CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

FINAL REPORT

PROJECT INFORMATION

1. **Project Title:** Developing Nutrient Budget and Early Spring Nutrient Prediction Model for Nutrient Management in Citrus

2. **Project's duration:** 3 years (2017-2019)

3. **Grant number:** 16-0707-SA

4. **Project Leaders:**

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A. Objectives

1. Develop nutrient demand curves to guide the quantity and time of fertilizer application in mandarin and orange based on crop phenology.
2. Develop an Early Season leaf sampling and nutrient prediction model for mandarin and orange.
3. Develop and extend nutrient Best Management Practices for citrus species.

B. Abstract

Increasing awareness of the environmental impact of excess nitrogen (N) and new N management regulations demand user-friendly tools to help growers make fertilization decisions. Currently, nutrient management decisions in citrus are based on leaf analysis and critical value interpretation which only indicates a deficiency or sufficiency and is performed too late to respond to deficiencies or plan N applications. In other high value crops such as Almond, Pistachio and Walnut, nutrient management is increasingly based on early season leaf sampling, stage of plant growth and estimated crop demand. This approach has not been developed for citrus species in California and hence citrus growers do not have improved fertilizer management decision tools to apply the right rate of fertilizer at right time, to optimize productivity and avoid environmental losses. Current approaches to nutrient management in citrus rely heavily on leaf sampling collected during late summer which is too late to respond to deficiencies or adjust fertilizer regimes. The utility of leaf sampling can be improved if samples are collected early in the season so that farmers have enough time to respond to current tree nutrient status. Protocols for early season leaf analysis have not been developed in citrus. In this project we monitored highly productive groves of mandarins and orange in Kern, Fresno, and Tulare Counties during two growing seasons. 25 highly productive orchards of each mandarin and orange were selected and a composite leaf sample from 20 trees in each grove were collected from fully expanded leaves from the spring flush and in the summer. The samples were analyzed for N, P, K, S, Ca, Mg, Zn, B, Mn, Cu and Fe. A holistic nutrient management protocol is being developed to guide the fertilization rate and time of fertilizer application as well as in season monitoring to adjust fertilizer rate to optimize yield and reduce leaching of nitrate to ground waters.

C. Introduction

Excessive use of nitrogenous fertilizers in high value agriculture crops has resulted in the contamination of ground water with nitrate and in many parts of California, ground water nitrate levels exceed the EPA standard of drinking water quality of 45ppm nitrate. This is partly due to lack of best nutrient management protocols. Currently nutrient applications in citrus are based largely on leaf sampling and application of critical value analysis. Critical value is the nutrient concentration in a standard leaf sample at which yield is 90% of the maximum yield. This approach provides an indication of adequacy or deficiency but little specific information on appropriate fertilizer rates or timing of applications. Although the critical value approach has been a valuable tool to identify deficiencies and toxicities this approach is not sensitive to over fertilization and is collected too late in the season to be used as a management tool. Leaf sampling has been found to be an inadequate tool for N management in high value crops since it is inadequately sensitive to N fertilizer applications.

In almond for example, N application in excess of crop demand (4,000 lb yield) from the just adequate amount of 275 lbs. N/acre to 350 lbs. N/acre did not significantly increase the concentration of N in leaves, additional yield, or tree growth. The insensitivity of leaf critical value to over fertilization in perennial crops may have contributed to the over application of N fertilizers and excess N being lost to the environment, resulting in the accumulation of N in the ground water in California.

'Crop logging', or 'nutrient budgeting' is a more sophisticated and appropriate method to make nutrient decisions. The nutrient budgeting approach requires an early season estimation of expected yield and tree nutrient status, a mid-season update of the yield estimate and in season adaptation of N applications. To establish this methodology, it requires development of annual nutrient uptake curves and methods to conduct nutrient sampling in the early spring. This approach has not been developed for the various species of citrus under the conditions of California.

In the US, a majority of the citrus are produced in Florida and California. There has been relatively few research study on total N demand of citrus species in California in 1960 and 70s and in Florida. The seasonal pattern of N demand in a relatively low yielding blood orange orchard was determined in a single orchard in Italy. Research conducted in Florida for a 340 filed box yield of mature orange, suggests an N demand for crop and tree growth of 100 lbs N per acre and suggests that an efficiency of 50-60% N use can be achieved. This rate of N loss will not meet the proposed N management guidelines being developed for California. Labanauskas and Handy (1972) conducted experiments in Valencia oranges in California in 1960s and found that Valencia orange removed 1.85 lbs N per 1000 lbs fresh fruit, but they did not monitor the seasonal N demand. Roccuzzo *et al.* (2012) conducted research in Red Blood Oranges in Italy and found 1.3 lbs N per 1000 lbs fresh weight and also reported seasonal changes in N demand. Given the demand of the Irrigated Lands Regulatory Program, there is a clear need for more precise, season, species and yield dependent information on N removal in citrus.

Applying N more than the crop demand not only increase the potential for nitrate leaching, but also affects fruit yield and quality. Embleton et al (1978) reported in Valencia orange where an increase in leaf N level were associated with a reduction in fruit size, juice % and ascorbic acid, and an increase in peel thickness, coarseness of peel texture and amount of green color on peel at harvest time. Increasing N concentration in leaves over 2.4% reduced fruit size, slightly increased number of fruits and had no effect on yield volume.

Currently, citrus growers in California apply 150-200 lbs N per acre in 3-6 splits and monitor N adequacy by collecting leaf samples from 5-7 months old leaves in late summer (Personal communication with Graig Kallsen, UCCE Citrus Farm Advisor, Kern County).

One of the major perceived constraints with current protocols for leaf sampling in fruit trees is that samples are collected too late in the growing season to be of use for current season nutrient management decisions. This problem is particularly evident since over 80% of N uptake occurs by the time results of a late summer tissue sampling are available to the grower. Late sampling limits the grower's ability to make in-season fertilizer adjustments and may encourage late-season fertilizer application that is inefficient and can result in groundwater contamination. In almond and pistachio an early spring tissue analysis to predict N concentrations in summer has been developed that provides enough time to adjust in-season fertilizer application. The same approach can be developed for Citrus.

