Leaf Zinc and Copper Concentrations of Mature Pistachio Trees in Response to Fertigation

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SUMMARY. Mature 'Kerman' pistachio (*Pistacia vera* L.) trees, located on the west side of the San Joaquin Valley of California on an alkaline clay-loam soil, were fertigated in 1997 and 1998 with three combinations of zinc (Zn) and copper (Cu) sulfate. Seasonal applications of Zn and Cu were injected at three separate times starting in spring and ending in summer. Efficacy of the treatments were compared by measuring the concentration of Zn and Cu in leaf tissue. Fertigated treatments were compared to trees receiving no supplemental Zn or Cu and to trees receiving a single foliar treatment of Zn and Cu each year. Soil Zn and Cu concentrations increased in the fertigated plots. Plots receiving the highest rates of Zn and Cu showed the greatest increase. However, at the recommended August leaf sampling period, only the foliar treated pistachio trees showed a significant increase in leaf Zn and Cu. The results demonstrate that after two seasons, a foliar application of Zn and Cu in April, two to three weeks after flowering, increased leaf-tissue concentrations of Zn and Cu to sufficiency levels. These foliar applications were more effective than fertigating with Zn and Cu sulfate.

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Application of some fertilizer nutrients and soil amendments through low-volume irrigation systems has proven to be fast, convenient and economical in comparison to foliar applications with less soil compaction and reduced risk of phytotoxicity. Pistachios grown in soils in the Central Valley of California may manifest Zn and Cu micronutrient deficiencies in the absence of a routine micronutrient fertilization program. Currently, Zn is commonly applied in a single foliar application of up to 40 lb / acre (45 $kg \cdot ha^{-1}$) of elemental Zn after harvest or as a late dormant spray. Previous research (Brown et al., 1993, 1994) has shown that foliar Zn was absorbed and transported within the tree when applied after flowering during early leaf development. The quantity of nutrients applied at this time must be reduced when compared to late dormant or postharvest treatments to prevent phytotoxicity.

Soil applied Zn and Cu may become fixed in alkaline soil and rendered unavailable for root uptake (Burk et al., 1995). Broadcast applications of Zn and Cu fertilizers would be expected to be more available to trees growing on acid soils. Zinc oxide and Zn sulfate have been shown to correct severe Zn deficiency symptoms in pecans grown on an acid soil having a lime-induced alkaline surface (Wood and Payne, 1997). However, the correction took 2 years to occur when the Zn was disked into the soil and more than four years if left on the soil surface. Chelating agents have been shown to improve solubility or uptake of micronutrients from the soil, especially in alkaline soils (Burt et al., 1995; Cadahia et al., 1988; Wallace and Wallace, 1983). Single applications of either 1.5 or 3 lb (0.7 or 1.4 kg) of Zn sulfate dissolved in water and sprinkled around individual trees during the late dormant stage did not significantly increase leaf Zn concentrations in pistachios (Brown and Zhang, 1997). In this same study similarly applied EDTA-chelated Zn chelated (15% Zn) at 3 lb / tree (1.4 kg / tree) did increase leaf Zn concentrations by 6 to 8 ppm ($mg \cdot kg^{-1}$) but the expense involved made this practice economically unattractive.

Rootstocks have been shown to influence micronutrient uptake from a range of soil types. *Pistacia atlantica* Desf. showed higher concentrations of leaf Cu and Zn when compared to *P. integerrima* Stewart or their hybrids. (Brown et al., 1994).

Most of the pistachios grown in the southern San Joaquin Valley are grown under low-volume irrigation systems. The objective of this study was to determine if multiple fertigations throughout the season with relatively inexpensive Zn and Cu sulfate would increase the level of these nutrients in August leaf-tissue samples and, if so, to establish guidelines as to the quantity of micronutrients required on the west side of the San Joaquin Valley.

