CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)

2009-2012 Final Report

Project Title:
Management Tools for Fertilization of the 'Hass' Avocado

Contract: 11-0437-SA

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Introduction

This project focuses on developing best management fertilizer practices to improve nutrient use efficiency (yield per unit input of fertilizer) and reduce environmental pollution related to excessive fertilizer applications. For the 'Hass' avocado (*Persea americana* L.) industry of California, fertilization rates and optimal leaf nutrient ranges have been borrowed from citrus for all nutrients except nitrogen (N), zinc (Zn) and iron (Fe). Competition from Mexico, Dominican Republic, Chile, Australia, Peru, and South Africa requires the California avocado industry to increase production per acre to remain profitable. Optimizing fertilization is essential to achieve this goal.

The development of best management fertilizer practices is particularly important for alternate bearing avocado trees, for which most growers rely on their August-September leaf analyses to form a nutrient budget for the following season. If not managed correctly, trees that are setting fruit in an off year receive more fertilizer than is needed. Over fertilization with nitrogen can significantly decrease avocado fruit size (Arpaia et al., 1996). However, properly timing soil-applied nitrogen can increase yield and fruit size and reduce alternate bearing of the 'Hass' avocado (Lovatt, 2001).

We believe that the deliverables of this project will increase yield, fruit size and profitability for California's 6,000 avocado growers, while protecting the groundwater. Information on best management fertilizer practices were supplied in two formats: 1) graphically – plots were developed documenting the stage-to-stage (month-to-month) changes in the concentrations of each essential mineral nutrient in vegetative and reproductive organs, and 2) Dynamically – A computer-based fertilizer model was developed.

Statement of Objectives:

1. Develop a phenology-based fertilization guideline for 12 nutrients which depict the changes in nutrient concentrations and contents in fruits.
2. Develop and evaluate online nutrient fertilization model to guide fertility management for avocados

Executive Summary:

A fertilization model and a user-friendly interface have been developed for avocado growers. The PIs completed the difficult task of quantifying nutrient uptake and partitioning during all stages of tree phenology by excavating 22 on- and off-crop trees. At excavation, trees were dissected into numerous tree parts (inflorescences, fruit, leaves, shoots, roots, etc.) and total weight of each component was recorded. Tree organs were analyzed for nutrient content of 12 essential elements. These data were used to develop a user-friendly web-based fertilizer model. This computer model enables growers to calculate their own fertilizer recommendations (nutrient, application time and rate) based on tree phenology and cropping status of the orchard. Input parameters include: 1) crop load or yield in the current year, 2) crop load or yield in the previous year, 3) canopy size and tree spacing, 4) leaf nutrient concentration levels, 5) soil texture, and 6) orchard location. Output parameters includes: 1) total nitrogen required, 2) timing of nitrogen application, 3) total potassium required, and nutrient removal of other macro-and micro-nutrients (e.g. P, S, B, Ca, Mg, Zn, Mn, Fe, and Cu). The output can be copied and pasted into MS Excel or printed.

In addition to nutrient recommendations, efficient irrigation practices can increase fertilizer nitrogen uptake and reduce or eliminate nitrate leaching to groundwater in avocado orchards. Frequency and amount of irrigation depends on weather, rainfall, and location. Irrigation requirements differ greatly where avocados are grown in California. For example, avocados grown in San Luis Obispo require less irrigation water than in San Diego (30 vs 42 acre-inches per year). To reduce over irrigation, growers select the avocado growing region (i.e. South Coast, Ventura/Santa Paula, or San Luis Obispo) of their orchard. If growers apply more water than required a warning appears in the program indicating that the risk of nitrate leaching is high.

Finally, graphs were developed for 12 nutrients indicating the changes in nutrient concentrations and content over the year. To synchronize fruit nutrient demand with fertilizer application, we recommend for:

N, P, Mg, S, Fe, and Zn – Apply these nutrients during the spring growing season after full bloom and repeat again the second year during the same time period. This strategy supplies nutrients to the recently pollinated flowers as well as the maturing fruit.
K and B – These nutrients are accumulated more rapidly during the second season of fruit development. Depending on the fruit load, a higher application rate may be needed to support the maturing fruit.
Ca – Since most of the Ca was accumulated during the first year of fruit growth, an abundant supply must be available during early fruit development.

Synchronizing the timing of fertilizer applications with plant nutrient demand is critical for the successful production of avocado fruit. It is also important to consider the right fertilizer source, rate, and placement of the added nutrients in order to meet the desired economic and environmental objectives.

Work Description and Results, Discussion and Conclusions

<u>Task 1.</u> *Develop graphs of month nutrient (N, P, K, Ca, Mg, S, Fe, Al, Mn, B, Cu, Zn) accumulation and concentration in tree organs over the season*.

<u>Task 1.1</u> *Changes in 'Hass' avocado leaf nutrient content over the season.*

Vegetative bud break occurred in April and nutrient concentrations decreased marked for N, P, and K during leaf expansion and growth (Figure 1). In contrast, leaf Ca, Mg, and (to a lesser extent) S concentrations increased following bud break. Nutrient levels for the macronutrients were in the adequate range based on the critical nutrient levels of avocado leaves. Similar graphs of macro- and micro-nutrient concentrations in the fruits and current season shoots have been developed.

