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

2004-2006 Final Report

Project Title:
Improving the Procedure for Nutrient Sampling in Stone Fruit Trees

Contract: #03-0652

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Introduction:

Mid summer is the recommended period of sampling leaves for nutrient analysis in fruit trees. This practice was first developed in the 1940s and was widely applied to orchards during the 1950s. In 1971 Leece compiled a list of 39 peach studies from seven countries and concluded, “with few exceptions, good agreement existed amongst the studies for any particular nutrient”. Thus, the practice became very widespread and is the standard to this date. The timing of about 100 to 140 days after bloom has been established because the concentration of most nutrients remains fairly stable during this time. This corresponds to the period from early June through late July in the central valleys of California.

We see at least two problems with this timing, especially in light of our modern era of environmental concerns and an emphasis on good sustainable fertilization practices. First, the timing of mid summer for sampling does not fit well into a sustainable fertilizer program since many fertility decisions need to be made early in the spring. Growers are generally most interested in fertility management as they watch their trees flower, leaf out and set a crop in the spring. By summer their interest has waned. Second, this timing also does not make sense from a tree physiological perspective. Many critical processes such as flowering, fruit set, initial fruit growth, and shoot growth are all happening in the early spring and should be dependent on tree nutrient status at that time. A dormant or early spring sample should give a good indication of stored nutrients and whether any are limiting.

This study will evaluate the nutritional status of several different plant parts in hopes of finding a reliable and consistent sampling procedure to help guide fertilization practices in the spring.

Statement of Objectives:

1. To test the feasibility of measuring boron, zinc and nitrogen (and other nutrients if possible) in stone fruit trees during the dormant season or early spring and relate those nutrient levels to the various components of yield and fruit quality.
2. To develop deficiency threshold values for these nutrients that can be used to guide fertilization decisions early in the season.
3. To test the usefulness of these threshold values in commercial orchards.

Executive Summary:

Using Zee Lady peach and Grand Pearl nectarine trees planted in 60 large sand tanks and by surveying over 60 commercial orchards in the San Joaquin Valley, we have been investigating the possibility of using dormant shoots to determine the nutritional status of peach and nectarine trees. Although we have not succeeded with every nutrient, we have made good progress and will continue our efforts even though this FREP project is over. The sand tanks were installed in 2000 and 15 different fertilizer treatments were imposed beginning in 2001. By 2004, there were clear signs of N, P, B and Zn deficiencies in individual trees. Shoot samples were taken from the trees in January of 2003, 2004, 2005 and 2006. In 2004 we proposed deficiency thresholds

for these four nutrients. In 2005 we tested these values in over 60 commercial orchards. After some refinement in 2006, our conclusions are as follows:

Nitrogen. Total nitrogen in dormant shoots is not a good indicator of tree N status. We are working to develop a test using arginine and/or other amino acids.

Phosphorus. P deficiency is rare in California peach orchards but a threshold of 0.12% P in dormant shoots should be a reliable guide to identifying the deficiency.

Boron. B deficiency is also rare in California orchards but the proposed threshold of 14 ppm could be used as a valuable tool in identifying orchards where B applications might be helpful.

Manganese. Minor leaf symptoms are observed when dormant shoot Mn levels drop below 8 or 9 ppm. However, treatment with Mn fertilizers is probably not necessary until the level drops even lower.

Zinc. We are still in the process of refining a sampling procedure for Zn. At this point we anticipate collecting shoots from the lower part of the tree in fall or early winter and have tentatively set the threshold at 15 ppm.

Potassium, Magnesium and Calcium. We hope to have trees deficient in these 3 elements within a year or two so deficiency thresholds can then be established.

<u>Work Description and Results, Discussion and Conclusions:</u>

Task 1: Establish relationships between late dormant or early spring tree nutritional status and parameters of tree performance (accomplished in 2003 and 2004).

