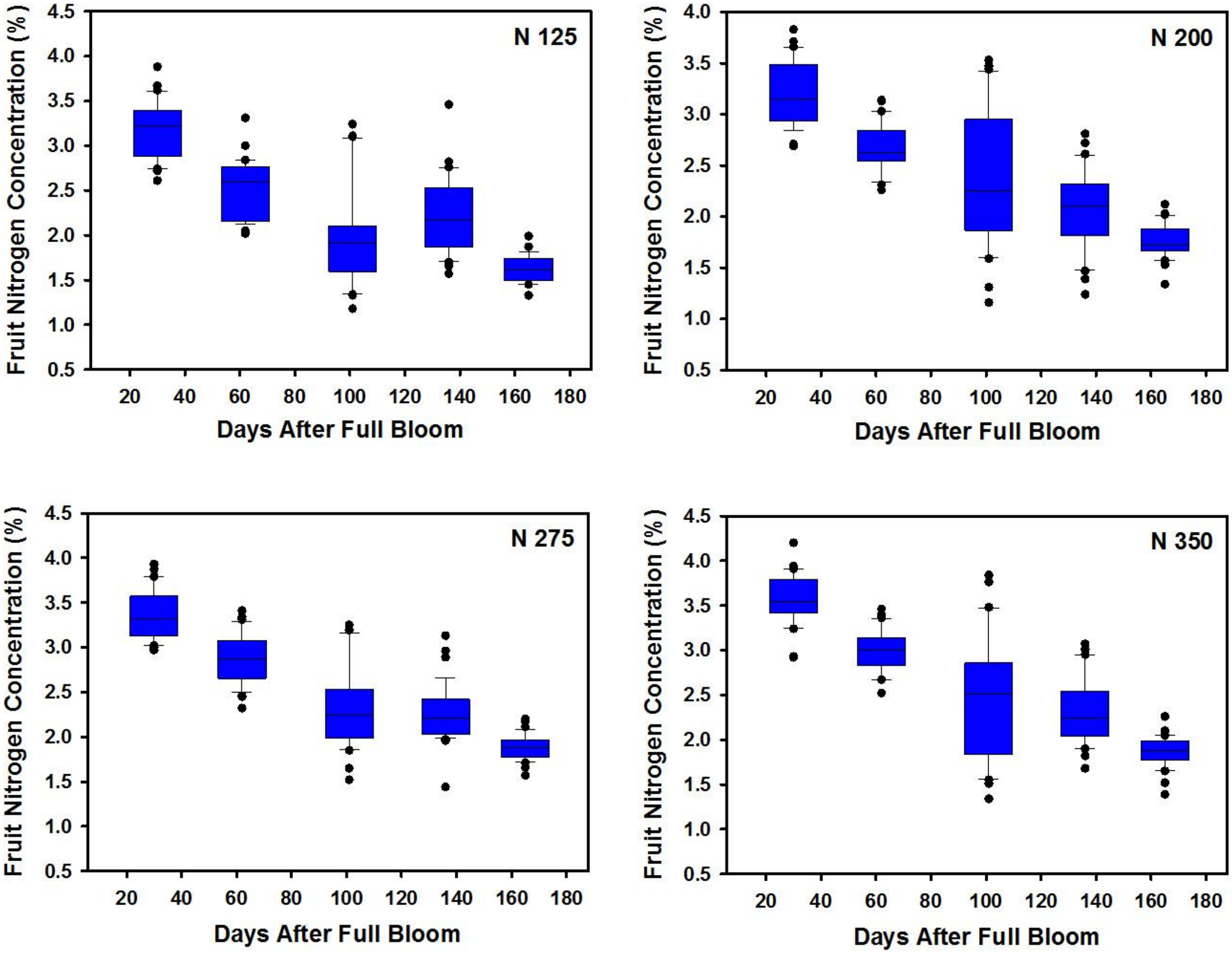

Figure 5. Nitrogen concentration in almond fruit over time for N rate treatments. Box plots illustrate the median of all samples (central line), the 25th and 75th quantiles (box edges), while error bars represent the 10% and 90% quantiles; outliers are shown as discrete points.

