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AvoResearch

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NITROGEN FERTILIZATION OF THE 'HASS' AVOCADO IN CALIFORNIA

What we know and what we don't know.

Carol J. Lovatt, Professor of Plant Physiology, Department of Botany and Plant Sciences, University of California, Riverside
Guy Witney, CAC Production Research Program Manager

SUMMARY:

Nitrogen (N) is one of 17 essential mineral nutrient elements required by avocado trees and all other plants. If deficient, tree growth, leaf expansion, fruit set and fruit size are reduced. In spite of nearly four decades of research, the management of N in avocado groves is poorly understood and recommendations vary widely. So what do we know? We know that nitrogen deficient avocado trees respond rapidly to applied N. Generally, the response is in the form of increased yield as well as shoot growth. However, if too much N is supplied, the trees may invest disproportionately in shoots and wood at the expense of fruit and so production may decline. Also, excessive N can result in poor postharvest quality and advanced ripening (Arpaia et al., 1996).

Using available crop nutrient removal data, and estimates of the amount of N lost through leaching and other natural processes, it is estimated that approximately 90 lbs. of N/acre are required each year to produce 11,000 lbs.

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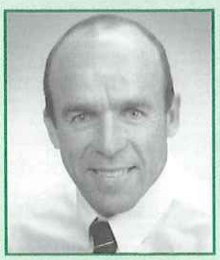
RESEARCH UPDATE

- **Dr. David Crowley (UC Riverside) recently set out a comprehensive trial at the Stehly Ranch near Valley Center, CA, to examine the effect of saline irrigation water on Hass grafted to 11 different rootstocks. In the future, we hope to identify salt tolerant rootstocks for California orchards through this research.**
- **Dr. Mary Lu Arpaia (UC Riverside) has launched a collaborative research project with Jan Delyser and CAC's Merchandising team. They are showing exceptional early results from their retail quality study. In one market, for example, reduced product waste resulting from early recommendations will save an estimated $ 500,000 in shrinkage per year.**

Watch for meeting notices in the AvoGreensheet or log onto
www.avocado.org/growers
for more information.



From The Editor

Guy Witney, CAC Production Research Program Manager

In the current issue of AvoResearch we have concentrated on the nutrient elements most often discussed in grower circles, namely nitrogen and zinc. The California Avocado Commission (CAC), through our Production Research Program, has a considerable history of investment in research on these two nutrients and we continue to support a nitrogen field study with Dr. Carol Lovatt at UC Riverside. In this issue, researchers have summarized much of what we know about nitrogen and zinc in tree nutrition, as well as providing some information on iron nutrition for completeness.

As with past issues of AvoResearch, we have a pullout insert that can be pinned up or saved. In this issue it is on Avocado Sunblotch Viroid. While many in the grower community know of this threat to our trees, some of the information presented here is likely new to most. Dr. Allan Dodds at UC Riverside is conducting ongoing research into this disease and he provides a great summary of what we now know. Please contact Allan if you feel you are able to help in the program (see details in the insert).

Lastly, Reuben Hofshi, Chair of the Production Research Committee, visits one of the centers of origin of the avocado: Mexico. In this article he extols the advantages of growing 'Hass' avocados in an almost ideal environment and challenges the California industry to use research to take advantage of the great genetic potential of the crop.

In This Issue

- Nitrogen fertilization of the 'Hass' avocado in California
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- Recognizing avocado sunblotch disease
- Hass cultivation in Mexico

California Avocado Commission

NITROGEN FERTILIZATION

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of avocado fruit (110 trees/acre, each producing 100 lbs. fruit). The recommended leaf N concentration for avocados is 2.2% (dry weight).

In Southern California orchards, N can come from several sources. While we often think of fertilizers as being the primary source of N for trees, there are often significant amounts of N in orchard irrigation water as well as inherent in some soils. For example, some well waters in the Corona foothills of Riverside County have sufficient N to meet the total demand of avocado trees (M. Arpaia, personal communication). Often overlooked, too, is the contribution of air pollution to the N supply. In the inland valleys with poor air quality as much as 30 lbs. of N/acre are contributed from particulates falling from the air (M. Yates, personal communication). Mulches are becoming a common site in many California avocado orchards and will also add N. It is a good idea to have the carbon/nitrogen ratio of your mulch analyzed and adjust your fertilization program accordingly. It is important for growers to test their irrigation water and soil for available N, as well as do routine leaf analysis to determine tree N status. Using this information, the amount of N needed to be supplied as fertilizer can be estimated.

We don't yet have a good understanding of the best time to apply N. In experiments where extra N was supplied to the tree during times when trees are thought to have increased demand (around mid-November and again in mid-April), yield and fruit size was significantly increased. However, this work needs to be repeated over several years and locations to gain confidence in recommending this practice. Currently, the best recommendation is to apply N in several small doses starting in February and ending in November. This supplies the tree through periods of demand while minimizing losses through leaching during winter rainstorms or heavy irrigation (Yates et al., 1993).

Nitrogen deficiency results in pale colored leaves, short leaf life, sparse foliage and reduced fruit yield.

To increase the efficiency of applied N and to supply trees during periods of anticipated demand, some work has been done with foliar (leaf applied) sprays. When foliar urea was applied to the spring flush leaves (2/3 fully-expanded), there was a significant increase in leaf N content. In experiments applying urea to the canopy when inflorescences are at the cauliflower stage, there was an increase in yield and fruit size distribution over the control.

Read on if you would like to know more detail on N in the tree, past research and future directions!

THE DETAILS:

Why do avocado trees need nitrogen fertilizer?

N fertilizer applied to avocado trees is predominantly used to synthesize protein. Other N-containing molecules include nitrate, ammonia, free amino acid precursors needed for protein synthesis, DNA and RNA, and nucleotides, the nitrogenous precursors of DNA and RNA synthesis. Since N is utilized in the synthesis of DNA, RNA and protein, which are essential for growth, and for the synthesis of hormones that direct cell division (cytokinins) and cell expansion (auxins), growing tissues are affected by N deficiency before existing tissues. Tree growth, leaf expansion, fruit set and fruit size are reduced by a lack of available N. Classic symptoms of N deficiency are pale green leaves and fruit, small leaves and fruit, low yields, reduced tree vigor, and when acute, chlorosis (yellowing) of leaf veins.

When nitrogen is applied as fertilizer, where does it go in the tree?

Avocado fruit are not "nutrient cheap." Research done in California, Australia and New Zealand has shown that avocado fruit are a major sink for N. Avocado fruit have the highest protein concentration of commercially produced fruit, including deciduous, subtropical or tropical tree crops (Hall et al., 1980). Whereas other fruit average 0.8% protein on a fresh weight basis (FAO, 1970), avocados routinely exceed 2.3% protein per unit fresh weight (Pearson, 1975; Slater et al., 1975; Hall et al., 1980).

