Avocado Production in California

A Cultural Handbook for Growers
Second Edition

Book Two – Cultural Care

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Book Two-Cultural Care *Second Edition*

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Book 2

Chapter 1

Irrigation

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Proper irrigation scheduling, with good quality water supplied to the trees through an efficient irrigation system, is a requirement for all avocado groves. One of the leading causes of poor yields in California is under-irrigation (not meeting the evapotranspiration requirement) because water is expensive, and growers either do not know how to schedule or they purposefully under-irrigate in order to reduce costs. Proper irrigation is further complicated by the accumulation of salts in the soil through poor leaching. The use of saline well water, saline surface water, or reclaimed water (if it is too salty) also reduces yields significantly and may not be sufficiently corrected with leaching.

This section shall discuss:

- Special challenges in avocado irrigation
- Reasons for irrigation
- Irrigation scheduling (frequency and how much water to apply)
- Moisture monitoring equipment
- Components of the irrigation system
- System maintenance considerations
- Water supply and quality considerations (dealing with salinity)

Figure 1. Reading a tensiometer, a key to irrigation scheduling.

Special Challenges in Avocado Irrigation

Avocado is a challenge to irrigate properly because it has a shallow feeder root system (80 – 90% of the feeder root length is located in the upper 8-10 inches of rootzone soil). The feeder roots are rather inefficient at water absorption because they have very few root hairs. Due to the location of the feeder roots soil moisture is consumed rapidly in the upper layer of rootzone soil. Many of the groves are on hillsides with a decomposed granite composition. These soils drain rapidly (which is good), but at the same time they don't store a lot of water. Therefore, the irrigator must be diligent at checking soil moisture with tensiometers, soil moisture meters or soil probes, and re-supplying the soil water before the trees become stressed. On the other hand, some groves are on heavy soils with high clay content. These groves often suffer from poor drainage and low oxygen content in the soil pore spaces resulting in direct damage to the roots and increased spread of avocado root rot.

Avocados are fairly heavy water users, and in Southern California where the water is expensive, some growers tend to irrigate substantially less than is required for optimum production. The trick to irrigation is meeting the water needs of the trees (which is dictated by weather), not to stress trees by irrigating infrequently, and not to waste water by over-irrigating. At the same time, there must be <u>some</u> over-irrigation (known as leaching) to leach the salts below the root zone in order to avoid the characteristic tip-burn on leaves at the end of the season.

Despite these challenges, avocados can be successfully grown in Southern California if the grower and the irrigator are diligent. Missing a series of irrigations for one to two weeks may initiate fruit drop in trees and ruin the production for that year.

Reasons for Irrigation

Avocado growers realize that irrigation is necessary, but they often don't know the many roles that water plays in avocado production.

- First and foremost, water plays a key role in the photosynthesis reaction that creates the carbohydrates for growth and fruit production. During photosynthesis, 6 molecules of carbon dioxide react with 12 molecules of water (in the presence of light and chlorophyll) to form one six-carbon sugar molecule, 6 molecules of oxygen, and 6 molecules of water. The six-carbon sugar molecules are the building blocks for plant growth, and the oils and sugars that fill the fruit. Without water, there is no plant growth. The leaf is the factory and it needs the raw materials (water and carbon dioxide) to produce the product (carbohydrates).
- Water is involved in all of the secondary reactions, including the production of amino acids and proteins, vitamins, hormones, and enzymes.

- Water provides the transportation medium for fertilizer salts and soil minerals to move to the roots, into the roots, and up to the leaves in the xylem (water conducting) elements.
- Water fills the cells and plant structures to maintain the proper shape of the structure. A wilted leaf is lacking in water and the leaf sags. This leaf loses the ability to intercept light properly.
- Cooling. Water passing through the stomata in the leaf provides a cooling effect. An over-heated leaf will usually shut down photosynthesis and may burn.
- Leaching. Irrigation water in California always contains salts and these must be leached below the root zone for the tree to grow properly. The build-up of salts can lead to tip-burned leaves; these leaves must drop and the tree must replace them with new leaves. Excessive leaf drop will lead to low fruit production and sometimes no fruit production. Leaching with extra water is the only way to reduce salt accumulation in the root zone.

Irrigation Scheduling

Irrigation scheduling is probably the most important cultural operation in avocado production. It is important for the grower to know both **frequency** of irrigation and **how much** water to apply during an irrigation event.

- **Frequency.** A method of determining when to irrigate should be learned by all growers. A rule of thumb is that irrigation timing should occur when about 30% - 50% of water available to the plant has been depleted from the soil. In the coarse soils (such as the decomposed granite soils on the hillsides), irrigating at 30% moisture depletion is best; whereas in heavier, clay-type soils, irrigating at 50% moisture depletion is probably best.

  Checking soil moisture. There are several ways to check soil moisture content. Probably the oldest method is to manually check the water content in the soil using a trowel, shovel, or soil tube. A soil sample is removed by digging 8 to 16 inches deep in the wetted area of the root zone, and a ball of the soil is formed in the hand. The texture of soil that has about 50% available water remaining will feel as follows:

  Coarse – appears almost dry, will form a ball that does not hold shape. As mentioned, in coarse soils, it is best <u>not</u> to let the soil get this dry. A ball of soil will just begin to fall apart when the soil moisture depletion approaches 30%.

  Loam – forms a ball, somewhat moldable, will form a weak ribbon when squeezed between fingers, dark color.

  Clay – forms a good ball, makes a ribbon an inch or so long, dark color, slightly sticky.

  Probably a better method to determine soil moisture is by using a **tensiometer** (see following section on soil moisture monitoring equipment). A tensiometer is a

water-filled tube with a porous clay cup at the bottom of the tube and a pressure gauge at the top of the tube. As roots pull water from the soil near the tensiometer, a tension builds inside the tensiometer as water is pulled through the porous clay cup. (Very little water actually leaves the tensiometer due to the small pore size in the clay cup; capillary tension keeps most of the water inside). The pressure gauge measures "tension values" in centibar units (cb). These water filled tubes with pressure gauges accurately reflect the amount of energy a plant needs to extract water from the soil. In a sandy loam soil, such as the San Diego hillside soils, 30 % moisture depletion equates to a tensiometer reading of about 20 cb. This is probably when an avocado should be irrigated. By the time the irrigator gets around to watering, the soil will usually be a little drier than 20 cb. In the more loamy valley floor soils, it is time to irrigate when the gauges read about 40-45 cb (equivalent to 30 % moisture depletion). (Tensiometer readings related to soil moisture depletion from Grattan et al. 1989).

Placement of the tensionmeters requires that they be within the wetted area of the root zone, usually about 2 – 3 feet away from the mini-sprinkler on the contour of the hill. Having two tensionmeters next to each other can be helpful in deciding when to turn the system on and when to turn it off. In shallow hillside soils, a tensiometer set at 8 inches deep in the soil is used to tell when to turn the system on (when cb = 20-25), and a deeper tensiometer set at 2 feet deep will tell when to turn it off (when cb = less than 10). In the more loamy valley floor soils, the shallow tensiometer can be installed at 1 foot deep, and the deeper tensiometer can be set at 3 feet deep.

Tensiometers are successful if they are maintained on a regular basis. Problems result if the are stepped on and broken by the pickers, and if the soil becomes too dry (the porous clay cup breaks suction from the soil when the reading is over 80 cb), or excessive air bubbles enter the tube. Tensiometers are available from farm supply stores or irrigation stores for about $60 - $70.

There are other devices on the market for measuring soil moisture. Gypsum blocks are effective, but they don't read well from 0 cb to 10 cb. Although the part in the ground is inexpensive, the reading device costs over $250. There is less maintenance with gypsum blocks than with tensiometers.

There are portable meters on the market for measuring soil moisture. These meters rely on an electrical current carried by water in the soil. Even the cheap $10 meters can give a rough estimate of the soil water content. None are very effective in rocky ground because their sensitive tips break easily and rocks block the electrical signal, giving a false reading.

