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

YEAR 2 ANNUAL REPORT (FINAL REPORT)

Project Title: Towards Development of Foliar Fertilization Strategies for Pistachio to Increase Total Yield and Nut Size and Protect the Environment **-** *A proof-of-concept project*

CDFA Agreement: No. 09-0584

Principal Investigator: Carol J. Lovatt

Principal Investigator's Address: Department of Botany and Plant Sciences, University of California, Riverside, CA 92521-0124; Phone: (951) 827-4663; Fax: (951) 827-4437; E-mail: carol.lovatt@ucr.edu

Co-Principal Investigator: Robert H. Beede

Co-Priciple Investigator's Address: University of California Farm Advisor, University of California Coopertaive Extension Kings County, 680 N. Campus Dr. Suite A, Hanford, CA 93230; Phone: (559) 582-3211; FAX: (559) 582-5166; E-mail: <bbeede@ucdavis.edu>

Cooperators:
Joseph C. MacIlvaine, President, Paramount Farming Company, 33141 E. Lerdo Highway, Bakersfield, CA 93308-9767, (661) 399-4456

Jason Haught, Ranch Manager, Ranch 4140 Dudley Ridge, 13654 Highway 33, Lost Hills, CA 93249, (661) 797- 6540, jasonh@paramountfarming.com

Project Goals: The goal of our research was to increase fruit set, yield, nut quality (increased percent split nuts, reduced percent aborted and blank nuts), and retention of floral buds for next year's crop with properly timed foliar fertilization. Three foliar fertilization strategies (discussed below) were tested for their capacity to successfully supply essential nutrients at key stages of pistachio tree phenology characterized by high nutrient demand, as well as application times reported to be efficacious through previous research.

Project 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 foliar applications of these elements have been shown to increase yield in other deciduous tree crops (Cowgill and Compton 1999, Jaganth and Lovatt 1998, Righetti n.d.). To date research into the response of pistachio trees to prebloom foliar-applied zinc have produced mixed results (Uriu 1986, Beede et al. 1990, Brown et al. 1993).

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 thiosulfate (S) into buds and/or leaves, especially during kernel filling when all but the most current pistachio leaves have a fully developed wax cuticle. Urea improved the uptake and efficacy of benzyladenine when hardened pistachio leaves were treated in June and July (Lovatt et. al. 2006). Researchers and growers report its use in foliar treatments (Righetti n.d.).

4. To calculate and disseminate a cost: benefit analysis to growers.

Executive Summary: 1. Problem.
Pistachio (*Pistacia vera* cv. Kerman) is like other tree crops in that flowering (pollination and fertilization), fruit development (Stages I and III), shoot elongation, and root growth compete at times for available nutrients. Economic gains in fruit retention, increased 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 (Peryea 1994, Cowgill and Compton 1999, Lovatt 1999, Boman 2002, 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 temperature, salinity, pH) render soil nutrients and soil-applied fertilizers less available to the plant. Under these conditions, foliar fertilization can provide the nutrients required for photosynthesis and other important metabolic functions essential to plant growth and productivity and protect the environment from excessive soil applications. For pistachio, like other deciduous fruit crops, foliar fertilization at early stages of tree phenology is deemed impractical because reproductive growth commences before vegetative shoot growth. Also, mature pistachio leaves, like those of many other crop plants, have a thick waxy cuticle shown to compromise uptake of some foliar-applied nutrients. **2. Project objective**. The goal of our research was to obtain a positive effect on nut size, percent split nuts, fruit set, and floral bud retention with properly timed foliar fertilization. An increase in any one of these yield components would increase grower net profit. We test the capacity of three foliar fertilization strategies to successfully supply key nutrients at phenological stages of high nutrient demand. At the end of the research, we will disseminate a cost: benefit analysis to growers. **Strategy (1):** Application of foliar fertilizer at bud swell to enhance flower nutrient levels (ovary and/or pollen) and increase fruit set. Despite uptake of only small amounts of nutrients, prebloom foliar applications of boron (B), zinc (Zn) and urea (N) have been shown to increase yield in other deciduous tree crops (Cowgill and Compton 1999, Lovatt 1999, Gonzalez et al. 2010). To test Strategy 1 the following treatments were applied at bud swell to green tip (a phenological stage of pistachio shown to be responsive to B foliar fertilization (Brown et al. 1995): (1) N [6 lbs/acre, urea (46% N, 0.25% biuret)]; (2) Treatment 1 combined with Zn [5 lb/acre, $ZnSO_4$ (36% Zn)] to test the capacity of urea to increase Zn uptake; (3) Treatment 2 combined with Treatment 4 (urea + zinc + boron); and (4) B [5 lb/acre, Solubor (20.5% B)], applied by some growers in mid- March to mitigate B deficiency and improve fruit set (Brown et al. 1995). We hope to determine whether using urea as a carrier provides any benefit in enhancing zinc and boron uptake. **Strategy (2)** Apply foliar fertilizer at 1/2- to 2/3-leaf expansion when the cuticular leaf waxes have not developed sufficiently to limit nutrient uptake and adequate surface area exists for uptake to be great enough to impact tree physiology. To test Strategy 2 the following treatments were applied:

(1) Zn [2 lb/acre, $ZnSO_4$ (36% Zn)]. This strategy is currently practiced within the industry, but no data exist to support a yield benefit; (2) N [6 lbs/acre, urea (46% N, 0.25% biuret)]; (3) Treatments 1 and 2 combined. Comparison of treatment effects will resolve whether urea increases Zn uptake and whether Zn and/or N increase fruit retention and yield. **Strategy (3)** Investigate urea as a carrier to increase K and N uptake once pistachio leaves are fully mature, prior to and during kernel filling. Urea improved the uptake and efficacy of benzyladenine when “hardened” pistachio leave were treated in June and July (Lovatt et. al. 2006). To test Strategy 3 the following treatments were applied in early June, early July and mid-August (application costs could potentially be reduced in the future by combining fertilizer with fungicide or navel orangeworm sprays): (1) K [10 lb/acre, KTS (0-0-25-17S)]; (2) K [10 lb/acre, KNO3 (13-0-38)]; (3) N [6 lbs/acre, urea (46% N, 0.25% biuret)]; and (4) Treatments 1 and 3 combined. Comparison of treatment effects on yield will determine whether urea increases K uptake and whether trees need only K or benefit from added N and/or S at this time. **Research approach.** In 2012, at the specified stages of tree phenology, foliar fertilizers were applied in 100 gallons of water per acre (industry standard) to 15 individual tree replications per treatment (including an untreated control) in a randomized complete block in a commercial 15-year-old 'Kerman' pistachio orchard. Sets of swollen flower buds or leaves on each tree were protected from the spray treatments and collected 7 to 10 days after application. Leaf samples were also collected at the end of July and in early August (the standard time for pistachio leaf analysis). Yield was determined for every data tree at harvest, and a 20-pound fruit sample was submitted to Paramount Farming for commercial assessment of split nuts, closed shell nuts, kernel weight, blank nuts and insect damaged nuts. **C. Criteria for success.** The research is a success if one or more properly timed foliar fertilization strategy increases an economically important yield parameter and grower net income. **3. Target audience** is the pistachio growers of California (>145,000 bearing acres), whose production costs (especially fertilizer) have increased dramatically**.** Producers of other deciduous crops and crops with thick waxy cuticles could also benefit from the results of this research.

Work Description: Plan for achieving the objectives.
The design used 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. 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. For this first study we did not adjust fertilizer rates for on- versus off-crop years. There are 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 (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 prior to Stage 1 foliar applications and again 7 to 10 days after the fertilizer 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 foliar fertilizer application. Leaves were also collected at the end of July and early 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 60 ºC, ground to 40-mesh, 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 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. A cost: benefit analysis was performed to determine the utility of the different foliar fertilizer strategies for pistachio production.

YEAR 2 – TASK 2:

Month of initiation: 1/12 Month of completion 12/12

Subtask 2.1: Monitor tree phenology and apply foliar fertilizer treatments at proper stage of tree phenology. Correct nutrient deficiencies identified in Year 1. At bloom, count inflorescences on last year's tagged shoots. Tag new branches and count initial number of floral buds. Just before each fertilizer application, select and cover leaves in each quadrant of the data trees, uncover leaves 4 hours later, and collect a subset of uncovered leaves 7 to 20 days later, at the standard time for leaf nutrient analysis and just prior to harvest. Immediately, wash, dry, grind leaf samples and send to the UC-DANR Laboratory for analysis.

Subtask 2.1 was initiated in January 2012 and was completed in September 2012.

Subtask 2.2: Determine the number of floral buds remaining on tagged shoots. Harvest individual data trees and submit a 20-pound sample per tree to Paramount Farming for quality analysis. Collect final soil sample for analysis and obtain irrigation water quality data.

Subtask 2.2 was initiated in September 2012 and completed in October 2012

Subtask 2.3: Statistically analyze data.

Subtask 2.3 was initiated in October 2012 and completed in

November 2012. Subtask 2.4: Prepare and send annual report to FREP.

Subtask 2.4 was initiated in November 2012 and completed in

January 2013. Results, Discussion and Conclusion:

Results –Year 2.

CHANGES IN PISTACHIO TREE NUTRIENT STATUS OVER TIME.