Zee Lady peach, Fortune plum and Grand Pearl nectarine trees planted in 60 large sand tanks in 2000 (see 2003 FREP report, “The Effect of Nutrient Deficiencies on Stone Fruit Production and Quality”) were used to establish these relationships. By 2004, there were clear signs of N, P, B and Zn deficiencies in individual peach and nectarine trees (Table 1). Several other nutrients also showed some indication of deficiency but not enough to establish thresholds.

Shoot samples were taken from all 180 trees in January of both 2003 and 2004. Root samples were taken at the same time in 2004. Flowers were sampled at full bloom in March of both years. All samples were dried, ground and analyzed for N, P, K, S, Ca, Mg, B, Zn, Mn, Fe and Cu. Measurements were made of yield and fruit quality components including flowering, fruit set, early fruit growth, early shoot growth, fruit drop, final fruit size, fruit defects, fruit quality and total vegetative growth. These parameters were then correlated with nutrient levels in each tissue. This report will include results from only the peach and nectarine trees.

Nutrient concentrations in dormant roots, dormant shoots, and flowers were all compared. A preliminary evaluation of newly emerging leaves was also made. Of these 4 tissues, dormant shoots appeared to be best for several reasons. First, it was a simple and easy sample to take. Roots took a lot more effort and flowers had to be sampled within a short period of time. Second, the timing was early enough to allow for correction before growth started. By the time of flowering and early leaf emergence, it was too late to affect processes such as fruit set and early fruit growth. Finally, nutrient concentrations in shoots correlated better with mid summer leaf levels and tended to be better than the other tissues at reflecting the wide range of added fertilizers. Some nutrients in the roots were consistently low no matter how much fertilizer had been added. Flowers, on the other hand, had just the opposite situation. Often, their nutrient concentrations were very high, even in trees showing evidence of deficiency. Therefore, shoot samples were chosen as the preferred tissue to use throughout this project.

In order to determine a deficiency threshold it is necessary to correlate nutrient concentrations to some sort of "problem" in the tree such as the occurrence of leaf symptoms or the inhibition of a physiological process. The only nutrient with distinct and unique deficiency

Table 1. Sand tank nutrient deficiencies 2004. Summary of deficiency symptoms and effects.

Nutrient	Evidence of Deficiency	July Leaf Sample: Published Deficiency Threshold (Peach)	July Leaf Sample: Lowest Level in Sand Tank Trees	Reduced Fruit Size	Other Symptoms and Comments
N	**	2.3%	1.61%	*	Greatly reduced shoot growth, good fruit quality
P	**	–	.06%	*	Fruit drop, nectarine cracking, early defoliation
K	–	1.0%	.82%	–	No clear deficiency effects
S	*	-	830 ppm	*	Reduced shoot growth, often closely correlated with N
Ca	*	–	.79%	–	A few fruit quality problems, some leaf symptoms in 2003, not 2004
Mg	?	.25%	.20%	–	Some leaf symptoms in 2003, not 2004
B	**	18 ppm	14 ppm	*	Reduced fruit set and shoot growth
Zn	**	15 ppm	5 ppm	*	Definite leaf symptoms, fruit quality problems
Mn	–	20 ppm	26 ppm	–	No deficiency, some plums as low as 23 ppm
Fe	*	60 ppm	39 ppm	*	Minor effects
Cu	*	–	3.1 ppm	*	Minor effects
Mo	?	-	<.05	–	Very low in plums

leaf symptoms was zinc. Deficiencies of the other nutrients often caused a general slowing of shoot and fruit growth without any distinguishing leaf marks. In these cases, total vegetative growth, as measured by growth in trunk cross sectional area, and final fruit size were useful in establishing deficiency thresholds. In addition, other processes such as fruit set, fruit drop and fruit cracking, were clearly affected by individual nutrients (Table 1). All of this information was used in establishing N, P, B and Zn deficiency thresholds for dormant shoots of peaches and nectarines.