<u>Task 1.2</u> *Changes in 'Hass' avocado shoot nutrient content over the season.*

Vegetative bud break occurred in March and macro-nutrient content increased markedly during the spring (Figure 2). Shoot macro-nutrient content peaked in late fall (mid-

October) and then leveled off during the winter months. During the following spring, nutrients in the shoot decreased. This decrease is likely the result of mobilization of phloem mobile nutrients (i.e. N, P, K, Mg, and S) out of shoots to support new leaf, shoot, and fruit growth during the next season.

In contrast, phloem immobile micro-nutrients (i.e. B, Ca, Cu, Fe, Mn and Zn) increased following bud break, suggesting that no remobilization is taking place (Figure 3). Nutrients such as Cu, Fe, and Mn increased linearly over the season, while B, Ca, and Zn levels followed a sigmoid function. For these nutrients, accumulation halted during the winter months.

Task 1.3 Dry *weight and mineral balance (g per tree) of 20-year-old 'Hass' avocado trees.*

The total mineral distribution in 20-year-old 'Hass' avocado trees is shown in Table 1. The leaves and branches were the primary reservoirs for the macronutrients (N, P, K, Mg, Ca, and S), though the leaves had consistently higher nutrient concentrations. The leaves and twigs comprised 12% of total dry weight yet contained close to 30% of the macronutrients (N, P, K, Mg, Ca, and S). In contrast, branches (stems greater than 2.5 cm in diameter) composed 50% of total tree dry mater, but less than 40% of tree N, P, K, and S. The roots contained 19, 21, 15, and 15% of the N, P, K and Ca, respectively. High Fe, Al and Na levels in roots likely resulted from soil contamination adhering to the roots. The fruit were extremely low in Ca and Mg.

No significant differences were found between month of tree excavation and nutrient content in the canopy branches. The canopy branches represented about one half of the total tree dry weight and between one fourth and one third of the total tree nutrient content. It is interesting that canopy branch nutrient content varied little over the season in avocado trees. In deciduous tree crops, such as pecan (Smith *et al.*, 2007), pistachio (Weinbaum et al., 1994), and walnut (Weinbaum and Van Kessel, 1998), most N used during the initial spring canopy growth flush and flowering was from storage pools in canopy branches. In these tree species, nitrogen in canopy branches is significantly reduced following the spring growth flush. In avocado this did not occur, likely because the canopy branches are highly buffered which minimizes nutrient fluctuations. For example, the spring growth flush in avocado trees coincides with leaf nutrient resorption from senescing leaves. Thus, nutrients required for the spring growth flush are likely supplied primarily from senescing leaves rather than storage pools in canopy branches. Understanding the dynamics of tree nutrient storage pools is important in developing a nutrient budget model for avocado trees.

Task 1.4 *Changes in 'Hass' avocado fruit nutrient content over the season.*

We developed macro- and micro-nutrient accumulation patterns in avocado fruits over the season. Fruits accumulated nutrients in a double sigmoid pattern for all nutrients analyzed except calcium (Figure 4a, b, c). Little fruit nutrient accumulation occurred during the winter months. The accumulation patterns, however, differed among the nutrients. Fruit accumulated nitrogen, phosphorous, magnesium, sulfur, iron, and zinc in a similar pattern to dry weight with about 50% of the total fruit nutrient contents occurring between bloom and 180 days after full bloom (DAFB) and 50% occurring from 330 to 420 DAFB. In contrast, only about 30% of the total fruit potassium and boron occurred between 0 and 180 DAFB, while 70% of the fruit K and B accumulated between 330 to 420 DAFB.

Fruit calcium content increased from full bloom until about 5 months following bloom and then remained constant for the next 8 months until fruit harvest in September (Fig. 4c). The lack of calcium accumulation after the initial fruit growth period may have been caused by the progressive malfunctioning of the xylem elements.

To match fruit nutrient demand with fertilizer application: 1) N, P, Mg, S, Fe, and Zn – apply 50% between full bloom and 210 DAFB and 50% between 330 to 420 DAFB; 2) K, and B – apply 30% between full bloom and 210 DAFB and 70% between 330 to 420 DAFB; Ca – apply 100% between full bloom and 210 DAFB. Matching fertilizer rates with nutrient removal values and good management such as optimal timing of fertilizer applications and placement, environmental pollution can be minimized.

High correlations were found between fruit dry weight and nutrient content (Figure 5). Best fit trend lines indicated that fruit dry weight was linearly related to fruit N and P content and exponentially related to fruit K. These data indicate that fruit dry weight can be used to estimate N, P, and K fruit content in well fertilized orchards. The differences in the nutrient accumulation patterns may reflect the various roles these nutrients play in the fruit. Unlike most fruits, cell division in avocado mesocarp tissue is not restricted to the first 30 days after anthesis but continues during fruit development and even occurs in the mature fruit attached to the tree. Indeed, cell division is the major factor that increases fruit size in the latter phase of fruit development. Both N and P play important roles in cell division and thus are required in order for the fruits to grow. Potassium is required for the production and transport of plant sugars that increase the weight of fruit. Therefore, the large influx of K into fruit may reflect the role it plays in sugar transport as fruit reach maturity.

Fruit accumulated the majority of their nutrients between full bloom and autumn and during the following spring. These periods of high fruit nutrient demand should coincide with fertilizer applications. Spring (April) fertilization with nitrogen over a four-year period, for example, increased yield by 50% over the control, where nitrogen was metered out in six N applications over the year (Lovatt, 2001). These increases occurred despite the lack of evidence of N deficiency in leaves. April nitrogen fertilization is critical to support fruit development of the current crop, fruit set for the following crop, and growth of the vegetative flushes.