Citrus yield and quality can be improved, and nitrate leaching potential can be significantly reduced by adopting better fertilizer management approaches including nutrient budgeting, early season leaf analysis and in-season monitoring and adaptive fertilization. This requires the development of a protocol to guide the rate and time of N applications and in-season monitoring to adjust fertilizer rate during season.

D. Work description

Activity 1. Develop nutrient demand curves that guide the quantity and time of fertilizer application in mandarin and orange (*Years 1 and 2*).

12-15 years old highly productive groves of each mandarin and orange were selected in Fresno County and another additional orange grove was selected in Tulare County (Figure 1). Trees that represent optimum leaf N concentrations (2.4-2.6% for oranges) and not showing any deficiency of other nutrients were selected.

Figure 1. Highly productive groves of mandarin (A-B) and orange (C-D) selected in Fresno and Tulare Counties for sampling.

Three trees of each species were excavated in March of 2017 and 2018 before flowering and were separated into small and large roots, trunk, scaffold, canopy branches, small branches, and leaves (Figure 2). Three additional trees of each species were also excavated at the end of the second season (2019) to determine total biomass accumulation during the growing season. Trees were excavated using a backhoe and were divided into the following parts for analysis: roots, trunk, scaffold, canopy, branches, and leaves.

Figure 2. Highly productive groves of mandarin and orange were excavated and separated into small and large roots, trunk, scaffold, canopy branches, small branches, and leaves.

In addition, we monitored three replicated blocks of trees of each species in Fresno county and one additional orange grove in Tulare county for changes in nutrient concentration in annual (leaves and fruits) and perennial organs (roots, trunk, scaffold, canopy branches and small branches) six times during the season at different phenological stages (Figure 3). The sampling was replicated in the second year of the project (2018-2019) by monitoring the same trees for changes in nutrient concentration and biomass. Samples were collected from different tree organs as follow:

- Roots: several root sections were dug randomly from around the trunk from roots <1cm and >1cm diameter;
- Trunk: two 5.0cm-deep holes were drilled;
- Scaffold: three 2.5cm-deep holes were drilled;
- Canopy branches: five 1.0cm-deep holes were drilled;
- Small branches: one and 2 years old branches were sampled randomly from each tree canopy;

- Leaf and Fruit samples: Leaves of different age from the same tree were collected. Fruit samples were also collected at the same time.

Figure 3. Fruit (A), branches (B), and trunk (C) sampling.

The samples were ground and are being analyzed for N, P, K, S, Ca, Mg, Zn, B, Fe, Mn and Cu at the UC Davis Analytical Lab.

Activity 2. Develop Early Season Nutrient Prediction Model for major species of citrus (*Years 1 and 2*).

25 highly productive orchards of each mandarin and orange were selected in Fresno, Tulare, Kern and Ventura Counties (Figure 4 and 5). A composite leaf sample from 20 trees in each grove were collected from fully expanded leaves from the spring flush. In the summer, 4 months old leaves from the same tree were collected. The samples were oven dried, ground, and sent to be analyzed for N, P. K, S, Ca, Mg, Zn, B, Fe, Mn, and Cu at the UC Davis Analytical Lab.

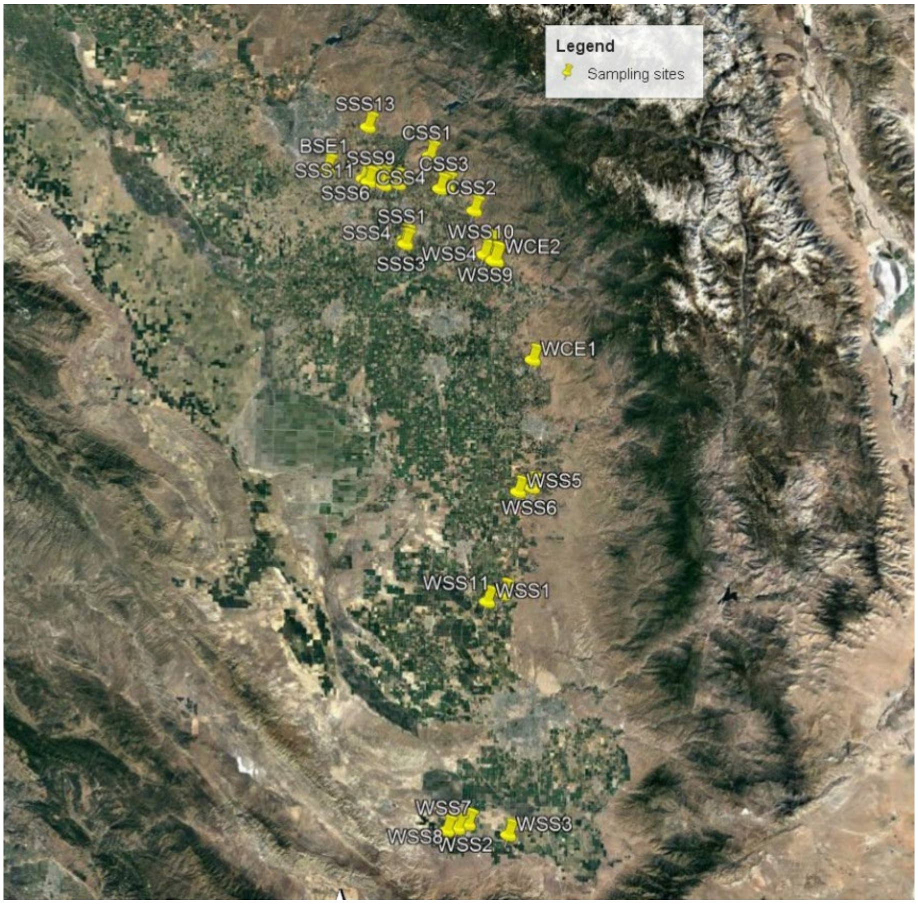

Figure 4. Location of the sampling sites in Fresno, Tulare, and Kern Counties.