Nitrogen (N). N deficiency was easy to impose on these trees growing in sand culture. Typical symptoms of reduced shoot growth, yellow leaves, reddish stems, smaller fruit size, more highly colored fruit, earlier ripening fruit and more smooth fruit finish were all observed. Mid summer leaf samples as low as 1.6% N were obtained, indicating extreme deficiency. At the other extreme, N levels over 4.0% were measured, creating a wide range of values with corresponding large differences in tree vigor. Despite these substantial differences, the result of the dormant shoot sampling was disappointing. Values ranged from .91 to 1.88%, but often the low N trees were no different than high N trees. It is still unclear why these results were obtained. Other nitrogen experiments conducted by the authors and other scientists suggest dormant wood is a good indicator of the N status of fruit trees. We continued to evaluate dormant wood N in the sand tank trees and in commercial orchards throughout 2006 but never obtained consistent results. Therefore, we have concluded this methodology will not work for nitrogen.

Phosphorus (P). P deficiency started showing up in a few peach trees in 2003 and was clearly evident in both peaches and nectarines in 2004. Symptoms included substantial reduction in both vegetative and fruit growth, fruit cracking in nectarines, more flattened fruit (side to side) in peaches, preharvest fruit drop in peaches and premature defoliation in both peaches and nectarines. As these leaves senesced, they tended to have more red or purple coloration rather than the typical yellow or orange color of well fertilized trees. Concentrations of P in dormant shoots varied from .06 to .18 % which is a little lower than the values found in mid summer leaf samples. Typical summer leaf values in the sand tank trees varied from .10 to .24 %. Most deficiency symptoms were particularly severe below shoot values of about .11 to .12 % P for both peach and nectarine.

Boron (B). Over the past couple of years, percent set in the peaches and nectarines has varied considerably from tree to tree (from 5 to 86%). Generally this has correlated best with tree B status, although other nutrients appear to have played a secondary role. Trees low in B also had smaller fruit size at harvest. Other than that, there were no other leaf symptoms or reductions in vigor to indicate a deficiency. Mid summer leaf concentrations ranged from 12 to 36 ppm B in the sand tank trees. Dormant shoot samples were considerably lower, but showed about the same variability, ranging from 8 to 22 ppm. Generally, when values dropped below about 13 to 14 ppm, there was a substantial decrease in fruit set or fruit size.

Zinc (Zn). In the spring of 2004, about half the sand tank trees exhibited some degree of Zn deficiency symptoms. Four pomology experts independently rated the trees on a scale from 0 to 5, with 5 indicating severe symptoms. The average of these 4 scores was graphed against dormant shoot Zn concentration for that tree. Although some trees with Zn values as low as 9 and 10 ppm showed no detectable deficiency symptoms, the majority of trees with these levels exhibited extreme deficiency. At concentrations above 20 ppm, there were no indications of deficiency in any trees. Several other yield components were also affected by Zn deficiency. Fruit size tended to be smaller and nectarine cracking was increased. A deficiency threshold of 20 ppm in dormant shoots applied to these parameters as well. As we continued to refine this procedure, we discovered a substantial gradient in dormant shoot Zn from the top to the bottom of the tree. We further concluded that dormant shoots at the lowest, most shaded location in the canopy was the best tissue for estimating tree Zn status. More detail is provided under Task 3 below. Based on this, we took dormant shoot samples in several experiments in 2006 and revised our threshold to 15 ppm (as an alternative, roots also worked well to estimate tree Zn status, with a threshold of 10 ppm).

At the conclusion of this project we have established that dormant shoots are a reliable tissue for determining the nutrient status of P, B and Zn in peaches and nectarines. Deficiency thresholds were proposed for these nutrients (Table 2) and were used to evaluate commercial orchards in the next phase of the project.

Table 2. Proposed deficiency thresholds of P, B and Zn in dormant shoots of peaches and nectarines. Dormant shoots should be taken from the lowest, most shaded part of the canopy.