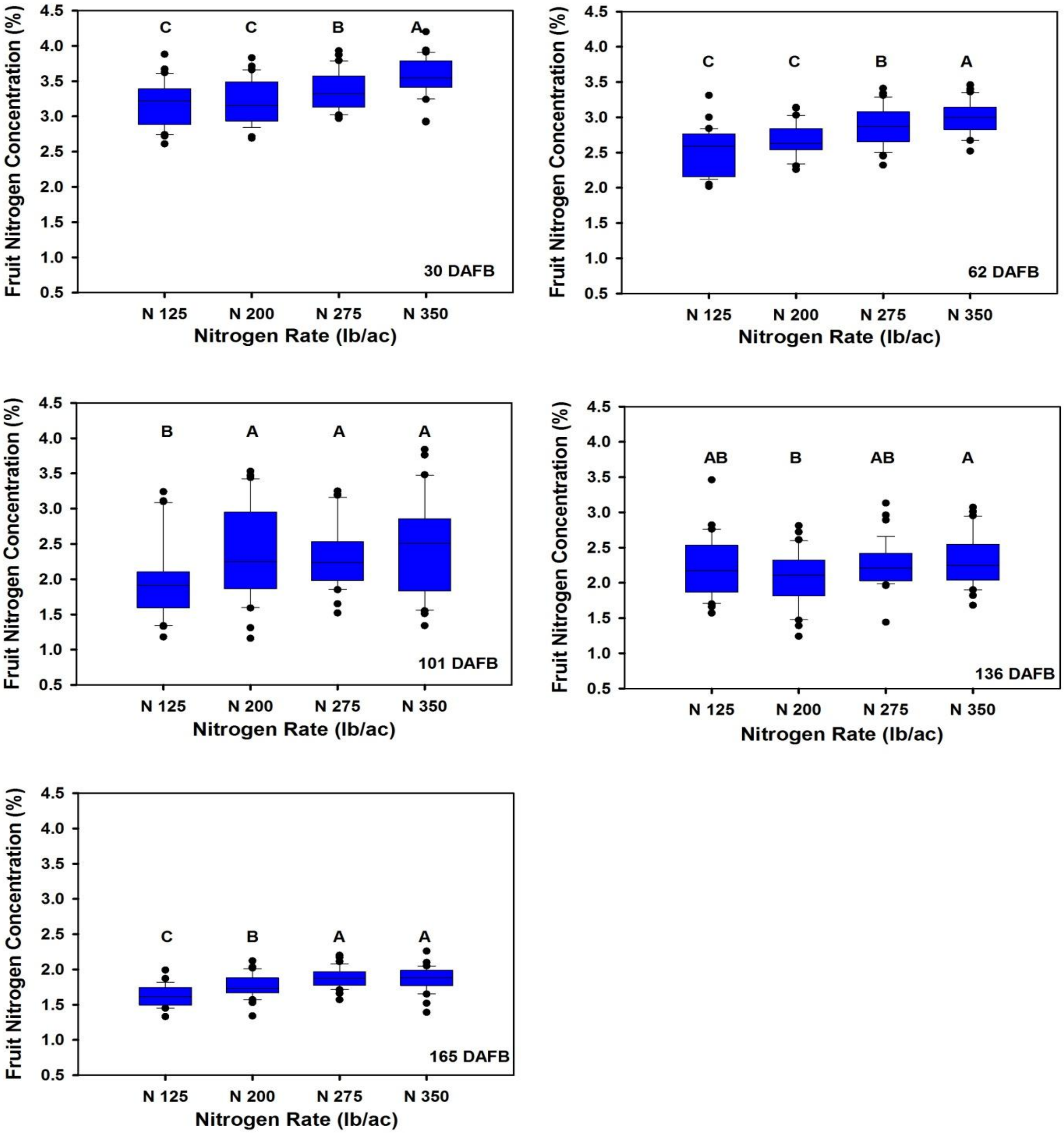

Figure 6. Fruit nitrogen concentration under different N rates. Box plots illustrate the median of all samples (central line), the 25th and 75th quantiles (box edges), while error bars represent the 10% and 90% quantiles; outliers are shown as discrete points.

Yield

Crop yield varied substantially throughout the orchard (**Figure 7**). Even though this experiment was only established in spring 2008, nitrogen treatments had a significant effect on crop yields in year 1 of the experiment (**Figure 8**). Maximum fruit yield (11,400 lb ac^{-1} – total dry fruit weight) was obtained from the highest N treatment (350 kg ha^{-1}), while minimum yield (10,300 lb ac^{-1}) was obtained from the lowest nitrogen treatment (125 kg ha^{-1}; **Figure 7**). The effect of the K rate treatments on fruit yield was not statistically significant.