Research in California has shown fruit N concentrations to be between 0.8% and 1.8% on a dry weight basis. Interestingly, fruit N content, like leaf N content, was independent of crop load and N fertilization rate. There is also a significant amount of N stored in the foliage and small branches of avocado trees. We (Lovatt, 1998) dissected an 8-year-old 'Hass' avocado tree on Duke 7 rootstock, which was bearing 148 lbs. fruit. The total N content of the fruit equaled 0.65 lb. Small branches with a total fresh weight of 144 lbs. stored 0.76 lb. N. Leaves and new shoots, which weighed only 55.5 lbs. total, contained 0.44 lb. N. Scaffolding branches, total fresh weight 155 lbs., had 0.33 lb. N. Other parts of the tree (trunk, roots) contained negligible amounts of N.

How much nitrogen fertilizer does a tree need each year?

"Crop nutrient removal" is a method used to calculate the amount of a nutrient taken out of the orchard by the harvested fruit in order to calculate the amount that must be replaced through fertilization to sustain yield. Fertilization rates based on nutrient removal are much improved by also knowing the amount of nutrient required to support annual vegetative growth, the amount of nutrient lost due to abscission of flowers, fruit and leaves, and fertilizer losses due to leaching, volatilization, and microbial action.

Research in Australia provided evidence that an additional 84% more N than that contained by the fruit was required to replace the N lost in fallen leaves and shed flowers and to compensate for N leaching, erosion and fixation (Dirou and Huett, 2001). N requirements for woody tissue and root growth were unknown. Thus, in Australia to produce 10 metric tons fruit/ha/year, a crop replacement rate of 70 kg. N/ha/year is required. This is equivalent to a N fertilization rate of 62 lbs./acre to produce 10,000 lbs. fruit/acre.

Data from California (Lovatt, 1998) was used to calculate an estimated N replacement value for a 'Hass' avocado orchard in California. Estimating a 10% loss in leaves each spring, there would be an approximate loss of 0.04 lb. N per tree annually. A 10% increase in vegetative shoot growth, root growth, and storage of N in branches would require 0.15 lb. N per tree. A yield of 100 lbs. fruit per tree would remove 0.43 lb. N at harvest. The amount of N lost due to abscission of reproductive structures during bloom and early fruit set is unknown. Using these values and a planting density of 110 trees per acre, the calculated annual replacement rate for N fertilization would be 68.2 lbs. N/acre in California. Estimating a 30% loss in N fertilization due to leaching, volatilization, and fixation would require another 20.5 lbs. N/acre. Thus, 88.7 lbs. N/acre would be required each year to produce 11,000 lbs. of avocado fruit per acre. Coincidentally, average yield for the 'Hass' avocado in California has been 5,700 lbs./acre for the last 25 years (Arpaia, 1998). In addition, corresponding replacement fertilization for P, K, Ca, Mg and possibly other nutrients would be required annually to maintain the proper balance in the tree's nutritional status.

When using fertilization replacement values, it is equally important to calculate the amount of N and other nutrients provided in the irrigation water, soil and organic matter. In addition, efforts should be made to reduce the amount of N, and other nutrients, that must be applied by reducing leaching, volatilization, and fixation. Soil and leaf analysis should be performed annually.

We are in the process of experimentally determining replacement values for other nutrients as well as improving the values we have for N. Our goal is to provide monthly, phenology-based, fertilizer replacement values for developing fruit, vegetative growth and N storage. In the interim, values presented here, while preliminary, are instructive.

Excess nitrogen may cause excessive vegetative growth at the expense of fruit.

When should nitrogen fertilizer be applied?

Whereas there are theories on "right" and "wrong" times to fertilize avocado trees, research quantifying the relationship between critical periods of tree phenology and the effect of application time and amount of fertilizer applied at specific times is still limited.

Embleton et al. (1968) conducted the first research on N fertilization of the 'Hass' avocado in California. In a five-year experiment they demonstrated that 'Hass' avocado trees had the highest mean yield at the highest annual rate of applied N (4.0 lbs./tree). Mean leaf N concentration was 2.13% for this treatment. Despite the fact that different rates of N fertilization resulted in significant differences in leaf N concentrations, there was no correlation with yield within a given year. Very similar results were obtained by Yates et al. (1993), who found that leaf N levels correlated well with the amount of N applied (0.8 lb. and 1.6 lbs. N/tree/yr.), but not yield.

In a seven-year study initiated with six-year-old 'Hass' avocado trees (Embleton and Jones, 1972), four different annual rates of N from 0.2 to 4.0 lbs. per tree were applied by splitting the total N in July and November or in February, July, and November. No treatment affected yield. The results suggested that 'Hass' avocado yields were insensitive to N fertilization rates, time of application, and leaf N concentrations in the range between 1.75% and 2.12%.

Lovatt (2001) recently completed a four-year experiment that addressed the question of whether yield of 'Hass' avocado could be increased by doubling the amount of N currently applied

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NITROGEN FERTILIZATION

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during specific stages of the tree growth cycles "phenology." Many California growers divide the total annual amount of soil-applied N fertilizer into small applications made during the period from late January to early November to protect groundwater from potential nitrate pollution. While research has shown that splitting nitrogen into several small doses will in fact reduce the potential for groundwater contamination by nitrates (Yates et al., 1993), there has been concern that the amount of N in the individual applications may be too little to meet the demand of the tree at specific stages of its phenology.

The control in this experiment was the practice of annually applying N as NH_4NO_3 (ammonium nitrate) at 150 lbs./acre in six small doses of N at 25 lbs./acre in January, February, April, June, July, and November. From these six application times, five were selected on the basis of tree phenology and additional N as NH_4NO_3 at 25 lbs. N/acre was applied at each time for total annual N of 175 lbs./acre. Two phenological stages were identified for which N application at 50 lbs./acre in a single application (double dose of N) significantly increased the four-year cumulative yield (lb. fruit/tree) 30% and 39%, respectively, compared to control trees *($P \leq 0.01$)*. In each case, more than 70% of the net increase in yield was commercially valuable large size fruit (packing carton sizes 60, 48 and 40). The two phenological stages were: (i) when shoot apical buds have four or more secondary axis inflorescence meristems present (around mid-November); and (ii) anthesis-early fruit set and initiation of the vegetative shoot flush at the apex of indeterminate floral shoots (approx. mid-April). When the double dose of N was applied at either of these two stages, the total pounds and number of large size fruit averaged across the four years of the study was significantly greater than the control trees *($P \leq 0.01$)*. Application of the double dose of N in April significantly reduced the severity of alternate bearing *($P \leq 0.05$)*. In this experiment, yield was not significantly correlated with leaf N concentration.