To determine the effect of available soil nutrients on tree nutrient status over time, independent of the foliar fertilizer treatments, we plotted bud and leaf nutrient concentrations for each sampling date for the untreated control trees in this orchard (Figs. 1 and 2). The orchard received 53.4 lbs N per acre from 15 April to 15 May and another 93.5 lbs N per acre from 16 May through 30 July. Leaf N peaked at the beginning of May (3.2%), decreased to 2.5% by mid-June, and remained at approximately 2.5% until the end of July and then dropped to just below 2.4% by mid-September. K (46.7 lbs/acre) and P (23.4 lbs/acre) were applied from 16 May through 30 July. There was a linear increase in leaf K from 0.96% in late March to 2.89% by October (the last leaf sampling date). Leaf P peaked at 0.39% at the end of March and decreased to 0.12% or less from June through October. Calcium steadily increased from 0.6% in April through end of August and remained stable at 2.5% through October. Magnesium increased gradually over the entire growing season from 0.21 to 0.43%. Changes in the leaf concentrations of N, P, K, Ca, and Mg over time were similar to those reported for Year 1 (See Appendix I, Fig. 1, for comparison between years). In both years the results were equivalent to those reported by Brown and Siddiqui (2011). In addition, changes in leaf S, B, Zn, Fe and Cu concentrations were similar to those reported previously (See Appendix I, Fig. 2, to compare Years 1 and 2). From March 30 through October, leaf B steadily increased from 40 ppm to greater than 1000 ppm in October (Fig. 2). Tree manganese status steadily increased from 34 ppm in March to 73 ppm in October. Iron decreased precipitously from March to early May (173 ppm to 28 ppm), but thereafter increased somewhat erratically to 98 ppm in October. Zinc and copper were highest in March (19 ppm and 14 ppm, respectively), decreasing to 13 ppm and 9 ppm in mid-May, respectively, and continuing to gradually decrease through October to less than 12 ppm and 6 ppm, respectively. No B, Mn, Fe or Cu fertilizers were applied to the soil in this experiment. The changes nutrient content of leaves collected before and after the time of fertilizer treatment from control trees reflect the changes in pistachio tree nutrient status through the growing season independent of foliar fertilization treatment. These changes, however, must be considered when interpreting the data reported for treated in Tables 1 to 6. Only effects due to foliar fertilizer treatment are discussed below.

EFFECT OF FOLIAR-APPLIED FERTILIZERS ON TISSUE NUTRIENT CONCENTRATIONS.

Effect of fertilizer applications at bud swell to green tip.

Prior to the first fertilizer applications at the start of the experiment, bud concentrations of all nutrients (P, K Ca, Mg, S, B, Zn, Mn, Fe, and Cu), except N, were not significantly different among trees in all treatments. (Table 1, horizontal rows labeled “before”). However, at the start of the experiment trees scheduled to receive urea or urea + B + Zn had significantly lower bud N concentrations than the untreated control trees, but equal to those of trees to be treated with urea + B or B alone. Thus, tree nutrient status was uniform for the data trees used in this experiment with the exception of N. In both years of the research, there was a significant decrease in the B concentration in buds from March 21 to March 30. In Year 1, buds collected 19 days after application of B alone demonstrated that bud B concentration was significantly increased. Buds for the other B fertilizer treatments were collected 8 days after the fertilizer spray for analysis and no differences in B concentrations were detected in these buds. In Year 2, buds were collected

9 days after B fertilizer treatment and no differences in bud B concentrations were detected. Thus, it seems that movement of B into buds is not detectable until approximately 19 days after treatment. In contrast, trees sprayed with B + urea + Zn or B + urea had significantly greater bud Zn concentrations than control trees or trees treated with urea alone or B alone detectable within 8 to 9 days after treatment ($P < 0.0001$) (Table 1). The significantly greater bud Zn concentrations for trees treated with B + urea + Zn or B + urea, even though the trees did not receive Zn fertilizer, also occurred in Year 1. Buds were not covered before spraying, so it is possible that trees treated with Zn retained Zn residue after washing. This, however, does not explain why trees treated only

with B + urea would have elevated Zn concentrations. We speculate that this treatment, as well as the B + urea + Zn treatment, stimulated bud growth, which increased the sink strength of buds and the mobilization of Zn into them from the subtending shoot.

Effect of fertilizer applications at 1/2- to 2/3-leaf expansion.
Prior to foliar fertilizer application at 1/2- to 2/3-leaf expansion (LE), there were no significant differences in leaf concentrations of N, P, K, Ca, Mg, S, B, Zn, Mn, Fe, or Cu among fertilizer treatments (Table 2). In contrast to Year 1, foliar urea applications in Year 2 did not increase leaf N concentrations above the control trees. Applying Zn alone or with urea at LE did not increase Zn concentrations in leaves collected 7 or 21 days later in either year. However, these treatments resulted in significantly greater leaf Zn concentrations compared to all other treatments by October (Table 7). It is possible that elevated leaf Zn concentrations might be detectable earlier than October; in this research no leaf samples were collected more than 21 days after treatment but prior to October.

Effect of fertilizer applications in June, July and August.
Mid-June. Prior to the mid-June fertilizer applications, there were no significant differences in leaf nutrient concentrations among treatments (Table 3). No significant changes in leaf nutrient status due to foliar fertilization were detected 21 days after application relative to the untreated control trees.

Mid-July. Leaf samples collected prior to treatment in mid-July showed that control trees and all trees receiving a N-containing foliar fertilizer in mid-June had significantly greater leaf N concentrations than trees treated with KTS, which contained no N. Also by mid-July prior to treatment, trees treated with KTS alone or KTS + urea in mid-June had significantly greater S concentrations than all other treatments, except the control (P = 0.0079) (Table 4). Leaves collected after treatment showed that trees receiving KTS (+/- urea) still had greater S concentrations than trees in all other treatments except the control and trees treated with urea (P = 0.0294). Analyses of leaves collected before and after fertilizer treatment, revealed that the mid- July KTS application did not significantly increase leaf S. Both foliar-applied KTS and KNO_3 treatments failed to increase leaf K, consistent with the results obtained in Year 1.

Mid-August. Leaves sampled pre-treatment in mid-August showed that trees treated in mid-July with KTS (+/- urea) and trees treated with urea alone had significantly greater S concentrations than trees in the KNO_3 treatment (P = 0.0294) (Table 5). After the mid-August fertilizer applications, trees treated with KTS (+/- urea) had leaf S concentrations greater than all other treatments, with trees treated with KTS plus urea having significantly greater leaf S concentrations than trees receiving KTS alone ($P < 0.0001$), consistent with urea enhancing S uptake. There were no other differences in leaf nutrient concentrations. Three foliar applications of KTS and KNO_3 failed to increase leaf K and three foliar applications urea or KNO_3 failed to increase leaf N above that of the control.

Comparison of the effects of application time and frequency. The relative efficacy of applying fertilizers to the canopy at specific phenological stages versus multiple applications is presented in Figure 3. The effect applying urea + B + Zn or urea + B on bud Zn concentration is readily apparent. (See Appendix I, Fig. 3, to compare the results from Years 1 and 2.)

Effect of foliar fertilizer applications on tree nutrient status in October. Several foliar fertilizer treatments had a significant effect on tree nutrient status by the end of the season. Soil fertilizers also affected leaf nutrient concentrations by October.

Nitrogen. Trees treated with urea in June, July and August had leaf N concentrations that were significantly greater than trees in all other treatments except trees receiving B at bud swell to green tip, urea + Zn at leaf expansion, urea + KTS in June, July and August and the control ($P = 0.0004$) (Table 6). Control trees had leaf N concentrations that were intermediate to and not significantly different from all other treatments, except trees receiving Zn at leaf expansion and KTS in June, July and August, which had the lowest leaf N concentrations.

Sulfur. Foliar-applied potassium thiosulfate (KTS) (+/- urea) in June, July and August significantly increased leaf S concentrations relative to all other treatments ($P < 0.0001$) (Table 6).

Phosphorus, Potassium, Calcium and Magnesium. There were no significant differences at the 5% confidence level in leaf P, K, Ca or Mg content related to fertilizer treatments by October (Table 6). Trees treated with KNO_3 or urea in June, July and August had greater leaf K concentrations than the control ($P = 0.0577$). It is worth noting that trees receiving foliar-applied KTS alone had one of the lowest leaf concentrations of potassium, whereas trees treated with KTS
+ urea had one of the highest, suggesting that urea enhanced K uptake through hardened leaves in June, July and August when these fertilizers were applied.

Zinc. Trees treated with Zn (+/- urea) at leaf expansion had significantly greater leaf Zn concentrations than all other treatments ($P < 0.0001$) (Table 7). The Year 1 results provided evidence that adding urea increased average leaf Zn over trees sprayed with Zn alone, suggesting that urea enhanced Zn uptake at this stage of leaf development. In Year 2, this effect of urea was not observed. Trees treated with Zn alone or Zn plus urea at LE had significantly greater leaf Zn concentrations than from trees in all other treatments. Thus, in both years of the research, foliar application of $ZnSO_4$ (+/- urea) when leaves are 1/2 to 2/3 expanded resulted in sufficient Zn uptake to maintain significantly greater leaf Zn concentrations as late as October compared to trees in all other treatments, despite the fact that increased leaf Zn content could not be detected 7 to 21 days after application at this stage of pistachio tree phenology.

Boron, Managnese, Iron and Copper. There were no significant differences in leaf B, Mn, or Cu content among treatments by October (Table 7). There were significant differences in leaf Fe concentrations among treatments, but the relationship to fertilizer treatment is unclear and was not observed in Year 1. For example, trees receiving foliar-applied urea in June, July and August had significantly greater leaf Fe concentrations than trees in all other treatments, except those treated with urea at LE or KNO_3 in June, July and August (P = 0.0310).

