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SOIL FACTORS ASSOCIATED WITH ZINC DEFICIENCY IN AVOCADO

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Abstract

Zinc fertilizers are being applied to many avocado orchards as part of a routine fertilization program. However, soil analysis data for several orchards in southern California suggest that extractable zinc is already present at very high concentrations in many orchards, and may even be approaching toxic levels. This research examined spatial variability in soil chemical factors, including: pH, salinity, extractable metal concentrations, and soil carbonate content in relation to the trace metal contents of avocado trees in a mature orchard located on a calcareous soil. The results strongly suggest that solution bicarbonate levels buffered by equilibrium with mineral calcium carbonate may be inhibiting zinc uptake and translocation. Thus, correction of zinc deficiency in soils already containing high concentrations of extractable zinc should focus on soil management techniques other than continued application of zinc fertilizers.

Introduction

Despite over 40 years of research on methods for correcting zinc deficiency, there is still little understanding of the soil factors that are responsible for the poor availability of zinc. Typically, zinc deficiencies occur in "hot spots" in avocado orchards that suggest specific soil factors such as pH, calcium carbonate content, irrigation patterns, or soil and drainage may be responsible for poor zinc uptake.[1] In other instances, root damage due to Phytophthora may impair the ability of the tree to take up trace metals in adequate quantities needed for growth.[9]

Calculations of the actual zinc requirement of an avocado tree show that a 1,000 kilogram tree needs approximately 20 grams of zinc over its 30 year life. Current recommendations for zinc sulfate applied at a rate of 7 Ib. per tree every 3 years convert to 32,000 grams of zinc, or around 3,000 ppm in the upper 10 cm of soil[1].This is in excess of the EPA guidelines which specify a maximum soil loading of 2,800 ppm for zinc, and represents a very low fertilizer use efficiency.

A recent survey of analysis reports for soil samples from different orchards in Ventura and San Diego counties shows that many orchards already contain between 50 and 100 ppm DTPA-extractable zinc. Most plants require only 1 ppm DTPA-extractable zinc, and in some species such as peanut, greater than 25 ppm is toxic. This strongly suggests that soil factors other than the quantity of extractable zinc may be responsible for causing problems with zinc deficiency.

To study this problem better, we conducted an in-depth analysis of spatial variability within a typical orchard on a calcareous soil, and analyzed the relationship between selected soil chemical factors and the occurrence of zinc deficiency. We also examined the differential response of the trees to fertilization with soil-applied zinc sulfate in relation to soil pH and calcium carbonate (lime) content.

Materials and Methods

A mature orchard (>15 years old) planted with 'Hass' avocado on Mexican root stocks was selected for in-depth study of soil factors associated with zinc deficiency. The orchard was planted on a moderately sloping (15-30%) hillside located in Ventura County, California, in the Las Posas Hills adjacent to the Santa Rosa River Valley. Soil on this site was characterized as a Soper loam containing patches of free calcium carbonate, and was 60 to 150 cm deep over conglomerate rock. At the start of the experiment, all of the trees within the study area were permanently numbered and mapped, and baseline nutrient analyses were conducted using leaf samples from individual trees.

Mapping of spatial variability was conducted by taking soil samples along a 60 x 80 meter grid within the orchard, with individual soil cores taken at 10 meter intervals across the hill and 15 meter intervals down the hill. The soil was sampled at two depths: 0-15 cm and 15-30 cm. The cores were placed in plastic bags for transport to the laboratory, after which they were air dried, pulverized to break up the aggregates, and sieved to pass a 1 mm screen.