Materials and methods

EXPERIMENTAL SITE. The experiment was located on the west side of the San Joaquin Valley in northwestern Kern County, in an Yribarren clay loam (Chang, 1988). The soil is calcareous, boric, alkaline and has an effective rooting depth of 60 inches (1.5 m) or more. The orchard was planted in 1983 with 'Kerman' and pollinizer 'Peters' on *P. integerrima* rootstock. Tree spacing was 15 ft (4.6 m) in the row and 20 ft (6.1 m) between rows. Each tree was irrigated by four 1 gal / h (3.8 $L \cdot h^{-1}$) emitters along a single hose line which wet an area about 5 ft (1.5 m) in width along the length of the tree row, or about 25% of the soil surface, during the peak irrigation period.

EXPERIMENTAL DESIGN AND ANALYSIS. This experiment consisted of five treatments (unfertilized; foliar applied; low, medium and high fertigation applied). Each treatment was replicated three times, except for the unfertilized control, in a randomized, complete block design. The unfertilized treatment was replicated six times, twice in each of the three blocks. Each of the 18 plots were five rows wide and 18 trees long. Data were collected from the central row in each plot and analyzed using ANOVA (Manugistics, 1997).

TREATMENTS. Three fertigation treatments were established and iden-

Table 1. Soil characteristics of the experimental site before treatments were applied, April 1997.

Soil depth (ft^z)	Saturation (%)	pH	Electrical conductivity (mmhos·cm^{-1})^y	Sodium absorption ratio (%)	Chlorine (meq·L^{-1})^x	Boron [ppm (mg·kg^{-1})]	Cation exchange capacity (meq/100 g of soil)^w
0–1	43.0 ± 4.2^v	7.70 ± 0.00	1.63 ± 0.83	2.5 ± 0.7	3.25 ± 2.62	0.65 ± 0.35	26.7 ± 7.40
1–2	43.0 ± 4.2	7.75 ± 0.05	1.28 ± 0.76	2.5 ± 0.7	4.15 ± 3.75	0.30 ± 0.00	27.3 ± 6.70
2–3	46.5 ± 4.9	7.60 ± 0.14	2.32 ± 0.85	3.0 ± 1.4	5.35 ± 3.32	0.25 ± 0.07	29.0 ± 0.07

^{z}1 ft = 30 cm.
^{y}1 mmhos·cm^{-1} = 0.1 S·m^{-1}.
^{x}From a saturated paste extract. 1 L = 1.06 qt.
^{w}100 g = 0.22 lb.
^{v}±1 standard deviation. Each value of the table is the average of two samples. Each sample is a composite of multiple subsamples taken from various areas of the experimental site.

tified as low, medium, and high in the text and figures. The low treatment consisted of a seasonal fertigation rate of 4.4 lb / acre (4.8 kg·ha^{-1}) and 3.3 lb / acre (3.7 kg·ha^{-1}) of elemental Zn and Cu respectively; the medium treatment consisted of 14.5 lb / acre (16.2 kg·ha^{-1}) and 4.6 lb / acre (5.2 kg·ha^{-1}) of Zn and of Cu; and the high treatment, 24.2 lb / acre (27.1 kg·ha^{-1}) and 9.9 lb / acre (11.1 kg·ha^{-1}) of Zn and of Cu. Further treatments included trees which received no supplemental Zn or Cu and is identified as unfertilized. The treatment receiving only foliar Zn and Cu is identified as foliar.

The total seasonal quantity of fertigated materials were injected in three equal applications on 23 May, 24 June, and 20 Aug. 1997 and 27 Apr., 8 May, and 30 July 1998. Except for the foliar applications, Zn and Cu was applied as Zn (35.5% metallic ion) or Cu (25% metallic ion) sulfate.

Fertigation was conducted while temporarily separating the plot from the irrigation taking place in the orchard. Fertigations were made using an engine-driven injection machine connected to a manifold which delivered the fertilizer to the irrigation system of the plot. The measured flow rate through each irrigation hose was about 1.2 gal / min (4.5 L·min^{-1}), which approximated the normal flow of the irrigation system. The duration of fertigation for each plot was about 20 min. The duration of the irrigation event for the experimental area during which the Zn and Cu were injected was about 72 h.