- **Amount of Water to Apply**
  Knowing <u>when</u> to water, as described above, does not tell a person <u>how much</u> to water (unless you are using the deep tensiometer to know when to turn off the system). The estimate of "how much to water" can be done by using CIMIS

(California Irrigation Management Information System), a system of weather stations that measure evapotranspiration (ETo) of eight-inch tall grass. Irrigation trials in California in the late 1980's and early 1990's resulted in crop coefficients (Kc) for avocado (Meyer et al. 1990). The crop coefficients were later increased slightly in the mid-1990's as a result of data from the Covey Lane irrigation trial in Valley Center, San Diego County (M.L. Arpaia, personal communication). Finally, as a result from analysis of the soil salinity in the various treatments at the Covey Lane trial, the avocado crop coefficients were increased to 0.86 for each month of the year (Oster et. al 2007). We prefer a crop coefficient of 0.7 because we can then adjust the amount of water applied using a leaching fraction and a distribution uniformity. The 0.7 crop coefficient was used in calculations in Tables 2 and 3. A step-by step procedure to calculate the amount of water to apply is presented in Appendix 1 at the end of this chapter.

CIMIS gives a fairly accurate water usage based on weather in the previous seven days, **but it does not predict the future weather**. If the available water holding capacity of the soil is known, and water is re-supplied to the soil when 30% - 50% of the moisture is depleted, irrigation scheduling can be fairly accurate. Growers should realize that, if the weather becomes suddenly very hot or windy after the irrigation is applied, they may need to water again to fill up the soil profile.

Historical Water Use. Some growers use the historical water use tables (average water use tables) to estimate the amount of water to apply. The historical water use table (Table 1) is an example of a table that was constructed from evapotranspiration data from the Escondido CIMIS station, averaged over a period of ten years (1988-1997). The author of this table used crop coefficients suggested by the USDA Soil Conservation Service (Haynes, 1998). As already mentioned, other tables (Tables 2 and 3) are based on crop coefficients developed by the University of California, resulting in slightly less water applied in the summer and slightly more in the winter. In all three of these tables, water use by an avocado tree is reported in gallons per tree per day in Escondido, an inland valley in San Diego County and in Santa Paula (an inland valley in Ventura County). **This is <u>not</u> to mean that the trees should be watered every day, it merely indicates how much water the tree is using, and is lost due to evaporation from the soil surface.**

Table 1. Historical Water Use Tables for Avocados in Escondido, CA. – Daily avocado irrigation requirements according to month of year and canopy diameter (gallons/tree/day)

Tree Spacing (feet): 20 x 20

Month	20	16	14	12	10	8
Jan	7	6	5	4	3	2
Feb	13	11	10	8	6	4
Mar	24	20	17	14	11	7
Apr	41	35	30	24	18	13
May	49	43	36	29	22	15
Jun	59	51	44	35	26	18
Jul	59	51	43	35	26	18
Aug	52	45	39	31	23	16
Sep	38	33	28	22	17	12
Oct	24	21	18	14	11	7
Nov	14	12	11	8	6	4
Dec	8	7	6	5	3	2

Notes: Table 1 represents the **average daily evapotranspiration** in gallons per day for avocados in Escondido, San Diego County. These figures are intended to be used as a GUIDE and are based on average weather conditions. Irrigation system emission uniformity is estimated to be 81%. Source of baseline data: Escondido CIMIS Station. Crop coefficients are from USDA Soil Conservation Service Manual 21. Table 1 is provided courtesy of the Mission Resource Conservation District, Fallbrook, CA.

Table 2. Historical evapotranspiration (Eto and ETc) and corrected daily water use by avocado in gallons/tree/day from a selected CIMIS station in San Diego County (Escondido)

	Monthly ETo	Daily ETo	Kc	Daily ETc	gal/day/tree (20' x 20' spacing)	gal/day/tree plus 10% leaching fraction	gal/day/tree plus leaching divided by 0.80 DU	water requirement per acre per day (109 trees/ac) gallons	water requirement per acre per month (109 trees/ac) gallons
Jan	2.53	0.08	0.7	0.06	14.3	15.7	19.7	**2,143.8**	66,458.5
Feb	2.66	0.10	0.7	0.07	16.6	18.2	22.8	**2,483.7**	69,543.6
Mar	3.91	0.13	0.7	0.09	22.0	24.2	30.2	**3,294.2**	102,119.2
Apr	5.34	0.18	0.7	0.12	31.1	34.2	42.7	**4,653.7**	139,610.0
May	6.12	0.20	0.7	0.14	34.4	37.8	47.3	**5,150.4**	159,662.6
Jun	6.88	0.23	0.7	0.16	39.9	43.9	54.9	**5,987.0**	185,597.6
Jul	7.34	0.24	0.7	0.17	41.3	45.5	56.8	**6,196.2**	192,081.4
Aug	7	0.23	0.7	0.16	39.4	43.4	54.2	**5,908.6**	183,166.2
Sep	5.49	0.18	0.7	0.13	31.9	35.1	43.9	**4,784.4**	143,531.6
Oct	4.21	0.14	0.7	0.10	23.7	26.1	32.6	**3,555.6**	110,223.9
Nov	3	0.10	0.7	0.07	17.4	19.2	24.0	**2,614.4**	78,432.6
Dec	2.48	0.08	0.7	0.06	14.0	15.4	19.2	**2,091.5**	64,837.6
Total gallons/ac for year (no rain)									**1495264.9**
Acre feet/ac for year (no rain)									**4.6**

Notes: Monthly Eto represents evapotranspiration in inches of water for 8-inch tall grass. Kc represents the crop coefficients developed for avocado by the University of California. Etc represents evapotranspiration in inches of water for avocado. DU is distribution uniformity of the average irrigation system; the lower the DU the higher the amount of water that must be applied to supply all trees with the minimum amount of water.

Table 3. Historical evapotranspiration (ETo and ETc) and corrected daily water use by avocado in gallons/tree/day from a selected CIMIS station in Ventura County (Santa Paula)

Ventura

	Monthly ETo	Daily ETo	Kc	Daily ETc	gal/day/tree (20' x 20' spacing)	gal/day/tree plus 10% leaching fraction	gal/day/tree plus leaching divided by 0.80 DU	water requirement per acre per day (109 trees/ac) gallons	water requirement per acre per month (109 trees/ac) gallons
Jan	1.95	0.06	0.7	0.04	11.0	12.1	15.1	**1,647.1**	51,059.6
Feb	2.93	0.11	0.7	0.07	18.3	20.1	25.2	**2,745.1**	76,863.9
Mar	3.3	0.11	0.7	0.07	18.5	20.3	25.4	**2,771.3**	85,909.8
Apr	4.27	0.14	0.7	0.10	24.8	27.2	34.1	**3,712.5**	111,374.3
May	5.01	0.16	0.7	0.11	28.3	31.1	38.9	**4,235.4**	131,296.1
Jun	5.98	0.20	0.7	0.14	34.7	38.2	47.7	**5,202.7**	161,283.5
Jul	6.59	0.21	0.7	0.15	37.2	40.9	51.1	**5,568.7**	172,630.1
Aug	6.71	0.22	0.7	0.15	37.7	41.4	51.8	**5,647.1**	175,061.5
Sep	5.49	0.18	0.7	0.13	31.9	35.1	43.9	**4,784.4**	143,531.6
Oct	3.78	0.12	0.7	0.09	21.3	23.4	29.3	**3,189.6**	98,877.3
Nov	2.68	0.09	0.7	0.06	15.5	17.1	21.3	**2,326.8**	69,805.0
Dec	1.95	0.06	0.7	0.04	11.0	12.1	15.1	**1,647.1**	51,059.6
Total gallons/ac for year (no rain)									**1328752.6**
Acre feet/ac for year (no rain)									**4.1**

Notes: Monthly Eto represents evapotranspiration in inches of water for 8-inch tall grass. Kc represents the crop coefficients developed for avocado by the University of California. Etc represents evapotranspiration in inches of water for avocado. DU is emission uniformity of the average irrigation system; the lower the DU the higher the amount of water that must be applied to supply all trees with the minimum amount of water.

Table 4. Water use from historical CIMIS data comparing Escondido to Santa Paula. This table assumes a year without any effective rainfall.