The results of the study suggested that time and rate of N application are factors that can be optimized to increase yield, fruit size, and annual cropping of 'Hass' avocado. The best treatments in this study and additional treatments are being tested in a second orchard. Several years of research in multiple orchards are necessary to learn under what climate and orchard conditions these results can be achieved with reliability before a University of California recommendation can be made. The results of the second experiment will contribute to this goal.

> *"Nitrogen fertilization provides a relatively inexpensive tool that can be used to manage tree vigor, optimize fruit set and size, and reduce alternate bearing."*

Why isn't yield correlated with the leaf nitrogen status of 'Hass' avocado orchards in California?

The N fertilization experiments of Embleton et al. (1968), Embleton and Jones (1972), Yates et al. (1993), and Lovatt (2001) were all conducted in alternate bearing orchards. Any treatment that affected yield altered the degree of alternate bearing of the trees. The amount of vegetative growth the tree produced and the amount of stored N the tree used or conserved was also affected. Both the large pool of stored N in avocado branches, and the variation in vegetative shoot growth in relation to yield, buffer the effects of yield on leaf N concentration. Thus, it is not unexpected that yield is not related to leaf N concentration. If your orchard bears unevenly, as most do, it will be difficult to obtain a good correlation between leaf N and yield.

In early fertilization trials when the optimum levels for many nutrients were not known, Embleton et al. (1968), suggested an alternate reason for N leaf content not correlating with yield. That is, in some cases another nutrient may have been in low supply and thus limiting production in spite of adequate available N.

Can nitrogen be supplied to 'Hass' avocado trees in California through the foliage?

It is clear that N uptake is more efficient at some times of the year than others. In California avocado flowering and fruit set are periods of high nutrient demand that frequently occur when soil temperatures are low. Low soil temperature reduces root metabolic activity, solubility of nutrients in the soil solution, and nutrient uptake and transport in the transpiration stream. Foliar fertilization can meet the tree's demand for a nutrient at times when soil conditions may render soil-applied fertilizers less efficient. For foliar fertilization to be successful, the nutrient must be taken up by leaves of the crop, or other target organs, and be phloem mobile. Mature leaves of the 'Hass' avocado growing in California are very inefficient in taking up N (Nevin et al. 1990). However, inflorescences and young spring-flush leaves do respond to foliar-applied low-biuret urea.

In a three-year experiment, low-biuret urea was applied to the canopy of 'Hass' avocado trees (0.35 lb. N/tree) in a commercial orchard during the "cauliflower stage" of avocado inflorescence development (Jaganath and Lovatt, 1998). All trees had optimum nutrient levels based on annual September leaf analysis. The "cauliflower stage" is characterized by elongation of the secondary axes of the inflorescence and late stages of pollen and ovule development within the flowers (Salazar-Garcia et al., 1998). Urea applied at this time significantly increased the number of viable ovules and number of pollen tubes that successfully reached the ovule and increased cumulative yield *($P \leq 0.05$)* (Jaganath and Lovatt, 1998). Foliar-applied urea resulted in a net increase in cumulative (three years) yield over the control of 4.4 tons/acre. The increased cumulative yield was accompanied by an increase in the

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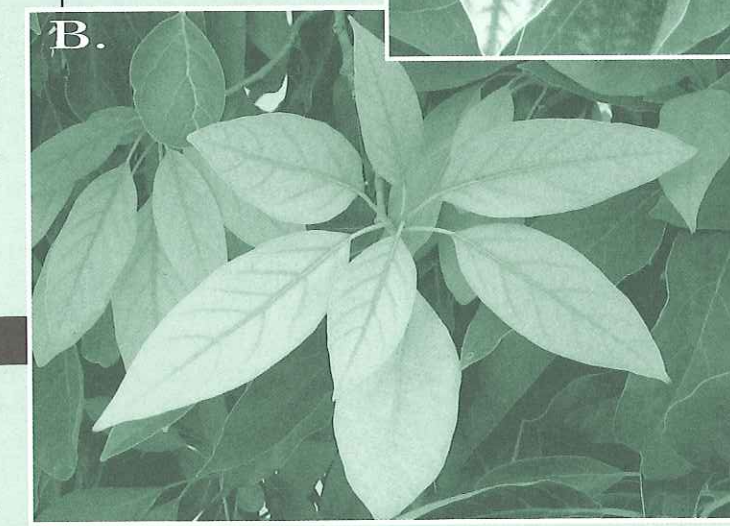
TRACE METAL NUTRITION OF AVOCADO

David E. Crowley[1], Woody Smith[1], Ben Faber[2], Mary Lu Arpaia[3]
[1]Dept. of Environmental Science, University of California, Riverside, CA
[2]UC Cooperative Extension, Ventura County, CA
[3]UC Kearney Agricultural Center, Parlier, CA

A. Zinc deficiency
Typical leaf zinc deficiency symptoms. Note the chlorosis (yellowing) between veins and the reduced leaf size (top).



B. Iron deficiency
Iron deficiency symptoms on new growth. Iron deficiency and zinc deficiency are easily confused.

SUMMARY

It is easy to confuse zinc and iron deficiency symptoms, so growers should rely on annual leaf analysis. Also, it is essential for avocado growers to know their soil pH, and soil iron and zinc levels before embarking on a fertilization program. For zinc, best results are with soil application through fertigation or banding, and there is no apparent advantage to using chelated zinc. For iron fertilization, the best solution is to use soil applied Sequestrene 138, an iron chelate. It is highly stable and can last for several years recycling many times to deliver more iron to the roots. It is important not to mix trace metal fertilizers with phosphorus fertilizers.

INTRODUCTION

Avocados require many different nutrients for growth that include both macro and micronutrients. Macronutrients such as nitrogen, potassium and phosphorus are generally provided as fertilizers. Micronutrients are those nutrients that are essential for plant growth and reproduction, but are only required at very low concentrations. Most micronutrients, or trace elements, are involved as constituents of enzyme molecules and other organic structures. Zinc and iron are important trace elements required for plant health. Zinc is an important component of a number of key metabolic enzymes as well as influencing protein synthesis, carbohydrate and auxin metabolism and membrane integrity. Iron plays a key role in the process of respiration and the manufacture of chlorophyll for photosynthesis.