Nutrient	**Proposed Deficiency Thresholds**
Phosphorus	.12%
Boron	14 ppm
Zinc	15 ppm

Task 2: Take the relationships developed in task 1 and test them in commercial orchards (accomplished in 2005 and 2006).

During July of 2004, leaf samples from 60 commercial peach and nectarine orchards were analyzed for 13 nutrients (N, P, K, S, Ca, Mg, Zn, B, Mn, Fe, Cu, Mo, Cl). These orchards varied greatly in age, soil type, cultivar, rootstock and vigor. Initially, sites were selected near those where Pete Christensen had documented B deficiency in grape vineyards. Additional orchards were randomly selected. Those orchards that tested lowest in N, P, B, Mn and Zn were sampled again in January 2005 using dormant fruiting shoots.

Based on these two samples we selected several orchards to work in during 2005. For phosphorus, we identified 4 peach orchards that were relatively low, but not deficient in P (no distinctly deficient orchards were found). To selected trees in each orchard P was added as liquid 0-52-0 to the soil in early spring. A rate of 256g P/tree was applied to 9 or 10 reps in each case.

For boron, again no distinctly deficient orchards were found but one peach and one nectarine orchard of relatively low B were identified. We also identified two plum orchards (Rosemary and Queen Rosa) that have generally had low set in the last few years. To all four orchards, B was applied foliarly at bloom at a rate of 2 lbs Solubor/acre. In the plums two applications were made, one at 30-40% bloom and one at 80-90% bloom. Ten replicates were used in the peach and nectarine field and six in the two plum orchards.

We have not yet been able to induce manganese deficiency in the sand tank trees, so no threshold has been established. However, in the survey of commercial orchards, several exhibited symptoms in the spring of mild Mn deficiency. In addition, each of these orchards tested very low in dormant shoot Mn. Therefore, two were selected for further testing. To the first orchard, selected trees were treated with both foliar (5 lbs Mn sulfate/100 gals) and soil (0.5 lbs Mn sulfate/tree) applications in the spring. Eleven single tree reps were used. In the second orchard, a soil application of the same rate was applied to six reps. Only trees showing symptoms were included in the trial.

In all the orchards, leaf samples were taken in July to determine effectiveness of the treatments. In addition, other parameters such as fruit set or yield were taken in select trials. We came to the following conclusions for each nutrient:

Nitrogen (N). Although we had tentatively set a threshold for N of 1.2% in dormant shoots, both the sand tanks and survey of commercial orchards suggested this value was not very consistent or reliable. We have concluded that total nitrogen in dormant shoots is not a good indicator of vigor and tree N status. Instead we have been pursuing the idea of measuring individual components of stored N in the tree. Specifically, arginine appears to be the principal storage amino acid in peach trees and several studies suggest it is a good indicator of tree N status. Our first attempt in 2006 produced poor results. We concluded we needed a better procedure for extracting arginine from dormant tissue. We are currently working on the procedure and will continue after completion of this project.

Phosphorus (P). In the four commercial orchards that were low in P (but not deficient), fertilizer treatments gave no positive results. Therefore, we have concluded that P deficiency is not a widespread problem in stone fruit orchards in the San Joaquin Valley, and that P applications will generally provide no benefit. However, in the sand tank trees we have consistently measured severe P deficiency symptoms in trees with dormant shoot values below 0.12% P. Therefore, we are certain this threshold will work for commercial orchards as well if truly deficient trees are ever identified.

We have also been experimenting with adding mono ammonium phosphate (MAP) to the planting hole of newly planted trees. In one case, a slight improvement in growth was measured. However, several other plantings showed no benefit. Thus, there may be situations where P is limiting the growth of young trees. We will continue to research this question after completion of this project.

Boron (B). In the commercial orchards that were low in B (but not deficient), boron sprays did not improve fruit set or yield in any of the locations. Mid summer leaf samples revealed adequate levels of B, even in the unsprayed control trees. Therefore, we conclude that B applications will generally provide no benefit to stone fruit orchards in the San Joaquin Valley. The threshold of 14 ppm B for dormant shoots was obtained from the sand tank trees and should apply to commercial orchards if B deficiency is ever identified.

