Book 2

Chapter 2

Avocado Fertilization

Author: Gary S. Bender

Avocado trees have relatively few mineral deficiencies in commercial orchards in California. The surface feeder roots seem to be very efficient at recycling nutrients from the decomposing leaf mulch under the trees. Generally, nitrogen should be applied to the trees on a yearly basis in order to maintain optimum production. Occasionally zinc and possibly other minor elements should be applied, and some research has indicated that additional phosphorus and potassium may be desirable for long-term improvement in yield on some soils. Recent research has indicated that avocados grown on highly acidic soils may benefit from additional calcium applied to the soil, and calcium has the additional benefit of helping roots to withstand infection by *Phytophthora cinnamomi,* the cause of avocado root rot. Leaf analysis is normally used to determine if trees are suffering from a mineral deficiency or excess, and the fertilizer program is adjusted accordingly. Starting in the 1970s, fertilizer application via liquid nutrient injection into the irrigation system has become increasingly popular, not only for the ease in application and reduction in labor costs, but also for the uniformity of application to each tree and within the root-zone of a given tree.

It should be remembered that there is no "magic bullet" fertilizer that will increase avocado production, unless that particular grove has a deficiency in a particular element. For instance, some growers believe that the more zinc applied to the grove the better, when in actuality high zinc levels could be just a waste of money, or at worst actually reduce yields. All nutrients should be within a relatively narrow range in the leaf analysis and in balance with each other.

Figure 1. Preparing a manure/horse shavings mix for fertilizing organic avocados.

A New Grower's Quick Guide

For the grower who has just purchased a grove and does not have a fertilizer program and/or does not have the leaf analysis from the previous year, a standard program used in farm advisor trials may serve until the next leaf analysis is taken. Experience has shown that Hass avocados generally require 1.5 – 2.0 lbs of actual nitrogen per tree per year. This amount of nitrogen is often divided and applied in six to nine monthly increments through the irrigation system during the growing season. The amount to apply each month is described below under "Application of Nitrogen through the Irrigation System".

For the grower who does not have a fertilizer injector on the irrigation system, the fertilizer must be hand-applied. A good hand-applied fertilizer schedule (used in some farm advisor trials) would be six pounds of triple 15 (15-15-15) applied per tree in late February or early March (equal to 0.90 lbs N/tree) followed by 3 pounds of calcium nitrate (15.5-0-0) per tree applied in June (equal to 0.47 lbs N/tree) and 3 pounds of calcium nitrate (15.5-0-0) per tree applied in September (equal to 0.47 lbs N/tree). Total nitrogen for the year would equal 1.83 lbs actual N per tree per year. Other types of fertilizers can be used successfully, including ammonium nitrate, calcium ammonium nitrate and urea, but this particular schedule was chosen to provide nitrogen, phosphorus and potassium during the early part of the bloom, and calcium nitrate was chosen to help counteract acid soils often occurring in groves on the typical decomposed granite soils found on hillsides in San Diego County. Urea is a more concentrated form of nitrogen (42% N), and is the cheapest form of granular nitrogen. Ammonium sulfate is generally not used as a fertilizer in avocado production because of its tendency to increase the acidity of the soil in the root-zone. This may not be a problem in alkaline (high pH) soils found in valleys in San Diego County and most soils in Ventura and Santa Barbara Counties, but it can be a problem in the acidic, decomposed granite soils on the hillsides.

Other fertilizers and fertilizer schedules can certainly be considered. A 21-7-14 fertilizer has been used for many years in avocado groves because it was thought that avocados need less phosphorus (7) and more potassium (14). Later in this chapter Dr. Carol Lovatt suggests a fertilizer schedule (special applications of N in April and November) that has been proven to boost yield.

In addition, if the grove has not had a zinc application lately, and especially if leaves are showing yellow mottling between the veins and leaves appear to be smaller than normal, an application of zinc might be indicated. Larger groves can be sprayed with zinc sulfate by helicopter at the rate of 8 lbs zinc sulfate with 3 ounces spreader in 20 gallons of water per acre (see Table 6). It is best to foliar spray trees when leaves are flushing (usually May – June). Recent research by Crowley has indicated that zinc sulfate applied through the irrigation system is probably the most efficient method of achieving zinc uptake in avocado trees. Severe zinc deficiency may require yearly applications, but eventually these applications usually last for 3 – 5 years. It is believed by some researchers that zinc application may be over-emphasized in the industry and may not be as necessary as once thought. Zinc application is discussed further under "Zinc" in this chapter.

New growers are often concerned about dead tissue at the tips of the leaves, known in the industry as "tip-burn". This is not a nutrient deficiency, but it is usually caused by a toxic accumulation of chloride in the leaves as a result of:

1. Saline irrigation water (often the case when irrigation is done with well water or reclaimed water),
2. Poorly leached soils resulting in salt accumulation in the root-zone,
3. Under-irrigation, also resulting in accumulation of salts in the soil,
4. Over-application of manures and sometimes fertilizers; or
5. Combinations of the above.

Often when the grove is up for sale or in escrow, the irrigation may be shut off or drastically reduced. The effect on the tree eventually shows up as tip-burn. These leaves will be dropped off from the tree in the winter and replaced by new leaves in the early spring (often at the expense of flowering and fruit set).

For a discussion of salinity and its effect on avocado, refer to Chapter 1 – Irrigation "Management of Salinity".

Nutrients and their Role in Avocado Production
<u>Nutrients Required by Avocados and Leaf Analysis</u>

It is generally accepted that plants require 16 essential nutrients. These include hydrogen, oxygen, and carbon derived from air and water; and 13 mineral nutrients, most of which are derived from the soil and water.

Hydrogen and oxygen (derived from water and carbon dioxide from the air) and carbon (derived from carbon dioxide) are the basic building blocks used in the creation of carbohydrates during photosynthesis. Water is also required for transport of minerals and plant food, provides the turgidity to maintain plant structure, cools the plant and enters into many chemical reactions necessary for plant growth. "Waste" products from plant growth include water and oxygen back to the atmosphere. As long as the avocado is irrigated properly, the grower does not have to worry about these elements.

The 13 elements remaining are divided into primary nutrients, secondary nutrients and micronutrients. This grouping is based on the relative amounts required by plants, but all are essential. Crowley describes the need for all elements as the "Law of the Minimum"; if only one element is deficient it eventually affects growth and yield of the entire plant in a negative manner. The primary nutrients required by avocados are nitrogen, phosphorus and potassium. The secondary nutrients required are calcium, magnesium and sulfur. The micro-nutrients are zinc, iron, manganese, copper, boron, molybdenum, and chlorine.

Nutrient Extraction from the Soil. Historically, growers in California have applied nitrogen annually, with applications of phosphorous, potassium, boron and zinc periodically to correct deficiencies found in leaf analysis. Jonathan Cutting in New Zealand suggested that we should consider the amount of mineral nutrients removed in fruit harvested from high yielding groves, and perhaps fertilize in ratios to replace these elements in order to maintain high yields. In Table 1 Cutting indicates that potassium is removed in the fruit load at a rate almost twice that of nitrogen. Of course, the soil provides a considerable amount of potassium naturally, and it is probably not necessary to completely supply potassium from fertilizer application. Unfortunately, avocado soils in California vary widely in type and fertility, and it is impossible to make a general recommendation for some elements such as potassium and phosphorous. Fertilizing to replace mineral nutrients lost in the fruit load is an area ripe for research in California.