	Escondido			Santa Paula	
	Water requirement per acre per day (109 trees/ac) gallons	**Water requirement per acre per month (109 trees/ac) gallons**		**Water requirement per acre per day (109 trees/ac) gallons**	**Water requirement per acre per month (109 trees/ac) gallons**
Jan	2,144	66,459		1,647	51,060
Feb	2,484	69,544		2,745	76,864
Mar	3,294	102,119		2,771	85,910
Apr	4,654	139,610		3,713	111,374
May	5,150	159,663		4,235	131,296
Jun	5,987	185,598		5,203	161,284
Jul	6,196	192,081		5,569	172,630
Aug	5,909	183,166		5,647	175,062
Sep	4,784	143,532		4,784	143,531
Oct	3,556	110,224		3,190	98,877
Nov	2,614	78,433		2,327	69,805
Dec	2,092	64,838		1,647	51,060
Total gallons/ac for year (no rain)		1,495,265			1,328,753
Acre ft/ac for year (no rain)		4.6			4.1

Historical Water Use Tables – Use and Misuse

As mentioned, the historical water use tables indicate the amount of water used on a daily basis by a mature avocado tree, averaged over a ten-year period. Growers may use these tables as a guide to be used with tensiometers. For instance, if the tensiometer reads 25 cb in a sandy loam soil, and it reaches this reading in 5 days in June, the irrigation would apply 295 gallons of water (5 days x 59 gallons of water per day). Caution should be used in using historical tables (see #4 below).

Historical tables are useful in that they emphasize some important points:

1. Avocados use water all year long. Rain in the winter usually (but not always) supplies a significant amount of the irrigation requirement. Some winters (such as the 2001-02 winter) had almost no rain and growers never stopped irrigating. Other winters may have a lot of rain, but it may all come in a short period of time. In this case, the term “effective rainfall” is used. This means that the amount of rain that meets the daily water use of the tree is counted as part or all of the water use requirement. Extra water from rain is lost, but actually is beneficial to the grove in leaching salt from the soil profile.

2. Water use changes according to the season because trees use water in response to temperature, humidity, sunlight and wind. Growers that set a timeclock to run the same number of hours each week usually end up under-irrigating in the summer and over-irrigating in the cooler months. Timeclocks are useful, but they need to be re-set often to meet the changing water needs of the trees due to changing weather.
3. Water use changes according to the number of leaves (total leaf surface). Leaf surface can be roughly estimated by the diameter of the canopy. Care must be taken to control weeds in younger groves, or stumped and top-worked groves, because the weeds will compete strongly for water.
4. The problem with the water use tables is that they represent an average water use for a 10-year period of time. **Current weather may vary significantly from average weather, and the grower should have the capability to adjust water application continuously through the year.**

Using CIMIS to Estimate Water Use

As mentioned, a better way to determine water use by an avocado tree in real time is to log onto the website www.avocadosource.com and follow the directions in Appendix 1 of this chapter. This website has a link to the state's CIMIS website www.cimis.water.ca.gov, and this website is useful for retrieving current and historical CIMIS evapotranspiration data and various weather data including temperature, humidity, wind speed, wind run, and rainfall. By using the CIMIS weather stations, one can estimate actual water use by a tree during the past week fairly accurately (assuming the micro-climate at the grove is the same as that at the CIMIS station). A word of caution: CIMIS does not predict the weather, so if weather becomes hotter and drier than the previous week, adjustments should be made to the irrigation schedule to match the demand.

The CIMIS calculator is handy for avocado growers because tree spacing can be used in the calculation to give gallons/tree/day. If the sprinkler output in gallons/hr is known, the run-time will be calculated.

Soils and Irrigation

The irrigation water requirement is driven by the weather, not by the soil type. In theory, a tree in a bucket of aerated water would use the same amount of water as a tree in a sandy soil, if the soil were supplied with plenty of water. The soil is important; however, because this is where the water is stored for times between irrigations. Sandy soils hold less water than clay soils; therefore, trees on sandy soils will have to be irrigated more often, but the water use by trees on clay soils vs. sandy soils will be the same during the same period of time. In addition, the heavier soils are usually deeper than the hillside decomposed granite soils, and there is more soil available for rooting and extraction of water by the tree. Shallow soils should be irrigated more often than deeper soils.

The Water Budget Irrigation Scheduling System

In the previous sections in this chapter, we have suggested that the best method to schedule irrigations is to use CIMIS to determine "how much" water the trees are using, and to use a tensiometer or soil probe to determine "when" to water. A variation of this method is to use CIMIS to determine daily water use in inches, and to schedule irrigations when the water use (evapotranspiration) equals 30% - 50% moisture loss in the soil. Attempts have been made to water soils knowing what the moisture holding capacity of the soil in question. For instance, if a sandy loam soil holds 1 inch of water per foot of soil, the soil is 2 feet deep, and the grower wants to water when the moisture is 50% depleted, then the irrigation would commence when 1 inch of water has been removed from the soil. How does the grower know when 1 inch of water has been removed? The grower checks the CIMIS data each day and when the Etc totals 1 inch, the irrigation water is turned on and runs long enough to supply 1 inch of water, plus a leaching fraction. In this example, if CIMIS indicates an ETc of 0.2 inches per day, then there should be irrigation every 5 days (5 days x 0.2 inches ETc = 1.0 inch water plus 10% for leaching). A key to using this method is to correct for the surface area of wetted soil under the tree. For example, ETc gives you the amount of water used by the tree in that 400 sq ft (20' x 20' spacing). If you wet the entire orchard floor with your sprinkler and you apply 1 inch of water (plus 10%), you have applied the correct amount. If your mini-sprinkler wets only 50% of the surface area, and you apply 1 inch of water, you have given the tree only ½ of its water requirement. Therefore, you would have to apply 2 inches of water in this area to supply the correct amount of water to the tree.

Using a computer to keep track of daily ETc, the grower can determine irrigation frequency in a particular soil, but there should always be a tensiometer to validate the irrigation frequency. However, the accuracy using this system is variable, probably due to the variability in soils and rock content in the soils (rocks do not absorb water). If a grower would like to experiment with this system, Table 5 is useful as it indicates the available water holding capacity of different types of soils.

Table 5. Available Water Holding Capacity. If the soil type is known, the water holding capacity of the soil can be calculated. If the soil type is not known, you can consult with personnel from the local USDA – Natural Resources and Conservation Service. They can tell you the soil type from standard soil maps.

Dominant Texture	In. water/In. soil	In. water/Ft. soil
Sand, Fine Sand	.05 - .08	0.6 – 1.0
Loamy Coarse Sand	.05 - .07	0.6 – 0.8
Loamy Sand	.06 - .08	0.7 – 1.0
Loamy Fine Sand	.08 - .11	1.0 – 1.3
Coarse Sandy Loam	.09 - .12	1.1 – 1.4
Sandy Loam	.10 - .13	1.2 – 1.6
Fine Sandy Loam	.13 - .15	1.6 – 1.8
Very Fine Sandy Loam	.14 - .17	1.7 – 2.0
Loam	.14 - .18	1.7 – 2.2
Silt Loam	.15 - .20	1.8 – 2.4
Clay Loam	.17 - .21	2.0 – 2.5
Clay	.14 - .16	1.7 – 2.0

Moisture Monitoring Equipment

Soil Moisture Monitoring

Tensiometers. The use of tensiometers has partially been described under "Irrigation Scheduling - Frequency" at the beginning of this chapter. Tensiometers are the most affordable devices for growers, measure soil moisture well in the upper ranges of moisture (0 – 70 cb), and are easy to install and read. Some tips for using tensiometers are:

1. Before placing the tensiometer, fill the tube with water and place it in a bucket of water over-night. In the morning, put a portable vacuum pump on the tensiometer and draw suction with the tensiometer in the bucket (special pumps are sold at irrigation stores for this purpose). The suction will draw tiny air bubbles out of the clay cup and cause water to fill the pores in the clay. Installing a tensiometer without doing this will cause the air bubbles to block the action of water movement in the clay cup, and the device might not work.

