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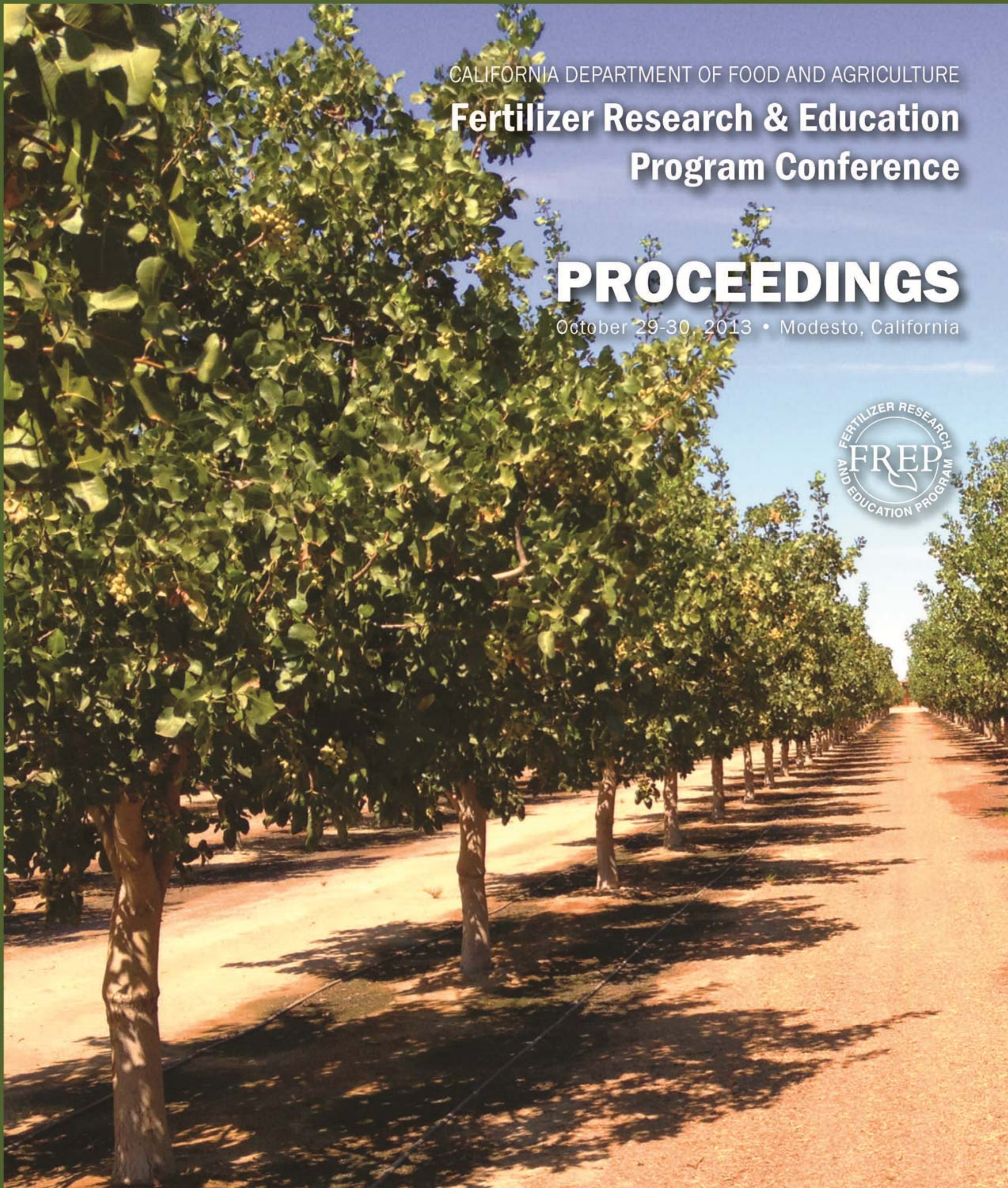

# Towards Development of Foliar Fertilization Strategies for Pistachio to Increase Total Yield and Nut Size and Protect the Environment


