

**CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM**

2009 Final Report

Project Title: Development of a Model System for Testing Foliar Fertilizers, Adjuvants and Growth Stimulants.

Project Leader: Patrick Brown
Department of Plant Sciences
UC Davis
Davis, CA 95616
(530) 752-8474 Fax (530) 752-8502
e-mail: phbrown@ucdavis.edu

Cooperators: R. Scott Johnson, Extension Specialist
U.C. Kearney Agricultural Center
9240 S. Riverbend Avenue
Parlier, CA 93648
(559) 646-6547, Fax (559) 646-6593
e-mail: sjohnson@uckac.edu

Objectives:

1. Develop a model system for testing the efficacy of a broad range of foliar chemicals.
2. Conduct tests of materials of greatest relevance to growers under standardized conditions. Undertake focused field verification.
3. Undertake focused field verification.
4. Conduct preliminary research on effect of plant anatomy (stomatal density and distribution, cuticle composition, leaf waxes and hairs etc) on foliar efficacy as a prelude to development of new and targeted formulations. (Future Goal)

Abstract: The goal of this project was to develop and test a model system to improve our understanding of the use and effectiveness of a broad range of foliar fertilizers, adjuvants and growth stimulants so that growers can make informed decisions to improve production efficiency and profitability. The impetus for this grant was derived from the difficulty in conducting field research and lack of understanding of the function and efficient use of the plethora of foliar chemicals in the market today is inadequate. This project aims to this challenge by providing an efficient and practical means to screen materials and application techniques and explore the factors that influence effectiveness of foliar chemicals.

The approach used here has been shown to be an effective method to determine the relative efficacy of a variety of foliar Zn, Ca, B, and Mn materials. Field validation of results derived from the model system are in general agreement however important differences in response were observed suggesting that while the model system can be used for initial screening that field verification is always recommended.

Results from replicate trials have shown a consistent and reproducible ranking of relative efficacy of Zn materials emerging, however, the absolute effectiveness of a material varies in direct relation with the background Zn concentration in the plant. Rate of application of inorganic Zn materials has an important effect on the efficacy of many, but not all, products. Relative performance of several widely used materials increasing as rate increased. For foliar Zn, Ca and Mn applications soluble inorganic forms of the nutrient element (sulfate and nitrate forms) are often as effective as more expensive specialty foliar formulations. The highest-efficacy specialty foliar formulations are however, generally more efficient, per mass of applied element, than the common inorganic salts. Low solubility inorganic salts (phosphates and oxides) exhibited generally low efficacy at least over the duration of experiments conducted here.

Trials with Zn and Mn foliar fertilizers demonstrate clearly that foliar applications of can result in substantial within plant transport when applied to young plant tissues. Applications of foliar Ca generally only results in a benefit to the sprayed tissue with relatively little internal mobility. In all instances however, the percentage of applied nutrient that enters the plant and contributes to long-term nutrient balance is relatively low suggesting that considerable potential exists for the development of enhanced efficiency foliar fertilizers.

Introduction: Foliar fertilization and the application of foliar stimulants, adjuvants and other non-pesticide materials (foliar chemicals) have become a central practice of many agricultural producers. Our understanding of these products, is however, remarkably poor and for the majority of foliar fertilizers used in Californian agriculture there is very little information on nutrient uptake, nutrient use efficiency, nutrient transport or the application conditions that optimize efficiency and return on investment.

Foliar chemicals are used for a number of reasons; some of which have a clear physiological and production rationale while others are of doubtful utility. Valid reasons for the use of foliar include the correction of low nutrient availability in soils (e.g. Fe deficiency in high pH soils), overcoming limitations induced by environment (foliar Zn in spring), overcoming excessive nutrient demand during fruit growth (N, K in nuts), targeted fruit quality enhancement and the need to ensure time critical delivery of nutrients to specific tissues (B to flowers and fruit, Ca to fruit). It is well documented that plant response to foliar applied nutrients in the field is an extremely complicated process, which depends on the nutrient status of the plant, species as well as timing of application and environmental factors (Weinbaum, 1988). As a result, contradictory results are often found with the same chemical and the same plant species but with different locations and under various conditions (Buchholz et al., 1998; Weinbaum, 1988). Field trials of foliar fertilizers have frequently been difficult to replicate, hard to interpret and hence poorly adopted by growers.