Soil pH and salinity were measured using saturation paste extracts.[6] Trace metal analyses were performed using DTPA extracts of 10 gram samples from each soil core. The extracts were filtered and analyzed for trace metal contents by atomic absorption spectroscopy. Soil carbonate content was measured using a pressure calcimeter.[6]

Fully expanded avocado leaves (15 per tree) were washed, dried in a forced-air oven at 60C for 3 days, and ground with a Wiley mill to pass a 1-mm-mesh sieve screen. Weighed subsamples were transferred to Teflon vessels for microwave digestion in 28% concentrated HNO_3, and 12% H_2O_2. Samples were analyzed using an atomic absorption flame spectrophotometer. Reagent blanks and apple *(Mains domestica* B, Nat. Inst. Standards and Technol. 1515) leaves were included with each analysis for quality assurance. Measured values for the standard reference materials were generally within 5% of the reported concentrations.

An experiment examining the affect of application time on uptake of soil-applied zinc sulfate was conducted using 15 randomly selected trees per treatment. Treatments consisted of a single application of 7 Ib zinc sulfate per tree which was applied to a different set of trees at the beginning of each month for six sequential months starting in April 1995. The fertilizer was placed in a 1-m wide band in the irrigation-wetted zone approximately 0.5 to 1.5 m from the base of the trunk. Uptake of zinc was monitored using leaf samples taken from individual trees at monthly intervals from June through October 1995.

Results and Discussion

To study soil factors associated with zinc and iron deficiency, we picked a site in which there were considerable differences in the trees with respect to visible symptoms of iron chlorosis and zinc mottle leaf. These soil data are summarized in ***(Figures 1-3),*** which show the differences in extractable zinc, soil pH, and soil carbonate content. These soil data should be examined in relation to ***(Figure 4),*** which shows the initial foliar zinc content of the trees in June (***Figure 4*** top) and the response of the trees to fertilization with zinc sulfate after leaf sampling in August (***Figure 4*** bottom). The front left axis of each plot in the figures corresponds to the picking road at the bottom of the hill. The distance uphill from the picking road is shown as the front right axis. Most of the zinc and iron—deficient trees were in the lower left corner of the field (0-20 meter range on the left front axis).

As suspected, there was significant spatial variability within the orchard for extractable zinc, iron, pH, and soil carbonate content that occurred over relatively small distances of 10 to 20 meters. Surprisingly, neither the concentrations of extractable zinc and iron, or pH, were consistently correlated with visual deficiency symptoms and foliar trace metal contents. Prior to applying zinc fertilizer, extractable zinc in the surface soil ranged from 0.4 ppm to 182 ppm *(**Figure 1**),* and 0.4 to 36 ppm in the lower horizon. These values for the surface soil span the entire range from subcritical to near toxic for soil zinc. Most plants require 0.5 to 1 ppm as the critical soil zinc level when using DTPA soil extracts.[8]

Foliar zinc contents of the trees in this orchard had a range of 22 to 51 ppm and a mean of 32 ppm *(**Figure 4**).* Although the lowest soil zinc content was measured in the corner of the field having zinc deficient trees, other adjacent trees with low zinc were in soil containing 10-20 ppm extractable zinc. Moreover, the response to zinc fertilizer for trees located in this hot spot section was relatively poor as compared to the rest of the orchard. After the trees were fertilized with 300 ppm zinc, trees at the top of the hill (back right axis) showed the greatest increase in foliar zinc, whereas the zinc-deficient trees in the lower left corner of the orchard only slightly increased their zinc contents *(**Figure 4**).* This strongly suggests that total soil zinc is not limiting zinc uptake, and that one or more other soil factors are responsible for inhibiting zinc uptake by the trees.

According to general principles of soil chemistry, the solubility of zinc and iron decrease by 100 and 1,000-fold, respectively, for every unit increase in pH. Thus soil pH was considered as a possible factor in causing problems with zinc uptake. In this orchard, soil pH varied from 6.4 to 7.6; but we observed that elevated soil pH was not consistently associated with either zinc or iron deficiency, nor with the poor response of hot spot trees to zinc fertilization. Many of the trees which showed the best response to zinc fertilizer were growing in the lower pH areas of the field, but several trees also responded well in the high pH areas.