Foliar applications were made with a 250-gal (935-L) capacity PTO-driven air-blast sprayer on 24 Apr. 1997 and 28 Apr. 1998 after flowering when the first developing leaves were about 50% fully expanded. In 1997, foliar application of Cu was applied at the rate of 0.05 lb / acre (0.06 kg·ha^{-1}) of elemental Cu as a 14% chelated powder in combination with 0.66 lb / acre (0.74 kg·ha^{-1}) of elemental Zn in the form of Zn sulfate (35.5%) at a rate of 100 gal / acre (935 L·ha^{-1}). In 1998, Cu was applied at the rate of 0.07 lb / acre (0.08 kg·ha^{-1}) using the same formulation as in 1997, 0.66 lb / acre (0.74 kg·ha^{-1}) of elemental Zn derived from Zn sulfate in a 12% liquid Zn product, and 9 oz (266 mL) of a spreader-penetrant adjuvant (a product containing 95% poly-1-p menthene) at a rate of 200 gal / acre (1870 L·ha^{-1}).

Soil sampling. Each soil sample was composed of a pool of five to seven subsamples collected within each plot. Soil was removed with augers from holes drilled 2 ft (61 cm) from an emitter on a line drawn perpendicularly to the hose. Emitter locations were coded to ensure that the same soil location was not sampled twice. In 1997, soil samples were taken in each plot in 1 ft (30 cm) increments to a depth of 3 ft (91 cm) on 4 Apr. and to a depth of 2 ft in intervals of 0.5 ft (15 cm), 1 ft and 2 ft on 1 Aug. In 1998, the soil was sampled to a depth of 1 ft on 21 Apr. and to a depth of 3 ft in 1-ft increments 18 Aug.

Leaf sampling. Leaf tissue samples consisted of the terminal leaflet of leaves from nonfruiting branches 6 to 8 ft (1.5 to 2.4 m) from the ground and from the center row of trees in each plot. Leaves sampled in August were fully expanded, while those in April and May were the largest on the branch but were still expanding. Leaf samples were collected from each plot, except foliar treated, on 5 May 1997 and were pooled by block. Leaves sampled on 2 Aug. 1997 and 21 Apr., 8 May, and 8 Aug. 1998 were kept separate by plot for statistical analysis.

Nut sampling. Nut meats were sampled at harvest on 9 Sept. 1997. Each sample consisted of nuts collected from bins filled from the center row of trees in each plot.

Soil, leaf, and nut tissue analysis. Leaf tissue, nut meat and soil samples were analyzed by the University of California, Department of Agriculture and Natural Resources Analytical Laboratory located in Davis, Calif. Analyses for soil Zn and Cu were made using equilibrium extraction of the ground sample using diethylenetriaminepentaacetic acid (DTPA) (Lindsay and Norvell, 1978) and subsequent determination by atomic absorption spectrometry (Franson, 1985). Leaf samples were washed in distilled water and dried at 158 °F (70 °C) for 48 h or more. Leaf and nut meat Zn and Cu concentrations were determined by microwave acid digestion of ground tissue (Sah and Miller, 1992) and atomic absorption spectrometry (Franson, 1985).

Results

Soil characteristics. The soil, as sampled within the wetted pattern of the irrigation system, was an alkaline, boric clay loam (Table 1).

Soil zn and cu concentrations. The trees and soil of the experimental site appear to be uniform across the site as no significant block effects appeared in any of the statistical analyses.

Uniform soil Zn and Cu concentrations were found before treatment applications (Figs. 1 and 2). Soil concentrations of Zn and Cu significantly increased in the 0 to 1 ft (30 cm) depth when fertigated at the medium and high treatment rates when compared to the foliar or unfertilized treatments. At the 1 to 2 foot (30 to 61 cm) level there was significant increase for Zn and Cu for the high fertigation treatment only.