Studies of foliar fertilizers conducted under controlled laboratory conditions, and frequently with excised tissues, have made significant contributions to our understanding of the principles involved in foliar uptake and can provide valuable insight into predicted field responses. Over the past decade the most significant advances in our understanding of foliar chemicals has been made by the German researchers Schonherr and Bucholz (see references in Fernandez and Ebert, 2005), who have determined that the cuticular membrane is the most important, or the sole pathway, for the foliar nutrients (Marschner, 1995). Recent evidence, however, suggests that stomatal penetration of aqueous solutions may be an important pathway for nutrient uptake that was overlooked in laboratory based experimentation in which stomata were absent or not considered (Fernandez and Ebert, 2005). While advances in fundamental understanding have the potential to greatly improve field application, there have been remarkably few attempts to use this information to explain field responses.

Determination of the relative nutritional effectiveness and physiological impact of the wide variety of foliar nutrient formulations available in the market for field and horticultural crops is an experimentally complex, time consuming and inexact science. For many growers, farm advisors, consultants and sales persons making recommendations on the use of the plethora of available foliar materials represents a tremendous challenge. Additionally, for companies that have produced quality, effective products, there is great difficulty in separating their product from those that are less effective.

Current approaches to determining the effectiveness of a particular nutrient formulation are crude and time consuming and do not easily allow for the determination of the biological or environmental factors that determine formulation effectiveness. Studies such as this are typically conducted in the field with the incumbent limitations on environmental control, replicability and reproducibility. Given the very significant degree of uncontrolled variability in field experimentation it is often very difficult to determine the true effectiveness of a product and misleading results can easily be obtained. Field experimentation rarely provides adequately robust information to truly determine the physiological basis underlying a superior material or approach, without this information, results of experiments cannot serve as good predictors of the effectiveness of an approach under different field conditions.

Our goal in this project was to develop a quick and easy system for testing foliar chemicals and to use that system to determine the most effective commercially available products. This was achieved by following the experimental steps outlined below.

Work Description:

Task 1: Establish a Model Growth System to Test Foliar Products:

A model system has been developed that allows for rapid replication, careful environmental control, precise foliar nutrient applications and intelligent sampling protocols to determine true nutrient use efficiency. The test-plant system (Arabidopsis),

which has a short 45-60 day life cycle (cultivar dependent) and a very distinct vegetative/floral transition period. Plants were grown in a controlled environment growth chamber in a system that prevents the inadvertent contact of foliar fertilizers with soil. Briefly, seed are germinated in plastic pipette tips pushed into the soil surface, the soil surface is then covered with plastic and the space between plant stem and pipette tip and pipette tip and plastic soil cover, is further protected with lanolin. This approach prevents foliar spray materials from reaching the soil surface. The rapid growth of the test plant allows us to determine both the degree of uptake and the movement of the foliar chemical within the plant. Since this test measures the combined effects of foliar absorption and within plant transport it can be viewed as highly rigorous. Foliar spray materials that do result in either foliar uptake or transport within the plant will be identified. With this system established we have now commenced a series of investigations of many commonly used foliar products.

We have tested five kinds of culture medium: 1), Sunshine potting mix #1; 2) vermiculite; 3) sand; 4), mixture of half Sunshine potting mix #1/half sand; and 5) Perlite. A test was conducted to validate that the system in use does not result in soil contamination and that all measured increases in reproductive tissue elemental content are the sole result of foliar uptake and transport. This was performed by application of a high concentration foliar Rb spray to plants of various degrees of maturity growing in the experimental system described above. Since Rb is not a naturally occurring element, any detection of Rb in the soil would be an explicit indicator that Rb spray had contaminated the soil surface.

Subsequent to initial model growth system development it was determined that trials with macronutrients (Ca and K) would require a new growth media with a greater capacity for precise and rapid manipulation of soil nutrient availability. A variety of growth materials were tested and a moderately effective approach was developed for Ca testing though no satisfactory approach to K testing was developed.