2. A hole in the soil is created either by augering or by pounding a special tool or pipe into ground to the desired depth (in avocado we recommend 8" depth for the shallow tensiometer). The tool should be the diameter of the tensiometer.

3. Pour a glass of water into the hole and gently set the tensiometer into the correct depth. It is very important to put the water in the hole to create the soil/cup

contact. **Do <u>not</u> pound the tensiometer in with a hammer.** Remember, the clay cup is fragile and a slight crack in the cup will cause the device to fail. Pack loose soil around the tensiometer and tamp. After installation, the irrigation system should be run to wet the loose soil and settle it around the tube.

4. Tensiometers should be located under healthy trees, at least one set of tensiometers per irrigation block. If the block contains both sandy soils and heavier soils, it is best to have a set of tensiometers in each soil type, but this may necessitate a re-design of the system so that an irrigation block has only one soil type.

5. Tensiometer cups will break suction from the soil if the soil dries excessively and the suction exceeds 80 cb; therefore, the soil can never get too dry. If the instrument breaks the suction, the needle on the vacuum gauge will drop to zero. At this point we assume air has entered the clay cup and the instrument should be removed, put in a bucket of water and pumped to get the air out. Instruments can be pumped while in the ground, but only after a long irrigation has saturated the soil.

6. Air bubbles will enter the tensiometer. When this is noticed, the top should be loosened and water in the reservoir at the top can be used to fill the tube (with the help of a pencil or wire).

7. The ceramic tip of the tensiometer may need replacement over time, especially in calcareous and saline soils. Sanding the tip may help to restore some of the porosity of the tip. Many growers send in their tensiometers once a year to the company for a tip change and a gauge check. Given the high cost of water, this is a small price to pay to ensure that the correct amount of water is being applied to the grove.

8. Tensiometers should be protected from the pickers. Invariably someone will step off the ladder and step onto (and break) the tensiometer. Putting an upside down garbage can on the tensiometer is usually enough to protect it during harvest.

9. The grove irrigator should be urged to write down the readings in a notebook. (Spot checking should be done to make sure that the readings in the notebook are correct!).

Gypsum Blocks. A gypsum block works by measuring the electrical resistance which indirectly measures the moisture between two electrodes in the block. The electrical resistance is read with a portable meter. A gypsum block usually lasts 2 – 3 years in a grove soil. The older gyspsum blocks worked better in the drier ranges of soil (in excess of 33 cb), thus they were not very accurate in the moisture ranges in which avocados are irrigated. Newer type of gypsum blocks (WaterMarks®) work very good above 10 cb. Wires in the soil should be protected from mice, voles and gophers by inserting then through plastic conduit.

Neutron Probes, Thermal Dissipation Sensors, and Radio Frequency Sensors. A variety of other types of sensors are used by researchers, but seldom used by growers due

to the expense; special training required, and in some cases, in-accuracies due to rocks in the soil. Further discussion on some of these instruments can be found in Grattan et al. 1989. Radio frequency sensors are being further developed for growers and will probably be available for a reasonable price shortly.

Components of the Irrigation System

Before planting the avocado grove, the irrigation system needs to be in place, ready for the trees. The various parts of the system can be assembled and installed by the grower, but it is usually best to use a qualified low-flow irrigation system designer for the plans. Several irrigation stores and farm supply stores have qualified system designers and they might design the system for free in return for purchase of the components.

The system should be designed to meet the water needs of the mature orchard during the peak irrigation period. It should be designed so that daily operation does not exceed 16 to 18 hours. This added irrigation capacity allows for "catch-up" in case of system breakdown, such as a pump breakdown that requires repair.

Many growers have water delivered by an irrigation district, but in some instances it may be cheaper (or the only alternative) to drill a well. The use of well water should be carefully considered; well water is usually of fairly good quality if the well is located near a river or a stream that runs year-round. Water from wells that are located in areas where there is low ground water storage is often saline, the source of this water is mostly leach water from groves. Some well water can be used if liberally mixed with good quality district water, but careful scheduling and leaching is very important throughout the life of the grove. There is usually some yield reduction associated with saline well water. Well water with an EC above 1.2 is usually not suitable for avocados.

If a well is the source of water, it is important to select a **pump and motor** that will deliver the correct pressure and flow-rate at the highest possible efficiency. The system designer determines the flow-rate and pressure to be delivered by the pump, and the pump dealer matches the motor to the pump for the greatest efficiency.

If the local water district is the source of the water, the system starts with a **water meter**, usually located near the street. Meters can be very expensive as they are seen as a source of revenue for the water district (see Table 6 for an example of costs at one water district), but starting out with the correct size water meter is essential in order to avoid problems when the grove is mature.

Water Meter Capacity. Irrigation systems should be designed to handle peak flow in the summer. As outlined in Table 2, the average water to use per tree (including leaching fraction and correction for emission uniformity) in July in Escondido is 57 gallons/tree/day (20' x 20' spacing). At 109 trees per acre, 5777 gallons would be used per acre per day, or 40,439 gallons per week.

If you plan to irrigate with 30 gallon/hr mini-sprinklers once a week, your application rate would be 30 gal/hr x 109 trees per acre = 3270 gal per hour per acre. To apply 40,439 gallons, it would take 12.4 hrs. (40,439 gallons/3270 gal/hr = 12.4 hrs). During this irrigation, water would be flowing through the meter at (3270 gal/hr / 60 min/hr = 54.5 gallons per minute or 54.5 GPM.

Water meters are rated in gallons per minute (GPM) (Table 7). In our example above, this 1 acre grove, if watered once a week, would require a 1½ inch meter in order to supply water at 54.5 GPM. If the grove were to be watered in 2 sets on 2 successive days (each set watering 55 trees), the GPM would be 27.25 GPM, and a 1 inch meter would be sufficient. If the grove were to be watered in 3 sets on 3 successive days, (each set watering 36 trees) the GPM would be 18.1 GPM, and a ¾ inch meter would be sufficient.

Another way to look at this is to decide how many acres can be irrigated based on the number of hours you want to be irrigating each week (example derived from USDA Soil Conservation Service, 1985). If you plan to irrigate 7 days a week, 18 hours a day, you need to figure out how many gallons per minute will be running through the meter. Using the calculations below, your water meter capacity requirement per acre is 5.4 GPM per acre.

40,439 gallons/acre/week / (7 days/week x 18 hr/day x 60 min/hr) = 5.4 GPM per acre. The number of acres you can irrigate at full capacity is shown in Table 7.

A more realistic example (with consideration for labor and downtime for repairs) might be irrigating at 5 days per week, 16 hrs per day. In this case you would be running more water through your meter, and less acreage could be irrigated.

40,439 gallons/acre/week / (5 days/week x 16 hr/day x 60 min/hr) = 8.4 GPM per acre.

Table 6. Water meter capacity

Meter size	**Capacity in GPM (1)**	**Suggested acreage served (2)**	**Acres at 5.4 GPM/acre (3)**	**Acres at 8.4 GPM/acre**	**Connection fees for FPUD and SCWA Combined (4)**
¾ inch	16 - 24	0 - 1	3.7	2.4	$ 9,492
1 inch	40	1 - 3.5	7.4	4.8	$ 15,188
1 ½ inches	80	3.5 – 8	14.8	9.5	$ 28,476
2 inches	145	8 – 15	26.9	17.3	$ 49,358
3 inches	265	15 – 35	49.1	31.5	$ 91,124
4 inches	440	35 – 80	81.5	52.4	$ 155,168
6 inches	840	80 +	155.6	100.0	$284,760

Notes:
(1) Information provided by Fallbrook Public Utility District
(2) Information suggested by Fallbrook Public Utility District

(3) Although theoretically possible, the almost around-the-clock irrigation to serve this acreage does not allow time for days off for labor, for downtime for system repair, or for "catch-up" irrigation.
(4) Total cost of meter includes meter and service line installation, Fallbrook Public Utility District connection fee, and San Diego County Water Authority connection fee. Fees listed are only the connection fees. Fees updated on July 1, 2012. Fees will vary considerably according to water district. Information provided by Fallbrook Public Utility District.