Soil carbonate, on the other hand, appeared to be strongly associated with poor ability of the trees to take up zinc, both at the beginning of the experiment and after zinc fertilizer had been applied *(**Figure 3**).* Carbonate levels shown in ***(Figure 3)*** are reported as grams per kilogram of carbonate carbon, and range from 0.0005 to 2.3. Trees in the lower, left corner of the field, which contained the lowest levels of zinc and iron, and which showed the least response to zinc fertilizer, were located in soil containing the highest soil carbonate levels; whereas, the most responsive trees were located in low carbonate areas.

Prior research on several crop plants has shown that the bicarbonate concentration of the soil solution is strongly correlated with the occurrence of both zinc and iron deficiency.[2,7] Dissolved bicarbonate has two effects on plant uptake of trace metals. The first effect involves pH buffering at the root surface, which limits the effectiveness of the normal root response to trace metal deficiency. As a specific response to iron deficiency, most plants release hydrogen ions (acid) into the soil around the roots to help dissolve trace metals. In citrus, the strength of this response is strongly correlated with the ability of various root stocks to resist trace metal deficiencies.[3] Avocados also have this response, but it is relatively weak in 'Hass' avocado on its own rootstock.[4] The trace metal uptake efficiency of other avocado varieties has not yet been well examined, but could easily be evaluated as part of a screening program.

The second effect of bicarbonate is related to impaired translocation of trace metals in the xylem. Normally, zinc and iron are complexed with citrate as soon as they are taken up by the roots. This complex holds the metal ions in a soluble form so that they can cross cell walls and move from the roots to the leaves. When bicarbonate is taken up by the roots, the pH of the xylem is increased, which causes citrate to preferentially form complexes with calcium rather than iron or zinc. Visual evidence for this poor translocation can be seen in the leaves of trace metal deficient plants, which typically have green veins, but yellow tissue between the veins (iron), or mottle leaf (zinc). In this case, the metals are not translocated out of the xylem vessels in the leaf veins into the leaf parenchyma tissue.

Recommendations

Based on this particular study, soil carbonate level appeared to be the primary factor that was responsible for zinc deficiency in avocado, rather than any problem with total soil zinc. If this is true for other similar orchards on calcareous soils, trying to solve the problem by applying high levels of zinc fertilizer is not the right approach. Instead, we should be concerned with managing the soil to reduce bicarbonate accumulation in the soil solution.

Soil solution bicarbonate concentrations are controlled by equilibrium with calcite (mineral calcium carbonate) and the amount of dissolved $C0_2$ in solution. The calcite localized in zinc and iron deficient "hot spot" soils sets up conditions for the problem, which becomes evident when carbon dioxide is released and accumulates in the vicinity of plant roots. Carbon dioxide originates from respiration of plant roots, or from microbial activity during organic matter decomposition. Once it is released into soil, it dissolves in the soil solution to form bicarbonate, and accumulates until it slowly diffuses out of solution into the gas—filled spaces in the soil pores. Thus, high bicarbonate concentrations are primarily a problem in poorly drained soils, or in soils that are maintained under wet conditions by over irrigation. The problem also may be further aggravated by a high bicarbonate content in the irrigation water and by high soil salinity.

The best solution to reducing bicarbonate accumulation is to increase soil drainage and aeration.[10] In sodium-impacted soils, this may be achieved by applications of gypsum and leaching to open up the soil and improve its drainage. Reduction of soil pH by acidification of the irrigation water also may have some utility. Lastly, allowing the soil to dry between irrigations may reduce bicarbonate accumulation in the soil solution.

In conjunction with this research, an experiment was also conducted on the best time to apply zinc fertilizer to the soil to optimize its availability to avocado. Zinc sulfate was applied at monthly intervals to sets of trees. Results of these data show that in a climatic zone associated with Ventura County, California, the best time of year to apply zinc sulfate is in May *(**Figure 5**)*. This corresponds to the period of new root growth and suggests that new roots are most efficient at taking up zinc. A possible explanation for this effect is that new roots do not yet have the calcium carbonate shell that forms around older roots. This carbonate shell is formed when water moves by bulk flow to the roots during transpiration of water from the tree. Excess calcium is excluded from the roots and precipitates as calcium carbonate in the root cell walls. Over the long run, excessive application of zinc may have unpredictable consequences on the productivity of soils used for avocado culture. As we develop best management practices that optimize soil quality and avocado yields, we should consider ways to increase zinc uptake by proper irrigation, careful fertilizer timing, and use of trace metal efficient root stocks for avocado production.