Task 2: Test a Variety of Common Foliar Products and Rates.

In addition to the system development and formulation trials (tasks 1,3,4) , a total of fourteen independent trials of commercial products have now been completed or are underway (Table 1). These trials have evaluated a total of 50 discrete products. In Zn trials, products have been contrasted at both fixed application rates of 400 ppm or at approximate field rates for tree crops in both model (Table 2, 7) and subsequent field testing (Table 8). In calcium, manganese and boron trials, materials have been contrasted at field rates only.

Task 3: Conduct Targeted Field Validation

Replication of results with select Zn products identified here have been conducted in Almond (Table 8) and in collaboration with Scott Johnson and are reported separately. The results of trials with the model system informed the selection of materials to be tested by Dr. Johnson and results were highly consistent across methodologies. Field trials on efficacy of most promising products were conducted in Almond in Spring 2009.

Task 4: Conduct preliminary research to develop new and targeted formulations.

On the basis of early results and theoretical considerations we have conducted tests to determine the relative influence of formulation, additives and surfactants on the uptake and transport of foliar applied Zn. This work has resulted in the development of a new and highly promising Zn formulation (UCD Formula 1). We have also tested results of model system trials in a second herbaceous species *Vinca minor* by applying droplets of 29 μl of 7.5mM ^{68}Zn labeled products to isolated portions of the leaf with or without the addition of 2000 ppm Ca as Ca Sulfate, and/or SAF-T-Side commercial spreader/sticker. The transport of Zn was determined by measuring the appearance ^{68}Zn in leaf regions outside the treated area.

Results and Conclusions:

Baseline conditions for plant growth have been established and Perlite has been adopted as the primary growth medium.

Growth conditions are: *Arabidopsis* was grown in a controlled environment growth chamber with day length of 16 hours and light intensity of $120 \mu\text{mol.m}^{-2}.\text{sec}^{-1}$, day/night temperature: 22/20°C, relative humidity 70%. A tray of 21"x10"x2.2" is used, which can hold 36 small pots (4 plants in a row x 9 rows). During foliar application, every two rows in each tray serves as one experimental unit so that every tray can handle 4 experimental units. The whole tray was fed with water and nutrients by root submersion technique. The soil surface is protected from spray drift by covering the entire surface with a plastic cover. A plastic pipette tip is then modified to form a tube (4 mm long, top inside diameter 3.5 mm and bottom inside diameter 3 mm) which is then inserted in the middle of the pot, through the plastic cover and into contact with the soil. Seeds are planted directly into this tube. Plant emergence then occurs through the tube. Subsequent to emergence the junction between plant stem and plastic is sealed with lanolin. The system prevents any contamination of rooting media with foliar spray.

Verification that foliar sprays do not result in soil uptake were performed with the application of Rb at 5,000 ppm sprayed to drip. Results clearly demonstrate the effectiveness of the system at avoiding soil contamination and validates that elemental enrichment found in reproductive tissues of foliar treated plants is solely the result of the foliar uptake and transport of the applied foliar material and not a consequence of soil contamination.

Zinc: Eight-model system and one field trial of common foliar Zinc products have now been completed. Table 2 provides a summary of the first 6 model-system trials. In all cases results represent relative efficacy in contrast to the unsprayed control and Zn Sulfate (400 ppm). In all trials to date the amount of foliar applied Zn that was subsequently measured in the reproductive tissues represented only from 0 to 15% of the total applied Zn thus illustrating the relatively low overall efficacy of all current foliar Zn materials. When provided at a uniform concentration of 400 ppm, materials with a high degree of solubility that provide Zn in the presence of putative complex forming compounds, as well as N-Zn, exhibited significantly more relative efficacy than inorganic

salts and insoluble Zn products. In general, products that contain amino acids were marginally less effective than products based on carbohydrate complexation with Zn EDTA and N-Zn being intermediate in efficacy (ranking 8).