As mentioned, it is very important to size the meter properly when the grove is installed. If the meter is under-sized, then the grove may be chronically under-irrigated and will be a poorly producing grove.

A **reduced pressure (RP) backflow device** (see local water district for requirements) is now required in California to prevent flow of fertilizer or pesticide-contaminated water back into the main water system. It is required that the backflow device be checked each year by the water district or a qualified representative of the water district. There is a fee for checking the backflow device. Many small groves (less than 2 acres) were installed using the house water meter, but backflow devices should be installed to prevent water from the grove back-flowing into the drinking water in the house. All wells should have a double check valve installed so that water from the irrigation system does not flow back into the well when the pump is turned off.

Next on the system will be **main valve**, sometimes followed by a **Bermad valve** or a valve operated by an electric solenoid connected to a timer. A Bermad valve is a valve in which a dial can be turned to select the quantity of water to be applied, after which it automatically turns off. The Bermad valve is popular with grove managers who have a lot of groves to irrigate. The Bermad valve does not require electricity, whereas the timeclock and electric valves should be located near a source of AC power. Long lasting DC batteries and solar powered systems are also available to power these valves.

A **flowmeter** and **pressure gauges** are essential parts of an irrigation system. The meter will tell how much water is being applied; knowledge that is critical for efficient irrigation scheduling. For example, a flow-rate that decreases during the season measured at the same pressure can indicate clogging of the system, while increasing flow-rate might suggest a leak in the system. It is also a good idea to compare readings from your flowmeter with readings from the water meter, to make sure the water meter is working properly. It is a good idea to locate a pressure gauge on each side of the filter; a difference in 5 psi on each side of the filter could indicate clogging in the filter and would necessitate cleaning.

Valves of various sorts help control the system. A main control valve is very important, particularly in the case of a well and pump. Sub-main valves are used in the grove to route the water to the sets. As mentioned, a backflow prevention device should be installed to prevent contamination of the water source.

Air/vacuum relief valves allow air to escape the system when the water is turned on, and allows air to enter the system when the system is shut down. The relief valves help prevent

"water-hammer" which can break an irrigation system apart. As the line drains, the valve eliminates the risk of line collapse due to vacuum and reduces the chance of soil being sucked into the system from a buried emitter. Check valves will prevent undesirable flow reversal in hilly terrain.

Injection equipment may be critical to prevent clogging of the low-flow system, however; it is also a great convenience for the application of fertilizers. There are three basic types of fertilizer injectors: Batch tanks, Venturi devices, and positive displacement pumps. The injection equipment should be used in a by-pass line, not directly into the main line going into the grove.

1. **Differential pressure tanks** or **batch tanks** are the simplest. Irrigation water flows in one side of the tank, and out the other end of the tank with the dissolved fertilizer. Batch tanks have the disadvantage that as irrigation continues the chemical concentration of the irrigation water decreases. If the chemical concentration must be kept constant, a batch tank should not be used; however, in most fertilizer applications constant chemical concentration is not important. The batch tanks should be rated to withstand the high pressures in some water systems, and they should be made of stainless steel or special coated steel. A chemical resistant plastic tank is used to store the liquid fertilizer. It is a good idea to have the storage tank sitting on a concrete pad with a concrete berm around the edges in case the plastic tanks starts to leak. A batch tank should have a flow meter out of the tank before the main irrigation line: the flow will usually be 2 – 3 gallons per minute. The batch tanks and storage tanks should be located near the road for easy loading from delivery trucks.

2. A **Venturi injector** is simple and inexpensive. It relies on a 10 to 30 percent pressure drop between the inlet and outlet of the injector in order to create suction to draw the liquid fertilizer into the irrigation system. Venturis are better at maintaining a constant concentration of material than a batch tank, but neither is as good as a positive displacement pump.

3. A **positive displacement pump** requires electricity, gasoline or water flow spinning an impellor to operate. This type of injector is the most complicated and expensive and is usually unnecessary for most avocado growers.

A **filter** should be located in the head unit, especially if the source of water is from a well or pond. With district water, the filter is normally located after the fertilizer injector in case fertilizers form precipitates that could clog emitters. If the source of water is from a well, the filter will be on the line before the injector to reduce sand wearing on the parts of the head unit. Wells should have a sand –media filter with backflushing capabilities. Some other types of filters, such as screen-vortex filters, or disc-ring filters, are also suitable.

Water from the local water district should also be filtered because dirt and grit enter their lines during repairs, and this has been known to clog drippers and mini-sprinklers. These

filters can be simple angle filters with a removable screen for cleaning, or disc-ring filters. Regular inspection and cleaning of filters should be part of the grove operations.

Mains and **submains** deliver water to the lateral lines and emitters. The size of the lines is balanced between the cost of larger PVC pipe versus the pressure losses occurring with water movement through smaller lines. In designing the system, the design engineer will take into account the slope and the friction loss in order to size the pipes properly.

Lateral lines are the pipelines that deliver water from the sub-mains to the emitters at the trees. They are usually made of polyethylene or PVC, although some older systems still use galvanized steel. The length and diameter of the laterals must not be too long, or of an incorrect diameter; if they are, the emitters may discharge water at different rates, resulting in non-uniform irrigation. Lateral lines should be installed on the contour of the hill.

Most of the older groves have buried PVC pipe between the trees, with PVC risers at the sprinklers, but many of the newer groves (especially those on the steep rocky slopes) are using the newer long-lasting polyethylene tubing on the ground, covered with leaves or soil to reduce UV degradation. An advantage of solid PVC is that they are impermeable to chewing damage by coyotes, but the risers are easily broken by pickers working in the grove. The polyethylene tubing is connected to the emitter on a stake with a ¼ inch diameter tubing; the tubing is usually about 1½ ft in length. The stakes get knocked over, but they are much easier to set back up than it is to repair a broken PVC riser in the ground. PVC lateral lines should always be glued using purple primer first, then a good quality gray glue (711) or a blue glue (not as strong but sets faster). A white (719) glue is stronger yet and is used mainly on main lines and sub-mains. It is a paste glue which fills in tiny bubbles and imperfections in the pipe.

Pressure regulators are pressure-reducing valves. They reduce a higher inlet pressure to a steady lower outlet pressure regardless of changing flow rates or varying inlet pressure. They can be installed after the filter at the head of the system as pressure regulating valves, as pre-set regulators at the head of laterals, as in–line pressure regulators, or as a part of the emitter itself (pressure compensating emitters). Pre-set regulators are usually set to hold pressure between 20 psi to 30 psi. It is best to have one installed on each lateral line as it emerges from the sub-main; it is especially important for hillside groves.

Pressure-compensating emitters are more expensive than standard emitters and may wear out sooner. In a reclaimed water trial in Escondido, pressure-compensating mini-sprinklers were used without pressure regulators on the lateral lines and 92% emission uniformity was achieved for two years in a row. During the third year, however, emission uniformity started to decrease and it was discovered that the silicon discs in the emitter were beginning to wear. Discs were replaced for ten cents a piece, and 92% uniformity was achieved again. Although wear is a problem, pressure-compensating emitters have a bright future, especially in hillside groves. Recently improvements have been made in the silicon discs, and it seems that these will be the mini-sprinklers of the future.

Pressure regulation is critical for uniform application of water, since the output of standard emitters varies with pressure. If an irrigation system has poor pressure regulation, then a majority of the trees will have to be over-irrigated so that all trees can have the optimum water application. **This is one of the main causes of water wasting (and money wasting) in avocado groves in California!**

Emitters come in all sizes and shapes as drippers, mini-sprinklers and fan sprays. Characteristic of all of them is that they do not wet the entire orchard floor. Drip emitters with outputs of ½ to 2 gallons per hour (gph) wet a small spot at the surface, thereby resulting in their being very effective at reducing weed growth.

The wetted pattern with drippers enlarges below the soil surface, and depending on the soil texture, this pattern can be a bulbous onion shape (loamy soils), or more like a stove pipe (sandy to granite soils). Much of the avocado acreage that was planted in the 1970's was set up with drip irrigation, but because of the stove pipe effect in the granite hillside soils, water distribution was not very good, and the trees grew rather slowly in some groves. Switching to mini-sprinklers improved the water distribution, was more efficient at leaching salts below the root zone, and created a larger volume of soil for roots to grow.