Effect of canopy applications of fertilizer on yield. No foliar fertilizer treatment significantly increased total dry weight of split nuts per tree in either year of the research. The foliar fertilizer treatments also had no effect on nut quality or kernel size (Table 8). Further, no fertilizer treatment had an effect on the 2-year cumulative yield (dry wt. split nuts per tree) or on yield or nut quality when averaged across the 2 years of the experiment by repeated measure analysis with year as the repeated measure. The orchard was alternate bearing with an average alternate bearing index (ABI) of 0.48 for the two years of the research. Fertilizer treatment did not influence ABI. The total kg split nuts (dry weight) was significantly greater in Year 1 (19.8 kg/tree) than in Year 2 (7.9 kg/tree) (P < 0.0001). The greater crop load in Year 1 resulted in smaller embryos (727 mg/embryo) than in Year 2 (769 mg/embryo) (P < 0.0001). Fertilizer treatments had no effect on average yield or average embryo size. The goal of achieving an increase in yield or quality by foliar fertilization was not achieved in this well managed orchard.

Discussion.

The experiment was well designed. With exception of differences in bud N concentrations among treatments prior to fertilizer application at the start of the experiment in Year 2, there were no significant differences in the tissue concentrations of any nutrient among the trees before they received any subsequent foliar fertilizer treatments. Based on the Year 1 October leaf analyses, differences in bud N concentrations among treatments in spring of Year 2 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, there was no carryover effect for buds collected at the bud swell to green tip stage or leaves collected at 1/2- to 2/3-leaf expansion.

In Year 2, as in Year 1, boron decreased in floral buds from ~mid-March to the beginning of April in the control trees. In Year 1, application of B alone at bud swell to green tip significantly increased bud B concentration, a result that was inadvertently discovered due to the delay in bud sampling until 19 days after fertilizer application. Buds from trees in all other fertilizer treatments applied at this stage of tree phenology in Years 1 and 2 were sampled 8 and 7 days after application, respectively, and no differences in bud B concentrations were detected. In both years of this research, 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 by mid-June (Beede 2004) and reaching 821 to 1019 ppm and 869 to 1290 ppm in October of Years 1 and 2, respectively.

In Year 2 as in Year 1, application of Zn (as $ZnSO_4$) (+/- urea) 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 N and the control trees had greater leaf N concentrations than trees receiving foliar fertilizer that did not contain N. Also, in July, trees treated with potassium thiosulfate (KTS) (+/- urea) in June had significantly greater leaf S concentrations prior to the second KTS application in July. 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 (Beede 2004). Phosphorus was below the critical value of 0.14% (Beede 2004) on 31 July at 0.13% and on 21 August at less than 0.12% for trees in all treatments. Leaf Mg averaged 0.33% to 0.40% among trees in all treatments in both July and August, below the critical value of 0.6% developed by Beede (2004) and the more recent value of 0.45% developed by Brown and Siddiqui (2011). Several nutrient concentrations exceeded the optimal range during July and August (the upper value is given in parentheses) (Beede, 2004): K (2.0%) ranged from 2.4% to 3.0%; B (250) ranged from 528 ppm to 751 ppm.

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, consistent with the results of Year 1. 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, but they too were not clearly related to fertilizer treatment, e.g., three applications of KNO_3 or 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 providing three foliar applications of potassium thiosulfate (+/- urea).

Despite the successful uptake of several nutrients at key stages of tree phenology and significantly greater concentrations of these nutrients through October, yield and fruit 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. 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.

Conclusion.

Uptake of B applied as Solubor ®during the bud swell to green tip stage of pistachio tree phenology was significantly greater in buds 19 days after treatment, but was not detectable in buds collected and analyzed 7 to 8 days after treatment. Zn (as $ZnSO_4$) (+/- urea) was taken up by leaves at 1/2- to 2/3-leaf expansion. In both years of the research, leaf Zn concentrations for these two treatments were significantly greater in leaves collected and analyzed in October compared to trees in all other treatments; Zn uptake was not detected in leaves 7 or 21 days after fertilizer application. It is possible that elevated Zn levels might be detectable prior to October; intermediate sampling dates were not included in this experiment. The results provided evidence that S (as thiosulfate) (+/- urea) was taken up by hardened leaves in June, July and August and resulted in significantly greater leaf S concentrations through October in both years of the research. Urea-N, but not nitrate-N (as KNO_3), was taken up by hardened leaves in June, July and August in both years. The goal of significantly increasing tree K status was not achieved with three applications of either KTS (+/- urea) or KNO_3, although in Year 2 trees receiving three applications of KNO_3 had October leaf K concentrations greater than untreated control trees at P = 0.0577. Combining urea with KTS increased October leaf K concentrations relative to trees receiving KTS alone. In both years of the research, trees that received three applications of urea (June, July and August) had the highest October leaf N concentrations, but not significantly greater than the control trees. The results suggest that it is difficult to get potassium or nitrate-N through the cuticle of harden pistachio leaves in sufficient quantity to consistently increase October leaf K or N. Although our research results demonstrated the successful uptake of several fertilizers by buds and leaves and the persistence of greater leaf concentrations of some nutrients through October as a result of foliar fertilizer applications, no yield or fruit quality benefit was obtained in either year of the research. The results indicate that when pistachio trees are adequately fertilized, additional fertilizer is without a yield benefit and not cost effective. However, the results of our research demonstrated that several foliar fertilizers could be used to supply nutrients in the case of deficiency. Foliar fertilizer sprays successfully elevated leaf Zn (2 years), S (2 years), and K (1 year) concentrations through October, respectively, and B and Zn concentrations of buds treated at the bud swell to green tip stage of phenology.

Project Evaluation:
No foliar fertilizer treatment increased yield, so from this point of view, foliar fertilization was not cost effective. However, we were able to demonstrate the successful uptake of B and Zn by buds at the bud swell to green tip stage and learned that bud sampling 19 to 21 days after foliar fertilization is more effective in detecting changes bud B concentrations but sampling 7 to 10 days after treatment was better for detecting changes in bud Zn concentrations. The increase in bud Zn concentration in response to B + urea treatment in both years of the experiment requires additional research for clarification. 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 (LE) that had not been detected when leaves were collected 7 to 21 days after treatment. Later sampling dates (not included in this research) might demonstrate that Zn uptake can be detected 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. Adding urea to the fertilizer sprays had a positive effect on the uptake of Zn applied as $ZnSO_4$ at LE (Year 1) and S applied as KTS (Years 1 and 2) and K applied as KTS (Year 2) to hardened leaves in June, July and August while successfully increasing leaf N concentrations above trees in other treatments but not the control, suggesting that urea might be a useful fertilizer amendment or alternative to the use as a wetting agent. Our results demonstrate that foliar fertilizers could be used to supply these 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 were diagnosed as low in B or Zn in August, bud B and Zn concentrations in spring could be increased with an application of Solubor or ZnSO4, respectively, at the bud swell to green tip stage.

Outreach Activities Summary:
None related to this project at this time.

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Table 1. Effects of fertilizers applied to the canopy of ‘Kerman’ pistachio trees at the bud swell to green tip stage of bud development on nutrient concentrations of buds collected on 30 March 2012 compared to buds collected before treatment on 21 March 2012. Buds were not covered during fertilizer application.

Nutrient (*concentration*)	Sampled	Treatment				*P*-value
		Zn	Urea-N	Zn + Urea-N	Control	
N (%)	Before	3.14 a^{Az}	3.18 a^{A}	3.21 a^{A}	3.18 a^{A}	0.6144
	After	2.58 b^{A}	2.56 b^{A}	2.60 b^{A}	2.55 b^{A}	0.8462
P-value		<0.0001	<0.0001	<0.0001	<0.0001	
P (%)	Before	0.243 a^{A}	0.254 a^{A}	0.253 a^{A}	0.256 a^{A}	0.3216
	After	0.162 b^{A}	0.158 b^{A}	0.165 b^{A}	0.161 b^{A}	0.4857
P-value		<0.0001	<0.0001	<0.0001	<0.0001	
K (%)	Before	1.61 b^{A}	1.61 b^{A}	1.63 a^{A}	1.60 b^{A}	0.8995
	After	1.71 a^{A}	1.74 a^{A}	1.69 a^{A}	1.70 a^{A}	0.9607
P-value		0.0110	0.0207	0.1225	0.0260	
Ca (%)	Before	0.9 b^{A}	0.9 b^{A}	0.9 b^{A}	0.9 b^{A}	0.8105
	After	1.3 a^{A}	1.2 a^{A}	1.2 a^{A}	1.3 a^{A}	0.1276
P-value		<0.0001	<0.0001	<0.0001	<0.0001	
Mg (%)	Before	0.20 b^{A}	0.20 b^{A}	0.21 b^{A}	0.21 b^{A}	0.2838
	After	0.28 a^{A}	0.27 a^{A}	0.28 a^{A}	0.29 a^{A}	0.4677
P-value		<0.0001	<0.0001	<0.0001	<0.0001	
S (%)	Before	0.166 a^{A}	0.167 a^{A}	0.169 b^{A}	0.171 a^{A}	0.6304
	After	0.178 a^{A}	0.168 a^{A}	0.174 a^{A}	0.174 a^{A}	0.5098
P-value		0.1643	0.8959	0.0385	0.6272	
B (*ppm*)	Before	127.1 b^{A}	97.4 b^{A}	115.8 b^{A}	109.0 b^{A}	0.6747
	After	226.0 a^{A}	177.0 a^{A}	210.0 a^{A}	213.5 a^{A}	0.5416
P-value		<0.0001	0.0003	0.0011	<0.0001	
Zn (*ppm*)	Before	18.79 a^{A}	18.41 a^{A}	18.13 a^{A}	18.96 a^{A}	0.7222
	After	14.14 b^{A}	13.10 b^{A}	13.04 b^{A}	13.34 b^{A}	0.2479
P-value		0.0003	0.0001	<0.0001	<0.0001	
Mn (*ppm*)	Before	42.6 b^{A}	40.5 b^{A}	41.5 b^{A}	43.2 b^{A}	0.6624
	After	61.0 a^{A}	52.7 a^{B}	57.1 a^{AB}	57.5 a^{AB}	0.0590
P-value		<0.0001	<0.0001	<0.0001	<0.0001	
Fe (*ppm*)	Before	27.1 b^{A}	27.4 b^{A}	28.7 b^{A}	27.6 b^{A}	0.5856
	After	35.9 a^{A}	33.5 a^{A}	32.9 a^{A}	33.2 a^{A}	0.1831
P-value		0.0015	0.0043	0.0299	0.0064	
Cu (*ppm*)	Before	9.55 a^{A}	8.54 a^{A}	9.33 a^{A}	9.83 a^{A}	0.1141
	After	9.35 a^{A}	7.80 b^{A}	8.75 a^{A}	9.04 b^{A}	0.2309
P-value		0.6942	0.0079	0.1910	0.0304	