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## INTRODUCTION

Pistachio (*Pistacia vera* cv. Kerman) is like other tree crops in that flowering (pollination and fertilization), fruit development, shoot elongation, and root growth compete at times for available nutrients. Economic gains in fruit retention, increased fruit or nut size, and marketable yield have been made during these stages with properly timed foliar fertilization of pistachio (Brown et al. 1995) and other tree crops (Lovatt 1999, Boman 2002, Wojcik et al. 2008, Gonzalez et al. 2010). Foliar fertilization is a rapid, efficient way to improve crop nutrient status during periods of high demand or when soil conditions (low or high temperature, low or high soil moisture, salinity, pH) render soil nutrients and soil-applied fertilizers less available to the plant or when nutrients (e.g., phosphate, potassium and trace elements) become fixed in the soil. Under these conditions, foliar fertilization can provide the nutrients required for photosynthesis and other important metabolic functions essential to plant growth and productivity. In addition, because foliar application of fertilizers can reduce nutrient accumulation in soil, run-off water, surface water (streams, lakes, ocean), and groundwater (drinking water supply), where they contribute to salinity, eutrophication or nitrate contamination, with negative consequences to the environment and humans, it is highly desirable to replace soil-applied fertilizers at least in part with foliar-applied fertilizers. For pistachio and other deciduous fruit crops, reproductive growth commences before vegetative shoot growth. Targeting developing floral buds and flowers with fertilizer sprays has resulted in yield increases in pistachio (Brown et al. 1995) and other tree crops (Lovatt 1999, Gonzalez et al. 2010, Righetti n.d.). Mature pistachio leaves, similar to many crop plants, have a thick waxy cuticle shown to compromise uptake of some foliar-applied nutrients.

The goal of our research was to test the capacity of three foliar fertilization strategies to successfully supply key nutrients at phenological stages of high nutrient demand and thereby increase nut size, percent split nuts, fruit set, and floral bud retention. An increase in any one of these yield components would increase grower net profit.

## OBJECTIVES

1. To test Strategy 1-The foliar application of boron (B), zinc (Zn) and urea (N) at bud swell to enhance flower nutrient levels (ovary and/or pollen) to increase fruit set. Despite uptake of only small amounts of nutrients, prebloom applications of these elements have been shown to increase yield in other tree crops (Jaganth and Lovatt 1998, Gonzalez at al. 2010, Righetti n.d.). Research testing prebloom foliar applications of Zn to pistachio trees has produced mixed results (Uriu 1986, Brown et al. 1995).
2. To test Strategy 2-The application of foliar fertilizers at 1/2- to 2/3-leaf expansion when leaves have a cuticle thin enough for nutrient uptake and sufficient surface area that the amount of nutrient taken up is large enough to enhance tree performance.
3. To test Strategy 3-The use of urea as a carrier to increase uptake of B, Zn, K and S into buds and/or leaves, especially during kernel filling when all but the most current pistachio leaves have a fully developed wax cuticle. Researchers and growers use urea in foliar treatments to improve the uptake of nutrients with limited evidence of its effect.
4. To calculate a cost: benefit analysis and disseminate it to growers.

## DESCRIPTION

The design of the experiment was a randomized complete block with 11 treatments, including an untreated control, and 15 individual tree replications of each treatment in a commercial orchard owned by Paramount Farming in Kings County. The 15-year-old 'Kerman' pistachio trees on Pioneer Gold 1 rootstock were planted in a row/tree spacing of 19 x 17 feet at 135 trees per acre (5.8 x 5.2 m at 333/ha). The experiment was conducted for 2 years to determine treatment effects on yield and its components (nut size, split nuts, kernel weight, stained nuts, insect-damaged nuts, blank nuts) and on retention of floral buds for next year's crop. There were buffer trees between treated trees within a row and buffer rows between treated rows. At the specified stages of tree phenology, foliar fertilizers were applied in 100 gallons of water per acre (934.6 liters/ha) (industry standard). Applications were made using a three-point fan sprayer producing strong canopy movement and fine droplet size. Sets of leaves in the four quadrants of the trees receiving fertilizer sprays were bagged just prior to fertilizer application and uncovered 4 hours later. Buds were sampled just prior foliar fertilizer applications and again 7 to 10 days after application for nutrient analysis. In Year 1, leaves collected 7 to 10 days after fertilizer application failed to show any response to treatment, whereas those collected 21 days after the fertilizer was applied revealed increased leaf nutrient concentrations in response to treatment. Thus, in year 2, leaves were collected 21 days after each treatment was applied. Leaves were also collected at the end of July and mid-August (the standard time for pistachio leaf analysis) and in October to determine if increased leaf nutrient concentrations in response to foliar-applied fertilizers persisted at a level sufficient to "preload" the tree for the following spring bloom. Samples were immediately stored on ice, taken to UCR, washed, oven-dried at 140 °F (60 °C), ground to 40-mesh (0.0165 inches, 0.4 mm), and sent to the UC-DANR Laboratory at UC-Davis for analysis. Tissues were analyzed for the following: N, S, P, K, Mg, Ca, Fe, Mn, B, Zn, and Cu by atomic absorption spectrometry and inductively coupled plasma atomic emission spectrometry. Additionally, one branch (bearing fruit) in each of the four quadrants of each treated tree was tagged and the initial number of floral buds per branch counted just prior to harvest. At harvest, individual tree yields were taken, and a 20-pound (9-kg) sample was submitted to Paramount Farming for quality assessment. Each year, treatment effects were determined by ANOVA ($P = 0.05$). After harvest in year 2, treatment effects on cumulative yield parameters were determined ($P = 0.05$). After harvest in year 2, a factorial analysis by year was used to test for treatment effects on yield, and quality, floral bud retention and leaf nutrient concentrations. The alternate bearing index [ABI = (year 1 yield - year 2 yield) ÷ (year 1 yield + year 2 yield)] was also calculated for each treatment. All data were statistically analyzed using the General Linear Model procedure of SAS. The cost to benefit of each foliar fertilizer strategy for pistachio production was analyzed.