When provided at full field rate, several inorganic Zn products that were shown to be marginally effective at 400 ppm showed significant improvement and performed as well as many of the high solubility complexed materials. Zn Sulfate provided at 400 ppm was only moderately effective (ranking 5), however when provided at 1500 ppm was ranked among the most effective products (ranking 8). Similarly, Neutral Zn which was shown to be largely ineffective when provided at 400 ppm was ranked among the most effective products (ranking 8) when provided at 1860 ppm. RNA Microphos improved from mildly effective (3) to moderately effective (7.2) when the application rate was increased from 400 to 5000 ppm. Highly insoluble Zn forms (Zn phosphate/oxides) improved from inefficient (ranking 1-3) to moderately efficient (ranking 7) as rates increased to 5000 ppm. The increase in efficacy of Neutral Zn may be a consequence of the increase in concentration of Zn Sulfate present in that blend.

A repeat test of the most promising commercial 'complexed or specialty' Zn formulations as well as the UCD formulation was performed in 2009 (table 7) at constant 500 ppm rates. Results were consistent with earlier experiments (table 2) with the CHO based products (Brandt Mani-plex and Floratine materials) generally performing better than other products while the inorganic complex formulation (UCD Experimental 1) was the most effective material.

A field test of Zn formulations was performed in 2009 and results measured in 2010. Three commercial Zn formulations (Mani-plex Zn, Metalosate Zn and Zn Sulfate) and two test materials (UCD A and UCD B) were applied just after full leaf expansion and Zn in leaves was measured the following year in May and June. Applications were made at commercial rates to 15 tree plots and replicated 4 times (60 trees total per treatment). By delaying measurements one full year the possibility of surface Zn contamination was eliminated.

At the earlier collection date (May) all Zn materials with the exception of Metalosate enhanced tissue Zn. A decline in leaf Zn concentration occurred with the later sampling date and likely reflects dilution of tissue Zn with leaf growth. At the second sampling date the two inorganic Zn products (Zn sulfate and UCD experimental A) were superior to all other materials.

Effect of Ca additions to Zn foliar Applications: Prior experiments in almond and pistachio suggest that addition of Ca to Zn sprays can enhance efficacy of Zn application. This observation was verified in several studies performed here. The application of calcium (table 3) to stable isotope enriched Zn sulfate significantly increased by 200% the amount of ⁶⁸Zn that was absorbed and/or transported to newly developed leaves in Vinca minor test plants. The use of the spray additive Safe-T-Side had no influence on relative efficacy of Zn sprays.

On the basis of the integrated results we designed a new foliar Zn formulation (UCD experimental 1 and UCD experimental 2) that was shown to be highly effective in both

the model system trials (Table 2 and table 7) and in field verification (table 8). Further development is required however to maintain stability of this product.

Calcium: Initial trials with Ca based foliar materials at uniform 400 ppm of all materials (current field rates for many of the commercial products) failed to result in any measurable Ca uptake and transport in the model system (table 4). This may have occurred because of the relatively short duration of the first experiment. A subsequent experiment of longer duration with three consecutive applications resulted in measurable Ca uptake and transport of all materials tested. No significant difference between any Ca containing products was observed (table 5).

Manganese: Trials of three Mn containing foliar fertilizers were performed in the model system (table 6). Relatively high Mn uptake and transport was observed in the model system which contrasts with the widely held belief that Mn is highly immobile in plants. All materials tested performed with equal efficacy.

Conclusion: The approach used here has been shown an effective method to determine the relative efficacy of a variety of foliar test materials. Complexed and chelated materials are generally more efficient on a mass of element basis, than inorganic sources however, the efficacy of several inorganic Zn products can be significantly enhanced by increasing spray concentrations. Due to label restrictions we did not test the efficacy of increased concentrations of the commercial products used here. Thus, while several CHO based commercial products were shown to be more effective than inorganic products when used at a standard 400 ppm (label rate), this advantage was reduced when the inorganic products were applied at typical field rates (1000 to 1860 ppm). This illustrates the important difference between results expressed as efficacy as opposed to efficiency. No calculation of relative cost efficacy or ease of application was attempted.

Overall the percentage of applied Zn that was apparently absorbed and transported to new tissues was very small (<10%) of the total applied materials indicating that overall efficiency of most Zn products is low.