The leaf prediction model is being developed and will be validated using samples from 25 groves of each mandarin and orange sampled in different counties.

Figure 5. Highly productive orchards of mandarin and orange were selected in Fresno, Tulare, and Kern Counties.

Activity 3. Develop and extend nutrient Best Management Practices for citrus (*Year 3*).

The combination of nutrient budget, seasonal changes in tree N content and in-season prediction of tissue nutrient status will help in developing a robust new fertilizer management tools for citrus growers of California. The finding from the research will help in development of the 'Right Rate' and 'Right Time' to guide N applications. A computer based model is being developed and will be available for the grower to estimate their crop fertilizer needs based on phenology, plant age, environment, crop load and yield.

E. Results:

Tree biomass and nutrient content

Total nutrient amounts per tree was obtained by summing the nutrient content of tree organs calculated by multiplying the dry weight of each tree organ by its nutrient concentration. Data refer to the average of three trees excavated in 2017, 2018, and 2019 for each mandarin and orange blocks. Branches and leaves accounted for the majority of the biomass in both orchards. Small branches and leaves also included a notable fraction of nutrients present in aboveground tissues as shown in Figure 6.

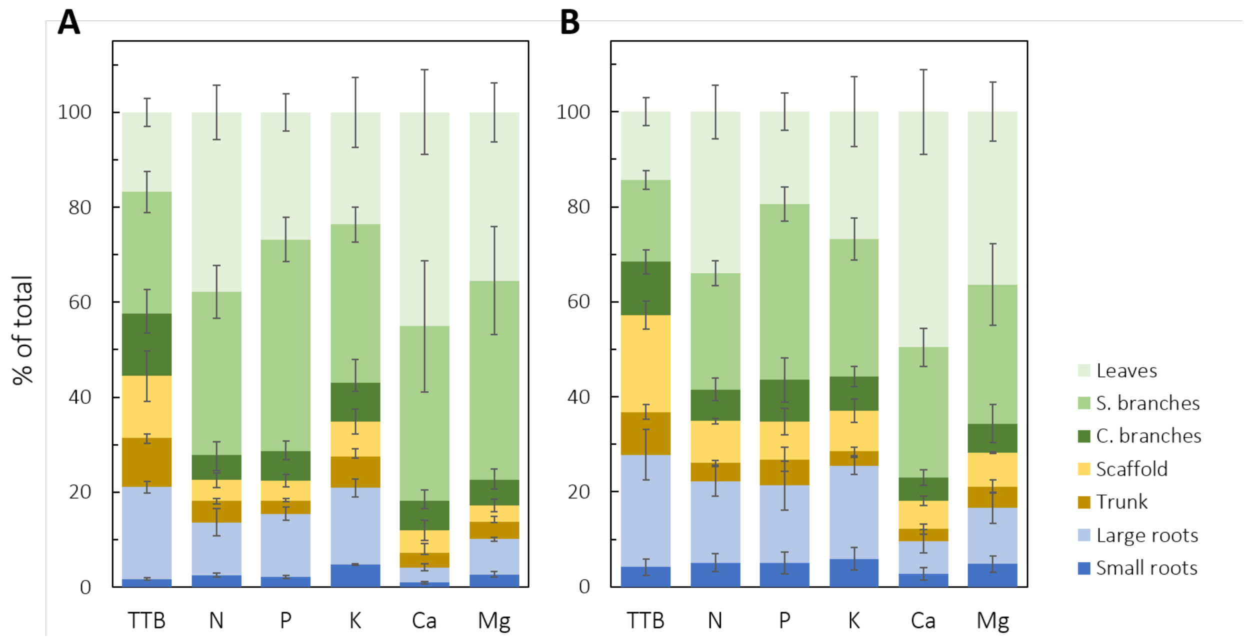

Figure 6. Tree partitioning (% of total) of total tree biomass (TTB) and macronutrients (N, P, K, Ca, and Mg) content. Data refer to Block I – Mandarin (A), and Block II – Orange (B). Bars represent standard errors.

Dynamics of Nitrogen uptake during the season

Seasonal N content in perennial organs (trunk, scaffold, canopy branches and roots), leaves and fruits of orange and mandarin trees are shown in Figure 7. Data refer to the average of 9 trees per orchard of each species. In general, the accumulation of N was rapid until the end of July/August for both species, while continued later with a lower rate. Low net accumulation of N after late October/early November was observed. From December to February the amounts of N present in the tree canopy remained stable or decreased, likely suggesting N translocation to fruits.