Manganese (Mn). In the commercial orchards low in Mn, treatments with foliar and soil-applied fertilizers alleviated symptoms and improved tissue Mn levels. However, the symptoms in untreated trees were minor and appeared to have had no effect on tree vigor or productivity. Therefore, a threshold that warrants treatment is probably lower than what we measured in these commercial orchards. We will continue to look for orchards with severe symptoms so a precise deficiency threshold can be established.

Task 3: Refine the relationships developed in task 1 and tested in task 2 (focus of the project in 2006).

After two years on this project we felt we had thoroughly researched the nutrients mentioned in task 2 above. Therefore, in 2006 we turned our attention to some of the other nutrients, hoping to establish dormant shoot threshold values for each. Specifically, we focused on several aspects of zinc and on inducing deficiencies of potassium, calcium and magnesium. Our progress is summarized below:

Zinc (Zn). We have made good progress in the area of sampling for this nutrient in peach trees but a number of questions still remain. First, it has become quite apparent that mid summer leaf values are not a good indicator of the Zn status of peach trees. In our survey of 60 commercial orchards, most were below the currently recommended threshold for mid summer leaf samples of 15 to 20 ppm. However, none of the orchards exhibited symptoms of Zn deficiency. Thus, the threshold is too high or the test is just not reliable. Dormant shoots appear to be a better tissue to sample. As long as care is taken in the selection of specific dormant shoots, this test looks to be an improved method for measuring the Zn status of a tree. There appears to be substantial variation in shoot zinc concentrations throughout the tree. For example, in December 2005, we found very large differences in Zn levels between upper, sun-exposed shoots and lower, shaded ones (Table 3). In the past we have followed the protocol for leaf sampling and selected shoots from the middle portion of the tree. However, we often found significant variability among samples, probably due to the sun exposure of individual shoots. Now we are pursuing the idea of sampling lower, shaded shoots as they seem to best indicate the true zinc status of the tree. Samples taken in December 2006 showed deficient trees all below 15 ppm Zn and healthy trees (including some commercial orchards) all above this threshold. Thus, we have set the deficiency threshold at 15 ppm for now but will continue to collect data after the completion of this project.

We are also investigating the idea of sampling shoots earlier than full dormancy. Another preliminary study showed that shoots at the time of leaf senescence gave a good indication (similar to the dormant timing) of tree zinc status. Thus, we envision a sampling protocol during September or October that could determine the need for a fall or dormant zinc application, which is the currently recommended timing. We hope to solidify this protocol within the next two years.

Table 3. The distribution of zinc throughout Grand Pearl nectarine trees as measured in dormant shoots, emerging leaves, and mid-summer mature leaves.

	Zinc concentration (ppm)		
Shoot location	12/05 Dormant shoots	4/06 Emerging leaves	7/06 Mature leaves
Low – Shaded	70.3 a*	52.6 a	18.8 a
Low – Sun-exposed	39.7 bc	-	-
Low – Base of suckers	32.6 cd	-	-
Mid-tree – Shaded	47.9 b	-	-
Mid-tree – Sun-exposed	28.5 de	47.6 b	18.3 a
High – Sun-exposed	19.1 ef	44.3 b	18.1 a
High – Top of suckers	16.3 f	-	-

* Values in columns followed by the same letter are not significantly different at p=0.05 by Duncan's Multiple Range Test.