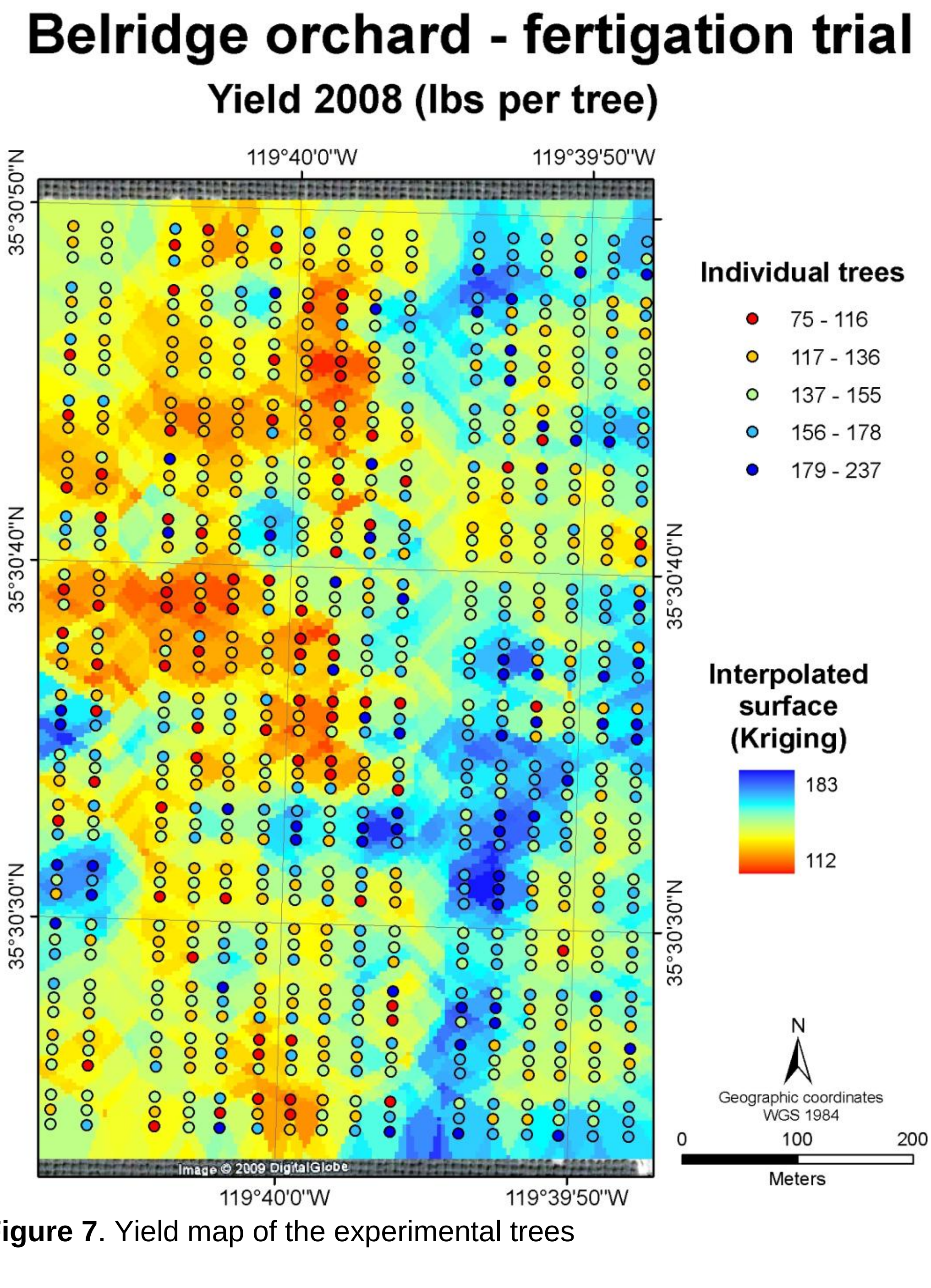

Figure 7. Yield map of the experimental trees

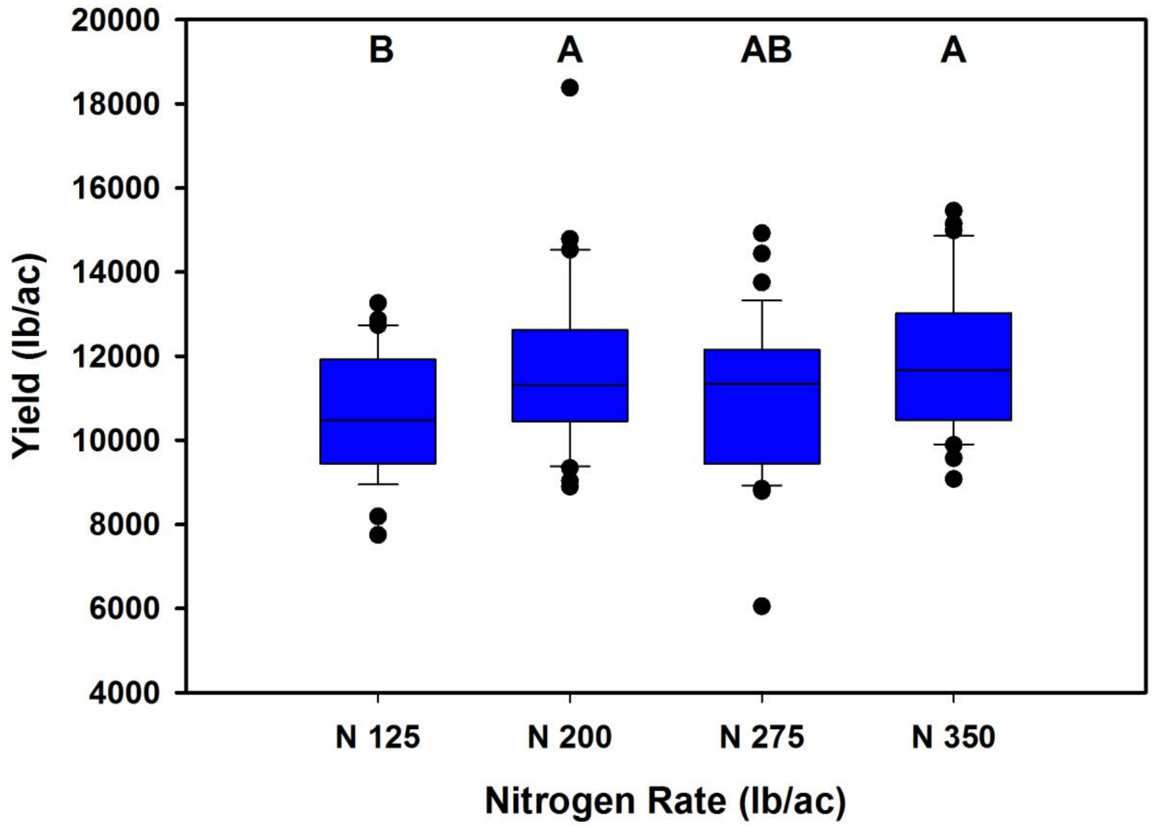

Figure 8. Effect of different nitrogen rates on almond yields at Belridge, CA in 2008.

Discussion:

Results from a single year of experimentation should be interpreted with care as treatment effects may not be fully established and multi-year effects cannot be discerned. Increasing nitrogen supply, however, significantly increased fruit yield and nitrogen concentration in the plant tissues and these differences existed between treatments at all sample dates. 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. The resorption of N and P was high for the lowest N rate (125 lb/ac) suggesting that relative tree demand can influence N resorption. Resportion 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 and Zn. 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 will be presented at the XVII International Plant Nutrition Conference in Sacramento, August 2009.

References:

Almond Board of California 2008. 2007 Almond Acreage Report. www.almond-board.com

Almond Board of California. 1972-2003. Years of Discovery. pp. 285-296.

ANR, 1996. Almond Production Manual. ANR Publication 3364. University of California Agriculture and Natural Resources.

Beutel J, Uriu K, Lilleland O. 1978. Leaf analysis for California deciduous fruits. In: Reisenauer HM (ed.) soil and plant-tissue testing in California. pp 11-14.