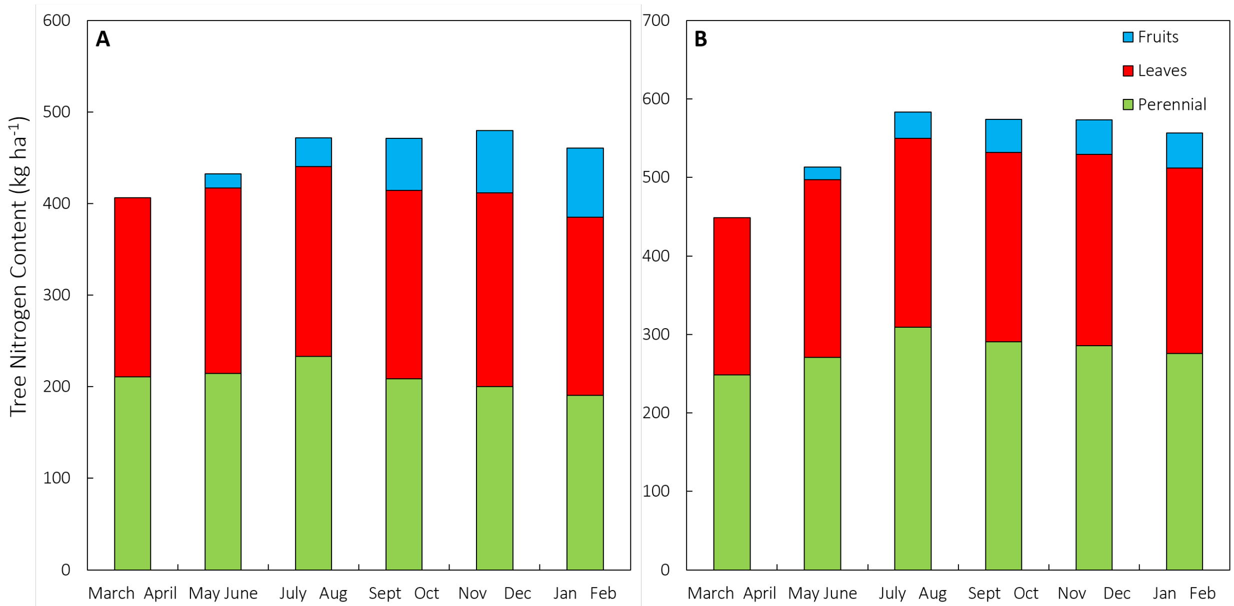

Figure 7. Seasonal trends in Nitrogen partitioning in fruits, leaves, and perennial organs (trunk, scaffold, canopy branches and roots) of mature orange (A) and mandarin (B) trees.

Seasonal nutrient content in aboveground organs (stems + leaves) and in leaves are shown in Figure 8 and 9, respectively. Data refer to the average of 9 trees per orchard. In general, the accumulation it was rapid until the end of June, while continued later with a lower rate. In general, no significant net accumulation of nutrients in the shoots after late October/early November was observed. From December to February the amounts of nutrients present in the tree canopy remained stable or decreased, likely suggesting nutrient translocation to perennial organs.

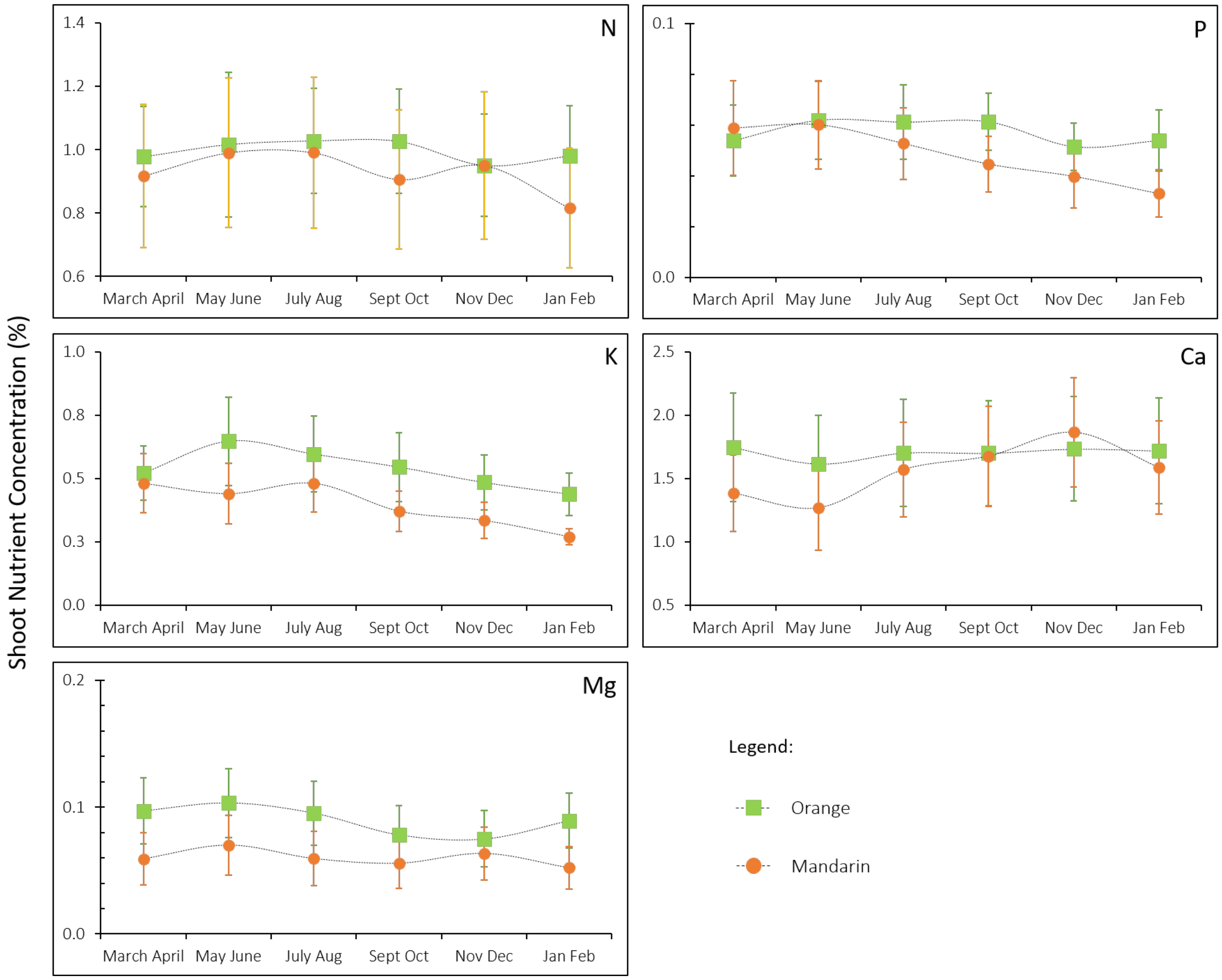

Figure 8. Seasonal trends in nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) accumulation in shoots (stem and leaves) during the season in orange and mandarin trees. Bars represent standard errors.