Table 1. Weight of the main mineral nutrients removed in 10,000 lbs of avocado fruit from one acre (After Cutting, 2000)

Mineral nutrient	% Dry weight	Pounds per 10,000 lbs fruit
Nitrogen (N)	0.54	35.6
Phosphorous (P)	0.08	5.4
Potassium (K)	0.93	60.4
Calcium (Ca)	0.10	0.8
Magnesium (Mg)	0.24	3.3
Chlorine (Cl)	0.07	
Sulfur (S)	0.30	3.5

Minor mineral nutrients	Parts per million	Pounds per 10,000 lbs fruit
Sodium (Na)	400	0.79
Boron (B)	19	0.04
Iron (Fe)	42	0.09
Zinc (Zn)	18	0.04
Manganese (Mn)	9	0.02
Copper (Cu)	5	0.01

Leaf Analysis. Leaf analysis is preferred over soil analysis as the method for determining optimum levels of nitrogen and other elements in avocado trees because nutrient levels in six-month old spring flush leaves have reached a steady state of mineral content useful for comparison. Leaf analysis ranges that are believed to be proper for avocados in California are presented in Table 2 (Goodall et al.1981). Soil analysis is not used for nitrogen because levels in soil constantly fluctuate depending on time of fertilizer application, growth flushes, leaching, and organic matter content of soil. Different varieties have their own nitrogen needs. In Fuerte, high levels of nitrogen in the leaf analysis (above 2.0 percent) is associated with reduced yield, whereas in Hass approximately 2.0 to 2.2 percent is believed to be the proper level in California (Goodall et al.1981, C.D. Gustafson, personal communication). Some researchers in New Zealand believe that the optimum level for nitrogen in Hass should be higher, in the range of 2.5 – 2.9% (Cutting, 2000). This range is based on their surveys of high yielding Hass groves. Research into proper nitrogen levels in the newer varieties such as Gwen and Lamb Hass has not yet been conducted. It is expected that the leaf analysis tables will become more defined as research progresses.

Table 2. Ranges of Elements for Interpretation of Leaf Tissue Analysis for Avocado

		Ranges for Mature Trees		
Element	**Unit**	**Low**	**Sufficient**	**High**
Nitrogen (N)				
Hass	%	<1.8	2.0 - 2.2	>2.2
Fuerte	%	<1.6	1.6 - 2.0	>2.0
Phosphorus (P)				
Fuerte	%	0.05 - 0.07	0.08 - 0.25	0.26 - 0.3
All Others	%	0.05 - 0.09	0.10 - 0.25	0.26 - 0.3
Potassium (K)	%	0.35 - 0.74	0.75 - 2.0	2.1 - 2.9
Calcium (Ca)	%	0.50 - 0.99	1.00 - 3.00	3.1 - 4.0
Magnesium (Mg)	%	0.15 - 0.24	0.25 - 0.80	0.9 - 1.0
Sulfur (S)	%	0.05 - 0.19	0.20 - 0.60	0.7 - 1.0
Boron (B)	Ppm	20 - 49	50 - 100	>100
Iron (Fe)	Ppm	20 - 49	50 - 200	>200
Manganese (Mn)	Ppm	15 - 29	30 - 500	>500
Zinc (Zn)	Ppm	<20	30 - 150	>150
Copper (Cu)	Ppm	<5	5 _ 15	>16
Molybdenum (Mo)	Ppm	0.01 - 0.04	0.05 - 1.0	>1.0
Chloride (Cl)	%	?	?	0.25 - 0.50
Sodium (Na)	%			0.25 - 0.50
Lithium (Li)	Ppm			50 - 75

Sampling for Leaf Analysis. In order to get the most benefit from leaf analysis, it is very important to take a proper sample. Leaf samples should be the youngest fully expanded and mature leaves available in the August-October period. These would normally be spring-cycle leaves, five to seven months old. It is recommended that forty leaves be taken for one sample, removing leaves from non-fruiting branches from random trees in the block (or grove) to be tested. Separate samples should be taken from blocks doing poorly, or blocks with different soil types. Leaves should be placed into paper bags and taken to the agricultural lab promptly. Plastic bags tend to trap moisture on the outside of leaves which may rot the leaves, but leaves that are too dry are difficult to wash during the preparation at the lab.

Nitrogen

Facts about Nitrogen. Of all the essential elements, nitrogen is most apt to be deficient in avocado soils if not applied on a regular basis. Nitrogen is generally applied through the irrigation system by means of a fertilizer injector, or hand applied as a dry fertilizer by scattering the fertilizer under the canopy of the tree (preferably in the wetted area of the sprinklers). While some types of orchard crops can be fertilized by foliar application of nitrogen, avocado leaves have such a thick cuticle and wax layer that nitrogen absorption through the leaf is very inefficient.

Nitrogen is taken up by roots mostly in the nitrate form (NO_3^-) and somewhat in the ammonium form (NH_4^+). Nitrate nitrogen is very mobile in the soil and easily moves with water to the roots where uptake occurs. Nitrate can be taken up quickly by plants, but it can also be leached below the rootzone easily and lost if the grove is being over-irrigated. Ammoniacal nitrogen is bound to the surfaces of soil particles and does not move readily to plant roots until it is converted to nitrate by soil bacteria in a process called nitrification. This process is temperature dependent; at 75°F nitrification can be completed in 1 to 2 weeks, but at 50°F this process may take 12 weeks or more. Therefore, nitrate acts like a quick release fertilizer for immediate use by the plant, and ammonium fertilizers are more like slow release fertilizers, available to feed the plant for a longer period of time. Many growers use a combination of these two forms of nitrogen to gain the advantages of both.

Urea can move through the soil with the water from an initial irrigation, but will be quickly converted to ammonium ions in the presence of moisture. Urea has a high percentage of nitrogen (usually 46% N) and is one of the cheapest forms of nitrogen in the market.

During the nitrification process, two molecules of ammonium nitrogen convert (in the presence of oxygen) to two molecules of nitrate ion, two molecules of water, and four ions of hydrogen. The positively charged hydrogen ions contribute to the acidity of the soil and if the soil has a low soil pH (below 6.0), the form of fertilizer applied should be changed to calcium nitrate until the problem is corrected. Ammonium sulfate is usually not used in avocado production because the tendency to cause acidic soils over time.

Nitrogen is also available to plants from the breakdown of organic matter in the soil. Soil organisms convert proteins in the organic matter to ammonium compounds in a process called *mineralization*. California soils are historically low in organic matter, so this aspect is not too important unless organic matter is added by way of mulches or manures. High carbohydrate-containing mulches (such as the wood-based green-waste abundantly available in California) are broken down by organisms in the soil that require nitrogen to function. These organisms can actually cause a nitrogen deficiency in soil until the mulch is degraded, the organisms die and the nitrogen is released back to the soil. Wood-based mulches may require extra nitrogen applications to help complete this process. (For more on organic fertilization, refer to "Organic Fertilization" at the end of this chapter).
Under saturated soil conditions, other types of soil bacteria convert nitrate to nitrogen gas and nitric oxide gas, which are then lost to the atmosphere. In this process, known as *denitrification*,

these bacteria are utilizing the oxygen in the nitrate ions for their growth processes. For this reason, fertilization should not be done after a long period of rain in which the soils are saturated.

Deficiency. Nitrogen deficiency in avocado is not common in California as most growers apply nitrogen annually. Occasionally a grove that has missed nitrogen fertilization for 2 or 3 years will show the following deficiency symptoms:

- Lack of vegetative vigor
- Pale green, small leaves
- Reduced yields
- Premature defoliation
- Leaves with yellow veins (severe deficiency)

Unfortunately, these exact same symptoms are also associated with other problems such as Phytophthora root rot and root asphyxiation due to water-logged soils. In these cases application of nitrogen will not fix the problem. If nitrogen deficiency is suspected, it should be confirmed by leaf analysis and an examination of other cultural problems in the grove.