Most trace elements are normally available in soil in sufficient quantities. When trace element deficiencies do occur, it is usually the result of chemical conditions in the soil that make metal elements insoluble and unavailable to the plant. This is especially true with zinc and iron that have very limited solubility at pH 6 or above. Trace metal deficiencies may also be caused by certain chemical reactions that occur in soils containing lime or that are irrigated with water containing high amounts of bicarbonate. Poor soil drainage and root disease can also be contributing factors that will limit the growth of feeder roots that are responsible for metal uptake. An understanding of which factors are causing a trace metal deficiency can be helpful in determining the best method to correct the problem, and whether or not the trees should be treated with a trace metal fertilizer.

Very often trace metal deficiencies are indicated by the appearance of leaf yellowing or, in the case of zinc, by the development of small round fruit. The first step in treating trace metal deficiencies is to determine exactly which metal micronutrients are limiting since both iron and zinc deficiencies can cause similar foliar symptoms. Although zinc deficiency is often considered to be the most common trace metal deficiency in Southern California, iron deficiencies are actually much more common. In both cases, the leaves show chlorosis (yellowing) that is caused by problems with chlorophyll synthesis ***(Figures A and B)***. Another possibility is that trees showing leaf chlorosis may simultaneously have both zinc and iron deficiencies, in which case both problems need to be corrected at the same time. For zinc, normal leaf levels should range between 20 to 40 ppm. Leaf deficiency symptoms will occur when the foliar zinc concentrations fall below 15 - 20 ppm. Iron deficiencies on the other hand occur at leaf concentrations below 35 - 50 ppm, although in some cases trees may show iron deficiency symptoms at much higher leaf concentrations. This latter problem is due to the uptake of bicarbonate from the irrigation water, which inactivates the transport of iron in the leaf tissue. In addition to problems caused by irrigation water, bicarbonate ions can also be produced in the soil when calcium carbonate (lime) dissolves and generates HCO_3^- ions. In situations where soils contain high levels of lime, it may be nearly impossible to correct trace metal deficiencies since the problem is not due to metal availability, but is instead a physiological problem in the plant tissue (Crowley and

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TRACE METAL NUTRITION

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Smith 1996). Fortunately, this problem usually occurs only in "hotspots" in the orchard, which attract attention but are not indicative of conditions throughout the orchard. In some cases, iron deficiency symptoms may even occur on one side of a tree but not on the other, which is due to root growth into lime pockets in the soil.

METHODS FOR CORRECTION OF TRACE METAL DEFICIENCIES

Under normal conditions, avocado trees will use naturally occurring organic matter-metal complexes that will solubilize zinc and iron and other metals and hold them in a form that can be taken up by the roots. These naturally occurring metal complexes are very effective in low pH soils. However, in situations where avocados do not obtain sufficient quantities of metals by natural processes, or where absolute quantities of the metals are limiting, such as in sandy soils, a variety of methods have been developed to correct trace metal deficiencies. These methods include foliar applications of zinc sulfate and zinc chelates (Goodall et al., 1979), trunk injections of trace metals (Whiley et al., 1991), or soil applications of zinc and iron fertilizers (Wallihan et al., 1958). When trace metal fertilizers are applied to the soil, they can be applied as metal chelates or as various metal salts such as zinc sulfate, zinc oxide, iron sulfate, and iron chloride. All of these materials can be applied directly to the soil or may be injected into the irrigation water. In general, chelated metal fertilizers are more expensive than metal salts but can be used in smaller quantities since they retain their solubility after they are added to soils. In contrast, inorganic metal salts will remain in solution only for a short time and will then precipitate into soil minerals that are no longer available to the tree. Metal chelate fertilizers can include many different chemicals that are usually referred to by their abbreviated names and include EDTA (ethylene-diamine-tetra-acetic acid), DTPA (diethylene-triamine-pentaacetic acid), or EDDHA (ethylene-diaminedi (o-hydroxyphenylacetic acid). All of these materials are water soluble, but it is important to choose the right one since they have different abilities to form stable metal complexes depending on the soil pH. For example, EDTA prefers to chelate calcium rather than iron or zinc at neutral to alkaline pH (pH > 7.0). In higher pH soils, iron and zinc chelated with EDTA will eventually be displaced by calcium and the metal ions will no longer be available to the tree. On the other hand, the metal chelator DTPA is relatively stable with zinc at high pH and may also be used to supply copper and iron. For iron fertilization, the best chemical is EDDHA (Sequestrene 138). This metal chelator is highly stable and can last for several years in the soil since it recycles many times to dissolve more iron in the soil and deliver it to the roots. The applied amount of a trace metal fertilizer depends on the type of fertilizer material as well as the severity of the deficiency. Chelates are generally provided in amounts of 1.4 to 1.8 oz. per tree, although in some cases much higher quantities may be required if the trees are located on a calcareous soil or a lime "hotspot."

With metal salts such as zinc sulfate or zinc oxide, it is much easier to apply too much fertilizer, as these materials are relatively inexpensive and have traditionally been recommended in excessive quantities. Available zinc is measured as the amount that can be extracted using DTPA under standardized laboratory test conditions, and represents only a fraction of the total zinc that is present in the soil. Embelton and Wallihan (1966) recommended the use of zinc sulfate at a rate of 7 lbs. per mature tree. This application was to be repeated every three years. However, if the standard recommendation is followed, the total zinc levels in the soil are instantly elevated to greater than 150 ppm under the tree after a single application of the fertilizer. These levels will quickly decline as the fertilizer precipitates out as new soil minerals, but will still maintain a very high level for one or two years. In contrast to the 150-ppm levels reached after fertilization, most plants have been found to require only 0.5 to 1 ppm of DTPA extractable zinc for normal growth (Soil Testing Plant Analysis Handbook, 1990) and plants such as peanut may even be poisoned when zinc concentrations exceed 36 ppm (Borkert et al., 1998). After reviewing soil analysis reports from commercial labs that were generated for avocado orchards in San Diego County, we found that many avocado orchards now contain DTPA extractable zinc concentrations that range between 100 to 200 ppm, or more than 100 times the normal levels that are needed by plants. Not only is this excessive, but if more zinc is applied, it may eventually accumulate to levels that exceed the legally allowable quantities for soil contamination under U.S. EPA regulations (presently 2800 ppm in U.S., 200 ppm in Europe). There is also the possibility that avocado tree roots might be temporarily damaged by excessive fertilization, although this has not yet been investigated. Growers should, therefore, augment their annual leaf analysis for zinc with soil analysis to minimize an excessive build-up of zinc in the soil.