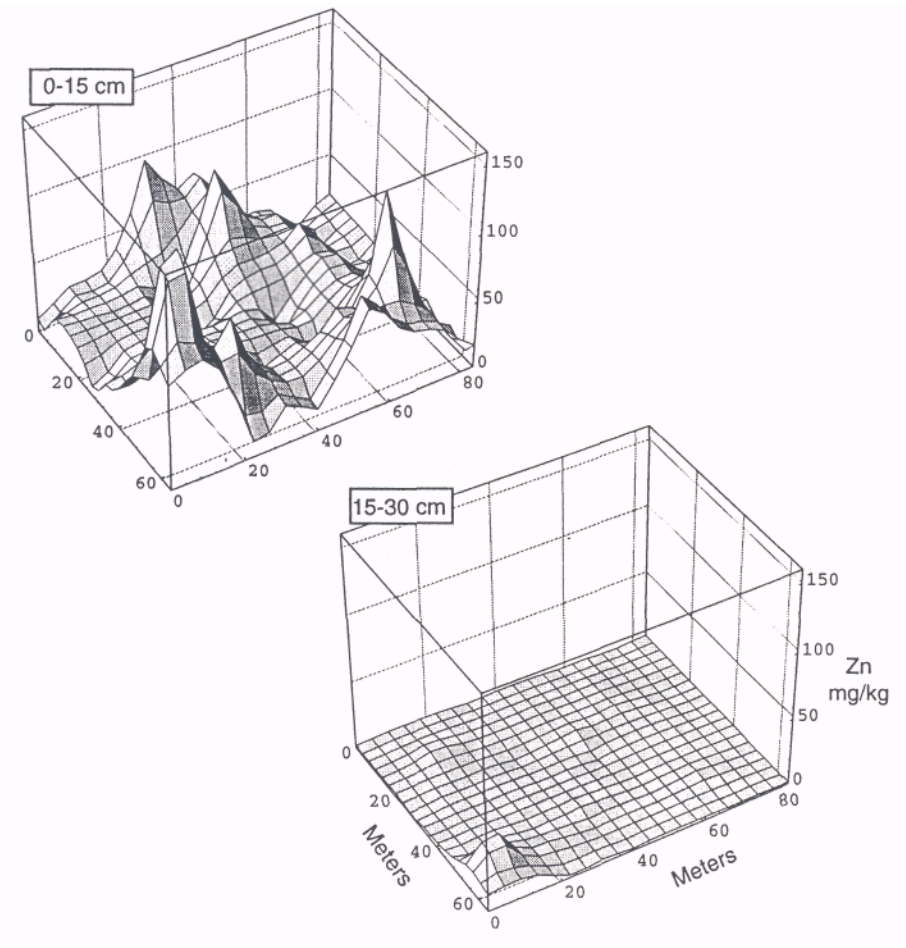

***Figure 1.** Spatial variability in DTPA-extractable (plant available) zinc concentrations in a calcareous soil planted with 'Hass' avocado in Ventura County, California. Soil was sampled at 10 x 15 meter intervals for a total of 42 sampling points, each at two depths. Top 0-15 cm; Bottom 15-30 cm.*