[z] Values in a vertical column followed by different lower case letters or in a horizontal row followed by different uppercase superscript letters are significantly different at the specified *P*- value by Fisher's Protected LSD Test.

Table 2. Effects of foliar fertilizers applied when leaves were between 1/2- and 2/3-leaf expansion on nutrient concentrations of sub-terminal leaves of 'Kerman' pistachio collected on 23 May 2012, 21 days after treatment, compared to leaves collected before treatment on 2 May 2012. Leaves were covered during fertilizer application.

Nutrient (*concentration*)	Sampled	Treatment				*P*-value
		Zn	Urea-N	Zn + Urea-N	Control	
N (%)	Before	3.14 a^{Az}	3.18 a^{A}	3.21 a^{A}	3.18 a^{A}	0.6144
	After	2.58 b^{A}	2.56 b^{A}	2.60 b^{A}	2.55 b^{A}	0.8462
P-value		<0.0001	<0.0001	<0.0001	<0.0001	
P (%)	Before	0.243 a^{A}	0.254 a^{A}	0.253 a^{A}	0.256 a^{A}	0.3216
	After	0.162 b^{A}	0.158 b^{A}	0.165 b^{A}	0.161 b^{A}	0.4857
P-value		<0.0001	<0.0001	<0.0001	<0.0001	
K (%)	Before	1.61 b^{A}	1.61 b^{A}	1.63 a^{A}	1.60 b^{A}	0.8995
	After	1.71 a^{A}	1.74 a^{A}	1.69 a^{A}	1.70 a^{A}	0.9607
P-value		0.0110	0.0207	0.1225	0.0260	
Ca (%)	Before	0.9 b^{A}	0.9 b^{A}	0.9 b^{A}	0.9 b^{A}	0.8105
	After	1.3 a^{A}	1.2 a^{A}	1.2 a^{A}	1.3 a^{A}	0.1276
P-value		<0.0001	<0.0001	<0.0001	<0.0001	
Mg (%)	Before	0.20 b^{A}	0.20 b^{A}	0.21 b^{A}	0.21 b^{A}	0.2838
	After	0.28 a^{A}	0.27 a^{A}	0.28 a^{A}	0.29 a^{A}	0.4677
P-value		<0.0001	<0.0001	<0.0001	<0.0001	
S (%)	Before	0.166 a^{A}	0.167 a^{A}	0.169 b^{A}	0.171 a^{A}	0.6304
	After	0.178 a^{A}	0.168 a^{A}	0.174 a^{A}	0.174 a^{A}	0.5098
P-value		0.1643	0.8959	0.0385	0.6272	
B (*ppm*)	Before	127.1 b^{A}	97.4 b^{A}	115.8 b^{A}	109.0 b^{A}	0.6747
	After	226.0 a^{A}	177.0 a^{A}	210.0 a^{A}	213.5 a^{A}	0.5416
P-value		<0.0001	0.0003	0.0011	<0.0001	
Zn (*ppm*)	Before	18.79 a^{A}	18.41 a^{A}	18.13 a^{A}	18.96 a^{A}	0.7222
	After	14.14 b^{A}	13.10 b^{A}	13.04 b^{A}	13.34 b^{A}	0.2479
P-value		0.0003	0.0001	<0.0001	<0.0001	
Mn (*ppm*)	Before	42.6 b^{A}	40.5 b^{A}	41.5 b^{A}	43.2 b^{A}	0.6624
	After	61.0 a^{A}	52.7 a^{B}	57.1 a^{AB}	57.5 a^{AB}	0.0590
P-value		<0.0001	<0.0001	<0.0001	<0.0001	
Fe (*ppm*)	Before	27.1 b^{A}	27.4 b^{A}	28.7 b^{A}	27.6 b^{A}	0.5856
	After	35.9 a^{A}	33.5 a^{A}	32.9 a^{A}	33.2 a^{A}	0.1831
P-value		0.0015	0.0043	0.0299	0.0064	

[z] Values in a vertical column followed by different lower case letters or in a horizontal row followed by different uppercase superscript letters are significantly different at the specified *P*-value by Fisher's Protected LSD Test

Table 3. Effects of June foliar-applied fertilizers on nutrient concentrations of sub-terminal leaves of 'Kerman' pistachio collected on 11 July 2012, 22 days after treatment, compared to leaves collected before treatment on 19 June 2012. Leaves were covered during fertilizer application.

Nutrient (*concentration*)	Sampled	Treatment					*P*-value
		KTS	KNO_3	Urea-N	KTS + Urea-N	Control	
N	Before	2.69 a^{Az}	2.67 a^{A}	2.70 a^{A}	2.75 a^{A}	2.68 a^{A}	0.2797
(%)	After	2.65 a^{A}	2.58 b^{A}	2.64 a^{A}	2.62 b^{A}	2.65 a^{A}	0.4178
P-value		0.2910	0.0140	0.1576	0.0439	0.1212	
P	Before	0.122 a^{A}	0.122 a^{A}	0.127 a^{A}	0.124 a^{A}	0.123 a^{A}	0.3623
(%)	After	0.116 b^{A}	0.113 b^{A}	0.115 b^{A}	0.117 b^{A}	0.113 b^{A}	0.3384
P-value		0.0236	0.0004	<0.0001	0.0182	0.0003	
K	Before	1.96 b^{A}	2.05 b^{A}	2.18 b^{A}	1.99 b^{A}	2.02 b^{A}	0.1563
(%)	After	2.21 a^{A}	2.31 a^{A}	2.40 a^{A}	2.24 a^{A}	2.25 a^{A}	0.2110
P-value		<0.0001	0.0006	<0.0001	0.0006	0.0016	
Ca	Before	1.6 b^{A}	1.6 b^{A}	1.5 b^{A}	1.6 b^{A}	1.5 b^{A}	0.4789
(%)	After	1.8 a^{A}	1.8 a^{A}	1.7 a^{A}	1.7 a^{A}	1.7 a^{A}	0.4410
P-value		<0.0001	0.0003	0.0003	0.0010	0.0008	
Mg	Before	0.34 a^{A}	0.32 a^{A}	0.32 a^{A}	0.33 a^{A}	0.33 b^{A}	0.6702
(%)	After	0.34 a^{A}	0.32 a^{A}	0.31 a^{A}	0.33 a^{A}	0.35 a^{A}	0.2517
P-value		0.6333	0.9338	0.4666	0.9440	0.0048	
S	Before	0.168 a^{A}	0.164 a^{A}	0.168 a^{A}	0.168 a^{A}	0.169 a^{A}	0.8995
(%)	After	0.166 a^{AB}	0.158 b^{B}	0.171 a^{AB}	0.162 a^{B}	0.178 a^{A}	0.0448
P-value		0.3801	0.0938	0.4525	0.2048	0.1584	
B	Before	377.5 b^{A}	337.0 b^{A}	414.1 b^{A}	333.5 b^{A}	347.4 b^{A}	0.6715
(*ppm*)	After	486.4 a^{A}	433.6 a^{A}	527.9 a^{A}	449.5 a^{A}	477.4 a^{A}	0.8133
P-value		0.0007	0.0065	0.0067	0.0012	0.0004	
Zn	Before	12.04 a^{A}	11.78 a^{A}	11.73 a^{A}	11.99 a^{A}	11.93 a^{A}	0.9835
(*ppm*)	After	11.70 a^{A}	11.44 a^{A}	11.46 a^{A}	11.73 a^{A}	11.29 a^{A}	0.8678
P-value		0.2201	0.2372	0.5545	0.5050	0.0528	
Mn	Before	65.3 a^{A}	58.6 a^{A}	64.7 a^{A}	64.4 a^{A}	68.1 a^{A}	0.4209
(*ppm*)	After	65.1 a^{A}	59.3 a^{A}	65.2 a^{A}	65.4 a^{A}	70.0 a^{A}	0.4609
P-value		0.9024	0.6566	0.7938	0.6514	0.1923	
Fe	Before	68.8 a^{A}	53.5 b^{A}	58.2 a^{A}	52.7 a^{A}	56.0 a^{A}	0.2263
(*ppm*)	After	61.0 a^{A}	62.0 a^{A}	91.7 a^{A}	59.5 a^{A}	58.1 a^{A}	0.2528
P-value		0.4877	0.0876	0.2158	0.0921	0.7109	
Cu	Before	7.31 a^{A}	6.98 a^{A}	7.23 a^{A}	7.28 a^{A}	7.43 a^{A}	0.9825
(*ppm*)	After	6.20 b^{A}	5.85 b^{A}	6.11 b^{A}	6.31 b^{A}	6.39 b^{A}	0.9456
P-value		0.0011	0.0093	0.0145	0.0008	0.0159	

[z] Values in a vertical column followed by different lower case letters or in a horizontal row followed by different uppercase superscript letters are significantly different at the specified *P*-value by Fisher's Protected LSD Test.