<u>Task 2.</u> Develop and evaluate online nutrient fertilization model to guide fertility management for avocados

Development of avocado nutrient fertilization model.

Calculating the appropriate rate of fertilizer to apply is a complex process that involves interpretation of leaf and soil analyses, and a range of orchard and site condition factors.

In a typical well-managed orchard with reasonably fertile soil, nitrogen, potassium and zinc are likely to be the only nutrients that need to be applied regularly. Thus, the fertility model developed for this project included these nutrients. Input factors used when developing the model included:

- crop load or yield in the current year;
- crop load or yield in the previous year;
- canopy size;
- leaf nitrogen and potassium;
- soil texture;

Inputs and outputs for the nitrogen and potassium fertilizer model for the 'Hass' avocado is shown in Figure 1. The model is simple to use with minimal inputs required. The model contains the following components:

Avocado Canopy Size

The relationship between tree canopy diameter and tree canopy nitrogen demand was determined from ^{15}N applications and tree excavation data (Table 2). The relationship was found to be a power function ($y = 7.39x^{1.9615}$), where y = canopy N (grams) and x = canopy diameter (meters). The demand for this nitrogen is distributed over four months: 1) 31% in early July 2) 31% in mid-August 3) 26% in mid-September, and 4) 13% in mid-October.

Climate Regime

Avocados are grown in three main areas in the state: San Diego, Ventura, and San Luis Obispo. The climate is very different between San Luis Obispo and San Diego. We developed irrigation requirements for these three main growing regions (Table 3). These irrigation requirement values were determined using the CIMMIS weather station data and crop coefficients from the Wateright program <http://www.wateright.org/states.asp?Option=Ag>.

Leaf nutrient adjustment

Leaf nitrogen and potassium levels affect the amount and timing of the fertilization recommendations. If leaf tissue nitrogen or potassium are excessive, nutrient recommendations are reduced. For example, 6 lbs N/a are subtracted from the budget for every tenth of a percentage above 2.6 %N. For potassium, 15 lbs of K_2O are subtracted from the budget for every tenth of a percentage above 1.0 %K. In terms of timing, if leaf nitrogen is low, the program recommends applying more N at the start of inflorescence bud break.

Avocado Fruit load

Avocado trees are unique among many tree species because fruits typically remain on the tree for 15 to 18 months after bloom. Two crops can be maturing on the tree at once (last season's and the current season's crop) with different nutrient demands. The model incorporates this complexity, by promoting users to input harvest data and yields of both the current and previous year's crop (Figure 6).

Macro- and Micro-Nutrient Removal in the Crop

The output results for a 10,000 lbs./a avocado crop are presented in Figure 6. Included in the soil potassium section of the CA fertilization model are common potassium fertilizers for growers to select. This model will do all the calculations converting pounds of elemental K to pounds of fertilizer. This feature should facilitate the use of this model.

Macro- and micro-nutrients removed in the avocado crop were included in the output of the model (Figure 6). Thus, growers will be able to determine nutrient removal values and access fertilization requirements. Finally, the output of the model enables growers to copy and paste output into MS Excel.

Comparison of the fertilizer model to Overseer

We compared output results of the current model (CA fertilization model) to a new nutrient fertility model (OVERSEER) recently published from New Zealand. The OVERSEER nutrient budget model calculates average annual flows in N, P,K, and S in avocado orchards. The model contains a database with information on nutrient concentrations of fertilizers and crop residues. The equations within the model are based on studies carried out in New Zealand. We analyzed nitrogen and potassium requirements using both programs at different yield levels (Table 4). Nitrogen requirements at the same yield level were similar in both programs; however, potassium requirements were about 20% greater in the CA fertilization model compared to OVERSEER. Likely, different soil types and parent materials between California and New Zealand caused these differences.

Development of fertilization models in other crops

This fertilization model interface and shell developed for avocados can be used for other crops in the future. Currently the model is being modified for the table and oil olives industries.

Outreach Activities Summary:
Our work was reported at many meetings during the time period of the project:

2009
November 17 – FREP/WPHA annual meeting – 175 in attendance
August 27 – California Avocado Commission research presentation – 30 in attendance
September 23 – Grower to Grower Advisor Seminar in Chico – 35 in attendance

2010
January 13 – Grower to Grower nutrient seminar in Modesto – 55 people in attendance
February 18 – UC Cooperative Extension grower meeting at UC Davis.
June 8 – Avocado nutrient grower meeting in San Luis Obispo – 29 in attendance
June 9 – Avocado nutrient grower meeting in Ventura – 36 in attendance
June 10 – Avocado nutrient grower meeting in Temecula – 40 in attendance
August 2 – American Society of Horticultural Science Annual meeting – 35 in attendance

2011
February 5 – UC Davis Medium Density Olive Symposium in Davis, California – 60
February 10 - California Avocado Commission, California Avocado Society, and UC Cooperative Extension grower meeting in San Luis Obispo– 30 in attendance
February 11 - California Avocado Commission, California Avocado Society, and UC Cooperative Extension grower meeting in Ventura– 25 in attendance
February 12 - California Avocado Commission, California Avocado Society, and UC Cooperative Extension grower meeting in Temecula– 35 in attendance
February 19 – Master Gardeners nutrient budgeting training in Orland – 25 in attendance
August 9 - California Avocado Commission, California Avocado Society, and UC Cooperative Extension grower meeting in San Luis Obispo– 20 in attendance
August 10 - California Avocado Commission, California Avocado Society, and UC Cooperative Extension grower meeting in Ventura– 25 in attendance
August 11 - California Avocado Commission, California Avocado Society, and UC Cooperative Extension grower meeting in Temecula– 30 in attendance