## RESULTS AND DISCUSSION

The experiment was well designed. There were no significant differences in the tissue concentrations of any nutrient among the trees in the different treatments before they received foliar-applied fertilizer, with one exception. At the start of the experiment in Year 2, bud N

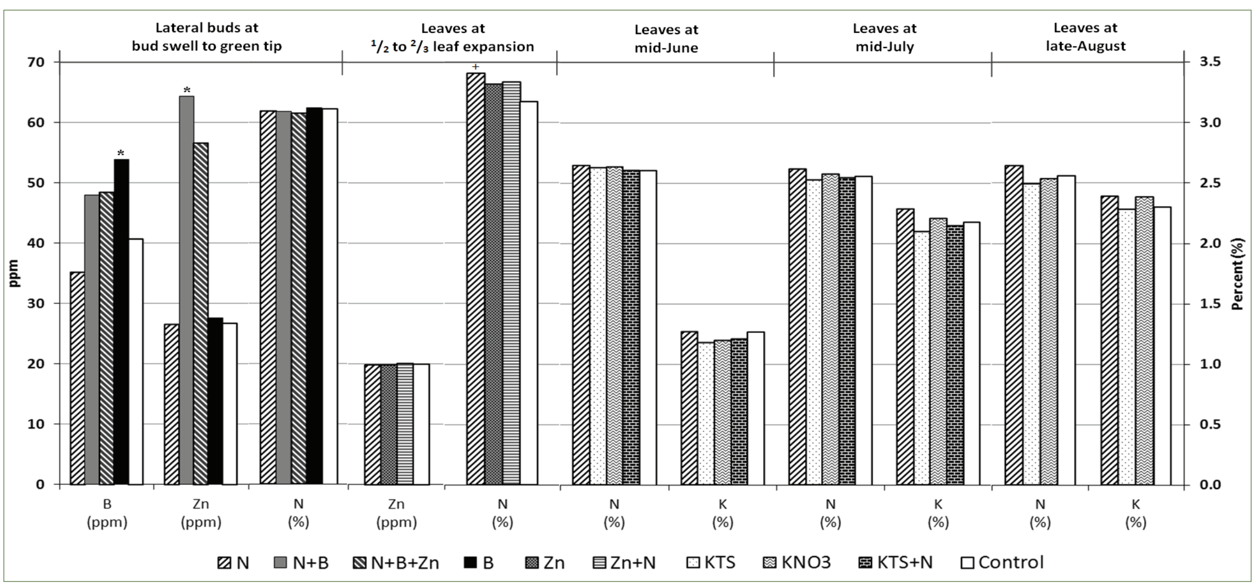


**Figure 1A.** Year 1 - Effects of foliar fertilizers applied at key stages of 'Kerman' pistachio tree phenology on bud or leaf concentrations of boron (B), zinc (Zn), nitrogen (N) and potassium (K). The fertilizers were: N, low-biuret urea; B, Solubor®; Zn, zinc sulfate; KTS, potassium thiosulfate; and $KNO_3$, potassium nitrate. Bars (means) with a * or + are significantly different from other means within the group at $P < 0.05$ or $P = 0.0535$, respectively, by Fisher's Protected LSD Test.

concentrations were different prior to fertilizer application. Based on the Year 1 October leaf analyses, these differences were not related to the effects of the previous year's N fertilizer treatments. In addition, despite elevated concentrations of B, Zn, N, S and Fe in leaves collected in October of Year 1, elevated levels of these nutrients were not detected in buds collected at the bud swell to green tip stage or in leaves collected at 1/2- to 2/3-leaf expansion in Year 2.