Table 4. Effects of July foliar-applied fertilizers on nutrient concentrations of sub-terminal leaves of 'Kerman' pistachio collected on 21 August 2012, 21 days after treatment, compared to leaves collected before treatment on 31 July 2012. Leaves were covered during fertilizer application. These trees also received these treatments in June.

Nutrient (*concentration*)	Sampled	Treatment					*P*-value
		KTS	KNO_3	Urea-N	KTS + Urea-N	Control	
N	Before	2.53 a^{Bz}	2.60 a^{AB}	2.67 a^{A}	2.59 a^{AB}	2.63 a^{A}	0.0406
(%)	After	2.32 b^{A}	2.31 b^{A}	2.35 b^{A}	2.34 b^{A}	2.38 b^{A}	0.8260
P-value		0.0006	<0.0001	<0.0001	0.0003	0.0003	
P	Before	0.130 a^{A}	0.127 a^{A}	0.130 a^{A}	0.127 a^{A}	0.131 a^{A}	0.5996
(%)	After	0.117 b^{A}	0.115 b^{A}	0.120 b^{A}	0.119 b^{A}	0.117 b^{A}	0.3865
P-value		0.0005	0.0015	0.0002	0.0164	0.0001	
K	Before	2.44 b^{A}	2.64 b^{A}	2.69 b^{A}	2.55 b^{A}	2.60 b^{A}	0.1603
(%)	After	2.66 a^{A}	2.83 a^{A}	2.97 a^{A}	2.88 a^{A}	2.77 a^{A}	0.1053
P-value		0.0167	0.0024	0.0003	<0.0001	0.0676	
Ca	Before	2.1 b^{A}	2.1 b^{A}	1.9 b^{B}	2.0 b^{AB}	2.0 b^{AB}	0.0666
(%)	After	2.4 a^{A}	2.5 a^{A}	2.3 a^{A}	2.4 a^{A}	2.5 a^{A}	0.3502
P-value		0.0082	0.0004	0.0002	0.0003	<0.0001	
Mg	Before	0.39 a^{A}	0.36 b^{A}	0.33 b^{A}	0.36 a^{A}	0.36 b^{A}	0.1169
(%)	After	0.40 a^{A}	0.38 a^{A}	0.36 a^{A}	0.38 a^{A}	0.39 a^{A}	0.6373
P-value		0.6639	0.0024	0.0182	0.1334	0.0829	
S	Before	0.184 a^{A}	0.160 a^{B}	0.166 b^{B}	0.183 a^{A}	0.170 a^{AB}	0.0079
(%)	After	0.181 a^{A}	0.163 a^{B}	0.176 a^{A}	0.182 a^{A}	0.175 a^{AB}	0.0294
P-value		0.6493	0.3032	0.0927	0.8773	0.4157	
B	Before	528.4 b^{A}	517.9 b^{A}	618.4 b^{A}	544.1 b^{A}	577.6 b^{A}	0.8817
(*ppm*)	After	724.1 a^{A}	618.0 a^{A}	751.4 a^{A}	671.8 a^{A}	649.0 a^{A}	0.7735
P-value		0.0004	0.0040	<0.0001	0.0163	0.0404	
Zn	Before	12.05 a^{A}	11.76 a^{A}	11.84 a^{A}	12.19 a^{A}	11.75 a^{A}	0.9431
(*ppm*)	After	11.65 a^{A}	11.45 a^{A}	11.09 b^{A}	12.00 a^{A}	11.24 b^{A}	0.5011
P-value		0.2363	0.4730	0.0363	0.5667	0.0358	
Mn	Before	78.4 a^{A}	68.3 a^{A}	70.8 b^{A}	72.2 a^{A}	76.4 a^{A}	0.6547
(*ppm*)	After	76.5 a^{A}	72.3 a^{A}	79.0 a^{A}	78.6 a^{A}	85.6 a^{A}	0.5778
P-value		0.7660	0.0514	0.0847	0.1714	0.2486	
Fe	Before	73.1 b^{B}	77.1 b^{AB}	89.5 b^{A}	74.2 b^{B}	72.1 b^{B}	0.0537
(*ppm*)	After	105.7 a^{A}	119.0 a^{A}	120.9 a^{A}	113.1 a^{A}	104.8 a^{A}	0.3402
P-value		<0.0001	0.0018	0.0111	0.0004	0.0002	
Cu	Before	6.34 a^{A}	6.36 a^{A}	6.33 a^{A}	6.71 a^{A}	6.86 a^{A}	0.9399
(*ppm*)	After	5.76 b^{A}	5.78 a^{A}	6.10 a^{A}	6.16 a^{A}	5.85 b^{A}	0.9776
P-value		0.0264	0.0939	0.4881	0.2287	0.0153	

[z] Values in a vertical column followed by different lower case letters or in a horizontal row followed by different uppercase superscript letters are significantly different at the specified *P*- value by Fisher's Protected LSD Test.

Table 5. Effects of August foliar-applied fertilizers on nutrient concentrations of sub-terminal leaves of ‘Kerman’ pistachio collected 13 September 2012, 23 days after treatment, compared to leaves collected before treatment on 21 August 2012. Leaves were covered during fertilizer application. These trees also received these treatments in June and July.

Nutrient (*concentration*)	Sampled	Treatment					*P*-value
		KTS	KNO_3	Urea-N	KTS + Urea-N	Control	
N	Before	2.32 a^{Az}	2.31 a^{A}	2.35 a^{A}	2.34 a^{A}	2.38 a^{A}	0.8262
(%)	After	2.15 b^{B}	2.21 a^{AB}	2.30 a^{A}	2.25 a^{AB}	2.28 b^{A}	0.0834
P-value		0.0008	0.1191	0.3498	0.1721	0.0940	
P	Before	0.117 a	0.115 a	0.120 a	0.119 a	0.117 a	0.3865
(%)	After	0.107 b	0.107 b	0.113 b	0.112 b	0.112 b	0.1372
P-value		0.0014	0.0002	0.0065	0.0423	0.0045	
K	Before	2.66 a^{A}	2.83 a^{A}	2.97 a^{A}	2.88 a^{A}	2.77 a^{A}	0.1053
(%)	After	2.69 a^{A}	2.86 a^{A}	2.95 a^{A}	2.88 a^{A}	2.74 a^{A}	0.1523
P-value		0.5475	0.4539	0.4608	0.9498	0.3337	
Ca	Before	2.4 b^{A}	2.5 b^{A}	2.3 b^{A}	2.4 a^{A}	2.5 b^{A}	0.3502
(%)	After	2.6 a^{A}	2.7 a^{A}	2.5 a^{A}	2.6 a^{A}	2.6 a^{A}	0.5860
P-value		0.0010	0.0080	0.0215	0.2094	0.0395	
Mg	Before	0.40 a^{A}	0.38 a^{A}	0.36 a^{A}	0.38 a^{A}	0.39 a^{A}	0.6373
(%)	After	0.38 a^{A}	0.37 a^{A}	0.36 a^{A}	0.38 a^{A}	0.37 b^{A}	0.8500
P-value		0.1182	0.1573	0.4582	0.7674	0.0288	
S	Before	0.181 a^{A}	0.163 a^{B}	0.176 a^{A}	0.182 b^{A}	0.175 a^{AB}	0.0294
(%)	After	0.180 a^{B}	0.148 b^{D}	0.161 b^{C}	0.196 a^{A}	0.167 b^{C}	<0.0001
P-value		0.8956	0.0024	0.0130	0.0891	0.0009	
B	Before	724.1 a^{A}	618.0 a^{A}	751.4 b^{A}	671.8 a^{A}	649.0 a^{A}	0.7735
(*ppm*)	After	731.6 a^{A}	651.0 a^{A}	845.3 a^{A}	718.6 a^{A}	699.8 a^{A}	0.6115
P-value		0.6847	0.2679	0.0561	0.1821	0.3340	
Zn	Before	11.65 a^{A}	11.45 a^{A}	11.09 a^{A}	12.00 a^{A}	11.24 a^{A}	0.5011
(*ppm*)	After	10.81 b^{A}	10.49 b^{A}	10.01 b^{A}	10.89 b^{A}	10.64 a^{A}	0.4514
P-value		0.0227	0.0142	0.0022	0.0012	0.1163	
Mn	Before	76.5 a^{A}	72.3 a^{A}	79.0 a^{A}	78.6 a^{A}	85.6 a^{A}	0.5778
(*ppm*)	After	79.8 a^{A}	71.7 a^{A}	79.6 a^{A}	79.9 a^{A}	85.3 a^{A}	0.6463
P-value		0.4101	0.7772	0.8691	0.6785	0.9077	
Fe	Before	105.7 a^{A}	119.0 a^{A}	120.9 a^{A}	113.1 a^{A}	104.8 a^{A}	0.3402
(*ppm*)	After	91.5 b^{A}	89.1 b^{A}	96.9 b^{A}	79.7 b^{A}	81.0 b^{A}	0.3276
P-value		0.0906	0.0208	0.0762	0.0069	0.0134	
Cu	Before	5.76 a^{A}	5.78 a^{A}	6.10 a^{A}	6.16 a^{A}	5.85 a^{A}	0.9776
(*ppm*)	After	5.79 a^{A}	5.24 a^{A}	5.28 b^{A}	5.89 a^{A}	5.41 a^{A}	0.8392
P-value		0.9365	0.1205	0.0314	0.4680	0.1650	

[z] Values in a vertical column followed by different lower case letters or in a horizontal row followed by different uppercase superscript letters are significantly different at the specified *P*- value by Fisher's Protected LSD Test.