2012
February 7 – Agronomy Society of America Plant and Soil Conference - 50 in attendance
July 29 – America Society of Horticultural Sciences Annual meeting – 35 in attendance
August 16 – UC Farm Advisor and Walnut board meeting on nutrient budgeting to decrease nitrate leaching to ground water – 20 in attendance
January 10 – Master Gardener training – 22 in attendance

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Table 1. Dry weight and mineral balance (g per tree) of 20-year-old 'Hass' avocado trees.

	Mineral balance (g per tree) of 20-year-old 'Hass' avocado in California						
	Leaves & Twigs	Branches	Trunk	Roots	Fruit	Total	Proportion removed by fruit %
Dry Wt	18.2	169	24	85	170	335	5.1
N	559	657	34	293	191	1734	11.0
P	118	129	13	85	53	399	13.3
K	373	610	56	251	377	1665	22.6
Ca	575	1093	95	317	6	2086	0.3
Mg	183	471	12	61	16	742	2.2
S	101	120	14	65	45	345	13.2
Al	1.1	4.4	0.7	32.7	0.0	39	0.1
B	1.8	3.6	0.4	1.7	1.4	9	15.9
Fe	3.4	6.4	0.9	22.0	0.3	33	1.1
Mn	3.0	3.6	0.3	1.3	0.1	8	1.1
Na	9.8	23.9	9.2	85.8	1.8	131	1.4
Zn	2.1	3.9	0.8	7.6	0.5	15	3.3

Table 2. Relationship between tree canopy diameter and tree nitrogen demand for 'Hass' avocado trees.

Tree Canopy Diameter (ft)	End of fruit drop period (early July)	6 weeks later (mid August)	4 weeks later (mid September)	4 weeks later (mid October)	Total
	------------------- Nitrogen Demand (ounces/tree) -------------------				
7	0.3	0.3	0.2	0.1	1.0
13	1.3	1.3	1.0	0.5	3.9
20	2.8	2.8	2.1	1.1	8.7
26	5.0	5.0	3.7	1.9	15.5
33	7.7	7.7	5.8	2.9	24.0

Table 3. Water requirement vs. tree age for the three major avocado growing areas in California developed from Wateright program (http://www.wateright.org/).

Tree Age	Tree Age vs Water Needed (feet per acre)		
	Ventura	San Diego	San Luis Obispo
1	0.4	0.5	0.5
2	0.7	0.9	0.9
3	1	1.5	1.3
4	1.2	2.2	1.8
5	1.4	2.5	2.2
6	1.6	3.2	2.4
7+	1.6	3.6	2.8

Table 4. Comparison of nitrogen (N) and potassium (K) requirements based on the avocado nutrient model currently under construction (CA fertilization model) and a nutrient model developed in New Zealand (Overseer) under different yield scenarios.

Yield (lbs/a)	CA fertilization model	Overseer	Difference between models	CA fertilization model	Overseer	Difference between models
	N Requirement (lbs/a)		(%)	K Requirement (lbs/a)		(%)
15000	49	53	-8.2	121	101	16.5
12000	41	42	-2.4	97	80	17.5
9000	32	32	0.0	73	60	17.8
6000	29	21	27.6	55	40	27.3