How Much to Apply. When leaf analysis is not used, or if a grove has been recently purchased and the history of fertilization practices is unknown, it is suggested that 150 to 200 pounds of elemental nitrogen per acre per year be applied to a mature Hass avocado grove. For other varieties of avocados such as Fuerte, Bacon, or Zutano, 100 to 200 pounds is suggested. The amount to apply can be reduced if the irrigation water contains nitrogen (common with well water or reclaimed water). If heavy leaching (for salinity control) is being practiced in the grove, nitrogen may have to be increased overall, or strategically applied so that the trees can absorb as much nitrogen as possible. For instance, when injecting fertilizer through the irrigation system, it would be better to inject the fertilizer at the end of the irrigation run followed by enough water to clear out the lines and leach the fertilizer into the top eight inches of soil.

If weeds or cover crops are allowed to grow, nitrogen may have to be increased to allow for competition. A good way to avoid this problem is to spray or mow the weeds/cover crop just before the fertilizer application. If cover crops are grown, they should be of leguminous types that are able to fix nitrogen from the air. It is difficult to determine if cover crops that fix nitrogen can significantly contribute to the fertilizer program because, in avocado production, the cover crop cannot be turned under into the soil due to the shallow growth nature of avocado feeder roots. If the cover crop is not turned under, much of the benefit from nitrogen is lost as ammonium gas is lost to the atmosphere during microbial decomposition. Weeds and cover crops are generally not an issue in mature avocado groves due to shading from the trees, but can be useful in young groves and pruned groves.

Hand Application of Fertilizers. In a mature grove (ten years old or older) the fertilizer requirement is normally calculated on a "per acre" basis. This is because we assume that, when the grove is beginning to crowd, there is a maximum number of leaves per acre that can intercept light on that acre of avocados, regardless of the number of trees. In Table 3 it is assumed that the nitrogen requirement per acre is 200 lbs. The 200 lb requirement is divided by the number of trees per acre to calculate the fertilizer application per tree. It can be seen that the fertilizers containing the higher percentage of nitrogen (such as urea) require less quantity per tree, an important consideration when labor costs are considered.

It is important to remember that the amount suggested in Table 3 is only a guide. The amount of nitrogen that should be applied to achieve the desired leaf level and yield varies from grove to grove depending upon past applications, soil type, irrigation, and yield from the grove in previous years. In a grove where there are strong differences in yield from tree to tree, Embleton suggests less nitrogen should be applied to trees with strong vegetative growth and dark green leaf color, and up to twice the grove average amount of nitrogen should be applied to trees with heavy fruit set, little new growth and pale leaf color (assuming these trees are healthy).

Fertilization of Young Trees. Young trees should be fertilized cautiously. Over-fertilizing may burn the roots, but under-fertilizing will result in poor growth. Young trees are generally fertilized every 4 – 6 weeks through the eight-month growing season (March – October). Suggested amounts of dry fertilizer for young trees are presented in Table 4, and suggested amounts of liquid chemical fertilizers for young trees are presented in Table 5. These suggested amounts are roughly equivalent to a level tablespoon of urea applied per tree monthly during the first year, ¼ cup every other month during the second year, 1/3 lb applied in February and again in July in the third year, and 1 lb applied in February in the fourth year.

Manures and soil amendments should not be added into the hole at the time of planting because of excessive salts and ammonia gas which are toxic to roots. Manures should only be used as a fertilizer on young trees if the manure is well composted and leached by winter rains.

Young trees are often mulched with straw or wood chips to reduce moisture loss from the soil surface. These materials do not supply nitrogen and, in fact, may actually tie up available nitrogen in the soil surface. Mulched trees may require a little bit of extra nitrogen to overcome this effect.

Table 3. Amount of Actual Nitrogen per Tree per Year (Mature Grove)

Amount of Fertilizer to Apply per Tree

Spacing	# Trees/ Acre	Actual N/acre (lbs)	Actual N/tree (lbs)	Triple 15	Ammonium Nitrate	Urea
				15-15-15	34-0-0	46-0-0
15' x 20'	145	200	1.4	9.3	4.1	3.0
20' x 20'	109	200	1.8	12.0	5.3	3.9
20' x 40'	54	200	3.7	24.7	10.9	8.0

Nitrogen Fertilizer Application through the Irrigation System. Applying nitrogen fertilizers through the irrigation system (known as "fertigation") has become very popular in orchard crops in California and especially in the avocado industry for several reasons (Lee 1980, Schwankl et al. 1993):

- Most of the groves have low volume irrigation systems which are well suited to fertigation
- Water is distributed relatively uniformly with low volume irrigation systems, and fertilizers are consequently well distributed
- The manager has flexibility in timing fertilizer applications
- Less fertilizer can be used because all of the fertilizer is being applied in the wetted area (where the roots are located)
- Costs, especially labor costs, are lowered
- Many avocado groves are located on very steep slopes. Consequently, fertigation is the only practical method of delivering the fertilizer to the trees

Dry fertilizers are added to plastic or stainless steel tanks containing water and mixed until the granules or crystals are dissolved and the desired concentration is reached. Some fertilizers (such as urea manufactured for application as granules) have a thin plastic coating over each granule. These coatings will not dissolve in water and tend to clog filtration systems. If dry fertilizers are to be mixed, ask the dealer for formulations that can be mixed in water.

Liquid fertilizers are often mixed at the farm supply store and delivered to the grove. The advantage is that the fertilizers are properly mixed with a known amount of nitrogen per gallon; the disadvantage is that the grower must pay for delivery of the water. The farm supply store is also able to offer guidance as to the proper amount of liquid fertilizer to inject into the system.

Lee Method for Calculating Liquid Fertilization. The proper amount of liquid fertilizer to inject is suggested in Table 4 by Bud Lee, farm advisor emeritus from Ventura County (Lee, 1980). In this table it is assumed that the manager will be injecting fertilizer on a monthly basis for eight months from March through October. In order to use the table, first determine the age of trees and find the factor for the material being used. Multiply the factor by the number of trees and add that many pounds or fluid ounces (depending on the material) to the injection tank.

<u>Example 1.</u> You have a block of 265 trees, 3 years of age, and want to use dry urea as a nitrogen source. The urea factor for a 3 year-old tree is 0.09 Multiplying 265 by 0.09 you get 23.85 pounds. That amount of urea should be added to the tank once a month for 8 months (March through October).

<u>Example 2.</u> You are using liquid UN 32 instead of urea. The UN 32 factor for a 3 year-old tree is 1.49. Multiplying 265 by 1.49, you get 394.85 fluid ounces. Divide this number by 128 fluid ounces/gallon, and you would add 3.1 gallons of UN 32 solution to the tank.

Table 4. Amount of Actual Nitrogen Requirement for Young Trees and Amount of Liquid Fertilizer to Apply per Tree per Month (Eight Monthly Applications March-October)

		Dry Pounds of Fertilizer			Liquid Ounces		
Tree Age (years)	**Actual Nitrogen/ Tree/Year**	**Urea (46%)**	**Amm.Nit (33%)**	**Ca Nit (15.5%)**	**Amm. Nit. (20%)**	**UAN-32 (32%)**	**Ca. Nit (9%)**
1	0.1 lb	0.03	0.04	0.08	0.76	0.45	1.7
2	0.2 lb	0.05	0.08	0.16	1.51	0.9	3.4
3	0.33 lb	0.09	0.13	0.27	2.5	1.49	5.6
4	0.5 lb	0.14	0.19	0.4	3.75	2.26	8.3
5	1.0 lb	0.27	0.38	0.81	7.57	4.51	16.8
10	1.5 lb	0.41	0.57	1.21	11.32	6.77	25.2

Liquid injection of fertilizers can also be calculated by using Table 5. Data is presented from three popular liquid fertilizers used in avocado production. In this table it is assumed that the fertilizer will be applied in nine equal applications from February through October.