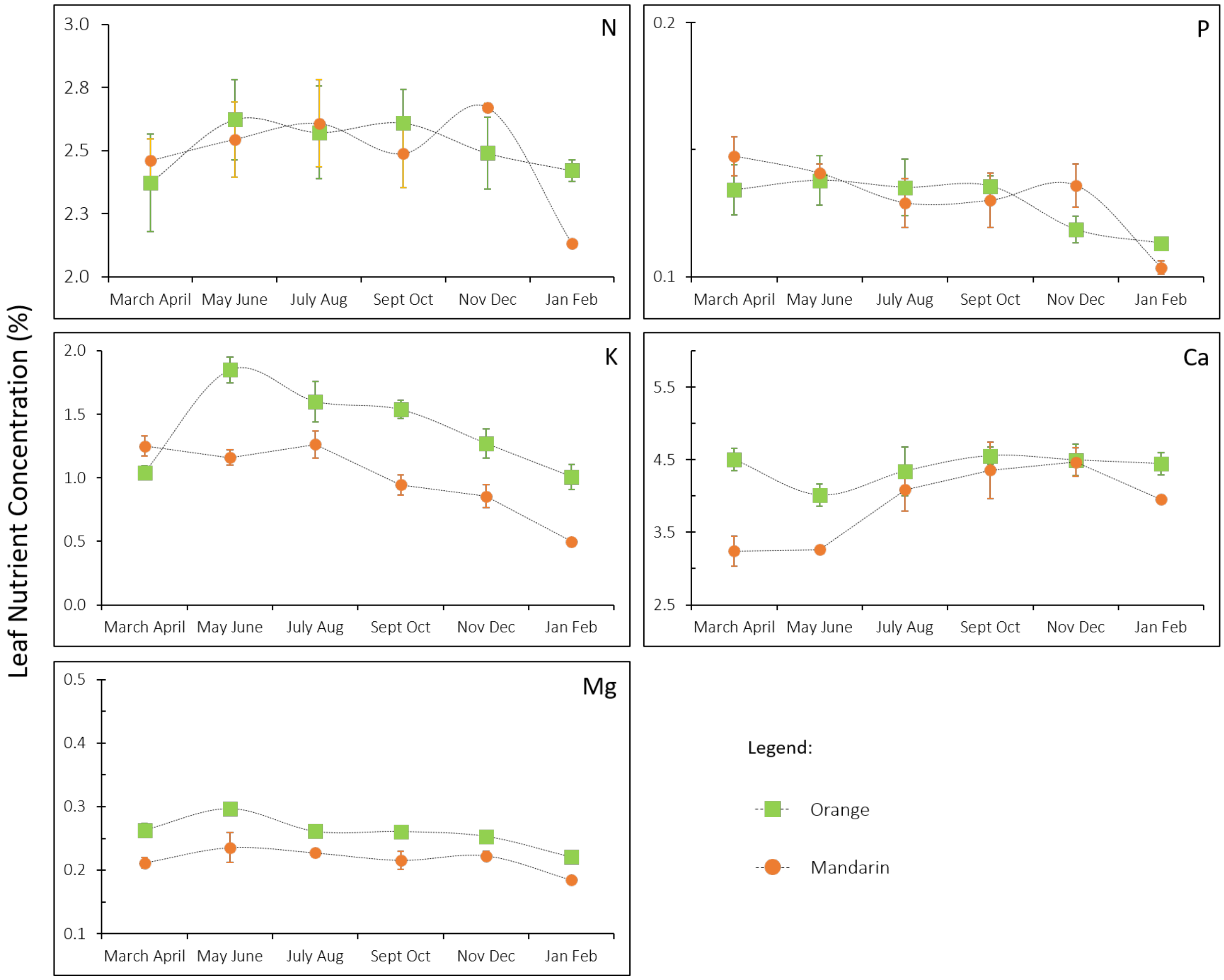

Figure 9. Seasonal trends in nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) accumulation in leaves during the season in orange and mandarin trees. Bars represent standard errors.

Seasonal pattern of nutrient accumulation in fruits

The patterns of N, P, K, Ca and Mg accumulation during the season are presented in Figures 10 and 11. The pattern of N accumulation over the season was generally consistent in both orange (Fig. 7) and mandarin (Fig. 8) fruits. Nitrogen accumulation occurred rapidly in the early season with 90% and 80% of the total N accumulated by September/October in orange and mandarin, respectively.

Phosphorus, potassium, calcium and magnesium accumulation pattern in fruits over time resembled the N accumulation curve in both species. In general, the concentrations of N, P, and K was high at the beginning of the season and stabilized until fruit harvest. Ca and Mg concentrations in fruit was high at the beginning of the season and declined until fruit harvest.