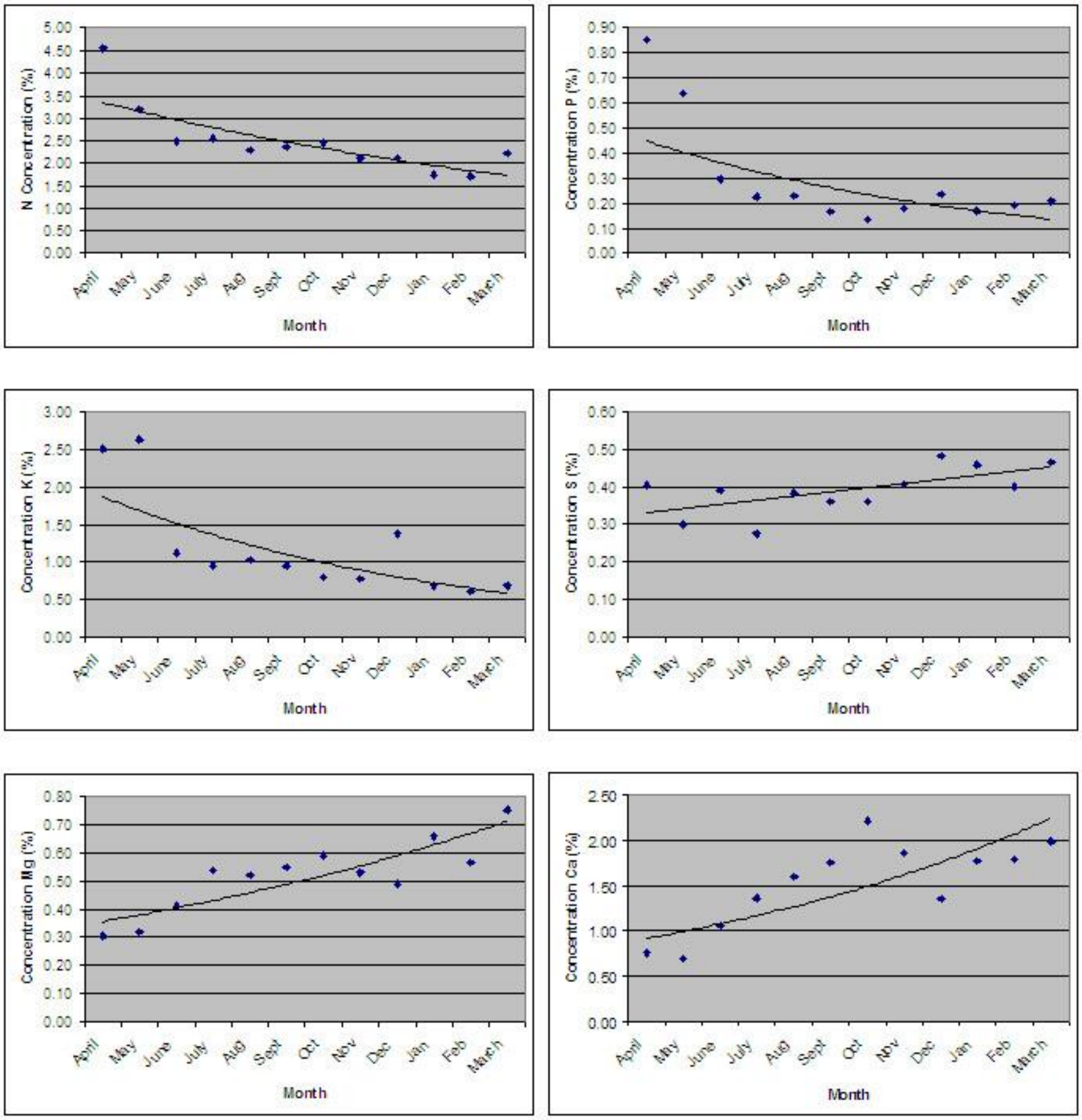

Figure 1. Leaf macro-nutrient concentrations over the season in 20-year-old ‘Has’ avocado trees.