Table 5. Liquid Fertilizers (Amount based on 9 monthly applications).
UN-32 (urea ammonium nitrate, density 11.06 lbs/gal, 3.34 lbs actual N/gal)

Tree Age	N/tree/year	Gal/tree/year	Gal/100 trees/mon	fl.oz/tree/mon
1	0.15	0.045	0.5	0.6
2	0.30	0.09	1.0	1.3
3	0.45	0.13	1.4	1.8
4	0.60	0.18	2.0	2.6
5	0.75	0.22	2.4	3.1
6	0.90	0.27	3.0	3.8
7	1.05	0.31	3.4	4.6
8	1.20	0.36	4.0	5.1
9	1.35	0.40	4.4	5.6
10	1.50	0.45	5.0	6.4
M	2.00	0.60	6.7	8.6

CAN - 17 (Calcium ammonium nitrate, density 12.64 lbs/gal, 2.15 lbs actual N/gal)

Tree Age	N/tree/year	Gal/tree/year	Gal/100 trees/mon	fl.oz/tree/mon
1	0.15	0.07	0.8	1.0
2	0.30	0.14	1.6	2.0
3	0.45	0.21	2.3	3.0
4	0.60	0.28	3.1	4.0
5	0.75	0.35	3.9	5.0
6	0.90	0.42	4.7	6.0
7	1.05	0.49	5.4	7.0
8	1.20	0.56	6.2	8.0
9	1.35	0.63	7.0	9.0
10	1.50	0.70	7.8	10.0
M	2.00	0.93	10.3	13.2

Calcium nitrate 15.5–0-0 (calcium nitrate, density 10.1 lbs/gal, 1.55 lbs actual N/gal)

Tree Age	N/tree/year	Gal/tree/year	Gal/100 trees/mon	fl.oz/tree/mon
1	0.15	0.10	1.1	1.4
2	0.30	0.19	2.1	2.7
3	0.45	0.29	3.2	4.1
4	0.60	0.39	4.3	5.5
5	0.75	0.48	5.3	6.8
6	0.90	0.58	6.4	8.2
7	1.05	0.68	7.6	9.7
8	1.20	0.77	8.6	11.0
9	1.35	0.87	9.7	12.4
10	1.50	0.97	10.8	13.8
M	2.00	1.29	14.3	18.3

For reference, the formula to calculate the amount of liquid calcium nitrate is as follows:
0.15 lbs actual N/yr x (1 gal/1.55 lbs actual N/gal) = gal calcium nitrate/tree/year

Injection Equipment. Three important pieces of equipment are necessary in order to do fertigation: A backflow prevention device, an injector, and a tank that will not corrode.

Backflow prevention devices are required by most water districts. Local regulations will determine the type of device (vacuum breakers or check valves). The devices are necessary to prevent contamination into the local water system or well in case a sudden loss of pressure in the system occurs while the fertilizer injector is pumping. They are also necessary in case the injector pump stops working while the irrigation water is flowing; in this case the water can back up into the chemical supply tank and overflow onto the ground. The local water district can supply information on the type required in that district, and they will also provide periodic inspection of the device.

If the injection pump is electrically driven, an interlock should be installed so that the injection pump will stop if the irrigation system pump shuts down. When the pump shuts down, water will often run back into the chemical tank unless a solenoid or check valve is installed after the injector. If an electrical solenoid is installed, it should be connected to the injector pump and interlocked to the irrigation pump (Schwankl and Pritchard, 1993).

Injection devices consist of differential pressure tanks, Venturi devices and positive displacement pumps. Differential pressure tanks are simply "batch" tanks in which a small amount of water flows into one end of the tank containing the fertilizer and flows out the other end to rejoin the main flow of water in the system. To make this work, the inlet pressure has to be a little higher than the pressure of water at the outlet connection. The tank and all of its hoses must be able to withstand the operating pressure of the irrigation system. These tanks are simple to use, but have the disadvantage that most of the fertilizer leaves the tank early in the irrigation rum. This means that, if an irrigation set last ten hours and most of the fertilizer is distributed in the first hour, there will be nine hours of irrigation to follow which could cause excessive leaching of fertilizer.

Another type of injector is a Venturi device; simply a short pipe with a constriction inside the pipe to create a negative pressure or suction at the throat of the constriction. Venturi devices will cause the water in the line to have a pressure drop between 10 to 30 percent from inlet to outlet, therefore they should not be installed into the main line, but rather should be installed parallel to the main line so that the injector can be turned off with a valve when injection is not occurring. Venturi devices are simple and have a better distribution of fertilizer into the system throughout the irrigation run, but they are not as good as the positive displacement pumps for precise distribution.

Positive displacement pumps utilize a piston or diaphragm to inject fertilizer at a constant rate. They are powered by electricity, gas or driven by water. They can be expensive (usually over $750) and can be an item targeted by thieves unless they are locked inside a fence or some type of structure.

A good storage tank is the third item necessary for fertilizer injection. Most fertilizers will store well in plastic tanks or mild steel tanks, but the more acidic materials, such as phosphoric acid, should only be stored in rubber-lined or stainless steel tanks.

When to Fertilize. The answer to the question: "When should I fertilize?" is still controversial. Proper timing for fertilizer application is complicated by the fact that avocado has a huge bloom in the spring which requires a lot of mineral nutrition and the tree often initiates shoot growth in the middle of the bloom period (new shoot growth is believed to be parasitic for nutrients, possibly diverting minerals away from the bloom and young fruit). We have periodically observed that, if entire nitrogen requirement for the year is applied during bloom, a high drop rate of bloom and young fruit sometimes occurs. After a career studying the mineral nutrient requirements of avocado, Dr. Tom Embleton at the University of California, Riverside (Embleton 1985) stated that "After the trees come into commercial bearing, the timing of nitrogen application does not influence fruit production. The critical factor is the amount of nitrogen applied per year. Therefore, the scheduling of nitrogen application can be at the grower's convenience. Although experimental evidence does not give statistically significant differences, there have been small but statistically nonsignificant increases in fruit production in favor of applying an appreciable amount of nitrogen prior to bloom." Embleton and former avocado farm advisors Don Gustafson, Bud Lee, and George Goodall often recommended about 2/3 of the yearly application of nitrogen be applied 4 – 6 weeks prior to the bloom, and another third be applied in June or split between June and September.

Since the advent of fertilizer injection, fertilizer is usually applied in split applications once a month, or during each irrigation event. In a trial conducted in Ventura, there were no yield differences between treatments where the yearly nitrogen application was split into twice a year, four times a year, or eight times a year, but significantly more nitrogen leached below the root system when the fertilizer was applied in greater amounts (such as in the twice a year program (Yates et al. 1991).

Dr. Carol Lovatt (Botany and Plant Science Dept., UC Riverside) conducted an interesting trial which attempted to answer the question: "When do you fertilize for best production?" She questioned whether avocado yield could be increased by supplying extra nitrogen at a specific stage of tree phenology, rather than dividing the nitrogen into equal portions for application throughout the year (Lovatt 2001).