Table 6. Effects of canopy-applied fertilizers on leaf macronutrient concentrations of ‘Kerman’ pistachio trees in October.

Treatment	Application time	N	P	K	Ca	Mg	S
		%					
Urea-N	Bud swell to green tip	2.37 bcd[z]	0.114 a	2.80 d	2.6 a	0.46 a	0.156 b
Urea-N + B	Bud swell to green tip	2.29 cde	0.115 a	2.96 abcd	2.6 a	0.44 ab	0.152 b
Urea-N + B + Zn	Bud swell to green tip	2.30 cde	0.115 a	2.85 cd	2.6 a	0.46 a	0.158 b
B	Bud swell to green tip	2.39 abc	0.116 a	3.05 abc	2.4 a	0.38 c	0.156 b
Zn	1/3 to 1/2 leaf expansion	2.27 de	0.116 a	2.89 abcd	2.5 a	0.42 abc	0.155 b
Urea-N	1/3 to 1/2 leaf expansion	2.36 bcd	0.115 a	2.89 abcd	2.4 a	0.40 bc	0.157 b
Zn + Urea-N	1/3 to 1/2 leaf expansion	2.38 abc	0.117 a	2.89 abcd	2.4 a	0.41 abc	0.161 b
KTS	Jun, Jul, and Aug	2.22 e	0.115 a	2.82 d	2.4 a	0.46 a	0.219 a
KNO_3	Jun, Jul, and Aug	2.31 bcde	0.114 a	3.10 a	2.5 a	0.42 abc	0.150 b
Urea-N	Jun, Jul, and Aug	2.49 a	0.122 a	3.10 a	2.5 a	0.41 abc	0.158 b
KTS + Urea-N	Jun, Jul, and Aug	2.42 ab	0.118 a	3.08 ab	2.5 a	0.43 abc	0.223 a
Control		2.39 abc	0.118 a	2.86 bcd	2.5 a	0.43 abc	0.162 b
P-value		0.0004	0.2365	0.0577	0.2237	0.1020	<0.0001

[z] Values in a vertical column followed by different letters are significantly different at the specified *P*-value by Fisher's Protected LSD Test.

Table 7. Effects of canopy-applied fertilizers on leaf micronutrient concentrations of 'Kerman' pistachio trees in October.

Treatment	Application time	B	Zn	Mn	Fe	Cu
		ppm				
Urea-N	Bud swell to green tip	1003.4 a[z]	11.96 c	73.6 a	104.9 bcd	5.41 a
Urea-N + B	Bud swell to green tip	1290.3 a	12.29 c	65.2 a	108.7 bcd	5.50 a
Urea-N + B + Zn	Bud swell to green tip	1069.5 a	12.23 c	72.3 a	103.2 bcd	5.50 a
B	Bud swell to green tip	1053.6 a	12.24 c	64.7 a	109.7 bcd	6.84 a
Zn	1/3 to 1/2 leaf expansion	1061.4 a	89.23 a	74.1 a	109.1 bcd	6.23 a
Urea-N	1/3 to 1/2 leaf expansion	902.3 a	12.71 c	63.1 a	120.1 ab	5.20 a
Zn + Urea-N	1/3 to 1/2 leaf expansion	1007.3 a	83.63 b	68.4 a	100.4 bcd	5.13 a
KTS	Jun, Jul, and Aug	1100.0 a	13.01 c	71.0 a	99.1 cd	6.40 a
KNO_3	Jun, Jul, and Aug	869.9 a	12.39 c	61.2 a	118.1 abc	6.05 a
Urea-N	Jun, Jul, and Aug	1127.4 a	12.59 c	69.9 a	134.1 a	6.46 a
KTS + N	Jun, Jul, and Aug	985.6 a	12.54 c	68.7 a	111.1 bcd	6.50 a
Control		1020.9 a	11.80 c	72.7 a	97.7 d	5.96 a
P-value		0.5061	<0.0001	0.4307	0.0310	0.6256

[z] Values in a vertical column followed by different letters are significantly different at the specified *P*-value by Fisher's Protected LSD Test.

Table 8. Effects of canopy-applied fertilizers on yield and nut quality of ‘Kerman’ pistachio, Lost Hills, CA. Harvest was 4 October 2012.

Treatment	Application time	Split nut dry wt.	Blank nuts	Dark stained nuts	Insect damage	Embryo dry wt.
		- *kg/tree* -	----------------------	%	----------------------	-- *mg/nut* --
Urea-N	Bud swell to Green tip	10.3 a[z]	4.3 a	0.7 a	4.4 a	768 a
Urea-N + B	Bud swell to Green tip	7.5 a	5.9 a	1.9 a	4.8 a	782 a
Urea-N + B + Zn	Bud swell to Green tip	9.2 a	3.2 a	1.1 a	5.1 a	772 a
B	Bud swell to Green tip	5.7 a	5.4 a	1.9 a	7.0 a	758 a
Zn	1/2 to 1/3 leaf expansion	8.3 a	5.2 a	1.3 a	5.5 a	779 a
Urea-N	1/2 to 1/3 leaf expansion	6.9 a	5.0 a	1.7 a	5.6 a	794 a
Zn + Urea-N	1/2 to 1/3 leaf expansion	7.4 a	5.8 a	1.5 a	5.0 a	784 a
KTS	Jun, Jul, and Aug	8.0 a	4.3 a	1.6 a	5.7 a	769 a
KNO_3	Jun, Jul, and Aug	8.6 a	5.0 a	1.3 a	4.9 a	758 a
Urea-N	Jun, Jul, and Aug	4.9 a	5.8 a	1.6 a	5.0 a	749 a
KTS + Urea-N	Jun, Jul, and Aug	9.5 a	4.4 a	1.3 a	5.2 a	754 a
Control		8.6 a	4.9 a	1.3 a	6.1 a	762 a
P-value		0.3925	0.1929	0.3927	0.4176	0.3371

[z] Values in a vertical column followed by different letters are significantly different at the specified *P*-value by Fisher's Protected LSD Test.

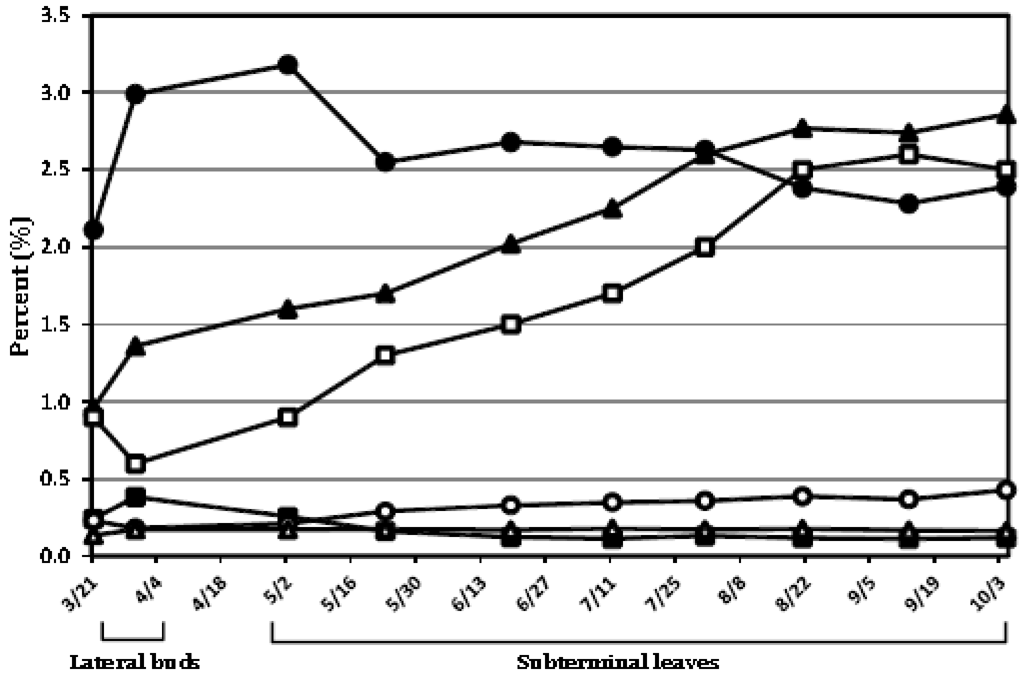


Figure 1. Comparison of the changes in bud and leaf nutrient concentrations of untreated (control) 'Kerman' pistachio trees, Lost Hills, CA, from March to October: (-●-) Nitrogen, (-■-) Phosphorus, (-▲-) Potassium, (-□-) Calcium, (-○-) Magnesium, and (-∆-) Sulfur.