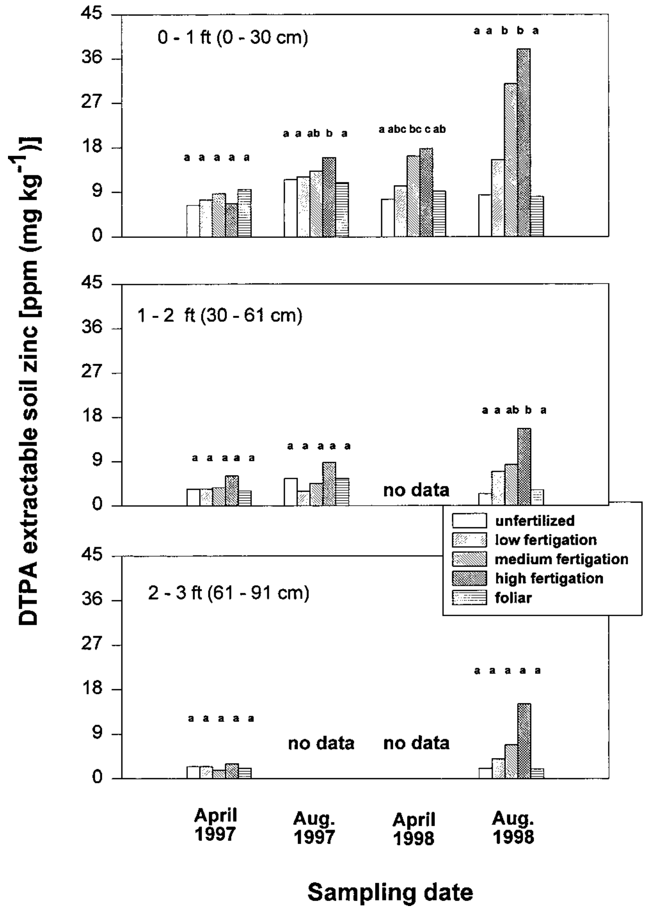


Fig. 1. diethylenetriaminepentaacetic acid (DTPA)-extractable soil zinc concentration with soil depth (0–1 ft, 1–2 ft, and 2–3 ft) and time, 1997 and 1998. Columns with the same letter are not significantly different ($P \leq 0.05$) according to Fisher's least significant difference test.

LEAF ZN AND CU. Leaf tissue concentrations in the unfertilized and fertigated treatments in Aug. 1997 were 10 to 12 ppm ($mg \cdot kg^{-1}$) Zn and 4.5 to 4.9 ppm Cu (Fig. 3). Concentrations were above established critical levels of 7 ppm Zn and 4 ppm Cu, but at the lower end of the recommended range of 10 to 15 ppm for Zn and below the 6 to 10 ppm range for Cu (Brown, 1995).

Leaf concentrations of Zn and Cu were higher in April 1998 than in August for all treatments. Except for leaves sampled in April 1998, leaf concentrations for both Zn and Cu did not differ significantly among trees which were not fertilized when compared to fertigated trees despite increased soil Zn and Cu levels in the fertigated treatments. Differences measured in leaf Zn and Cu concentrations among fertigated treatments in April 1998, were no longer apparent in May 1998. Trees treated with the April foliar application showed significantly higher Zn and Cu concentrations in August as compared to unfertilized and fertigation treatments.

Nut meats from the 1997 harvest showed no increase in Zn or Cu concentration, which averaged 18.5 and 9.5 ppm respectively, as a result of foliar or fertigation treatments.

Discussion

The results demonstrate that for the Kerman variety of pistachio grafted on *P. integerrima* rootstock cultured on an alkaline calcareous clay loam soil that Zn and Cu sulfate at the rates used in this study will not significantly increase August leaf tissue concentrations after 2 years of fertigation. Multiple fertigations of Zn sulfate within a single season and over 2 years did not