In her experiment, a control treatment of mature Hass trees (consisting of 20 randomized, replicate trees) were fertilized with six applications per year at the rate of 25 lbs/acre actual N (as NH_4NO_3) per application, applied in late January-early February, mid-April, mid-June, mid-July, late August-early September, and late October-early November. This treatment was considered the "control treatment based on a typical grower application". This treatment was compared to five other treatments (each treatment with 20 replicate trees), all with the same basic fertilizer schedule as the control trees, but with extra nitrogen applied at strategic times during specific growth phases:

1. January, extra 25 lb N/acre, budbreak and ovule initiation.
2. February, extra 25 lb N/acre, beginning of the cauliflower stage of bloom, pollen formation.
3. April, extra 25 lb N/acre, anthesis, fruit set and initiation of the spring vegetative flush.
4. June, extra 25 lb N/acre, end of Stage 1 of fruit development and end of the June drop period.
5. November, extra 25 lb N/acre, end of the fall vegetative flush and beginning of flower initiation within the buds.

At the end of the fourth year of the study, the four-year cumulative yield per tree indicated the extra N applied in April or November increased yield of Hass avocado 31% and 39% respectively when compared to control trees not receiving the extra N. The yield from the November treatment was significantly better (statistically, p=0.05) than yield from the trees receiving the extra dose of N in January, February, or June. Cumulative yield was significantly greater for trees receiving extra N in April compared to the control trees not receiving extra N, or the trees receiving extra N in January or February.

The treatments receiving the extra nitrogen in April or in November also resulted in increased production of large-sized fruit of commercial importance (sizes 60, 48, and 40). The extra nitrogen applied in April resulted in the statistically significant reduction in alternate bearing as measured by the alternate bearing index. Based on this study, Lovatt suggested that timing of fertilizer application may be more important than previously thought by fertilizer researchers.

Nitrate Contamination of Groundwater. Nitrogen applied in excess of plant need must go somewhere. This may be lost to runoff into nearby surface waters, or it percolates below the root zone of plants and ends up in groundwater. Many areas rely on well-water for drinking, and if the nitrate level in drinking water is above 10 ppm, it may cause a disease known as methemoglobinemia or "blue baby syndrome". The well water contamination is a problem that is becoming worse in California and may result in legislation that would be burdensome for growers. It is in everybody's interest to reduce groundwater contamination as much as possible.

One of the most important ways to reduce groundwater contamination is to control water application. If water is applied in excess of plant requirements, nitrates will move below the roots and continue down into the water table. Better water management strategies are presented in Chapter 1 – Irrigation.

Zinc

Avocado has a small but essential requirement for zinc. Zinc is an important constituent of several enzyme systems and it controls the synthesis of indoleacetic acid, a plant growth regulator. In the acid sandy hillside soils of San Diego County, the zinc that is present is readily dissolved and leached out of the root zone when the soil is irrigated (Crowley 1992). This deficiency can be corrected by adding zinc sulfate to the soil, or spraying trees with zinc sulfate or zinc chelates. In the more alkaline soils of Ventura and Riverside Counties, zinc may be present in the soil but unavailable since trace metals become more insoluble as pH increases. Mild symptoms include yellow mottling between the veins on the leaves, small rounded fruit, and shortened internode length, and with severe deficiency tree decline and death has been known to occur. Zinc deficiency can be a chronic problem and difficult to correct when trees are fertilized with high rates of phosphorus (Goodall et al.). This problem is common in organic groves where poultry manure, which usually has high phosphorus content, has been used for several years.

Deficiency Symptoms. Leaf mottling usually starts in the terminal leaves and progresses to the older leaves. New leaves remain smaller than normal. In advanced stages a marginal burn develops on the new, stunted leaves and twig dieback occurs. The distance between the leaves on the stem is shortened, giving a crowded "feather duster" appearance (Goodall et al. 1981). Fruit may develop to be small and rounded (Cutting, 2000).

Leaf Analysis. Although widely discussed in the industry, there is no evidence to support higher optimum levels in leaf analysis than the 30 – 150 ppm range proposed by California avocado researchers Goodall, Embleton, and Platt. In fact, in the "on-crop" year of 1993, Arpaia and Bender noted high yields from Hass avocados (over 16,000 lbs/acre in their rootstock trial at South Coast Field Station, Irvine, CA) from trees that had zinc levels in the deficiency range (20 ppm) (Arpaia and Bender, unpublished). In this trial, although yields were good, typical zinc deficiency symptoms of mottle leaf and round fruit were noted.

Correction of Zinc Deficiency. Zinc fertilizers can be applied either by soil application, foliar sprays or through the irrigation system. On the acid soils of San Diego County, soil application has long been done by scattering zinc sulfate over the wetted area of the root-zone. Care should be given not to apply it right at the base of the trunk since this can result in bark death at the point of contact. Chelated forms of zinc may correct the deficiency but these are more expensive and appear to have no advantage over zinc sulfate (Crowley 1994, Goodall et al. 1981). On alkaline soils (pH>7.0) it has been suggested that, if the soil is not too highly buffered by calcium carbonate, zinc deficiency could probably be corrected merely by acidifying the soil with sulfuric or phosphoric acid (Crowley, 1992).

In a trial conducted on alkaline soil (pH 7.8 – 8.0) with free calcium carbonate, David Crowley (Dept. of Environmental Sciences, UC Riverside) found that soil banding with zinc sulfate in February at the rate of 7 lbs/tree gave the best result (compared to application through the irrigation or by foliar spray), increasing zinc in the leaf analysis from 42 ppm (pre-treatment analysis) to 87 ppm (August analysis). A quarterly application of zinc sulfate through a simulated irrigation system (annual rate of 7 lbs/tree applied in four equal applications) also gave a good result, increasing zinc levels from 43 ppm to 75 ppm. Application of zinc chelate through the simulated irrigation system (application rate 0.16 lbs /application x 4 applications) was unsuccessful at raising zinc concentrations in the avocado trees. Due to the high cost of zinc chelate, Crowley suggested that an application of liquid zinc sulfate through the irrigation system would be the most cost effective method of zinc application. Suggested rates for soil application are found in Table 6.

Prior to Crowley's thorough study of zinc application, the industry standard was to apply foliar sprays of zinc sulfate once a year, usually in May, either by ground rig or by helicopter. It was observed that zinc deficiency would be corrected in the outer canopy, but zinc deficiency symptoms often remained in the inner canopy. In a study using radioactive Zn-65 spotted onto individual leaves, Crowley found that zinc did indeed move to adjacent tissue in the same leaf that had the spot of Zn-65, but zinc did not move to the leaf above or below the spotted leaf. This finding explained why zinc deficiency often remained in the inner canopy of trees treated with a foliar spray, and has given cause to speculate that continuous foliar sprays may lead to zinc-deficient roots.

Crowley concluded that:

- Foliar applications of zinc may correct marginal deficiencies in the outer canopy leaves directly in contact with the spray, but there is no evidence for transport to the inner canopy, fruit, or roots.
- Application of zinc sulfate in the irrigation water should be timed with new root growth. Rates of 10 – 50 lbs/acre should be sufficient to correct deficiencies, except for trees in highly calcareous hot spots.
- Zinc deficiency should be determined by leaf sampling of affected trees. Zinc should not be applied on a yearly basis without a determination of need by leaf analysis.

Table 6. Suggested amounts of zinc sulfate (36%) and liquid zinc sulfate (12%) to apply via soil, water, and foliar spray

Tree age (yrs)	Surface banded 36%, 3-5 year schedule, lbs/tree	Water application 12% liquid zinc low rate, annual application, gal per 100 trees	Water application 12% liquid zinc high rate, annual application, gal per 100 trees	Foliar spray, 36% zinc sulfate applied in 20 gal water/acre, lbs/100 trees
2	0.7	0.7	3.6	0.8
3	1.0	1.0	5.2	1.1
4	1.5	1.5	7.7	1.7
5	2.0	2.1	10.3	2.3
6	2.5	2.6	12.9	2.9
7	3.0	3.1	15.5	3.4
8	3.5	3.6	18.1	4.0
9	4.0	4.1	20.7	4.6
10	5.0	5.1	25.9	5.7
Mature	7.0	7.2	36.2	8.0

Note: Low rate of liquid zinc sulfate is based on annual applications of 10 lbs zinc sulfate/acre (or 100 trees at maturity). High rate of zinc sulfate is based on annual applications of 50 lbs lbs zinc sulfate/acre (or 100 trees at maturity). Liquid zinc sulfate (12%) contains 1.38 lbs zinc sulfate/gallon.