FIELD EVALUATION OF FOLIAR AND SOIL APPLIED FERTILIZERS

To evaluate the currently recommended methods of zinc fertilization and better determine how much zinc is needed, we conducted a three-year experiment in Ventura County to compare different zinc formulations and application methods (Crowley et al., 1996). Results of these experiments showed that for soil applied fertilizers, zinc sulfate was the most effective while zinc chelates were the least effective and most expensive. Trees fertilized with the zinc chelates at the manufacturer's recommended rate were no different than unfertilized control trees. In comparison, zinc sulfate (7 lbs. $ZnSO_4$ 36% per tree) applied either as a quarterly simulated irrigation or annually as a single soil application, increased foliar zinc contents to 75 and 90 ppm, respectively. However, as reviewed above, this concentration is excessive and much lower quantities could probably be used to adjust the leaf tissue contents to levels between 20 and 40 ppm. In this experiment, we also examined foliar applications of zinc sulfate or zinc oxide and an organic complexed zinc fertilizer, zinc metalosate. In general, all the foliar applied materials appeared to be effective based strictly on foliar tissue analysis. However, with foliar applied fertilizers there is considerable difficulty in determining how much of the zinc actually penetrates the leaf tissue versus how much remains on the leaf surface where it can be detected by tissue analysis but is of no use to the plant. In our study, this problem was particularly evident with zinc oxide, which was easily washed from the leaf surface using a diluted hydrochloric acid. Previous research also has shown that there may be problems with translocation of foliar applied zinc (Kadman and Lahav 1978). If this is true, then when the tree is sprayed, the leaves that come into direct contact with the spray may have sufficient zinc, but the rest of the canopy as well as roots and fruit may still have deficiencies that could affect their growth and physiology.

To further investigate this question, we carried out experiments similar to those that were conducted in Israel by Kadman and Lahav (1978), in which radioactive zinc was used as a tracer to follow zinc uptake and translocation. In our research, zinc was applied as a 1-cm spot to either the top or bottom of newly expanded leaves. Using photographic film and another method (liquid scintillation counting) to quantify the movement of the radioactive zinc, we showed that virtually all of the applied zinc sulfate remained in the spot where it was applied and that only a small amount (around 5%) moved out into the leaves above and below the treated leaf (Crowley et al., 1996). Similar results were obtained with both zinc metalosate and zinc EDTA. We also examined a number of surfactants with a range of chemical properties to determine if these materials would increase leaf zinc penetration. In general, surfactants were beneficial for spreading the zinc over the leaf surface, but resulted in only a small increase in uptake. Altogether, our results suggest that all of the tested materials are only effective in treating the outer leaf canopy that comes in direct contact with the foliar spray and are probably of little benefit to the rest of the tree.

RECOMMENDATIONS

Leaf tissue analysis provide the most valuable tool for diagnosing trace metal deficiencies. It may be worthwhile to test different areas in the orchard before deciding to treat the entire orchard with a fertilizer. Many groves located on calcareous soils may contain "hot spots" where trees will show iron and zinc deficiencies that are not easily corrected using fertilizers or foliar applications. If there are only a few affected trees, it may be best to either spot treat these trees, or accept the fact that these trees will have metal deficiencies.

An orchard that is producing 10,000 lbs. of fruit per acre will remove 220 grams (~ 1/2 lb.) of actual zinc per acre per year. At the present time, zinc fertilizers tend to be excessively used. For example, it is a common practice in San Diego County to apply 6 lbs. of zinc sulfate (36%) every five years to mature trees. This is equal to 47 pounds of actual zinc per acre per year or nearly 100 times more than that which is removed. Consequently, many avocado orchard soils are probably being over-fertilized. If leaf tissue analysis reveal that zinc deficiencies are occurring in the orchard, the grower should keep good records to monitor how the orchard has responded to the zinc fertilizer and thereby determine the amounts that should be applied annually as a standard maintenance program. The exact response to zinc or iron fertilizer will vary from orchard to orchard depending on the soil pH, organic matter levels, soil texture, and salinity. Although zinc fertilizers have traditionally been applied during the winter months when no other fertilizers are applied, our research clearly shows that soil applied fertilizers are taken up best during the period of new root growth in the spring and early summer.

If fertilization is necessary, a good starting level is 3.5 ounces of actual zinc per tree. Many growers apply liquid zinc sulfate in one or two applications per year at a rate between 7 to 30 gallons per acre per year. The recommended rate given above(3.5 oz./tree) translates to 17 gallons of liquid Zn sulfate (12% Zn) per acre for orchards planted at a density of 110 trees per acre. Following application of the fertilizer in the spring, leaf analysis should be taken in the period between late August and early September. The amount of fertilizer to apply the following spring can then be adjusted according to the tree response that was obtained the previous year. In our experience, trees that contain greater than 50 ppm Zn will show little or no response to additional fertilizer even when it is applied in high quantities.

Commercially formulated liquid zinc sulfate fertilizers are sold by the gallon and contain 12% zinc by weight. The liquid is kept at pH 4 - 5 to keep it in solution and to permit better availability to the trees. In addition to the premixed liquid fertilizers, liquid zinc fertilizers also can be prepared using the powder form of zinc sulfate, which is very soluble. However, this material is exothermic and can be mixed in small amounts only. Solid zinc sulfate is 36% zinc by weight and has low solubility in its granular form. This is the reason it is used for soil banding.

A variety of methods can be used to apply the fertilizers. Banding fertilizers are effective for spot treating areas in the orchard, but are also expensive since they must be hand applied. There is also a greater tendency to apply excessive quantities that result in very high immediate concentrations that diminish over the next five to six years as the zinc or iron precipitates into insoluble minerals that cannot be extracted by the DTPA soil test. Although not yet tested, there is concern that very high levels of zinc that occur in the soil immediately after banding may be inhibitory to root growth. Repeated soil application treatments may also lead to accumulation of total zinc to hazardous levels. Thus, the best way to apply zinc and obtain the greatest fertilizer use efficiency is to apply it in smaller amounts at more frequent intervals. This can be accomplished by injecting the trace metal fertilizer into the irrigation water. However, if fertigation is used, zinc and iron fertilizers should never be mixed with phosphorus fertilizers as this will result in precipitation of