While the system used here has proven effective as a screening tool it is essential that all materials be tested under field conditions and in the species of interest.

REFERENCES/LITERATURE REVIEW:

- Buchholz A, Baur P, Schonherr J. 1998. Differences among plant species in cuticular permeabilities and solute mobilities are not caused by differential size selectivities. *Planta* 206: 322-328.
- Fernandez V, Ebert G. 2005. Foliar iron fertilization: a critical review. *J. Plant Nutr.* 28: 2113-2124.
- Schonherr J, Fernandez V, Schreiber L. 2005. Rates of cuticular penetration of chelated Fe-III: role of humidity, concentration, adjuvants, temperature, and type of chelate. *J. Agric. Food Chem.* 53: 4484-4492.

- Weinbaum SA. 1988. Foliar nutrition of fruit trees. In: Neumann PM (ed.) Plant growth and leaf applied chemicals. CRC Press Boca Raton, Fla. Pp. 81-100.
- Wittwer SH, Teubner FG. 1959. Foliar absorption of mineral nutrients. *Ann. Rev. Plant Physiol.* 10: 13-32.

Table 1: Record of experimental trials conducted. (Individual and summarized data are provided in table 2-8)

Experiment Number Title	Products tested*
1: Zinc foliar trial: <i>All applied at 400 ppm Zn.</i>	Zn-EDTA (10%), NZn (5%), Neutral Zn (52%), Zn fulvic (7%), Zn lignosulfonate (7%), Zn Metalosate (7%), Zn Sulfate (36%)
2: Zinc foliar trial <i>All applied at 400 ppm Zn in solution</i>	Zn-EDTA (10%), NZn (5%), Neutral Zn (52%), Zn fulvic (7%), Zn lignosulfonate (7%), Zn Metalosate (7%), Zn Sulfate (36%).
4: Zinc foliar trial <i>All applied at 400 ppm Zn in solution</i>	NZn (5%), Zn Oxide (40%), Zn Metalosate (7%), Krystal Klear Zn (9%), Bionutrient Zn (8%), ProNatural Zn (5.8%), RNA Microphos (52%), BioLink Zn (8%), BioMin Zn (7%), Zn Sulfate (36%), RNA Zn Nitrate (10%)
5: Zinc foliar trial <i>All applied at 400 ppm Zn in solution</i>	NZn (5%), Zn Oxide (40%), Zn Metalosate (7%), Krystal Klear Zn (9%), Bionutrient Zn (8%), ProNatural Zn (5.8%), BioLink Zn (8%), BioMin Zn (7%), Zn Sulfate (36%), RNA Zn Nitrate (10%)
7: Zinc foliar trial (Vinca)	Influence of surfactants and Calcium on Zinc foliar uptake and transport.
8: Zinc foliar trial (Almond)	Influence of surfactants, formulation and Calcium on Zinc foliar uptake and transport in field grown Almonds.
9: Zinc foliar trial <i>All applied at 400 ppm Zn in solution</i>	NZn (5%), Zn fulvic (7%), Zn Metalosate (7%), Krystal Klear Zn (9%), Bionutrient Zn (8%), ProNatural Zn (5.8%), BioLink Zn (8%), BioMin Zn (7%), Zn Sulfate (36%), Zn lignosulfonate (7%), Zn-EDTA (10%), RNA Zn Nitrate (10%)
10: Zinc foliar trial <i>All applied at field rates.</i>	Zn Oxide (40%), Zn fulvic (7%), , Zn Metalosate (7%), Bionutrient Zn (8%), ProNatural Zn (5.8%), RNA Microphos (52%), Zn Sulfate (36%), RNA Zn Nitrate (10%), Zn Oxide (40%), Neutral Zn (52%).
11: Calcium-boron trial 1 <i>All applied at field rates.</i>	BioMin Ca, FoliCal (Monterey), Ca Nitrate, Ca Chloride, UCD Experimental Ca, Ca-glycinate.
12: Calcium-boron trial 2 <i>All applied at field rates.</i>	CaCl ₂ , 34%; Ca(NO ₃) ₂ ; 11%, Wuxal Calcium, 15%; Calcium Phosphite (Vigor Cal, 4%); Calcium citrate complex (FoliGro Calcium, 6%); ProNatural Calcium, 5%; NDemand Calcium, 5.5%; Foli-cal (Brandt), 10%; Actagro Ca, 7%; Cell-Mate-F +/- X-100, 8%.
13: Manganese Trial <i>All applied at 500 ppm.</i>	UCD Experimental Mn; Mani-plex Mn; Mn Sulfate (Technical grade).
14: Foliar Zn – Almonds <i>All applied at field rates.</i>	Zn Metalosate (7%); Mani-Plex Zn (7%); UCD Experimental A; UCD Experimental B; Zn Sulfate (36%).