Growers may wish to apply zinc mixed with certain insecticides that are used during the spring to control thrips, but zinc should not be applied with sabadilla (Veritran D) sprays for thrips control because the taste of zinc apparently discourages the thrips from feeding on the sabadilla-molasses combination (Bender 1998).

Zinc in Relation to Certain Soils. Crowley reported that, in a thorough study of a grove suffering chronic zinc deficiency in the Ventura area, leaf analysis levels of zinc did not have any relationship with extractable zinc in the soil (Crowley 1995). He did note that trees with low levels of zinc in their leaf analysis had high levels of bicarbonate in the soil under those trees. Some trees that had relatively high levels of zinc in the soil showed low levels of zinc in the leaf analysis, especially if those soils had high levels of bicarbonate (above 1 g CO_3-C). These trees did not respond well to fertilization with 7 lb zinc sulfate/tree.

Crowley explained that bicarbonate can reduce uptake of zinc and iron at the root surface (there may be differences in uptake according to rootstocks, but this has not been researched yet). Bicarbonate also has the tendency to raise the pH inside the xylem fluid. Under higher pH conditions, citrate forms complexes with calcium instead of zinc or iron in the xylem fluid. Zinc and iron need to be complexed with citrate molecules in order to cross cell walls, and this does not happen under high pH conditions in the xylem fluid. This is why cells along the veins are still able to get enough zinc and iron from the xylem fluid, but the metals cannot translocate into the cells between the veins, thus creating the yellowed, mottling effect between the veins.

Crowley concluded that applying more zinc to soils that are high in bicarbonate is not the answer. Cultural management should probably be concentrated on opening up the soil structure to allow carbon dioxide to escape as a gas rather than dissolve into bicarbonte. This can be achieved by not over-irrigating, allowing the soil to dry somewhat between irrigations, and applying gypsum to the soil to flocculate soil particles to increase drainage. Acidification of the soil in the root-zone with acid-type fertilizers may also be useful.

In another experiment Crowley tried to determine the best time of year to apply zinc sulfate to avocados. By applying zinc to different sets of trees during different months, it was determined that May is the best time to achieve uptake in California; this time was associated with the first flush of roots during the year in the Ventura area. Future research may concentrate on screening and selecting rootstocks for efficiency of zinc uptake (Crowley 1995).

Phosphorus

Phosphorus (P) deficiency is rare in California, but when it occurs it can be extremely debilitating to avocado trees. Several groves in the Rancho California region near Temecula almost died from P deficiency until the problem was diagnosed and corrected. Some P applications to trees that do not exhibit deficiency symptoms may be beneficial in the long term.

Deficiency symptoms. There are no specific symptoms for P deficiency. A tree tends to be stunted, lacks vigor and can suffer twig dieback in extreme cases. Small leaves occur much like trees with zinc deficiency, except that the mottling leaf pattern does not occur. Randomly distributed necrotic areas may occur on leaves with severe deficiency. Often the whole grove is not affected; the problem tends to occur in isolated, random groups of trees (Goodall et al. 1990).

Leaf analysis. Leaf analysis is useful for determining P deficiency. If the leaf concentration is less than 0.10% (Hass and other varieties) or less than 0.8% (Fuerte), the grove should be treated with P.

Control. P levels in trees can be improved by application of liquid phosphoric acid in the irrigation system or as a band of dry fertilizer containing P applied in the irrigation wetted pattern. A positive response has been observed with application of five gal/acre of phosphoric acid in a mature grove through the irrigation system. This was followed by an annual application of three gal/acre, sufficient to keep the leaf analysis in the adequate range.

Dry fertilizer applied at the rate of 2.5 lbs of P_2O_5 per tree as a band in the wetting pattern should correct P deficiency. This treatment should last 3-5 years (Goodall, 1990).

In recent years some growers have been treating trees with phosphorous acid to improve tree health. This is registered as a fertilizer in California, but it is very slow release as it requires soil microbes to convert it to phosphate to become available for P uptake.

Yield improvement. It is unclear as to whether P should be included in the fertilizer program if the leaf analysis shows levels in the adequate range. During the course of a nitrogen trial conducted in the Valley Center region of San Diego County from 1988 – 1993, a companion P trial and a potassium (K) trial were also conducted. The researchers on this project were M. L. Arpaia, J. Meyer, G. Bender, and G. Witney. While the nitrogen trial was reported, data from the P and K trials were never formally presented. An examination of the yield data according to P treatments was presented in *The Avocado Quarterly* (Francis 1997).

The P trial consisted of 0 lbs/tree, 4 lbs/tree and 8 lbs/tree of P_2O_5 (applied as triple super phosphate). In the first year of the trial yields were adversely affected by high winds, and yields were reduced by thieves in the second year. Therefore, yields for the last four years of the trial (1990 – 1993) are presented.

The four-year cumulative total production showed 341 lbs of fruit per tree for the 4 lbs P, 268 lbs/tree for the control (no P), and 262 lbs/tree for the 8 lbs P. During the four-year period, yield increased 27% with the 4 lb P rate, but decreased slightly at the 8 lb rate. The effect was difficult to see during the trial because, in two out of the four years, no differences were seen. Therefore, it could be that avocados may have a requirement for P for long-term yield improvement, at least in some soils. Francis concluded his review of the project by stating "Because the results show progressive improvement over time, it can be surmised that the benefit of applying phosphorus will continue to increase with each succeeding year over a zero-phosphorus fertilization program. This could be another explanation of why many groves decline in production as they get older."

Potassium

Potassium is used by avocado trees in fairly large quantities during the summer as fruit is filling, but potassium deficiency is thought to be rare in avocado. Probably not enough research has been conducted to determine if yields of Hass avocado could be improved with additional fertilizer application. A twelve-year trial on Fuerte in California that raised the leaf analysis from 0.9% to 1.3$ showed that applied potassium had no effect on yield (Embleton and Jones, 1964).

One of the problems with determining potassium deficiency symptoms is that the leaf symptoms (tip burn, margin necrosis and interveinal necrosis) is very much like chloride and sodium toxicity, which is far more common in California.

Potassium is taken up from the soil solution in the form of potassium ions (K^+). Potassium is not synthesized into compounds, but remains in ionic form in the plant. It is required in the opening and closing of stomata by guard cells, important for efficient water use. It is also required for root growth and resistance to disease, increased size, and quality of fruit and helps increase winter hardiness (Ludwick 1990).

Deficiency symptoms (Lahav and Kadman, 1980)

- Brownish-red necrotic spots between the veins on mature leaves
- Small fruit or shriveled seeds
- Slow growth
- Thin twigs, dieback

Control. Since little is known about potassium deficiency in avocado, it is difficult to recommend a control procedure. The fertilizer trial at the Cashin Ranch in Valley Center (described above in the Phosphorus section) also had a potassium trial. Potassium was supplied to the trees at the rate of 4 lbs/tree and 8 lbs/tree. The higher rate of K led to a small increase in yield after four years of harvest (Arpaia et al. unpublished). Since the crop load contains a high percentage of potassium (compared to other mineral elements), potassium application during the period of rapid fruit size increase may be more important that previously thought. However, it was concluded by authors reviewing potassium research that "K is an important nutrient for normal growth of avocado trees. "However, once minimum requirements are met there seems little opportunity to use this nutrient as a management tool to increase yield" (Lahav and Whiley, 2002).