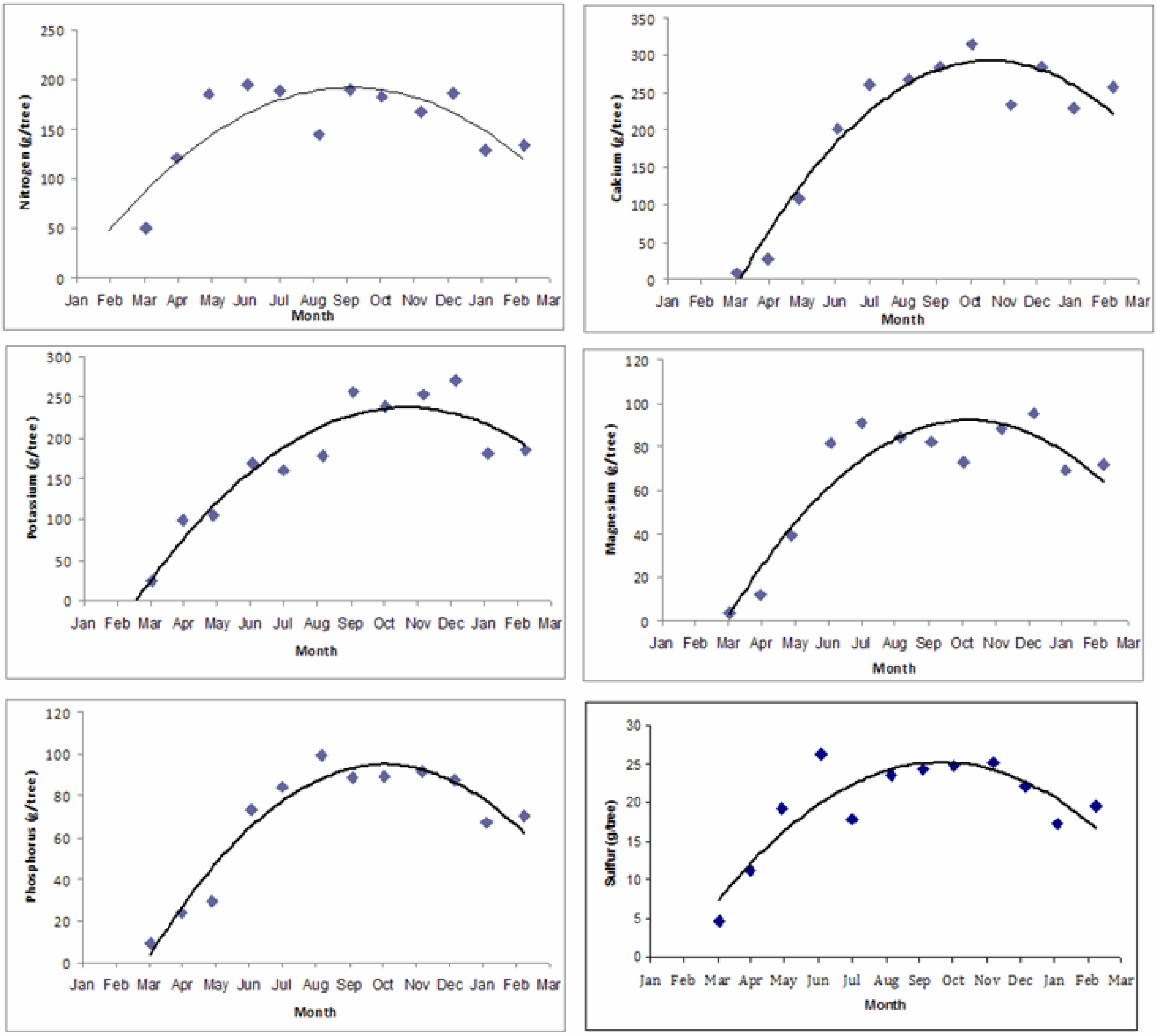

Figure 2. Macro-nutrient accumulation in current seasons shoots over the season in 20-year-old ‘Hass’ avocado trees.

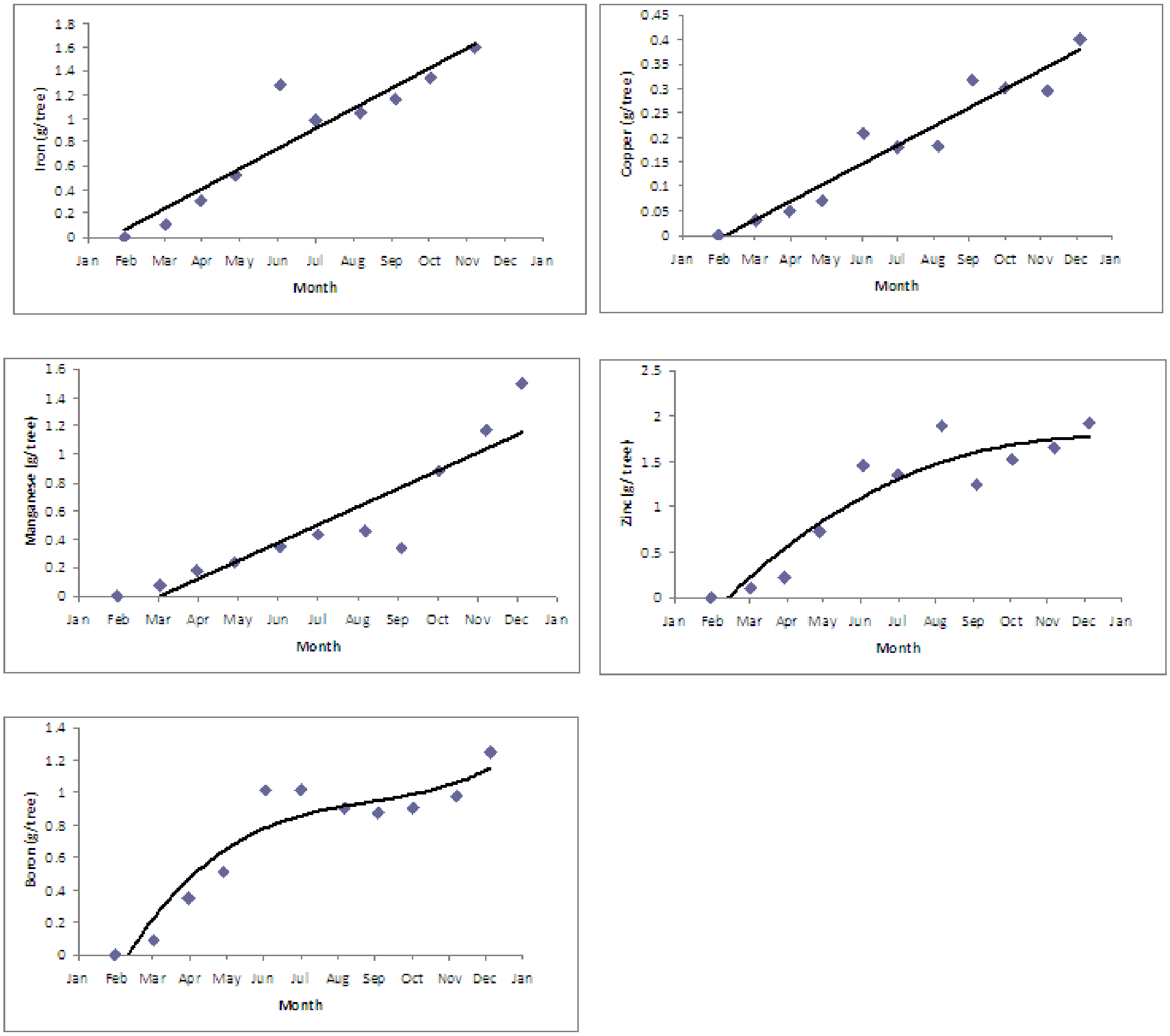

Figure 3. Micro-nutrient accumulation in current seasons shoots of 20-year-old ‘Hass’ avocado trees over the season.