Drippers can be used successfully, however, if enough water is applied to meet the irrigation requirement and drippers are added as the trees age. Drippers are very good with young trees. As the trees grow, more emitters and a second lateral should be added. Typically, 6 to 8 drip emitters should be able to meet the requirements of the mature avocado tree, depending on the soil type. It should be realized that, if a tree is using 50 gallons of water a day in the summer, and the tree has eight 2-gallon per hour drippers, and the trees are being watered every three days, the run time will be a little over nine hours. In the past, some growers severely under-watered their trees by thinking the system could be turned on just once a week.

Drippers are notorious for their maintenance requirements; the tortuous path emitters have fewer problems. These emitters rely on a long, relatively large channel to reduce water flow, rather than just a small opening.

Chlorine or acid injection will prevent clogging problems, but "walking the lines" must always be done to detect clogging and other problems such as pressure blowouts, damage from weed clearing, damage from falling branches and damage from coyotes chewing on the lines.

Mini-sprinklers, most with a rotating orifice called a spinner, put out from 4 to 30 gph and wet a much larger surface area than drip emitters. Because the discharge flow is higher than that for drippers and their orifice is larger, there are less problems with clogging; however, the use of filters upstream is still important.

In sandier textured soils where lateral subsurface movement of water is small, a mini-sprinkler is often a preferred choice. One of the major drawbacks of some mini-sprinklers is that output with distance from the emitter varies. The amount of water placed on the

outside 2/3 of the wetted pattern may be as little as 1/3 of the amount placed on the inside of the wetted pattern. This distribution means that salt can accumulate in the outer part of the wetted pattern, and near the emitter the water will often go below the root zone and is wasted. The mini-sprinkler should always be placed on the up-hill side of the tree; excess water will move under-ground down the slope and wet roots down-hill from the tree trunk. Despite poor wetting patterns, we have found that roots tend to grow and develop where the water is located, so poor wetting patterns may not be as important as previously thought.

Fan sprays are often designed to overcome the poor output uniformity of min-sprinklers by directing fingers of water in various directions. There are a number of patterns that can be obtained: butterfly, rectangular, etc. Both mini-sprinklers and fan sprays can be found in less than 360° patterns. With trees that are 1 – 2 yrs old, fan sprays are often used in a 90° pattern aimed at the tree. When trees are 3 – 5 yrs old, fan sprays are often changed to 180° pattern aimed at the tree; and when trees are 6 yrs or older, emitters are changed to full circle mini-sprinklers.

At least one manufacturer makes a mini-sprinkler in which a cap snaps off, and the water is directed downward in a 1foot diameter pattern at the base of new trees. After the 2nd or 3rd year, the twirler is put back on and a full circle mini-sprinkler in created, good for the older trees.

In some groves, especially groves on heavier clay soils, the risk of trunk canker caused by Phytophthora citricola is high. In these groves it is important that the tree trunk be kept as dry as possible. Some mini-sprinklers have 300° patterns, and the dry section of the pattern can be aimed at the tree trunk.

There are many brands of emitters and many models within each brand. Although quality of low-flow emitters has markedly improved in the last 25 years, there can still be some problems in their manufacture. All emitters should be checked closely after installation to make sure water is flowing properly.

Information about specific emitter performance can be obtained from both the Center for Irrigation Technology at Fresno State University and through the Cooperative Extension in the Department of Land, Air, and Water Resources at U. C. Davis.

System Maintenance Considerations

What Is DU?

The measure of the efficiency of an irrigation system is its distribution uniformity (DU). A DU of 100% means that every emitter is putting out exactly the same amount of water. If some emitters put out more or less than the average of the whole system, the DU is less than 100%.

A high level of DU is important since the system must run longer for those trees receiving a lesser amount of water to get an adequate amount. In addition, some trees may be getting more water than they need, resulting in a condition that may not be good for the overall health of the trees, and the waste of water.

Because of pressure losses in lines and uneven terrain, it is impossible to achieve 100% DU, but 80% is attainable and 95% is not unheard-of. Even in a new, well-designed system, clogging and leaks can rapidly reduce distribution uniformity. The way to ensure a high DU is through maintenance.

DU needs only be measured once a year to evaluate the performance of a system.

How to Measure DU

Distribution uniformity is measured by selecting a specified number of emitters and measuring their output. If you have 100 emitters, lay out an evenly spaced grid across the orchard so that all parts of the orchard can be sampled. Identify a minimum of 12 emitters that will be sampled; however, the more emitters sampled, the more accurate the measure of DU.

Turn the system on, and upon going to the first emitter, invert the emitter over a graduated cylinder or measuring cup and capture the water for a specified time, such as 15 seconds. The length of time used to capture water is limited only by the capacity of the cylinder, and length of time you want to be standing there.

After sampling the emitters, arrange the amounts from low to high. Add the values up and find the average. Then look at the amounts that come from the ¼ of the emitters putting out the least (known as the "low quarter"). Take their average, and divide this by the average of all the emitters.
Multiply by 100 to get the percentage of DU. If DU is less than 80%, something must be done. If it is greater than this, it might still be possible to improve the efficacy of the system.

A convenient method of measuring drip systems is to use a 35 mm film can. When the film can fills in 30 seconds, that emitter output is 1 gallon per hour. If it fills in half the time, it is a 2 gallon per hour emitter.

To determine DU when the can does not completely fill, take the proportion of the filled can as the emitter output. For example, if the 1 gallon per hour emitter only fills a percentage of the can in 30 seconds, use the percentage in the summation of values.

Example: Martha measures 12 emitters and finds 8.5, 8, 7, 8, 7.5, 6.5, 7, 7.5, 8, 8, 8.5, 7.5 ounces in her graduated cylinder after 20 seconds of capture. The values are arranged from low to high, summed and averaged:

6.5
7
7
7.5
7.5
7.5 average = 92/12 = 7.66
8
8
8
8
8.5
8.5
92.0

The "low quarter" amounts are summed and averaged:

6.5
7
7
7.5
28 average low quarter = 28/4 = 7

The "low quarter" average is divided by the average of all the emitters:

7/7.66 x 100 = 91% DU

Martha has a system with a DU of 91%. That is pretty good and hopefully she can deep it high through proper maintenance.

What to Do About A Low DU

Presumably the system was designed correctly. If the low DU is caused by pressure differences in the system, it may be necessary to install pressure regulators or pressure compensation emitters. If there is not enough pressure to run the system, it may be necessary to break it into two or more irrigation blocks with separate valves. The major culprit of low DU, though, is poor maintenance.

Routine maintenance includes checking for leaks, backwashing filters, periodically flushing lines, chlorinating, acidifying, and cleaning or replacing clogged emitters.

Coyotes are very prone to biting and puncturing polyethylene tubing to get water. Thus, in coyote country walking the lines to inspect for leads is critical. Pup season in spring and when surrounding hills have dried out in fall are times when most coyote damage is encountered.

Often putting a pan of water out for them can decrease the amount of damage. Sometimes it may be necessary to repair the lines before every irrigation. Also, during and after harvest when emitters and lines may have been kicked or tramped on by pickers is another time when leaks or bent emitters may be found.

Clogged emitters can often be identified visually by reduced flows. Sometimes the sound is changed. Sound can be helpful also in identifying spinners on mini-sprinklers that are jammed.

Back flushing filters should be done whenever there is a 5-pound per square inch (psi) reduction in outflow pressure. Clogged filters reduce the system pressure and lower application rates.

Depending on the model of emitter, distribution uniformity may be decreased. The frequency of back flushing depends on water quality. Automatic backwashing filters are available and are relatively inexpensive. They will initiate backwashing as soon as a large enough pressure differential exists.

Flushing lateral lines, opening the lines and allowing them to run clear, is essential, especially with drip systems. Filters trap only the larger sediments. The laterals will gradually accumulate the smaller fraction which can eventually clog the emitters.

Emitters may need to be cleaned or replaced due to clogging. It is important to identify the cause of clogging. Acid and chorine injection should be a regular program if organic slimes or chemical precipitates are a problem.