Brown P. H, and Uriu K. 1996. Nutrition deficiencies and toxicities: diagnosing and correcting imbalances. In: Almond production manual. University of California, Division of Agriculture and Natural Resources. Publication 3364.

Halevy J. Marani A. Markovitz T. 1987. Growth and NPK uptake of high yielding cotton grown at different nitrogen levels in a permanent-plot experiment. Plant and Soil 103, 39-44

Huett DO 1986. Response to nitrogen and potassium of tomatoes grown in sand culture. *Aust.* J. *Exp.* Agric., 1986, 26, 133-138

Karlen, D.L; Flannery, R. L and Sadler E. J. 1988. Aerial Accumulation and Partitioning of Nutrients by Corn. Agron. J. 80:232-242

Meyer RD. 1996. Potassium fertilization/foliar N/P/K/B studies. In: Almond Board of California. 1972-2003. Years of Discovery. pp 291-292.

Nyomora AMS, Brown PH, Krueger B. 1999. Rate and time of boron application increase almond productivity and tissue boron concentration. HortScience 34: 242-245.

Reidel EF, Brown PH, Duncan RA, Heerema RF, Weinbaum SA. 2004. Sensitivity of yield determinants to potassium deficiency in 'Nonpareil' almond (*Prunus dulcis* (Mill.) DA Webb). J Hort. Sci Biotech. 79: 906-910.

Uriu K. 1976. Nitrogen rate study. In: Almond Board of California. 1972-2003. Years of Discovery. p 287.

Weinbaum SA, Carlson RM, Brown PH, Goldhamer DA, Micke WC, Asai W, Viveros M, Muraoka TT, Katcher J, Teviotdale B 1990. Optimization of nitrogen use. In: Almond Board of California. 1972-2003. Years of Discovery. pp 289-290.