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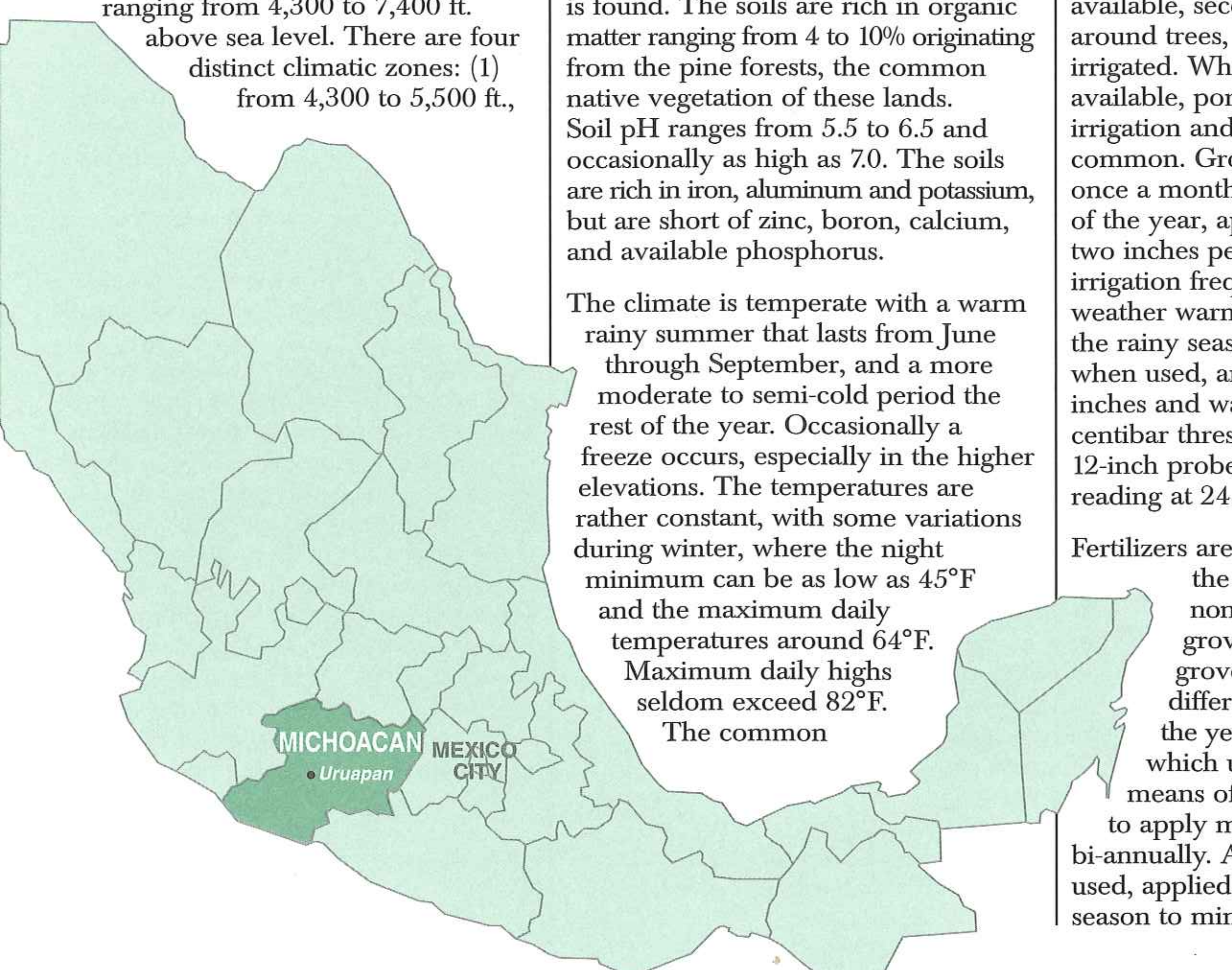
HASS CULTIVATION IN MEXICO

Reuben Hofshi, Chair,
Production Research
Committee CAC

Mexico is the world's largest producer of Hass avocados. It produces over 65% of the world's Hass avocados with an average yearly production exceeding 1.5 billion lbs. It is the dominant player in many global markets when its avocados are in season. Mexico has an increasing presence in the U.S. market with further expansion being contemplated by the U.S. government. Most of the Mexican Hass avocados are grown in the state of Michoacan in west-central Mexico. Although other states in Mexico grow the Hass variety, the oldest groves, dating back to 1961, are located near the city of Uruapan. Michoacan is the only state in Mexico permitted to export Hass avocado into the U.S.

Michoacan accounts for 82% of the total acreage planted to avocados in Mexico and for 84% of its production. Currently there are close to 190,000 acres of avocados in Michoacan with 95% or 180,500 acres planted to Hass. Hass avocados are grown at elevations ranging from 4,300 to 7,400 ft. above sea level. There are four distinct climatic zones: (1) from 4,300 to 5,500 ft., (2) from 5,500 to 5,800 ft., (3) from 5,800 to 6,500 ft., and (4) from 6,500 to 7,400 ft. Thirty percent of the Hass planting is in zone one, 40% is in zone two and three, and the remaining 30% is in zone four. Different temperatures, humidity, average fruit production and of course different maturity periods distinguish these zones. The occurrences of a variety of pests and diseases are also delineated by these zones. Average production in well-maintained groves is the highest in zone one, at 26,700 lbs. per acre and the lowest at 13,000 to 16,000 lbs. per acre in zone four.



There are several soil types in the production zones. These soils are classified as Andosoils, which are mostly volcanic in origin, ranging from volcanic ash to coarser volcanic soil. Some areas have heavier soils that contain varying levels of clay. It is in these soils where limited manifestation of root rot (*Phytophthora cinnamomi*) is found. The soils are rich in organic matter ranging from 4 to 10% originating from the pine forests, the common native vegetation of these lands. Soil pH ranges from 5.5 to 6.5 and occasionally as high as 7.0. The soils are rich in iron, aluminum and potassium, but are short of zinc, boron, calcium, and available phosphorus.

The climate is temperate with a warm rainy summer that lasts from June through September, and a more moderate to semi-cold period the rest of the year. Occasionally a freeze occurs, especially in the higher elevations. The temperatures are rather constant, with some variations during winter, where the night minimum can be as low as 45°F and the maximum daily temperatures around 64°F. Maximum daily highs seldom exceed 82°F. The common relative humidity ranges between 75-80% year round, with occasional dipping to as low as 60%. Rainfall is between 40-70 inches per year. There are over 1,000 light hours per year available for photosynthesis.

Over 80% of all groves have some type of supplemental irrigation during the dry months, while the rest of the groves depend solely on rainwater during the wet season. In some cases, there is no water available for irrigation. It is the moisture holding capacity of the deep volcanic soils, coupled with the high air humidity and mild temperatures that keep the non-irrigated groves viable. The trees, under most circumstances, show no sign of tip burn on their leaves. Where water is available, it is of very high quality containing insignificant amounts of salts. In some areas, water is actually trucked to groves and basins around individual trees are filled with water. Where unpressurized canal water is available, secondary canals fill basins around trees, or the groves are flood irrigated. Where pressurized water is available, portable rainbirds, drip irrigation and micro-sprinklers are common. Growers tend to irrigate once a month in the cool, early part of the year, applying approximately two inches per irrigation period. The irrigation frequency is increased as the weather warms until the beginning of the rainy season in June. Tensiometers, when used, are placed at 12 and 24 inches and water is applied when a 20 centibar threshold is reached on the 12-inch probe and even at a lower reading at 24 inches.