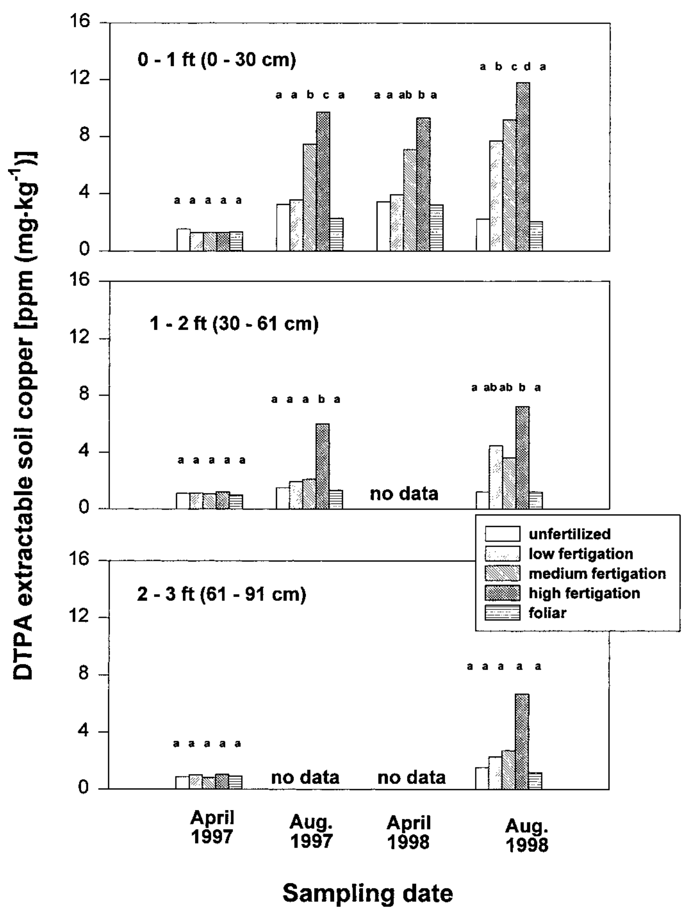
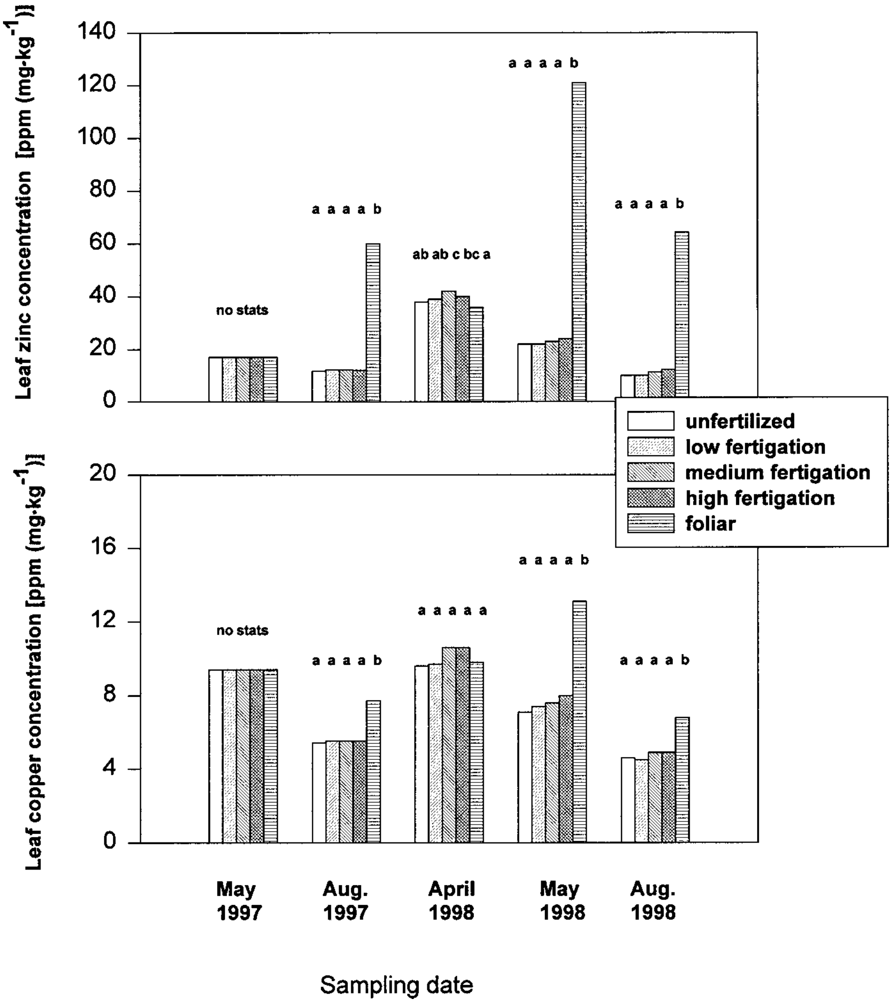


Fig. 2. Diethylenetriaminepentaacetic acid (DTPA)-extractable soil copper concentration with depth (0–1 ft, 1–2 ft, and 2–3 ft) and time, 1997 and 1998. Columns with the same letter are not significantly different ($P \leq 0.05$) according to Fisher's least significant difference test.

increase leaf Zn concentration more than did the single March application reported by Brown and Zhang (1997).