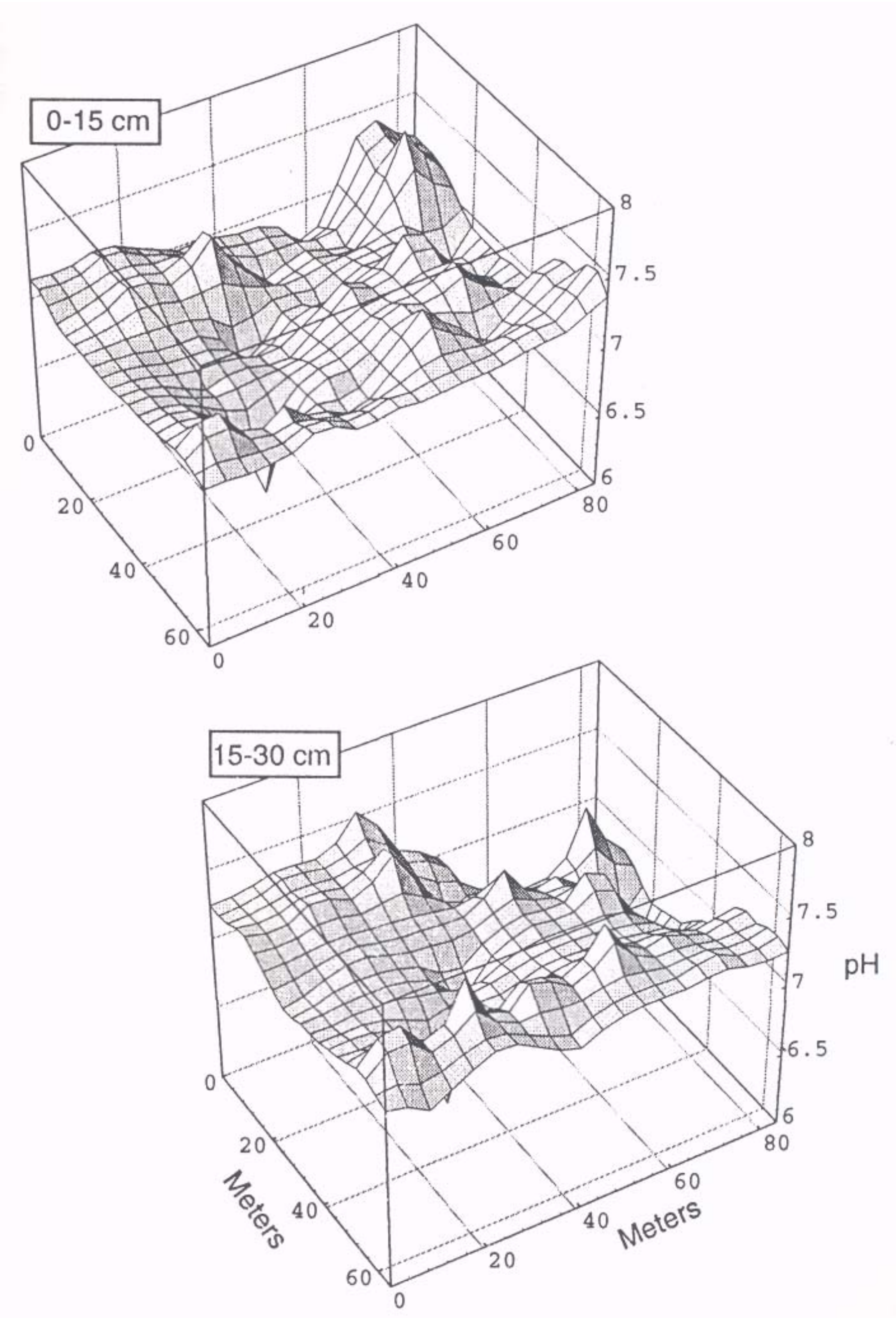

***Figure 2.** Spatial variability in soil pH for a calcareous soil planted with 'Hass' avocado located in Ventura County, California. Soil sampled at two depths.*