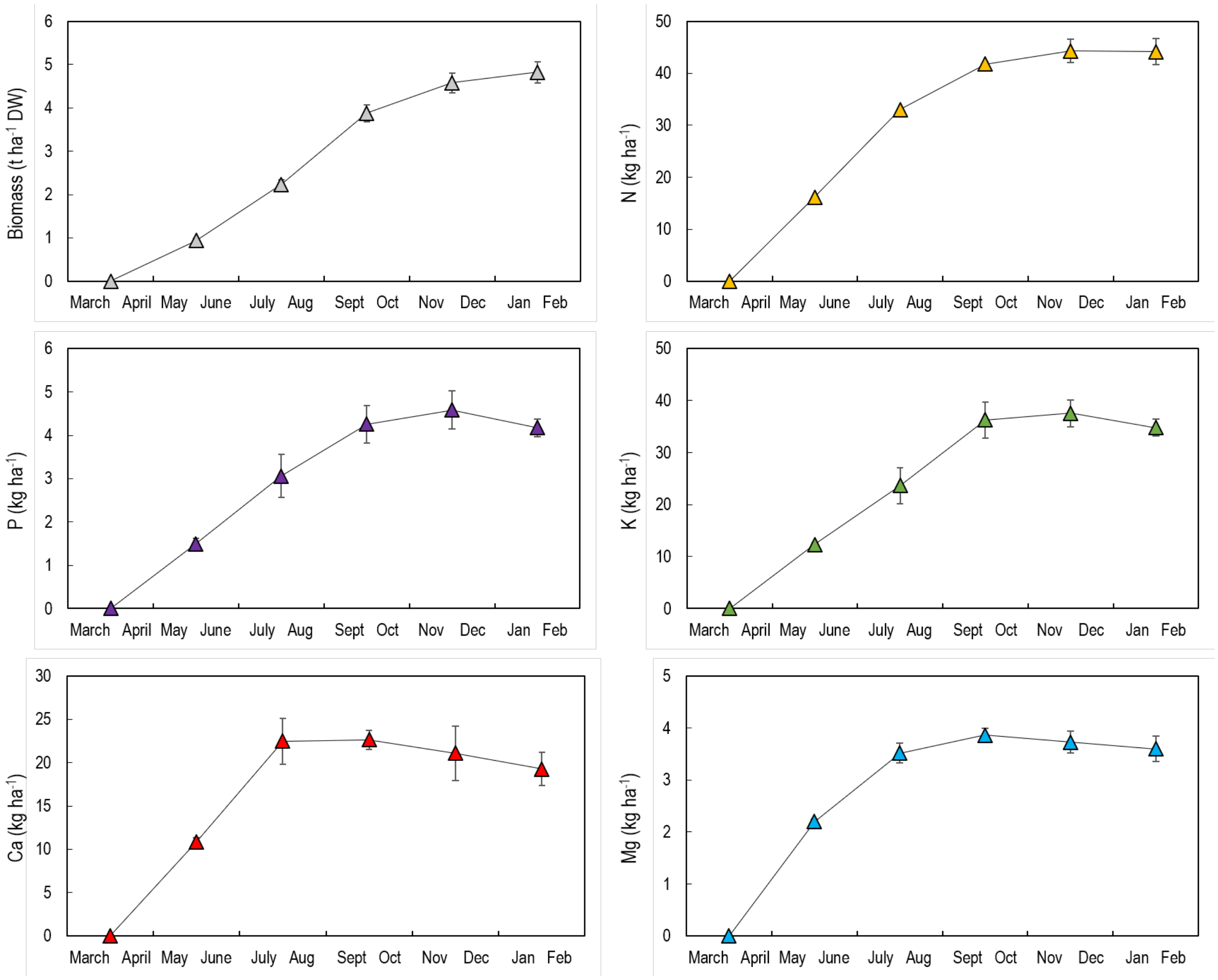

Figure 10. Seasonal trends in biomass and macronutrients accumulation in fruits of orange trees. Bars represent standard errors.