Fertilizers are applied manually during the rainy season in the non-irrigated or flood-irrigated groves. Sprinkler-irrigated groves are often fertigated at different intervals throughout the year. One common practice, which used to be the only means of fertilizing in the past, is to apply manure either yearly or bi-annually. All types of manure are used, applied just prior to the rainy season to minimize salt damage, in a wide band along the drip line. The quantity applied is equivalent to 110 lbs. per year. Some growers apply compost made of 30% manure, 30% straw or spent sugar cane, 30% topsoil, a small amount of calcium carbonate (lime) and ordinary or triple super-phosphate. Phosphate in the soils rapidly becomes unavailable by forming insoluble compounds such as iron, aluminum and calcium phosphates. The addition of large amounts of phosphates, (4.4 lbs./year), not as part of a compost mix, is likely to create problems for the growers in the long run. Nitrogen, in the form of ammonium nitrate or urea, is applied at the rate of 4.4 lbs. of actual N per tree per year. Potassium (2.2 lbs. per tree per year) is applied mainly as potassium chloride, which is inexpensive and highly soluble. About 1 lb. of granular zinc sulfate is also applied per tree once a year. In general however, trees do not appear to be excessively lush; leaves are smaller than in California, paler and with a more reduced leaf density.

Most commercial groves are monocultures of the Hass variety grafted on Mexican seedling rootstocks. Only occasionally does one encounter a native Mexican (criollo) variety or Fuerte trees in well-maintained commercial groves. In the suburban areas, where small groves are located, there is a higher incidence of native or other known varieties such as Nabal and Fuerte.

Farmers generally do not introduce honey bees to the groves for pollination purposes. In previous years hive placement in groves was more common, but with the Africanization of bee colonies, the honey bees became more aggressive to the point where farm workers were being stung repeatedly forcing the removal of the colonies. Currently, hives are being restocked by imported milder queens allowing the reintroduction of honey bee colonies in the avocado groves. The opinion of most is that the avocado flowers are pollinated by an assortment of wasps and other insects that visit the groves during bloom. Having little competition from wild flowers and other blooming trees, the avocado trees appear to be well visited and pollinated. Dr. Gad Ish-Am has been searching in Mexico and Guatemala for the natural pollinator of the avocado. He and his associates have identified several local species of stingless bees (*Apidae, Meliponinae*) and the Mexican Honey Wasp (*Brachygastra mellifica*) that were extensively visiting the avocado flowers. Studies conducted in Michoacan by Lucy Quiñones to investigate if Hass would set fruit in the absence of a pollinator vector indicated that there was no fruit set when the trees were caged and insects were excluded.

There are five distinct blooms and fruit set periods in most growing zones. In the lower elevations there is a more pronounced early fruit set. The first bloom, or off-bloom ("crazy flower" or "flor loca" in Spanish), occurs in September. The off-bloom fruit in the warmer zones are indistinguishable from regular fruit but are distinctly larger than the rest of the following fruit set. Only in the cooler areas is the off-bloom fruit round and smooth-skinned like California Hass off-bloom. The second bloom, which occurs in October, produces the "chancy" bloom ("venturera" in Spanish). Early bloom ("avancada" in Spanish) occurs in November. The regular bloom, which produces the majority of the fruit set, occurs in January and February and could be subject to freeze in the upper elevations. The late bloom, particularly in the upper elevations, occurs in March ("Marceña" in Spanish). In elevations lower than 5,500 ft. off-bloom fruit could reach maturity in June; in the cooler zones during August. (Dry matter standards are the same as in California.) Lower elevation groves are picked by the end of May, while the highest groves can pick their late bloom fruit as late as August. Some of the mature fruit from all zones are very similar in appearance to fruit from Santa Barbara County where mild webbing on the avocado peel is noticeable. The webbing and deformities are caused by thrips. The majority of the Hass avocados are indistinguishable in appearance from Hass fruit harvested anywhere in the world and with fine flavor. The notion that Mexico is 'out' of Hass avocados in certain months of the year is erroneous. In Michoacan there are normally plenty of Hass avocados 365 days of the year. As in any other growing area, Mexico has a peak production period that lasts from August through April, with a significant decline in May through July.

A variety of pests and diseases are encountered in Michoacan. Brown mite is a problem that appears to be more pronounced in dusty areas. Good predator activity keeps things in balance, but pesticides applications are recommended for more severely infested groves. The pests that can significantly affect productivity are a variety of thrips (*Frankliniella, Scirtothrips aceri, Liothrips perseae* and *Scirtothrips perseae*). The thrips attack young leaves, flowers and young fruit and can cause drop and malformation and severe scarring of the fruit. Certain weeds are hosts for the thrips when conditions on the avocado trees are not favorable. During bloom, vegetative growth and fruit formation, one of several insecticides is recommended. Application schedules are at 10% of bloom, full bloom, at the end of the blooming period, and at the early fruiting stages. Persea mite (*Oligonychus perseae*) or white spider ("araña blanca," as it is called in Mexico), is gaining ground but appears to be more prevalent in warmer areas and in less healthy groves. The avocado seed weevil (*Conotrachelus perseae*) is said to be localized to certain warmer areas, below 5,500 ft. and mostly affects the local native varieties and other avocado varieties in poorly cared for groves. The insect lays its eggs on small to medium size fruit and the resulting larvae penetrate the fruit and work their way to the seed. The seed is the food source for the larvae, and often the seed is completely pulverized and destroyed. The infested fruit drops prematurely and the pupation stage takes place in the ground. The adult climbs the tree and feeds on leaves to complete the cycle, which occurs twice and sometimes three times a year with a life cycle of approximately 164 days. There has been a concerted effort to eradicate this pest. Dropped fruit in infested plots must be collected and burned and a variety of pesticides applied to both the trees and the ground are recommended. Infested fruit is seldom marketed since affected fruit tend to drop in early stages of development or its size is too small. The stem borer (*Copturus aguacatae*) is another devastating insect pest. The female bores small holes in terminal branches and lays one egg per hole. The emerging larvae bore tunnels along the interior of the branches in the beginning of pupation. Defoliation and

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breakage of affected branches with fruit can result. At times the stem borer may also lay eggs in the fruit. There are two annual generations of the adult borer, from early June to mid-September, and from late December until early March. The removal of affected branches, which are later burned, is the best method to interrupt the biological cycle. This practice is one of the requirements imposed on Michoacan farms that export fruit to the U.S. Pesticides are also used, mainly Malathion and metallic Parathion.