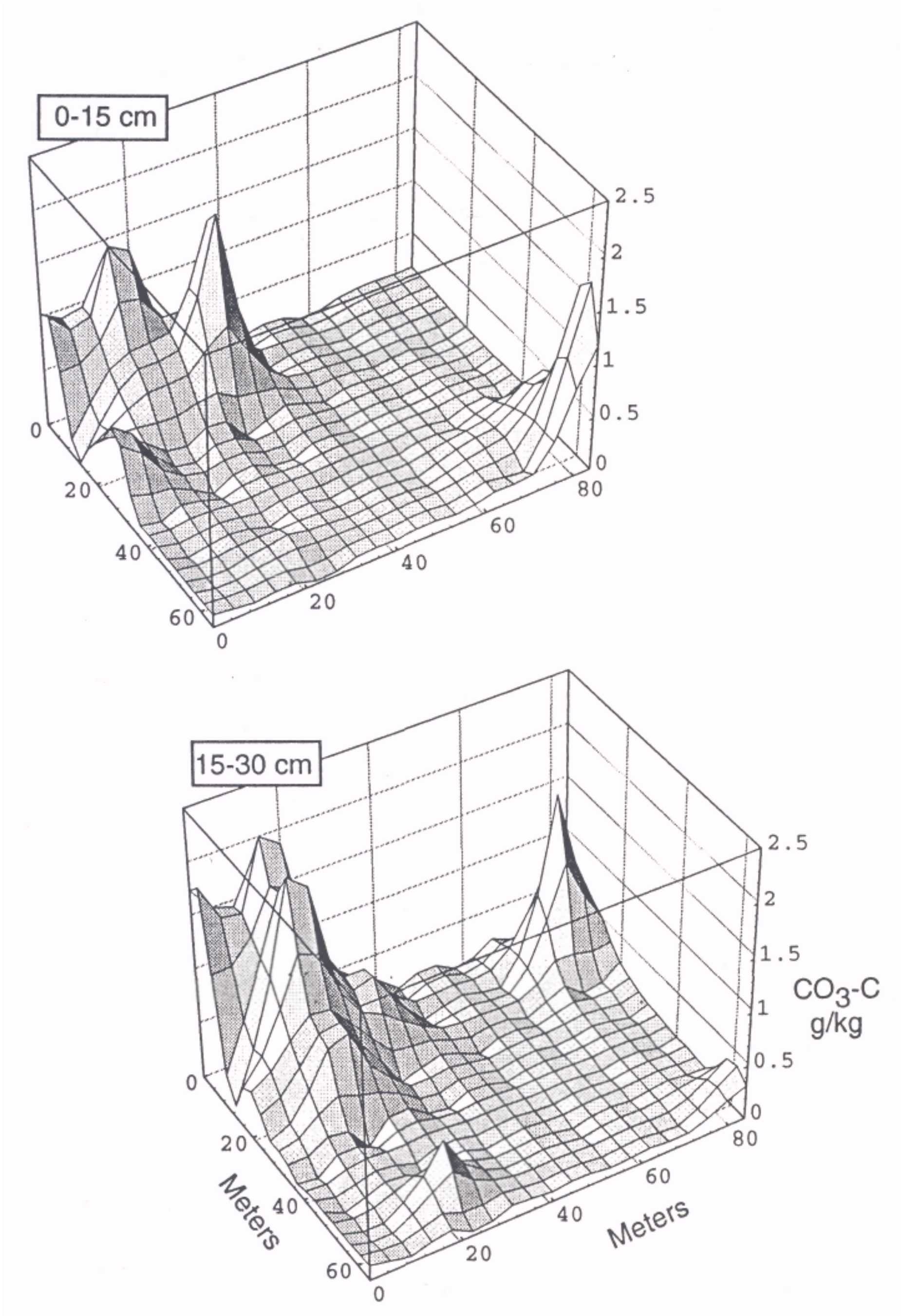

Figure 3. *Spatial variability in soil carbonate content in a calcareous soil planted with 'Hass' avocado in Ventura County, California. Soil sampled at two depths.*