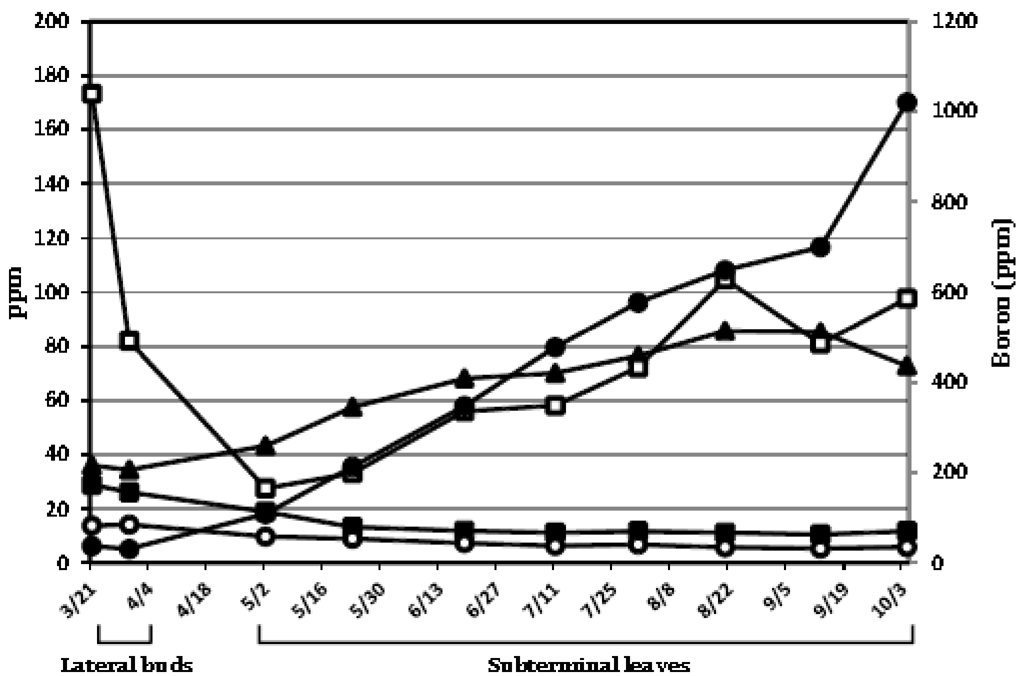


Figure 2. Comparison of the changes in bud and leaf nutrient concentrations of untreated (control) 'Kerman' pistachio trees, Lost Hills, CA, from March to October: (-●-) Boron, (-■-) Zinc, (-▲-) Manganese, (-□-) Iron, and (-○-) Copper.

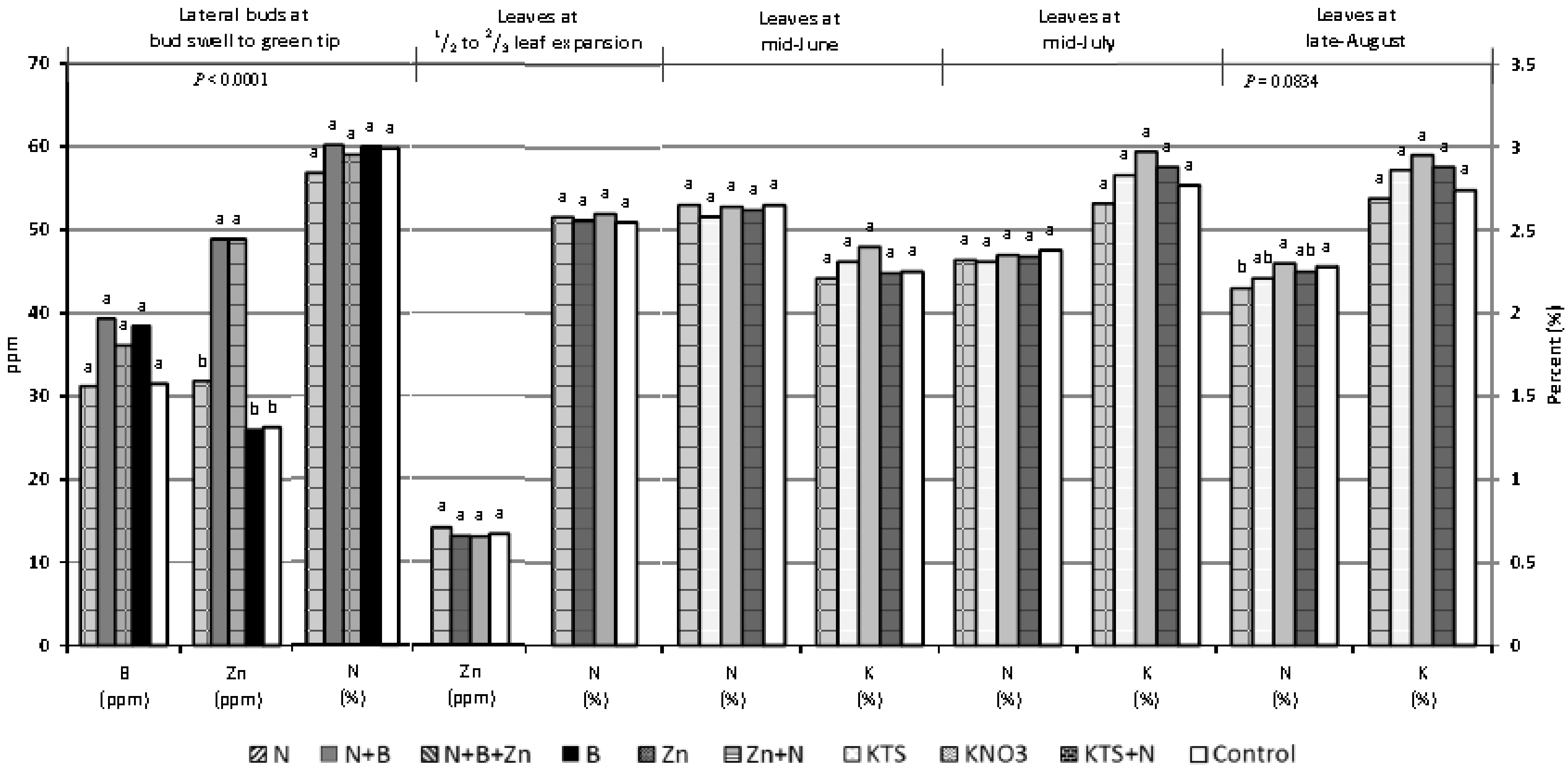
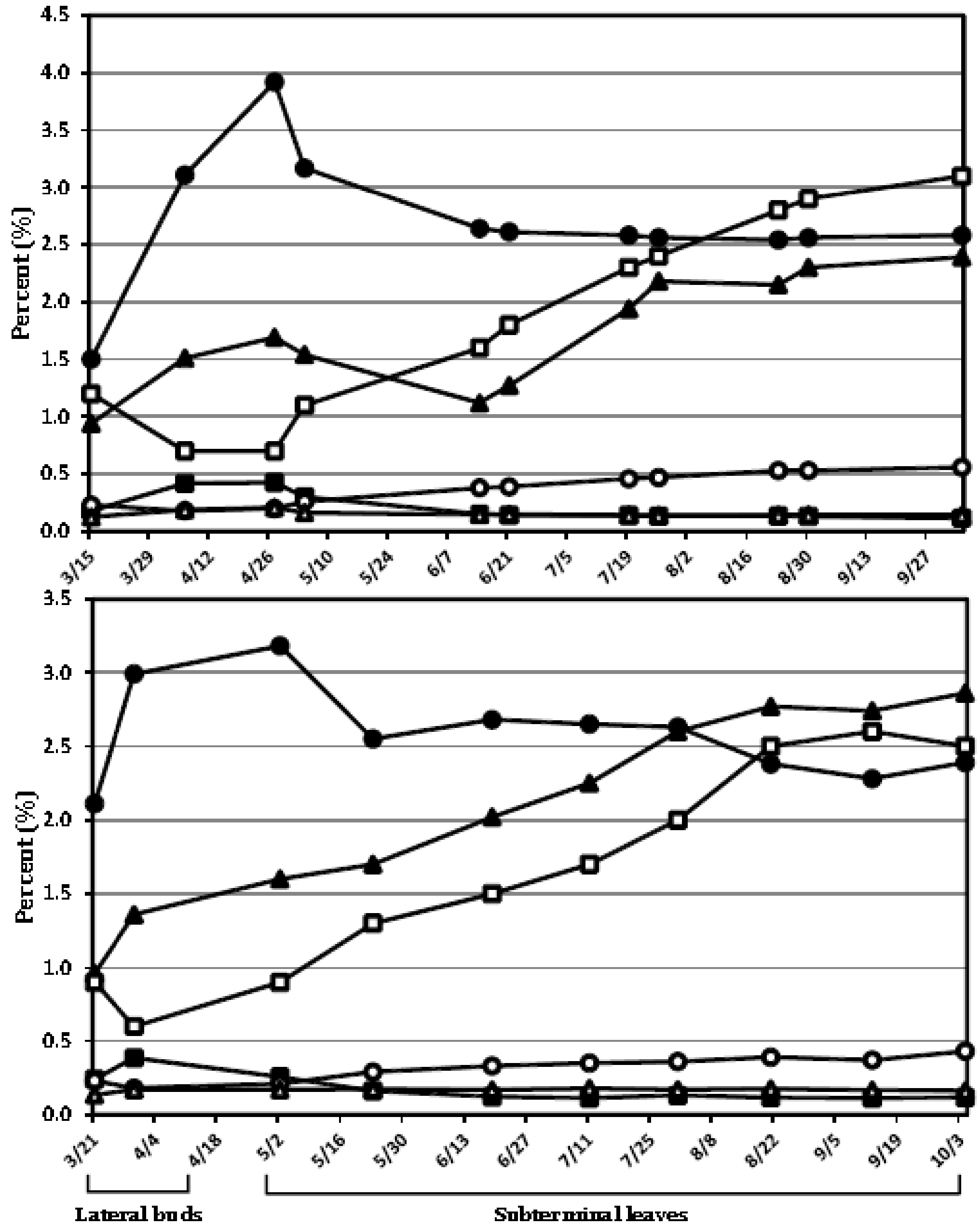


Figure 3. Effect of foliar fertilizers applied at key stages of 'Kerman' pistachio tree phenology on bud or leaf concentrations of boron (B), zinc (Zn), nitrogen (N) and potassium (K) in Year 1 (upper panel) and Year 2 (lower panel). The fertilizers were: N, urea; B, Solubor; Zn, zinc sulfate; KTS, potassium 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.