Iron

Iron deficiency is relatively rare in California avocado groves, although it does appear in some groves in Santa Barbara and Ventura counties. When it occurs it is usually associated with alkaline soils high in calcium carbonate, and soils that are overly wet and cold. Iron is rarely "lacking" in the soil, but becomes increasingly insoluble and unavailable to the plant as the soil pH increases.

Deficiency Symptoms. Iron deficiency appears first on new leaves. In mild forms of deficiency, leaves show a network of green veins against a background of light green tissue between the veins. Interveinal tissue becomes yellow as the deficiency progresses and the veins eventually lose green color. In severe cases the leaves may show tip and marginal burn, leaves will drop and twigs will die. Iron chlorosis may occur on individual limbs or the entire tree.

The yellow color is due to inhibition of chlorophyll formation in the leaves. A critical minimum level of iron in the foliage is 40 ppm, but using leaf analysis to diagnose iron deficiency can be misleading. Iron is known to form complexes with phosphorus in leaf tissue; high bicarbonate uptake from wet soils may also complex with iron and inactivate the metal for usage by the plant. According to Crowley, leaves with an iron content of 100 ppm can still show signs of iron deficiency (Crowley, 1992).

Control. Iron is naturally present in most soils, but is less available to the plant when the soil is high in lime (calcium carbonate), or when the soil is water-logged and has low oxygen content. Iron deficiency can often be corrected merely by using less water during an irrigation event or by lengthening the days between irrigations.

If the iron deficiency is caused by alkaline soil (pH above 7.5) with high lime content, an application of elemental sulfur at 2 to 4 tons per acre may be necessary to lower the pH (Faber, 1997). A regular mulching program should also be initiated as the decomposition of the mulch into organic acids will eventually lower the soil pH.

Applications of iron sulfate at the rate of 5 lbs/tree has also been recommended to correct the deficiency. For best results, the iron sulfate is applied into holes dug into the soil beneath the leaf mulch. For a quick "green-up", and to double check to see if iron deficiency is the problem, a 1% solution of iron chelate (Sequestrene 138-Iron) may be sprayed on the foliage.. Foliar sprays must be repeated in order to supply iron to new developing foliage. Goodall et al. reported that soil application of iron chelate at the rate of ¼ to ½ pound per mature tree in May or June gave good results, but the application and material costs are expensive and may have to be repeated yearly (Goodall et al. 1981).

The Mexican rootstocks (Topa Topa, Duke, and Ganter) appear to be less susceptible to iron deficiency compared to the Guatemalan rootstocks.

Manganese

Similar to zinc and iron deficiency problems on alkaline soils, manganese is occasionally deficient. The leaf pattern is similar to iron deficiency, but the bands of green tissue along the veins are wider than the narrow green veins characteristic of iron deficiency. Manganese deficiency can be corrected by applying 2-4 lbs of manganese sulfate per tree, placed in several holes dug into the soil under the leaf mulch.

Copper

Copper deficiency has not yet been recognized as a problem in California avocado groves, but occasionally a grower will report that his/her leaf analysis shows less copper than the 5ppm recommended by Embleton. An avocado grove with a leaf analysis of 2-3 ppm copper in the Valley Center region of San Diego County was sprayed during mid- bloom of the year 2000 with a copper chelate, but trees did not respond with increased fruit set (Bender, unpublished). This particular grove also showed signs of chloride tip burn.

Typical copper deficiency was reported by Cutting (Cutting 2000) in New Zealand. He reported the symptoms of copper deficiency as follows:

- Dull appearance of older leaves
- Prominent leaf veination
- Reddish-brown leaf color
- Premature defoliation and twig dieback

Copper deficiency in citrus in Florida has been corrected by application of copper fungicides or copper chelate fertilizers to the foliage, or by applications of copper sulfate to the soil at the rate of 5 to 25 lbs/acre. If copper deficiency is suspected in avocado, consult with a farm advisor to eliminate other possible causes.

Boron

Boron is necessary for pollen germination, successful growth of the pollen tube through the stigma, style and ovary to the ovule, and for the cell divisions required to produce sperm cells. Boron sprays are used in some deciduous fruits as a bloom spray to enhance pollen tube growth, especially during cool, overcast and wet weather conditions. Recent work by Carol Lovatt in California indicated that boron-deficient groves may benefit from boron sprayed onto the bloom, but groves with higher boron levels may not benefit, and actually might have less fruit set than trees not sprayed with boron.

Deficiency Symptoms. Deficiency symptoms were not recognized until 1995 in Australia. The following symptoms reported in Australia are seen occasionally in California (from Smith et al. 1995):

- Marginal necrosis of younger leaves
- Crimped (corrugated) and bumpy regions between veins of younger leaves
- Shot holes in leaves (often confused with looper damage in California)
- Loss of apical dominance, often resulting in multiple shoot production
- Prostrate or downward growth of branches
- Swelling of stem nodal regions (chronic symptoms)
- Splitting of the midrib on the under side of younger leaves
- Uneven lamina development of younger leaves - cell expansion stopped on one side of leaf followed by localized necrosis
- Fruit distorted with a crooked neck and malformed on the shortened side

Control. California researchers have not established a clear and consistent need for boron applications, but the grower may want to try a boron application if the leaf analysis indicates boron levels to be below 50 ppm. Boron applications should be done very carefully because boron excess can be toxic. A foliar application at 10 liters (10.5 qts) water containing 10g Solubor (per tree) at 30% flowering should be sufficient. (Cutting, 2000).

Organic Fertilization

Many growers have expressed interest in growing avocados organically. The production of organic avocados would seem to be a natural progression since most of the pests are already under biological control. The only practice that requires a change is the method of fertilization. Non-government certifying agencies such as California Certified Organic Farmers (CCOF) require not only that fertilizers be derived from composts, manures, and natural deposits of certain types of minerals (such as rock phosphate to supply phosphorous), but also that the soil organic matter be increased over time with applications of organic matter under the trees. CCOF requires that a new grove be under an organic program for three years before the grove can become certified. Other certifying agencies usually require shorter time periods.

Application of composts or manures to avocado trees is considerably more expensive than injecting chemical fertilizers through the irrigation system, and the price received for organically-produced avocados would have to be considerably higher to justify the costs. Currently, composts must be hand applied via wheel barrow and buckets since most California groves are on terrain too steep for tractor-pulled manure spreaders. Some growers are experimenting with compost tea injected into irrigation systems, but the composts undergo anaerobic digestion in tanks prior to injection. It remains to be proven that liquid from anaerobic digestion through an irrigation system is beneficial to avocados.

Despite the concern that organic materials may not be justified from a price standpoint, there is considerable evidence that the application of organic materials to soils may be important for long-term health of the trees. In general, organic matter provides the following benefits to soil (Chaney et al. 2000):

- Increase biological activity – supplies nutrients, energy and habitat for beneficial soil organisms.
- Nutrient reservoir – decomposition of soil organic matter releases nutrients, particularly nitrogen, phosphorous and sulfur, which can be taken up by plants.
- Retention of nutrients in available form – because humus molecules have many negative charges, they can interact with positively charged ions such as potassium, calcium, magnesium, and hydrogen.
- Aggregate formation – soil organic matter increases the aggregation of soil by several mechanisms resulting in a desirable crumb-like structure.
- Increased porosity – increases in aggregation tend to improve the pore structure of the soil; changes in soil physical characteristics such as pore structure can alter water retention properties and the water infiltration rate in soil.