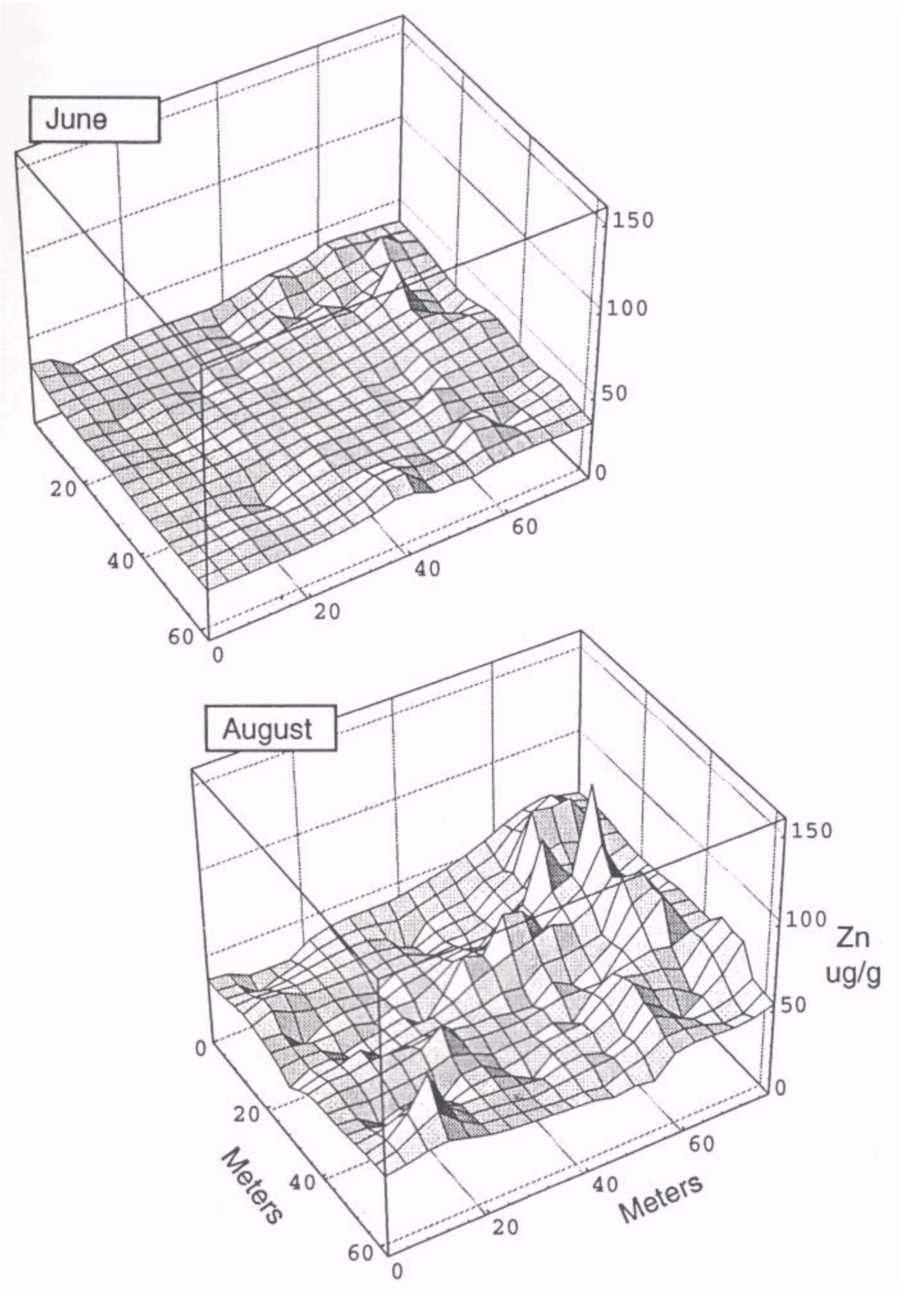

Figure 4. *Spatial variability in foliar zinc concentrations for 'Hass' avocado planted on a calcareous soil in Ventura County, California. Top figure: before fertilization with zinc sulfate. Bottom figure: after fertilization with 7lb zinc sulfate per tree.*