APPENDIX I



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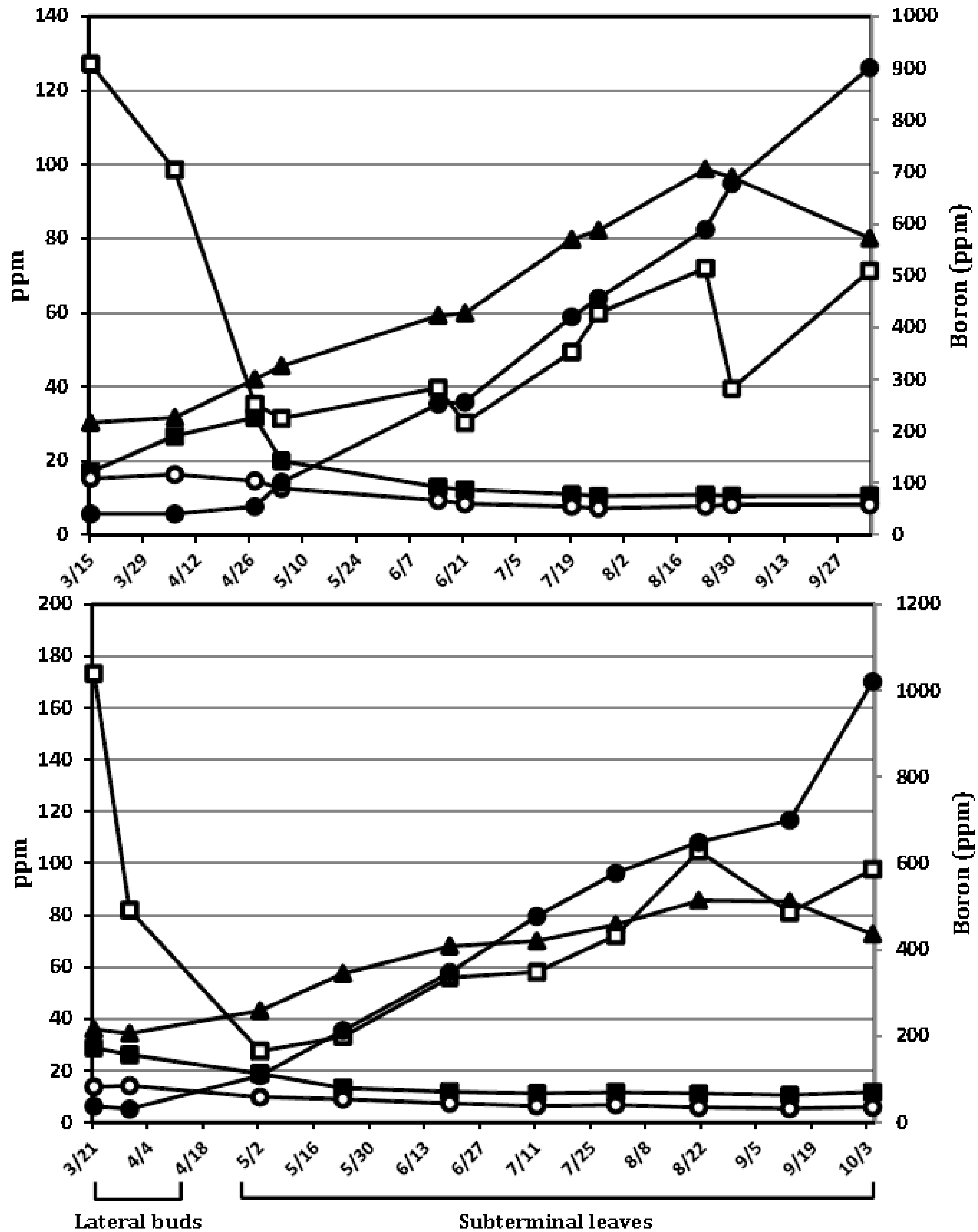

Figure 2. Comparison of the changes in bud and leaf nutrient concentrations of untreated (control) 'Kerman' pistachio trees, Lost Hills, CA, from March to October in Year 1 (upper panel) and Year 2 (lower panel): (-●-) Boron, (-■-) Zinc, (-▲-) Manganese, (-□-) Iron, and (-○-) Copper.

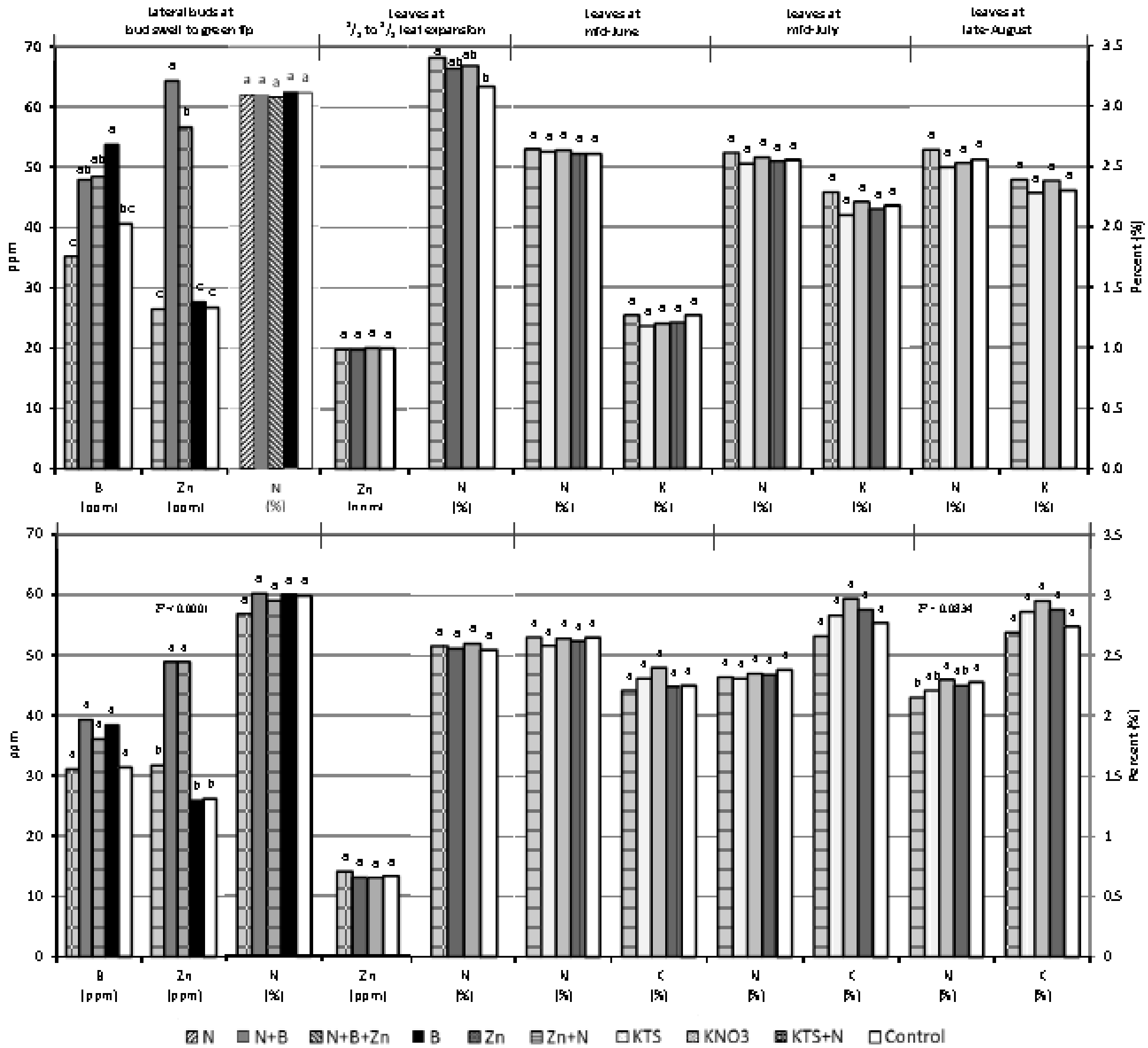

Figure 3. Comparison of the effects of foliar fertilizers applied at key stages of 'Kerman' pistachio tree phenology on bud or leaf concentrations of boron (B), zinc (Zn), nitrogen (N) and potassium (K) in Year 1 (upper panel) and Year 2 (lower panel). The fertilizers were: N, urea; B, Solubor®; Zn, 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.