Specific types of organic matter, namely "greenwaste" consisting of chipped wood from tree limbs, has been shown by Downer, Faber, and Menge to reduce populations of Phytophthora cinnamomi in soil, the fungus that causes avocado root rot (see Chapter 4 – Diseases).

There are important drawbacks to organic fertilization, especially in avocado production. Manures and certain types of composts (spent mushroom compost for instance) are often high in salt. Fertilizer salts are usually acceptable, but sodium chloride is toxic to avocados in excessive concentrations, causing the familiar "tip-burn" symptom on leaves. These types of organic materials should be allowed to sit through a winter and allow the rain to leach out the salts before application under the trees. Weed seeds that survive the composting process are also a problem, and high carbon greenwaste can actually tie up nitrogen in the soil and reduce nitrogen in the leaf analysis in avocados for up to two years (J. Menge, personal communication). After this period, nitrogen levels may go into the excess range in the leaf analysis. Another drawback is a chronic zinc deficiency often seen with repeated applications of manures. The high phosphorous content in poultry manures can tie up zinc in the soil, making it unavailable for uptake by roots.

There has been very little research in California on proper methods for fertilizing avocados organically. Most growers will apply nitrogen through applications of composted chicken manure, usually applying a 50-pound bag per tree twice a year. Other growers will apply composted greenwaste at a rate of ½ cubic yard per tree, often amended with chicken manure, dairy manure, or blood meal to increase the nitrogen content. However, it is not necessary to apply the same amount of organic matter each year because mineralization of nitrogen, after a high release rate the first year, declines to a release rate of 5% – 6% per year from the initial application. Therefore, as the years go by, application rates of organic matter should gradually decline so as to achieve a steady release rate on nitrogen in the soil.

Nitrogen content in manures and composts is variable. Table 7 indicates nitrogen content (phosphorus, potassium, and sulfur content) from various sources, but it should be remembered that these materials are surface applied, not incorporated into soil because of the danger of injuring roots. Because of this surface application, 15% – 30% of the nitrogen may be lost to volatilization as ammonia gas (Sutton et al. 1983).

Table 7. Plant Nutrient Content (Dry Basis) of Selected Manures and Composts (Chaney et al. 2000, unpublished data from S. Pettygrove)

Description	Total N	Ammonium N	P_2O_5	K_2O	S
	Lbs. per ton				
Non-composted poultry					
Turkey/rice hull litter	35	4	53	37	6
Fresh broiler/rice hull	78	6	51	53	9
Fresh layer	79	8	125	67	16
Aged layer	43	9	164	79	14
Non-composted dairy/steer					
Fresh dairy separator solids	43	1	17	12	10
Fresh dairy corral scrapings	47	2	26	141	12
Aged dairy separator solids	41	1	13	8	9
Aged steer corral scrapings	26	5	31	66	8
Composts					
Broiler/rice hull compost	38	2	86	50	11
Dairy	27	1	27	57	9
Dairy/gin trash	31	1	22	57	14
Dairy/steer	33	0	17	51	9
Dairy/poultry	34	2	39	66	10
Gin trash	47	0	18	75	29

In the example cited where 100 lbs of aged chicken manure is applied to one tree in a year, using Table 7 we can use the formula 43 lbs N/2000 lbs manure x 100 lbs applied per tree = 2.15 lbs actual N applied per tree. If we assume a mineralization rate of 50%, there will be 1.08 lbs N available to the tree the first year. But, since the manure is surface applied, and if there is a 30% loss of ammonia to the air through volatilization, there will only be 0.76 lb actual N available to the tree that year. There are a lot of assumptions involved with this fertilization program. For this reason, leaf analysis should always be done in order to adjust the organic fertilization program.

LITERATURE CITED

Anderson, C.A., 1988. Part II, Noninfectious (Abiotic) Diseases. p57: Compendium of Citrus Diseases (eds. J.O. Whiteside, S.M. Garnsey, and L.W. Timmer). American Phytopathological Society.

Bender, G. S. 1998. Application of Sabadilla (Veritran D) for Thrips Control. University of California Cooperative Extension County Publication, San Diego County.

Chaney, D. E., L E. Drinkwater, and G. S. Pettygrove. 2000. Organic Soil Amendments and Fertilizers. University of California Sustainable Agriculture Research and Education Program, University of California Pub. 21505.

Crowley, D. E. 1992. Soil Fertility and The Mineral Nutrition of Avocado, Circular 92/1. California Avocado Society and the California Avocado Development Organization.

Crowley, D. E. and W. Smith. 1995. Yearbook of the California Avocado Society:171-183.

Crowley, D. E., W. Smith and B. Faber. 1994. Zinc Nutrition of Avocado. Yearbook of the California Avocado Society:155–165.

Cutting, J. 2000. Avocado Nutrition. Avocado Growers Manual. New Zealand Avocado Growers Association.

Embleton, T.W. and W.W.Jones. 1964. Avocado Nutrition in California. Proc. of the Florida State Horticultural Society 77: 401-405.

Faber, B., 1997. Chapter 5, Soil Fertility Management. 1997 Cherimoya Handbook. Published by the California Cherimoya Association.

Francis, L. 1997. Phosphorus…It's Beneficial. The Avocado Quarterly Number 43. California Avocado Society: 2,3,11.

Goodall, G.E., T.W. Embleton, and R.G. Platt. 1981. Avocado Fertilization - University of California Leaflet 2024.

Goodall, G. E., T. W. Embleton, and R. G. Platt. 1990. Avocado Fertilization. Revision of University of California Leaflet 2024, Handbook for California Avocado Growers, California Avocado Society.

Lahav, E. and A. Kadman. 1980. Avocado Fertilization. Bulletin of the International Potash Institute No. 6. Worblaufen-Bern, Switzerland.

Lahav, E. and A.W. Whiley. 2002. Irrigation and Mineral Nutrition. In: Whiley, A.W., Schaffer, B. and Wolstenholme, B.N. (eds.) Avocado: Botany, Production and Uses. CABI Publishing, Oxon, UK. :259-297.

Lee, B. W. 1973. The Efficacy of Aerial Applications of Zinc to Avocado Trees, California Avocado Society Yearbook 56:121-123.

Lee, B. W. 1980. "Nitrogen Application with Drip Irrigation". Avomation. University of California Cooperative Extension, Ventura County, California.

Lovatt, C.J. 2001. Properly Timed Soil-applied Nitrogen Fertilizer Increases Yield and Fruit Size of Avocado. J. of American Soc. of Hort. Sci.126:555-559.

Ludwick, A. E. (ed.) 1990. "Essential Plant Nutrients". Western Fertilizer Handbook, Horticulture Edition: 63- 88.

Schwankl, L and T. Prichard 1993. "Fertigation" Low-Volume Irrigation. (L. Schwankl, B. Hanson and T. Prichard eds.), University of California Cooperative Extension Dept. Land, Air, and Water Resources, Davis, California: 89-91.

Smith, T.E., R.A. Stephenson, C.J. Asher, and S.E. Hetherington. 1995. Boron Nutrition of Avocados – Effects on Fruit Size and Diagnosis of Boron Status. Austr. Avo. Frs. Conf. 1995, Freemantle, Australia.

Sutton, A.L., D.W. Nelson, and D.D. Jones. 1983. Utilization of Animal Manures as Fertilizer. Cooperative Extension, Purdue University, West Lafayette, Indiana.

Yates, M.V, D.E. Stottlemyer, J.L. Meyer, and M.L. Arpaia. 1991. Irrigation and Fertilizer Management to Minimize Nitrate Leaching in Avocado Production. Proc. Sec. World Avocado Congress 1992, Volume I:331-335.