* Mention of a product trade name or commercial enterprise does not imply endorsement of this product or commercial enterprise by the author or the University of California, Davis.

Table 2: Integrated results of six independent trials of Zn foliar materials. Five trials were conducted at standardized Zn concentrations in final solution (400 ppm), an additional trial was conducted at field concentrations determined as the approximate median of label rates. Where a single concentration is listed it implies that field rate does not vary significantly from 400 ppm. Overall rankings represent an integration of relative efficacy of product in comparison with control and with 400 ppm Zn Sulfate which was utilized in all experiments.

Material Name*	Concentration (ppm)	Overall Ranking 1 = no significant difference from control; 2-4 = small increase in tissue Zn; 5-7 = consistent and significant increase in tissue Zn; 8-10 = consistent very significant increase in tissue Zn.	Comments
Zinc FL 1-0-0	400 ppm	1	40% Zn as Zinc Oxide. Miscible in water, solubility limited.
Neutral Zinc	400 ppm	1	52% Zinc Oxide and Sulphate.
Zn Phosphate/Oxide	400 ppm	3	52% Zn as phosphate/oxide mixture. Miscible in water, solubility limited.
Zinc Fulvic Acid	400ppm	4	7% Zinc fulvic acid complex.
Zinc Sulfate	400 ppm	5	36% Zinc sulfate. Variability in response between experiments.
Chelate Zn 1	400 ppm	6	9% synthetic chelated Zn.
Zinc Lignosulfonate	400 ppm	6.5	7 – 10% Zinc sulfate Lignosulfonate.
Chelate Zn 2	400 ppm	6.6	8% Zn, hydroxy-carboxylic, amino acid complex.
Zinc nitrate	400 ppm	7.0	10% Zn as Zn nitrate. Variability in response between experiments.
Zn Phosphate/Oxide	5000 ppm	7.2	52% Zn as phosphate/oxide mixture. Miscible in water, solubility limited.
Amino Zn 1	400ppm	7.2	5.8% Zn Amino Acid.
Complex Zn 1	400 ppm	7.3	7% Zinc Sulfate, Citric Acid, Glycine.
Amino Zn 2	400 ppm	7.3	7% Amino complexed Zn.
Complex Zn 2	400 ppm	7.3	8% Zinc.
Zinc EDTA	400 ppm	8	10% EDTA complexed Zn.
Neutral Zinc	1860 ppm	8	52% Zinc Oxide and Sulphate.
Zinc Sulfate	1500 ppm	8	36% Zinc sulfate.
NZn	400 ppm	8.4	5% Zn as Zn Nitrate with Urea and Urea Ammonia Nitrate.
Zn CHO complex 1 (Floratine Bioscience)	400 ppm	8.6	6% Zinc carbon complex.
Zinc CHO Complex 2 (Brandt Manni-plex)	400 ppm	9	7% Zinc carbon complex.
UC Davis Formula 1	1000 ppm	10	25% Zn. Non-commercial product. Zn sulfate and Zn nitrate with organic complex and adjuvants.

* Mention of a product trade name or commercial enterprise does not imply endorsement of this product or commercial enterprise by the author or the University of California, Davis.

Table 3. Influence of calcium and surfactant addition on efficacy Zn transport in Vinca minor.