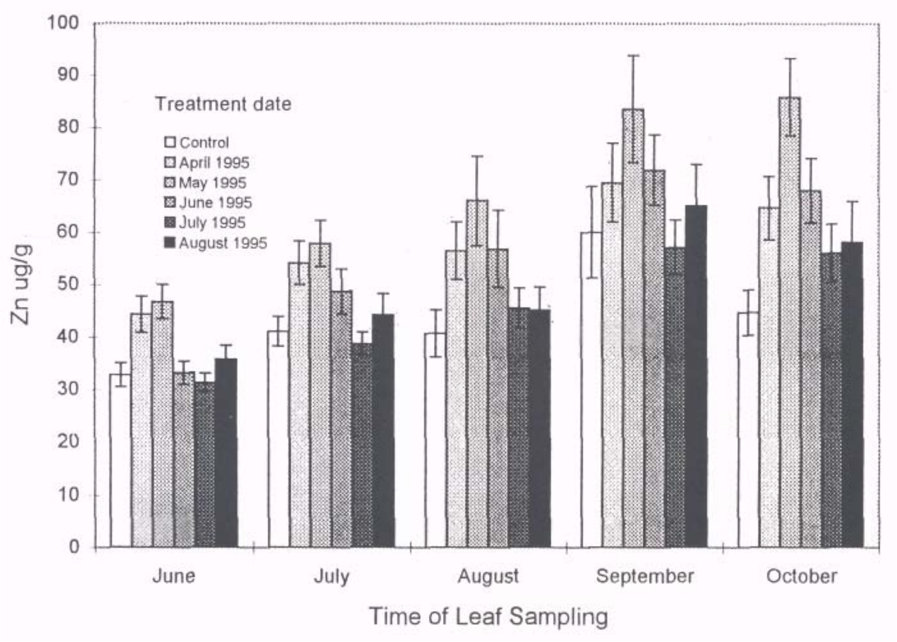

Figure 5. *Changes in foliar zinc concentrations for 'Hass' avocado trees on a calcareous soil after fertilization with 7 Ib zinc sulfate per tree. Fertilizer was applied once to individual sets of 15 trees timing indicated by treatment date in the figure legend. Vertical bars indicate 1 standard error of the mean.*

Literature Cited

1. Crowley, D.E., W. Smith, B. Faber, and J.A. Manthey. 1996. Zinc fertilization of avocado trees. Hort Sci. 31:in press.
2. Forno, D.A., S. Yoshida, and C.J. Asher. 1975. Zinc deficiency in rice. I. Soil factors associated with the deficiency. Plant Soil 42: 537-550.
3. Manthey, J.A., D.L. McCoy, and D.E. Crowley. 1994. Stimulation of rhizosphere iron reduction and uptake in response to iron deficiency in citrus rootstocks. Plant Physiol. Biochem. 32:211-215.
4. Manthey, J.A. and D.E. Crowley. 1996. Leaf and root responses to iron deficiency in avocado. J. Plant Nutr. in press.
5. Marschner, H. 1986. Mineral Nutrition of Higher Plants. Academic Press. San Diego, CA. 674 p.
6. Methods of Soil Analysis. Part 2: Chemical and Biological Properties. 1982. Eds. A. Page, R.H. Miller, and D.R. Keeney. American Soc. of Agronomy, Inc. Madison, WI. 1159 p.
7. Shi, Y., D.H. Byrne, and D.W. Reed. 1993. Iron chlorosis development and growth response of peach rootstocks to bicarbonate. J. Plant. Nutr. 16:1039-1046.
8. Soil Testing and Plant Analysis. 1990. Ed. R.L Westerman. Soil Sci. Soc. Am. Madison, WI. 784 p.
9. Whiley, A. W., KG. Pegg, J.B. Saranah, and P.W. Langdon. 1987. Influence of Phytophthora root rot on mineral nutrient concentration in avocado leaves. Aust. J. Experim. Agric. 27:173-177.

10. White, PR, and A.D. Robson. 1989. Poor soil aeration or excess soil $CaCO_3$ induces Fe deficiency in lupins. Aust. J. Agrie. Res. 40:75-84.