In both Years 1 and 2, boron decreased in floral buds from ~mid-March to the beginning of April in the control trees. Buds from trees receiving fertilizer applications at the bud swell to green tip stage of tree phenology and sampled 8 and 7 days after application showed significant differences in bud Zn concentrations but no differences in bud B concentrations. However, when sampled 19 to 21 days after application, trees treated with B showed a significant increase bud B concentration. After the green tip stage of phenology, boron accumulated throughout the growing season, with all trees having equally excessively high leaf B concentrations significantly above the suggested optimal range of 150 to 250 ppm (Beede 2004) by June and reaching 821 to 1019 ppm and 869 to 1290 ppm in October of Years 1 and 2, respectively.

In both years of the research, Zn (as $ZnSO_4$) (+/- urea) applied at 1/2- to 2/3-leaf expansion resulted in significantly greater leaf Zn concentrations than trees in all other treatments, a result that was not detectable until October. In July, trees that received a June application of urea and the control trees had greater leaf N concentrations than trees receiving foliar fertilizer that did not contain N. Also, trees treated with potassium thiosulfate (KTS) (+/- urea) in June had significantly greater leaf S concentrations in July prior to the second KTS application. By October, trees in these two treatments had significantly greater leaf S concentrations than trees in all other treatments.

The standard time for collecting pistachio leaves for nutrient analysis is late July through mid-August. Analysis of leaves collected on 31 July and 21 August indicated that N, Ca, Zn, Mn and Cu were all within the optimal range, leaf P and Mg were below the critical value, and K and B exceeded the optimal range (Beede 2004). In Years 1 and 2, trees receiving three foliar applications of urea alone in June, July, and August had significantly greater leaf N concentrations by October than trees that received three foliar applications of $KNO_3$, suggesting that N as $NO_3$ was not taken up by hardened pistachio leaves. However, in Year 2 the relationship between N fertilization treatment and leaf N concentrations was not as strong as in Year 1. By October there were significant differences in leaf K concentrations that were also related to fertilizer treatment, e.g., three applications of $KNO_3$ (+/- urea) resulted in greater leaf K concentrations than the control ($P = 0.0577$). In the case of S, significant differences in October leaf S concentrations were clearly due to the fertilizer treatments, with trees receiving three foliar applications of KTS (+/- urea) having the most leaf S.

The relative efficacy of foliar fertilizers applied at specific phenological stages versus multiple applications is presented in **Figure 1**. Note that **Figure 1** does not illustrate the differences in tissue nutrient concentrations before and after fertilizer treatments. The increase in bud Zn concentration in response to foliar-applied urea + B is apparent in both years of the research, consistent with