Critical concentrations for Zn and Cu in pistachio have been established based on late July or August tissue samples. In addition to sampling leaves in August, we sampled leaves in April 1998 to determine if Zn or Cu differed in response to the previous season's treatments prior to any current season Zn or Cu applications. Medium fertigated trees showed significantly more leaf Zn than did the unfertilized or foliar treated trees at the April, 1998 sampling date suggesting a small response of trees to increased Zn in the root zone (Fig. 3). Leaves were sampled in May 1998 to detect if transient increases in Zn or Cu occurred in the treatments as a result of April and May

Fig. 3. Leaf Zn and Cu concentration with time, 1997 and 1998. Columns with the same letter are not significantly different (*P* ≤ 0.05) according to Fisher's least significant difference test.



fertigation. No increase in leaf concentrations of Zn or Cu were detected in the fertigated treatments at the May sampling date.

Based on soil analysis, the concentration of Zn and Cu were increased in the root zone of fertigated trees (Figs. 1 and 2). Apparently, however, the Zn and Cu remained unavailable for tree absorption or the increase in soil concentration was not sufficient to increase leaf concentrations (Fig. 3). Possible deep leaching of Zinc and Cu through the root zone was probably not an important factor in the lack of leaf absorption because of the presence of an alkaline clay loam soil with a slow water infiltration rate, a drip system that provided only sufficient water when run continuously to meet the peak estimated evapotranspiration requirement of the crop, and the observation that a relatively higher concentration of these elements were found in the top foot of soil. Zinc and Cu is less available to plants on alkaline soils. Wood and Payne (1997) did not began to measure increased leaf Zn in pecans until the third year after a heavy broadcast Zn application and then only if the fertilizer had been lightly disked into the acid soil lying beneath the limed surface layer. Fertigation with Zn and Cu sulfate does not appear to increase pistachio absorption of these nutrients in alkaline soils based on the result of our experiment.

As evidenced by earlier work (Brown et al., 1993, 1994, 1997) the April postflowering foliar application of Zn and Cu appears to be an effective method of increasing leaf Zn and Cu leaf levels. The issue of the transportability of the Zn in pistachio leaves to other tissues was investigated by (Brown et al., 1994; Zhang and Brown, 1999a, 1999b), who found that Zn is absorbed and transported. How much of the Cu is absorbed foliarly remains an unanswered question. In our study, the leaves analyzed for Zn and Cu in August had not yet been produced by the tree in April when the foliar applications were made. Yet, as mature leaves in August, they tested 500% higher in Zn and 60% higher in Cu than the unfertilized or fertigated leaves suggesting that Zn and Cu were transported out of treated leaves into new leaves. However, the Zn and Cu foliarly absorbed in 1997 in our study, was apparently not available for transport to the new leaves of 1998 at the April sampling date, indicating that there may be little storage of these nutrients in the tree over the winter. Brown and Zhang (1997) reported a similar lack of carryover between years with foliar applied Zn.

Zinc or Cu concentration of nut meats from the September harvest in 1997 did not differ among treatments suggesting that Zn and Cu mobility in the flower and developing rachis is limited.

The results of this study, based on the concentration of Zn and Cu in the leaf tissue in August shortly before harvest, suggest that a foliar application of 0.3 lb / acre (0.4 $kg \cdot ha^{-1}$) of chelated Cu (0.05 lb / acre of Cu metal derived from $CuNa_2EDTA$) and 2 lb / acre (2.2 $kg \cdot ha^{-1}$) Zn sulfate (35.5% metallic Zn) may boost leaf concentrations of these nutrients to a level that meets or exceeds the seasonal crop requirement. In comparison, fertigations of Zn and Cu sulfate had not significantly raised August leaf tissue levels after two years in this alkaline, clay loam soil.

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