If earwigs or other insects getting into the emitters are the problem, it may be necessary to replace the emitters with bug proof models. Although some brands of emitters are designed to be disassembled and cleaned, nearly all the drip emitters are sealed. Most micro-sprinkler models clog at the orifice in the head and can be cleaned and reinstalled.

Water Supply and Quality Considerations

Water Supply

Most low-flow systems require relatively frequent applications of water during peak demand periods. With drip systems it may be as frequent as once a day. In some areas water is delivered by the irrigation district on a basis that may cause difficulty in following an “on demand” frequency.

In this case it is necessary to work out an agreement with the agency supplying water. If the infrastructure will not allow frequent deliveries, a pond or tank system should be installed to provide a reservoir. If not, a well should be considered.

In Southern California, water supply to groves was cut-back by many of the water districts in the drought years in the early 1990's. Given that we live in a desert with most of our district water being delivered from the Colorado River, it would seem that our groves may be in peril in the future, especially if California enters a prolonged drought. Many growers have invested in wells (not always very productive and often saline), but a well may serve as a good back up in case of water cut-back.

Water Quality

Water quality has always been a concern in avocado production in Southern California and will be more important as growers are forced to use more ground water and reclaimed sewage water for irrigation. Avocado is one of the most sensitive of the tree crops in California to total dissolved solids (TDS, or total salts). The chloride ion, usually a major component in the salinity spectrum, is specifically toxic to avocado, causing the familiar "tip-burn". During the course of a five-year experiment with 100% ETc reclaimed water in Escondido (average EC = 1.5) yield was reduced 40% compared to yield with 100% ETc potable district water (average EC = 0.7). Adding 40% extra reclaimed water (140% ETc) still reduced yield 27% compared to 100% ETc district water, and a 50/50 blend of reclaimed/district water reduced yield 27% compared to district water (Bender and Miller, 1996).

Salts reduce yield in avocado in a number of ways:

1. As salts accumulate in soil the osmotic potential increases, making it difficult for roots to extract water from the soil. In extreme cases of salt accumulation, water may flow out of the roots into the soil, decreasing root turgor and collapsing the roots. This has been shown to happen at an EC of 4 in the irrigation water.
2. Sodium may accumulate in the soil, displacing calcium and magnesium ions; as a result soil structure deteriorates leading to poor water penetration into the soil. Fortunately this is rarely seen in hillside decomposed granite soils, but has occurred in some heavier soils with a finer soil particle structure.
3. High concentrations of salts in the water may facilitate the uptake of one or more of the ions present so that an accumulation may result in an interference in the metabolism of the plant. Avocado specifically has problems with chloride, sodium and sometimes boron.

As mentioned, avocado is especially susceptible to chloride toxicity. The chloride ions enter the roots, move to the leaves in the transpiration stream and slowly accumulate in the leaf tips over the course of the growing season. At levels over 0.25% in the leaves, tissue starts to die causing "tip-burn". This tip-burn syndrome usually begins to show in September and October. Some tip-burn is inevitable, but severe tip-burn will mean a substantial yield reduction for at least two years. Yield reduction occurs because the trees will drop the damaged leaves (the trees' method for ridding itself of the unwanted chloride) and replace them with new leaves. The new flush of leaves occurs in late winter-early spring, just when the trees should be flowering. Consequently, flowering on those trees is usually sparse and weak, with little fruit set apparent in late spring. Therefore, fruit harvest will be very light from those trees in the following year.

Sodium can also enter the roots and has been shown to accumulate in the roots, trunk and branches, possibly to toxic levels (Oster and Arpaia 1992).

Understanding the Lab Analysis. Soil samples sent into the lab are saturated with distilled water to a paste, then the water is drawn from the soil by vacuum extraction. Since salinity is the total quantity of salts dissolved in water, and salts in water conduct electricity, an easy way to measure salinity is to obtain an electrical conductivity (EC) reading between two electrodes in the water sample. This is reported to the grower in units of EC. EC was previously reported by labs in millimhos per centimeter (mmhos/cm), but now these units are reported by most labs in decisiemens per meter (dS/m). (Some municipal labs still report in mmhos/cm, a value which is 1000 times higher than dS/m.)

The electrical conductivity of the soil extract is known as EC_e, whereas the electrical conductivity of a water sample is known as EC_w.

The relationship between electrical conductivity of the water (EC_w) and total dissolved solids (or salts) (TDS) is: EC_w (in dS/m) x 640 = TDS (in mg/L)

Sometimes TDS in mg/L is reported in parts per million (ppm); the numbers are same.

Yield Reduction with Salinity. Ayers (1977) suggested that a 10% reduction in yield would be expected to occur when TDS in the irrigation water reached 760 ppm (EC_w = 1.2) assuming a leaching fraction of 10%. A yield reduction of 25% would be expected to occur when TDS reaches 1088 ppm (EC_w = 1.7) assuming a leaching fraction of 14% , and a yield reduction of 50% would be expected when TDS reaches 1536 ppm (EC_w = 2.4), assuming a leaching fraction of 20%. These are theoretical yield reductions based on tree growth in solution culture; these have not been verified by experiments with actual harvest data. As mentioned at the beginning of this section, actual harvest data from the reclaimed water trial seem to suggest that the effect on yield is even worse than that suggested by Ayers. Oster et.al (2007) calculated that yield would be reduced if the EC of the soil water increased above 0.7.

It is important to note the dominant anion in the water when evaluating salinity. For a water with bicarbonate as the dominant anion, the salinity hazard is much lower than if the dominant anion were chloride. Thus, waters with the same TDS could perform significantly different depending on the types of anions.

When chloride and sodium exceed 100 ppm in the water, or when boron exceeds 1 ppm, there should be an alerted concern for ensuring adequate leaching of the root zone to prevent accumulation of these ions.

Management of Salinity. Salinity management is essential and is inter-twined with irrigation scheduling but is not given enough attention from growers. How many growers do soil samples in the middle of summer to check salt accumulation in their soils? Very few!

- **Utilize a source of water with the best quality available.** This is by far the best management strategy. In Southern California, this usually means using district water. If cost or availability is a problem, then the following strategies should be considered.
- **Leaching**. Leaching has not been well-researched in avocados, but we believe that growers should leach every irrigation by adding extra water above the 100% ETc requirement. In the discussion of irrigation scheduling, 10% extra water was added onto the irrigation requirement (ETc) for leaching, thus every irrigation contains a leaching fraction. Is 10% high enough? Probably for district water, but the leaching fraction will vary according to the quality of the irrigation water. The classic Rhoades equation is used to calculate the leaching requirement (LR):

$$LR = EC_w/(5EC_e - EC_w)$$

where EC_w is the salinity of the applied water (expressed as electrical conductivity of the water sample), EC_e is the salinity of the soil in the wetted area under the trees.

According to the tables in the Western Fertilizer Handbook (Anon. 1990, adapted from Ayers, 1977), a soil extract EC of 1.3 is the threshold before yield reduction begins in avocado. If district water with an EC_w of 0.9 was being applied, and the soil EC_e was 1.3, the equation for leaching requirement would be as follows:

$LR = 0.9/(5 \times 1.3 - 0.9)$
$LR = 0.9/6.5 - 0.9$
$LR = 0.16$ or 16%

If a poorer quality water was being used, such as the reclaimed water in the Escondido trial, the leaching requirement would be higher:

$LR = 1.5/(5 \times 1.3 - 1.5)$
$LR = 1.5/(6.5 - 1.5)$
$LR = 0.3$ or 30%

Given that most groves in San Diego County require about 3 – 3.5 acre feet per acre per year, with a poor quality water such as described above, the grower would need to apply about 1 extra acre foot of water to maintain yield. Unfortunately, because of the toxicity of chloride specifically to avocado, there may still be a significant yield reduction, as evidenced by the results from the reclaimed water trial.
- **Soil Monitoring.** Random soil samples should be pulled with a soil probe from areas within the wetted pattern of the mini-sprinklers. The top inch of soil should be scraped off, then a sample taken from 1" – 8", and another deeper sample taken from 8" – 16". Do not take samples from the very edge of the wetted pattern as these will always be high in salinity. Send them to the lab and have them checked for TDS, chloride, and sodium. These samples should be taken in mid-summer. Results may alert you to do a long leaching irrigation before tip-burn occurs.