<u>Potassium (K), Magnesium (Mg) and Calcium (Ca).</u> Since we have not been able to induce K, Mg or Ca deficiency in the sand tank trees, we decided to take drastic measures in 2006. Our main source of irrigation water for the tanks has significant levels of all 3 of these cations. Therefore, our first step was to install a water softening system for the Minus Mg and Minus Ca treatments. The company that supplied the ion exchange tanks was willing to recharge them with K instead of Na (typical of most domestic water softeners) so we didn't need to worry about salt problems. For the Minus K treatment, we used a source of deionized water for irrigation. There is a Reverse Osmosis (RO) unit in the greenhouse complex at KAC. Water from the RO unit was trucked over to the sand tanks and stored in a 5,000 gallon storage container. By late summer we observed minor symptoms of K deficiency in one peach tree. Its leaf K concentration was 0.76%. Several other trees had leaf levels below 1.0% and hopefully will show symptoms in 2007. In the Minus Mg treatment, leaf concentrations as low as 0.40% were measured but no symptoms were observed. Soil samples taken in September showed very low soil Mg so deficiency could be induced by 2007 or 2008. The situation is not as hopeful for the Minus Ca treatment. Leaf Ca levels have measured about 1.5% but probably need to drop below 1.0% for true deficiency. Soil Ca levels are still fairly high. This treatment will be continued through 2007 to see if progress can be made.

<u>Summary.</u>

With regard to our original objectives, we have concluded the following for each nutrient:

Nitrogen. Total nitrogen in dormant shoots is not a good indicator of tree N status. We hope to develop a test using arginine and/or other amino acids.

Phosphorus. P deficiency is rare in California peach orchards but a threshold of 0.12% P in dormant shoots should be a reliable guide to identifying the deficiency.

Boron. B deficiency is also rare in California orchards but the proposed threshold of 14 ppm could be used as a valuable tool in identifying orchards where B applications might be helpful.

Manganese. Minor leaf symptoms are observed when dormant shoot Mn levels drop below 8 or 9 ppm. However, treatment with Mn fertilizers is probably not necessary until the level drops even lower.

Zinc. We are still in the process of refining a sampling procedure for Zn. At this point we anticipate collecting shoots from the lower part of the tree in fall or early winter and have tentatively set the threshold at 15 ppm.

Potassium, Magnesium and Calcium. We hope to have trees deficient in these 3 elements within a year or two so deficiency thresholds can then be established.

Outreach Activities Summary: Information from this project was presented to many different audiences between 2004 and 2006. The following list summarizes the main presentations:

1. FREP Annual Meeting on Nov. 9, 2004 – 60 in attendance
2. Winter Tree Fruit Meeting on Dec 1, 2004 – 160 in attendance
3. 5th International Symposium on Mineral Nutrition of Fruit Plants on Jan. 21, 2005 in Talca, Chile – 70 scientists from around the world.
4. Plant and Soil Conference on Feb. 2, 2005 in Modesto – 75 researchers and consultants.
5. Pomology Extension Continuing Conference on March 17, 2005 in UC Davis – 30 pomologists.
6. Fresno State University nutrition class on May 3, 2005 at Kearney Ag Center (KAC) – 10 students.
7. Nickels Soil Lab Field Day on May 11, 2005 in Arbuckle – 200 growers and consultants.
8. Almond Farm Advisor tour on May 17, 2005 at KAC – 20 university researchers, specialists and farm advisors.
9. UC Variety Display and Research Update on July 1, 2005 at KAC – 30 growers and consultants.
10. Department of Plant Sciences seminar on Oct. 10, 2005 at UC Davis – 15 researchers and students.
11. Fertilizer Research and Education Program annual meeting on Nov. 30, 2005 in Salinas – 50 consultants, scientists and fruit industry representatives.
12. Tree Fruit Research Meeting on Feb. 14, 2006 in Reedley CA. Presented fertilization/nutrition update to 25 PCAs.
13. Fowler Packing grower meeting on Mar. 21, 2006 in Fowler CA. Presented a talk on stone fruit fertility management to 70 fruit growers.
14. Cooperative Extension Fruit Tree Meeting on Mar. 30, 2006 in Palmdale CA. Presented a talk on fruit tree fertility to 20 growers and consultants.
15. This topic was also the subject of a couple of tree fruit magazine articles in 2006.