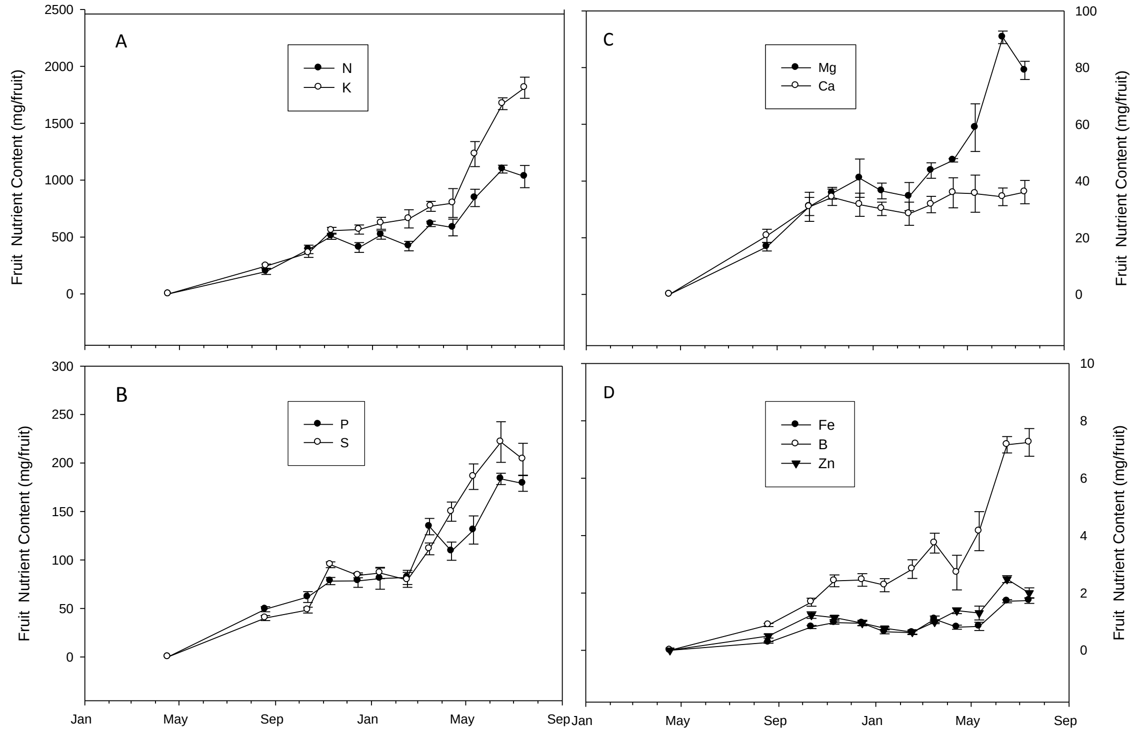

Figure 4. Nitrogen, potassium (A), phosphorus, sulfur (B), calcium, magnesium (C) and iron, boron, and zinc (D) accumulation in avocado fruits from bloom to harvest.

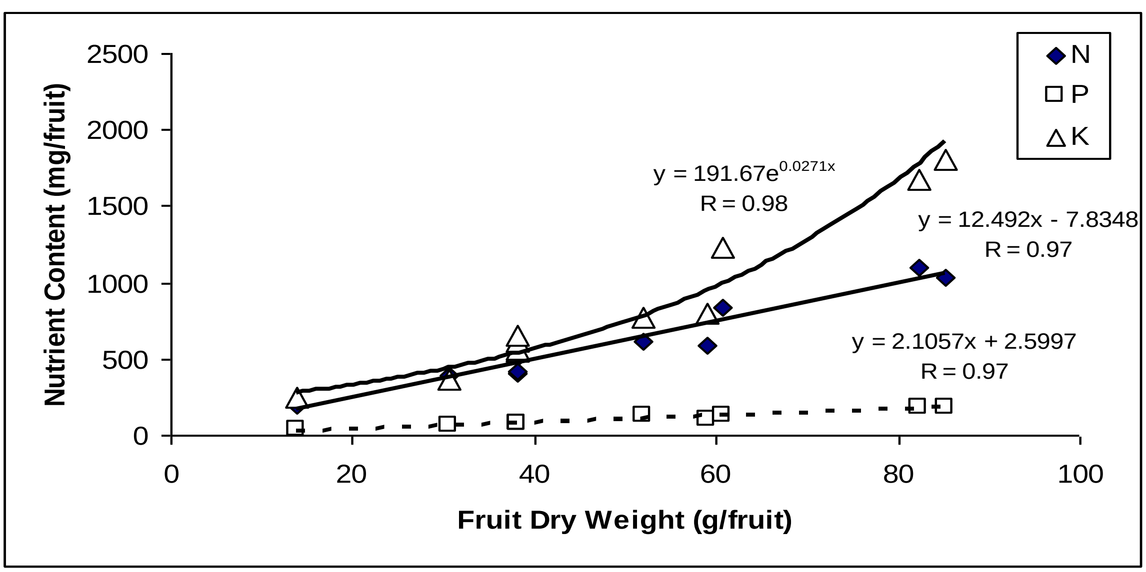

Figure 5. Relationship between dry matter content and nitrogen, phosphorus, and potassium accumulation in avocado fruits over the season.