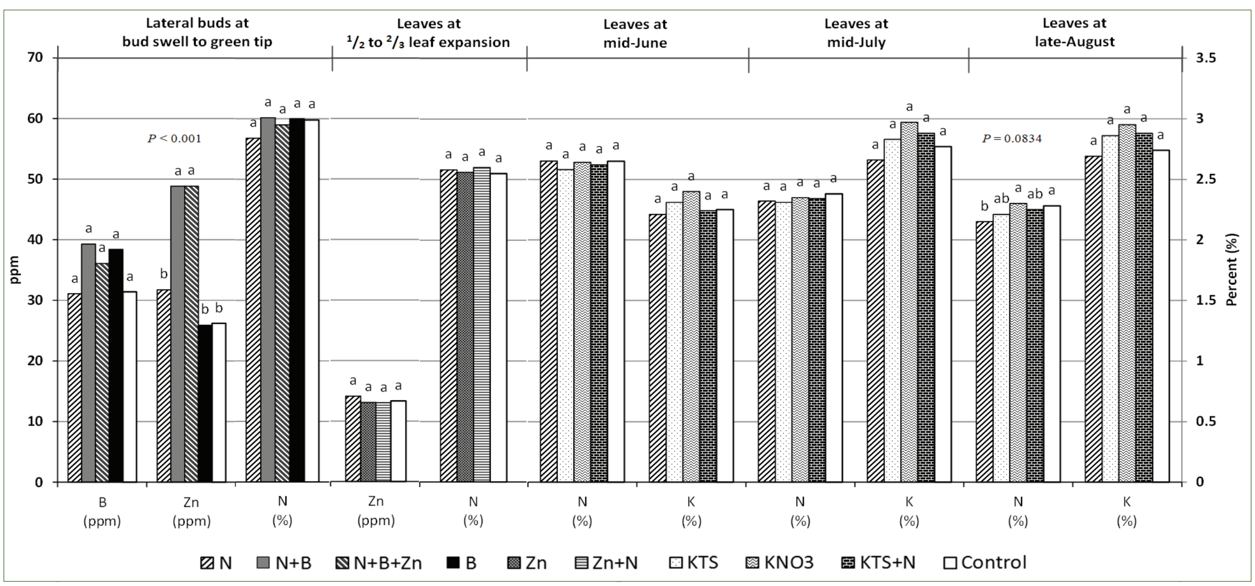


**Figure 1B.** Year 2 - Effects of foliar fertilizers applied at key stages of 'Kerman' pistachio tree phenology on bud or leaf concentrations of boron (B), zinc (Zn), nitrogen (N) and potassium (K). The fertilizers were: N, urea; B, Solubor®; Zn, zinc sulfate; KTS, potassium thiosulfate; and $KNO_3$, potassium nitrate. Bars (means) within a group with different letters are significantly different from other means within the group at the specified P-value by Fisher's Protected LSD Test.

increased uptake of soil Zn.

Despite the successful uptake of several nutrients at key stages of tree phenology and significantly greater concentrations of these nutrients through October, yield and nut quality were not increased by any foliar fertilizer treatment in either year of the research. The orchard had an alternate bearing index (ABI) of 0.48 for the two years of the experiment. Year 1 was the on-crop at 5,833 pounds per acre (6,538 kg/ha) followed by an off-crop of 2,560 pounds per acre (2,869 kg/ha). Fertilizer treatments had no effect on ABI, 2-year cumulative yield or 2-year average yield. The results indicate that when pistachio trees are adequately fertilized, additional fertilizer is without effect and not cost-effective. For a complete description of the results of this research, please see the final report at http://www.cdfa.ca.gov/is/pdfs/Pistachio_2009.pdf.

## CONCLUSIONS

The results provided clear evidence of the successful uptake of B as Solubor® and Zn as $ZnSO_4$ by buds at the bud swell to green tip stage when buds were sampled 19 to 21 days after foliar fertilization for B and 7 to 10 days after treatment for Zn. The increase in bud Zn concentration in response to the B + urea treatment in both years of the experiment requires additional research for clarification, but contributes to the growing evidence suggesting that foliar fertilizers enhance soil nutrient uptake. Sampling leaves in October at the end of the season proved a highly reliable sampling time for determining which foliar-applied fertilizer treatments successfully supplied a sufficient amount of nutrient to last through harvest into October and provided evidence of the significant uptake of Zn (+/- urea) applied at 1/2- to 2/3-leaf expansion that had not been detected when leaves were collected 7 to 21 days after treatment. Later sampling dates (not included in this research) should be tested to determine whether Zn uptake is detectable before October. Our results provided clear evidence that the optimal time after application for detecting uptake of a foliar-applied nutrient is different for different nutrients. Thus, to fully test the uptake of nutrients applied as foliar-fertilizers, multiple sampling dates must be included in the research.

Adding urea to the fertilizer sprays had a positive effect on the uptake of Zn applied as $ZnSO_4$ at 1/2- to 2/3-leaf expansion (Year 1) and on the uptake of S as KTS (Years 1 and 2) and K as KTS (Year 2) applied to hardened leaves in June, July and August, while also successfully increasing leaf N concentrations above trees in other treatments but not the control. These results suggest that urea might be a useful fertilizer amendment or an alternative wetting agent. Our results demonstrated that foliar fertilizers could be used to supply the above nutrients in the case of deficiency. Interestingly, despite elevated nutrient concentrations in the October leaf analyses, no differences in bud nutrient concentrations related to the October leaf nutrient concentrations were detected the following spring. Thus, if an orchard was diagnosed as low in B or Zn by standard leaf analyses in late-July to mid-August, bud B and Zn concentrations could be increased at the bud swell to green tip stage with an application of Solubor® or $ZnSO_4$, respectively. In addition, Zn can be supplied successfully as $ZnSO_4$ when leaves are 1/2- to 2/3 expanded, with uptake enhanced by the addition of urea. Urea can be used to supply N and to improve the uptake of K and S as KTS when leaves are fully hardened.

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