Treatment	$^{68}\text{Zn}/^{67}\text{Zn}$ ratio
Ck	4.72 ± 0.12^a
^{68}Zn Sulfate	6.45 ± 1.31^a
^{68}Zn Sulfate + CaCl_2	13.4 ± 2.59^b
^{68}Zn Sulfate + SAT-T-SIDE	5.27 ± 0.16^a
^{68}Zn Sulfate + CaCl_2 + SAT-T-SIDE	14.3 ± 3.55^b

Table 4. Comparison of efficacy of foliar calcium formulations.

Trial was conducted in Arabidopsis model system with materials applied to vegetation at concentrations approximating normal field application rates (200-400 ppm in solution). Calcium uptake and transport to reproductive structures was determined by measuring Ca concentrations in reproductive tissues. Reproductive tissues received no direct foliar applications and hence represent Ca that was both absorbed by the leaf and transported to the reproductive tissues.

Experimental design: 6 plants per replicate tray, 4 replicate trays per treatment.

Application December 17th, harvest Jan 2nd.

Product (Chemical or Trade Name)	Concentration (ppm in final spray solution, sprayed to wetness with Triton X1—surfactant)	Mean Calcium Concentration (%) in Reproductive Structures. Statistical separation at 5%.
Control	0	1.1 ^a
Calcium Chloride (technical grade)	400	1.07 ^a
Calcium Nitrate (technical grade)	400	1.18 ^a
Wuxal Calcium	200	0.98 ^a
Calcium Phosphite	400	1.09 ^a
Calcium Citrate Complex	400	1.0 ^a
ProNatural Calcium	400	1.2 ^a
N Demand Calcium	400	1.1 ^a
Foli-Cal	400	1.1 ^a
Actagro Calcium	200	1.1 ^a
Floratine Cell-Mate F plus X100	400	1.1 ^a
Floratine Cell Mate F	400	1.0 ^a

Note: Results suggest that spray application rates were not high enough to allow for detectable Ca transport to reproductive structures or that duration of experiment was insufficient.

Table 5. Comparison of efficacy of foliar calcium formulations.

Trial was conducted in Arabidopsis model system with materials applied to vegetation at concentrations approximating normal field application rates (200-400 ppm in solution). Calcium uptake and transport to reproductive structures was determined by measuring Ca concentrations in reproductive tissues. Reproductive tissues received no direct foliar applications and hence represent Ca that was both absorbed by the leaf and transported to the reproductive tissues.

Experimental design: 6 plants per replicate tray, 6 replicate trays per treatment.

Application Feb 22nd, harvest Mar 18th.

Product (Chemical or Trade Name)	Concentration (ppm in final spray solution, sprayed to wetness with Triton X1—surfactant)	Mean Calcium Concentration (%) in Reproductive Structures. Statistical separation at 5%.
Control	0	1.33 ^a
Calcium Chloride (technical grade)	400	1.63 ^b
Calcium Nitrate (technical grade)	400	1.51 ^b
Bioimin Calcium	200	1.58 ^b
UCD Experimental Ca (50% Calcium nitrate, 50% Calcium chloride – buffered)	400	1.51 ^b
Calcium Glycinate	400	1.4 ^{a,b}
Foli-Cal	400	1.53 ^b

Table 6. Comparison of efficacy of foliar manganese formulations.

Trial was conducted in Arabidopsis model system with materials applied to vegetation at concentrations approximating normal field application rates (200-400 ppm in solution). Manganese uptake and transport to reproductive structures was determined by measuring Mn concentrations in reproductive tissues. Reproductive tissues received no direct foliar applications and hence represent Mn that was both absorbed by the leaf and transported to the reproductive tissues.

Experimental design: 6 plants per replicate tray, 5 replicate trays per treatment.

Application Feb 22nd, harvest Mar 18th.

Product (Chemical or Trade Name)	Concentration (ppm in final spray solution, sprayed to wetness with Triton X1—surfactant)	Mean Manganese Concentration (ppm) in Reproductive Structures.
Control	0	8.3 ^a
UCD Experimental Mn	500	12.2 ^b
Maniplex Mn	500	14.11 ^b
Mn Sulfate	500	15.11 ^b

Table 7. Comparison of efficacy of foliar Zinc formulations.