Many other pests and humidity-related diseases are present throughout the region. These range from Amorbia and Omnivorous Looper to whitefly in the insect realm. A range of chemicals is used for the various pests, from Malathion and metallic Parathion, to Omite and sulfur, to Dipel, Benlate, Zineb and others. Diseases and disorders include anthracnose, ring neck and several manifestations of *Fusarium.* Cankers caused by *Fusarium* and *Phytophthora* are found throughout the region, especially in high temperature and humidity zones and in poorly ventilated groves. The cankers are commonly scraped clean and a paste of Bordeaux and Benlate is applied. This is being replaced by some farmers with a technique of poking holes four inches apart all over the infected area and applying to them, without the need for scraping, the Bordeaux-Benlate mix. (This practice is similar to the hole drilling in trees for the application of phosphorous acid formulations. The tool is 5/8 inch in diameter, screwdriver-size pointed poke, which is driven in an angle and stopping at the wood.)

Avocado groves are found on a variety of terrain ranging from flat to moderately steep hillsides. The Hass trees, grafted on Mexican seedling rootstocks, are planted in different spacings, either in squares or hexagonally. The recommended initial planting distance is either 16 by 16 ft. eventually thinned to 32 by 32 ft., or 22 by 22 ft. which is later thinned to 44 by 44 ft.

The Hass trees, in comparison to their native counterparts, are not as large. The tallest trees in thinned and well managed groves reach the height of 40-50 ft. and cover a radius of at least 15 ft. Fruit set in the better groves is tremendous, and what is limiting, in many cases, is the ability of the branches to support the heavy weight of the fruit. Many of the large trees are supported with metal cables, often a quarter to half-inch thick, strung from one major branch to the next. A crop load of 880 to 1,100 lbs. of fruit per tree is common in these quality groves, even in the cooler areas. The trees appear to be at their maximum potential for production. In at least one grove that I visited in 1995, many trees seem to have a set closer to 2,000 pounds per tree. The owner stated that he picked 2,970 pounds from one Hass tree. Fruit size, even with the high production, is acceptable by any standard. The breakdown is: 10% large fruit, ranging from 9.35 to 12.9 ounces; 50%-60% medium fruit, ranging from 7.4 to 9.35 ounces; and 30% small fruit, ranging from 6 to 7.4 ounces. There are other sizes at both extremes, but they are of minimal quantities.

The fruit from tall trees is picked by workers operating cherry-pickers, while others climb the trees, without ladders, and pick into picking bags which, when full, are lowered to the ground with ropes. It is not unusual to see three or four pickers working one tree. Picking poles are constructed differently, and only fruit designated for export is carefully picked in a fashion and with tools similar to what is common in California. The picked avocados are placed into plastic boxes each containing roughly 40 lbs. They are then transported to local packinghouses for processing and shipping. Fruit destined to the U.S. is packed in specially-designated packing facilities following the protocals outlined by USDA-APHIS. The average cost of harvesting and hauling to the packinghouse amounts to 1.5 cents per lb., with a slightly higher rate for the fruit designated for export. Avocados for all markets are disinfected with a fungicide such as Thiabendazole, mainly to inhibit anthracnose. The avocados are graded and packed in wooden boxes for the local market, in 8.8 and 13.2 lbs. carton flats for export to Europe, and 25 lbs. lugs for export to the U.S. The Mexican market takes a mixture of sizes and grades in the same box, divided into small, medium, and large fruit.

Most of the fruit produced is sold in Mexico, where the demand is constantly increasing. There are over 85 million inhabitants in Mexico with a per capita avocado consumption rate that is the highest in the world, approaching 20 lbs. This market can absorb most of the Hass produced in Mexico, and could become a *de facto* importer of Hass which is the preferred variety by the Mexican consumer. Additionally, fruit with reasonable levels of oil content, not exceeding 25%, can end up processed by one of the several processors of pulp and guacamole. The market for processed products has increased rapidly in the last few years, and several retail outlets and fast food restaurants in the United States are purchasing large quantities of the products from Mexico. France and some Eastern European countries are also purchasing pulp and finished products. The Mexican product is made solely from Hass avocados, and over 100 million lbs. per year are being processed. There are several avocado oil processing plants in the area, but their business is limited mainly to the cosmetic industry.

To the student of avocado production a visit to "Hass Heaven" is an experience that confirms that very high production could be defined and attained. It is a challenge to observe and learn the mysteries of these native lands of the avocado.

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NITROGEN FERTILIZATION

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number of commercially valuable large size fruit (packing carton sizes 60, 48 and 40). Treatments were cost-effective. Note that due to increased formation of flowers with double pistils, urea should not be applied to orchards with leaf B concentrations >150 ppm.

Urea, as a foliar spray at the "cauliflower stage" of inflorescence development, requires good coverage of the developing inflorescences. Under Southern California conditions, leaves of the 'Hass' avocado do not take up urea at this stage of flower development because they are fully mature (Nevin et al., 1990). In contrast, application of low-biuret urea (22 lbs. N/acre) to spring flush leaves when they were 2/3 fully expanded significantly increased percent leaf N. Leaves at this stage of development have sufficiently thin cuticles and adequate surface area to take up urea effectively. However, it is not known yet if applying urea at this time has a positive effect on yield. These results taken together provide evidence that foliar-applied urea can efficiently meet the demand of the 'Hass' avocado tree for N and/or stimulate specific physiological processes resulting in increased yield and fruit size.

CONCLUSION:

Nitrogen fertilization provides a relatively inexpensive tool that can be used to manage tree vigor, optimize fruit set and size, and reduce alternate bearing. However, it must be emphasized that good stewardship of soil-applied fertilizer and a complete, balanced fertilization program are necessary to realize the potential benefits of N fertilization.

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Measuring fruit yield in one of Dr. Carol Lovatt's nitrogen fertilization field trials.

TRACE METAL NUTRITION OF AVOCADO

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zinc or iron phosphate in the irrigation line, that will cause plugging of the irrigation emitters. Foliar fertilizers can be applied to new leaf tissue, but so far they appear to have very limited efficacy as compared to other methods. In general, soil applications are preferred to foliar application since the trace metals can be absorbed by the roots and translocated throughout the tree and into the developing fruit.

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Editorial comments should be addressed to Guy Witney: **gwitney@avocado.org** or to the address below.

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