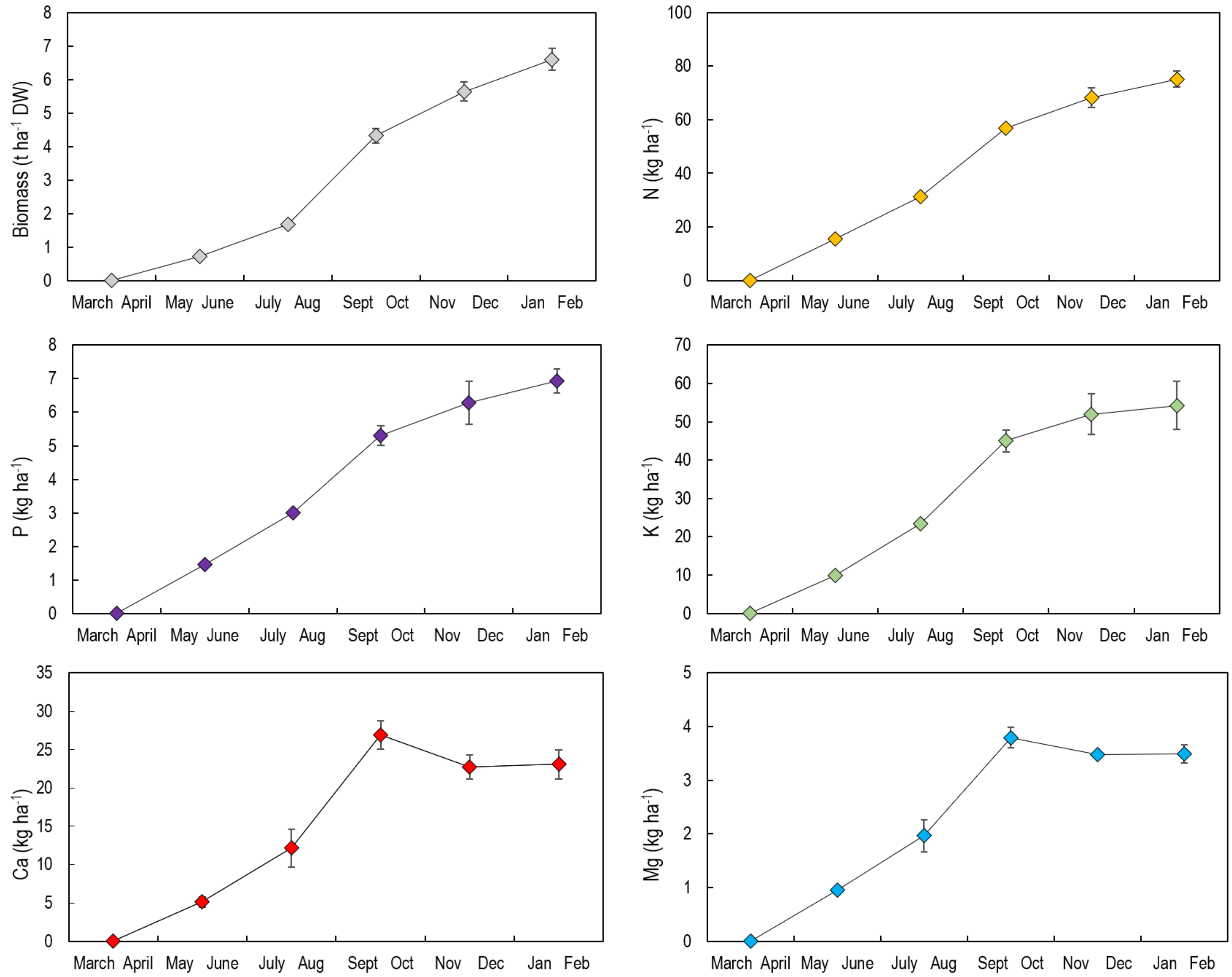

Figure 11. Seasonal trends in biomass and macronutrients accumulation in fruits of mandarin trees. Bars represent standard errors.

F. Discussion and Conclusions

To improve our understanding of whole orchard nutrient balance, we collected nutrient concentrations and biomass of all major organs of mature field grown citrus trees by whole tree excavation, sequential tissue sampling and nutrient analysis in trees grown under "ideal" nitrogen rate treatments. The amount of nutrient accumulated in perennial organs over two years (2017-2019) was determined as the difference between the total tree nutrient at the completion of each season.

The methodology used in this research allowed to estimate the annual amounts of nutrients that field grown orange and mandarin trees absorbed and allocated to above ground organs. Knowing the dynamics of nutrient uptake during the season is a requirement to allow the management of the timing of nutrient supply with nutrient needs and to avoid nutrient losses, especially Nitrogen (NO^-_3).

The seasonal demand of N in citrus is high early in the season from March through August with 80-90% of the total N accumulated by September in both species. Nitrogen uptake rapidly occurs from bloom and during fruit development, which also coincides with vegetative growth, and decreases during fruit maturation. Most of the other nutrients (P, K, Ca, Mg) followed the same pattern with a rapid accumulation at early stages of fruit growth and a decrease accumulation during fruit maturation.

Fruits are an important sink for nutrients and the pattern of nutrient accumulation through the season is largely driven by the pattern of fruit growth with most nutrients accumulated from cell division to cell enlargement. Nitrogen accumulation occurred rapidly in the early season with 90% and 80% of the total N accumulated by September/October in orange (Figure 12-A) and mandarin (Figure 12-B), respectively. In general, citrus fruit development starts with an initial increase in fruit size and this phase is completed by late August to early September; once the fruit reaches full size then fruit maturation starts. By September, fruits had gained 70-80% of their total weight. The majority of nutrient accumulation in citrus trees coincided with cell division-enlargement and the rate of fruit N accumulation decreased markedly after fruit maturation. In oranges, the export of Nitrogen was estimated to be 1.5 lbs. per 1000 lbs. of fruits and in mandarins, the export of Nitrogen was estimated to be 1.3 lbs. per 1000 lbs. of fruits. Biomass N accumulation was estimated to be 0.1 lb. of N per mature citrus tree.

To guide the fertilizer application in orchards, data about total amounts of absorbed nutrient should be integrated with information of their fate in the ecosystem. While we can assume that nutrients contained in fruits and those stored in the tree framework directly or indirectly leave the system – and therefore their reintegration to the soils should be considered, – part of the absorbed nutrients returns to the soil through leaf abscission, pruning wood or root death, where they are potentially available to be re-absorbed by tree roots, after their decomposition and mineralization.