Trial was conducted in Arabidopsis model system with materials applied to vegetation at standardized application rates (500 ppm in solution). Zinc uptake and transport to reproductive structures was determined by measuring Zn concentrations in reproductive tissues. Reproductive tissues received no direct foliar applications and hence represent Zn that was both absorbed by the leaf and transported to the reproductive tissues. Experimental design: 6 plants per replicate tray, 4 replicate trays per treatment. Application Feb 22nd, harvest Mar 18th.

Product (Chemical or Trade Name)	Concentration (ppm in final spray solution, sprayed to wetness with Triton X1—surfactant)	Mean Zn Concentration (ppm) in Reproductive Structures.
Control	0	31.9 ^a
Actagro Zn	500	32.8 ^a
Actagro Zn plus Monarch	500	28.2 ^a
Zn Metalosate	500	34.2 ^b
UCD Experimental Zn A	500	43.1 ^d
EDTA Zn	500	34.3 ^b
Lignosulfonate Zn	500	35.0 ^b
Floratine Zn	500	37.0 ^{b,c}
Zn Manni-plex	500	39.0 ^{b,c}

Table 8. Field comparison of efficacy of foliar Zinc formulations.

Trial was conducted in 12 year-old Nonpareil almond. Experimental design: 15 trees per plot sprayed to drip at equivalent of 125 gallons per acre with Activator 90 surfactant. Application May 18 and May 30, 2009. Leaf samples collected May and June 2010.

Product (Chemical or Trade Name)	Concentration* (ppm in final spray solution) Application May 2009	Mean leaf Zn concentration (ppm). May, 2010	Mean leaf Zn concentration (ppm). June, 2010
Control	0	20.5 ^c	14.5 ^b
Zn Metalosate	400	21.6 ^c	15.5 ^b
Manni-Plex Zn	400	22.2 ^{b,c}	16.7 ^{a,b}
UCD Experimental Zn B	1000	23.8 ^a	16.9 ^{a,b}
UCD Experimental Zn A	1000	24.0 ^{a,b}	17.6 ^a
Zn Sulfate	1860	26.0 ^a	18.0 ^a

*Rates reflect typical label rates for almond.

Outreach Activities:

The PI presented results directly related to this project at a number of events.

May 18th, 2008: International Colloquium on Mineral Nutrition of Fruit Trees, Portugal (200 Participants)

July 21st, 2008: American Society of Horticultural Science Annual Meeting Talk: New considerations for Nutrient Sampling and Analysis. 150 participants.

August 18th, 2008: Napa Grape Nutrition Talk. Foliar Fertilizers, Nutrient Sampling and Analysis. 35 attendees

November 6th, 2008: Actagro Annual Nutrition Management Day. Talk: Management of micronutrients in tree crops. 400 Attendees.

November 13th, 2007: CDFA/WPHA Annual Conference. Micronutrients in Almonds and Pistachio. 300 Attendees.

December 10th, 2008: Almond Conference. Hot topics in nutrient management of Almond. 500 Attendees.

Jan 2009. Growers Breakfast Speaker, Blue Diamond Almond Growers, 900 attendees

Feb 14-16, 2009, Fluid Fertilizer Foundation, Scottsdale, 120 attendees.

June 17, 2009. Tri Valley Almond Day, Modesto.

July 29-31. Int Soc, Plant, Soil Analysis, Santa Rosa, 150 attendees.

Feb 2, 2010. Calif Agronomy Society, Visalia. 220 Attendees.

March 23-26th 2010. International Fertilizer Association and New Ag Conference, Miami. 300 attendees.

Publications (In Press):

Foliar Fertilization. 2012. Victoria Fernandez, Thomas Sotiropoulos, Patrick Brown. *This 200 page book on foliar fertilization will be published by the International Fertilizer Association in late 2012 and contains significant information derived from research conducted under this grant. This book is targeted toward industry professionals.*

Almond Manual, 2012. Management of Nutrients. Patrick Brown, Sebastian Saa, Saiful Muhammad. *A major revision of the industry standard management handbook with sections on foliar fertilization drawing heavily from this grant.*