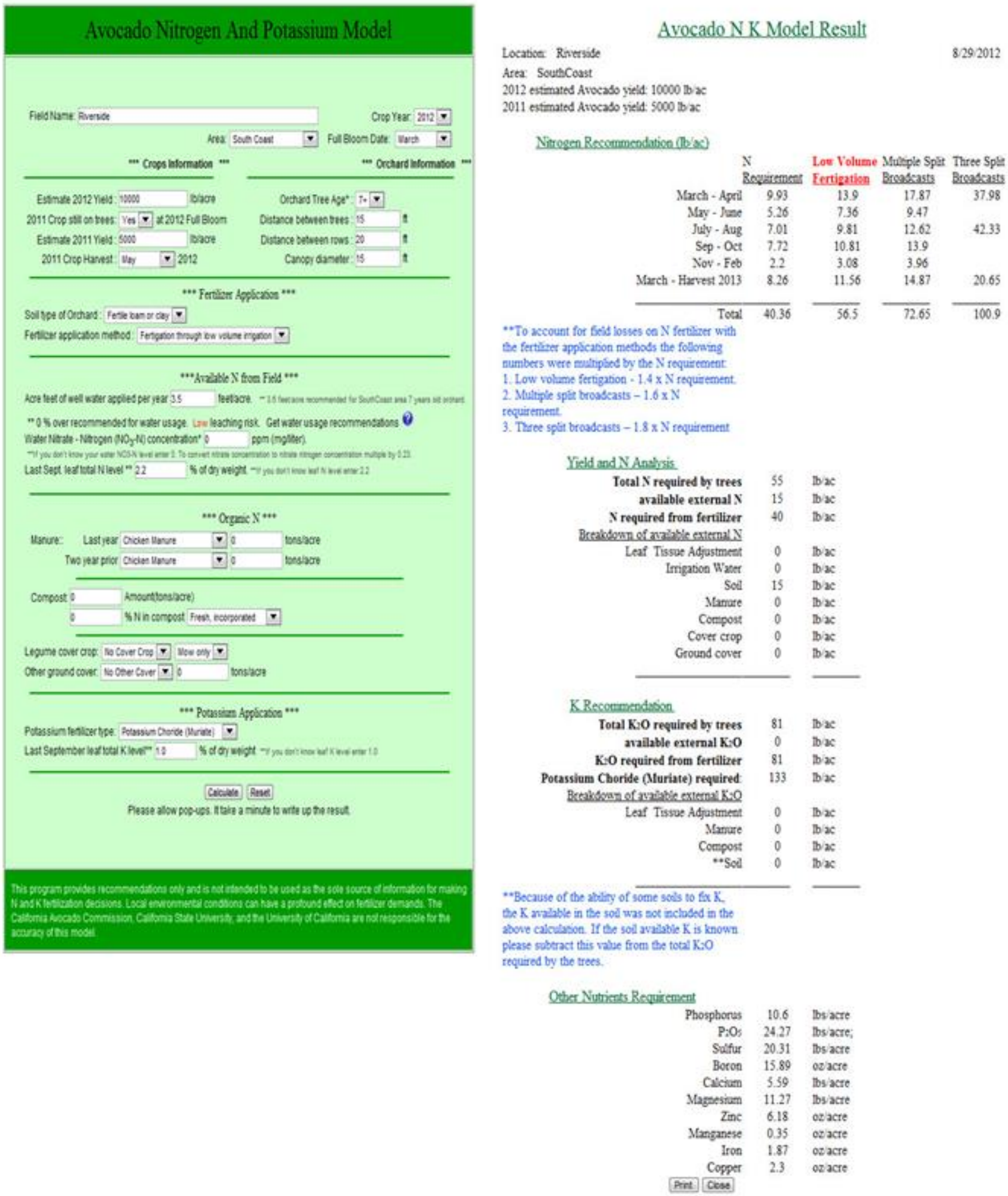

Figure 6. Nitrogen and potassium fertilizer model for the ‘Hass’ avocado in California, input (left) and output (right) based on 10,000 lbs./a avocado crop.

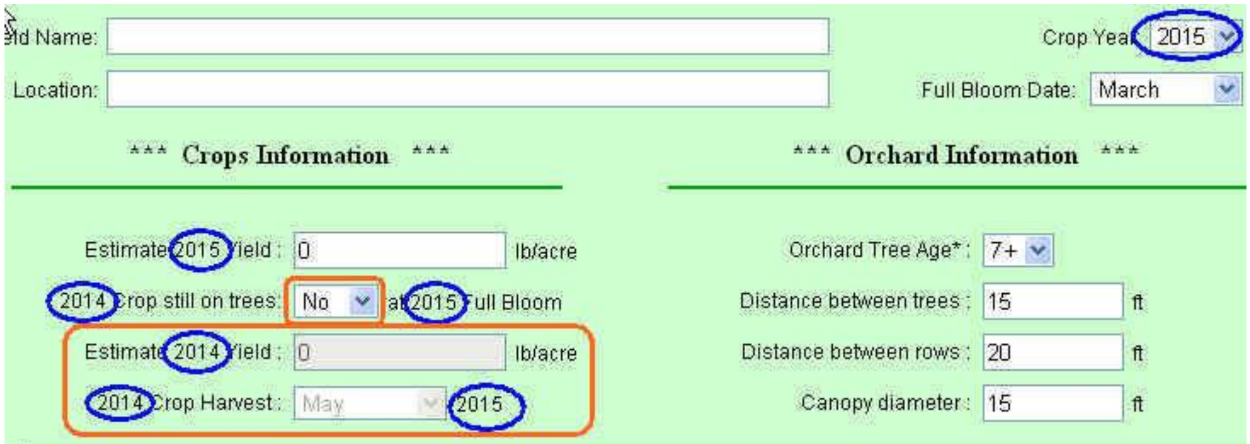

Figure 7. Model modifications that include nitrogen requirements from this year's crop and last year's fruit.