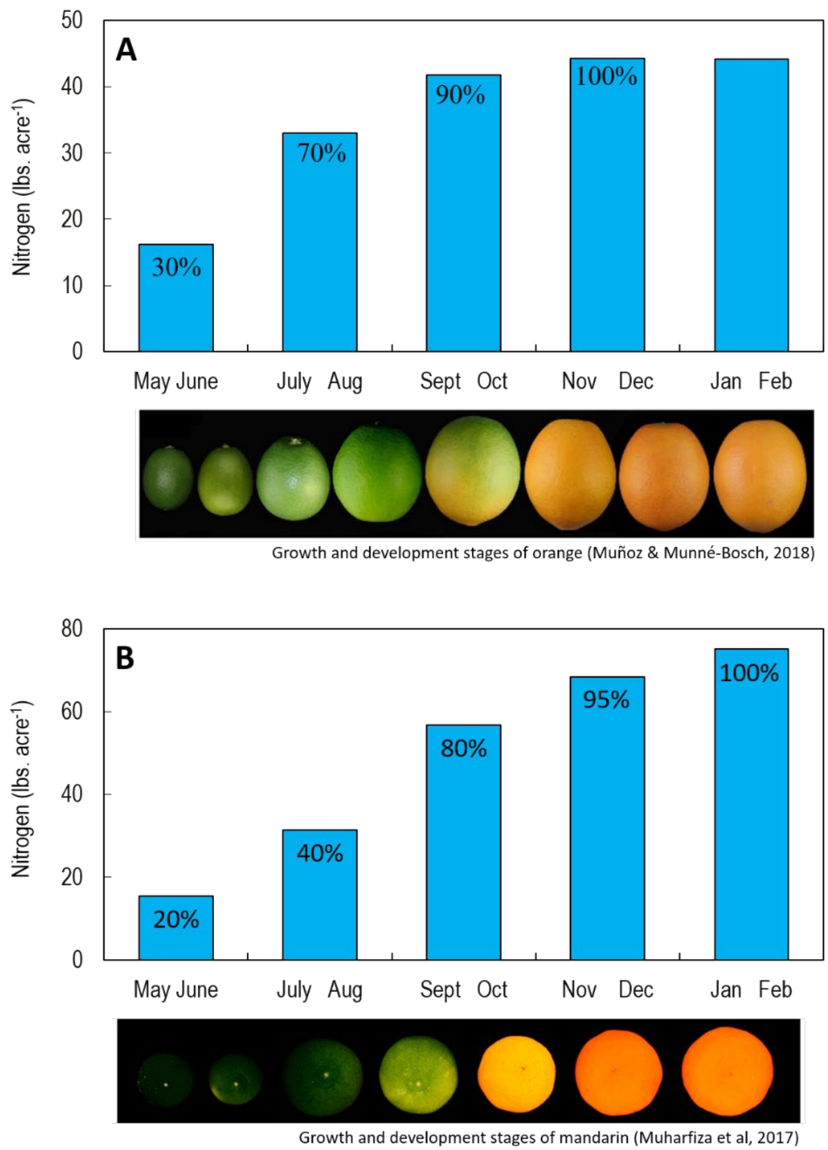

Figure 12. Nitrogen accumulation in orange (A) and mandarin (B) fruits at different growth and development stages.

Our data suggest that nutrients should be available in the soil for root to uptake by citrus trees from March to November. In contrast, from December to February, no significant net increase in nutrient was observed during this period. In conclusion, fertilizer rate decisions in citrus orchards should be based on nutrient export in expected yield while fertilizer application rates and timings should be based upon the pattern of nutrient accumulation in fruits.

G. Project Impacts

As a best management practice fertilizer in a citrus orchard should be based on expected yield estimated at flowering and fruit set followed by analysis of leaves to diagnose any deficiency. The combination of nutrient budget determination, nutrient response information, improved sampling and monitoring strategies, and yield determination provide a theoretically sound and flexible approach to ensure high productivity and good environmental stewardship.

H. Outreach Activities Summary

Publications:

Amaral, DC; Brown, PH. Developing Nutrient Budget and Early Spring Nutrient Prediction Model for Nutrient Management in Citrus. *Research paper in preparation*.

Amaral, DC; Brown, PH. Assessing nutrient uptake by field-grown citrus trees in California. *Research paper in preparation*.

Amaral, DC; Brown, PH. Monitoring a citrus orchard: leaf sampling for nutrient analysis. *Extension paper in preparation*.

Presentations:

Brown, PH. Nitrogen Management in Citrus. Fruit Growers Laboratory, Inc. Grower Appreciation Workshop. 2020. Fresno, CA.

Amaral, DC. Nitrogen Management in Citrus. CDFA Proceedings. 2019. 27TH ANNUAL FREP CONFERENCE.

Amaral, DC. Nitrogen Management in Citrus. CDFA Proceedings. 2018. 26TH ANNUAL FREP CONFERENCE.

Brown, PH. Nitrogen Management in Citrus. CDFA Proceedings. 2017. 26TH ANNUAL FREP CONFERENCE.

Websites:

Developing Nutrient Budget in Citrus Groves. https://blogs.cdfa.ca.gov/

UC Scientist Gives Orchards a Whole New Color Scheme.
https://www.plantsciences.ucdavis.edu/news/uc-scientist-gives-orchards-whole-new-color-scheme

I. Factsheet/Database Template

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2. Grant Agreement Number: 16-0707-SA

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4. Start Year/End Year: 2017-2019

5. Location: Fresno, Visalia, and Bakersfield.

6. County: Fresno, Kern, and Tulare.

7. Highlights:

Results demonstrate that fertilizer use in Citrus can be optimized and considerable nitrogen losses can be reduced if nitrogen applications are synchronized with the actual tree demand. This project provides the baseline data to achieve this goal.

- Nitrogen use efficiency can be optimized by adjusting fertilization rate based on realistic, orchard specific yield, accounting for all N inputs and adjusting fertilization in response to spring nutrient status and yield estimates.
- Orange offtake of N was 1.5 lb. per 1000 lbs. fruit
- Mandarin offtake of N was 1.3 lb. per 1000 lbs. fruit
- Overall, biomass N accumulation was 0.1 lb. of N per citrus tree
- Nitrogen accumulation occurred rapidly in the early season with 90% and 80% of the total N accumulated by September-October in orange and mandarin, respectively.
- Applications to match demand in as many split applications as feasible is recommended

8. Introduction:

Environmental legislation is forcing a change in farming practices because of many years of excess N application and loss of N below the root zone and consequent contamination of water resources. One of the main opportunities to optimize nitrogen fertilization is to synchronize applications with plant crop demand and apply N coincident with root uptake. This project has provided the data needed to correctly estimate the right rate and right time of fertilizer application for efficient and environmentally sound practices in Citrus.

9. Methods/Management:

In this project we monitored highly productive groves of mandarins and orange in Kern, Fresno, and Tulare Counties during two growing seasons. A holistic nutrient management protocol is being developed to guide the fertilization rate and time of fertilizer application as well as in season monitoring to adjust fertilizer rate to optimize yield and reduce leaching of nitrate to ground waters.

10. Findings:

This project has allowed the development of improved nitrogen management practices for citrus growers. Nutrient budget curves were developed for the major nutrients and data on timing and quantity of N and other nutrient uptake and removal from orchards was derived. Budget curves quantify the time course of nutrient uptake and total plant demand as determined by tree yield and nutrients required for growth. Yield potential determines fertilizer strategy and there is a large negative impact on overall efficiency that occurs in years or orchards of poor yield in which standardized fertilization strategies are used. Fertilizing accordingly to predicted yields will dramatically enhance nutrient use efficiency. Findings of this research has been adopted by the Citrus Board of California as the new standards for nutrient management and are being widely publicized and distributed.

J. Copy of the Product/Result

This research will be adopted by the Citrus Board of California industry as the new standards for nutrient management and will be widely publicized and distributed. This research project has been presented at grower, industry, extension, CDFA, ASA and university venues including keynote presentation during the years of the project in conferences. A webpage summarizing this work will be posted on the Citrus Board's main grower information portal and on the University of California Fruit and Nuts Website.