- **Blending.** Another strategy that has not been researched is to do preferential blending. For instance, should the better quality water be used during the more sensitive periods in the growth cycle, such as bloom and fruit set, and the more saline water used during late summer and/or winter?
- **Irrigation Frequency.** It has often been noted that by decreasing the time between irrigation sets, and keeping salts in solution with constant leaching through the root zone, avocados may be able to grow and produce with more saline water. The strategy has been used with the more saline waters in Israel, to the point where they do daily drip irrigation.

- **Rootstocks.** The Mexican race of avocado is used primarily for rootstocks in California, but it is the most sensitive of the three races to salinity. The West Indian race is more tolerant, and certain selections may show improved tolerance over those used right now. The upper threshold of chloride in the soil extract is reported to be 5 meq/L for Mexican rootstocks, but 8 meq/L for West Indian rootstocks (Anon. 1990), or 180 ppm chloride for West Indian, 145 ppm chloride for Guatemalan, and 110 ppm for Mexican rootstocks (Maas 1984, Westcott and Ayers 1984). A rootstock salinity trial was conducted in San Diego County by Crowley and Arpaia using West Indian selections from Israel versus Mexican selections from California and South Africa. The West Indians appeared to be doing better than the Mexican selections, but they were hurt badly by a freeze in January, 2007 (one of the reasons we don't use West Indians in California). The trees were brought back and harvested in 2010 (Bender et. al 2010). Surprisingly, Dusa, one of the selections from South Africa, did the best, and several selections from Israel (West Indian selections VC 801, VC 218 and VC 207) did very well with the saline water (EC of 2.5). There is a distinct possibility that, in the future, we may be able to use more saline water in conjunction with an improved rootstock for avocado.
- **Mulches and Manures.** Some mulches and almost all manures contain a lot of salt. If salinity is a problem, organic growers should change from manures and mushroom compost (a manure-based product) to composted greenwaste to reduce the salt load coming into the grove. If manures are to be used, they should be aged and allowed to sit through at least one winter of rain before being spread under the trees.
- **Sodium Adsorption Ratio (SAR).** The SAR is another water quality measure that can be helpful in alerting a grower of potential water problems. The SAR is reported on the lab analysis when you send in a water sample for an "agricultural analysis". The SAR is the ratio of the amount of sodium to the sum of magnesium and calcium in the water. When this ratio exceeds 6, there is a strong tendency for sodium to accumulate in the soil. Leaching and the application of gypsum (calcium sulfate) soil amendments should be considered when the SAR is high.

LITERATURE CITED

Anon. 1990. "Water and Plant Growth", Chapter 2, Western Fertilizer Handbook – Horticulture Edition. A. E. Ludwick (ed). Interstate Publishers, Inc., Danville, Illinois.

Ayers, R. S. 1977. Quality of Water for Irrigation. Journal of the Irrigation and Drain Div., ASCE. 103:135-154.

Bender, G., D. Crowley and M. L. Arpaia. 2010. The search for salinity tolerance; an update on a frozen rootstock trial. Topics in Subtropics 8(3): 5-7.

Bender, G. S. and R. Miller. 1996. Avocado irrigation pilot project, a five year study report. Public Works Department Utilities Division, City of Escondido.

Grattan, S. R., R. L.Snyder, and F. E Robinson. 1989. "Yield threshold soil water depletion", Irrigation Scheduling, A Guide for Efficient On-Farm Water Management. D. A. Goldhammer and R. L. Snyder (eds). Publication 21454, University of California Division of Agriculture and Natural Resources, Oakland, California.

Maas, E. V. 1984. Salt tolerance of plants: The Handbook of Plant Science in Agriculture. B.R. Christie (ed). CRC Press, Boca Raton, Florida.

Meyer, J. L., M. L. Arpaia, M.V. Yates, E. Takele, G. Bender, and G. Witney. 1990. Irrigation and fertilization management of avocado. Calif. Avocado Soc. Yrbk. 74: 71-83.

Oster, J. D. and M. L. Arpaia. 1992. Hass avocado response to salinity as influenced by clonal rootstocks". Proc. World Avocado Congress II. Vol. I:209-214.

Oster, J.D. and M.L. Arpaia. 2007. Comments about crop coefficients for Hass avocado on Mexican seedling rootstocks. Avocadosource.com.

Oster, J.D, Stottlemyer, D.E. and M.L. Arpaia. 2007. Salinity and water effects on 'Hass" avocado yields. J. Amer. Soc. Hort Sci 132(2):253-261.

Westcott, D. W. and R. S. Ayers. 1984. "Water quality criteria", Chapter 3, Irrigation with Reclaimed Municipal Wastewater – A Guidance Manual. Report No. 84-1 WR, California State Resources Control Board, Sacramento.

Book 2

Chapter 2

Avocado Fertilization

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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

Nutrients Required by Avocados and Leaf Analysis

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.

Example 1. 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).

Example 2. 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.

Book 2

Chapter 3

Diseases

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ANTHRACNOSE

Pathogen: *Colletotrichum gloeosporioides*

SYMPTOMS AND SIGNS

Anthracnose symptoms can develop on flowers, fruit, leaves, or twigs. Infected fruit is the most serious concern, but most fruit damage does not develop until after harvest. External symptoms are difficult to see on ripe 'Haas' fruit because of its dark skin color. Unhealthy or dead leaves are the most obvious symptom in groves. Spots form on leaves, beginning as yellow, then brown discolorations that coalesce into large dead areas. Necrosis occurs across or between leaf veins, on leaf margins, and most often at leaf tips. If disease is severe, trees drop many leaves prematurely. New shoots can develop brown or purplish lesions, and shoots may dieback. Infected flower heads can turn dark and die without producing fruit, or young fruit may form and then drop.

Before harvest, brown to black lesions less than 0.2 inch (5 mm) in diameter develop around lenticels on infected fruit. These small discolorations can be overlooked while fruit are still on the tree, and lesions usually do not enlarge until fruit ripens after harvest. Large lesions sometimes occur on avocados on the tree, usually after infected fruit is injured by insects or mechanical wind rubbing.

After harvest, lesions become blacker, larger, and increasingly sunken. Lesions eventually spread over the entire fruit surface and throughout pulp. When the fruit is cut in half through one of the lesions, rot extending into the flesh often exhibits a hemispherical pattern. Decayed pulp initially is firm, but becomes soft and putrid as decay advances. Pink spore masses may form on the fruit surface and, under wet conditions, a slimy mass of pink spores erupts through the fruit skin.

COMMENTS ON THE DISEASE

Colletotrichum gloeosporioides is widespread in avocado and citrus groves. It normally is of little importance because unusually large numbers of spores are required to produce damaging infections. Low humidity and no rain during much of the growing season limit disease development in California. With extended foggy or rainy conditions and mild winter temperatures, and where many dead leaves and twigs and mummified fruit accumulate in trees, the fungus can produce enough spores to cause a disease problem. Spores spread in splashing water and can cause infection anytime from fruit set to harvest.

Once infected fruit starts to ripen, temperatures of 75°F and above will accelerate anthracnose development, while temperatures below 59°F retard disease development.

Fuerte, Rincon, and Wurtz scion cultivars are more susceptible to anthracnose than Hass. Healthy trees often recover from foliar infections and defoliation once conditions become dry. Anthracnose becomes a postharvest problem after the grove has been excessively wet for extended periods. Poor growing practices and mishandling of fruit during or after harvest greatly increase the potential for significant fruit loss.

MANAGEMENT

Control anthracnose primarily with good cultural practices in the grove and proper preharvest and postharvest fruit handling. Prune out dead limbs and twigs where fungi sporulate. If many dead leaves are entwined in the canopy, knock them out of the tree. Prune low limbs to at least 2 feet (60 cm) off the ground to reduce humidity within canopies by improving air circulation. Dispose of dead wood and old fruit away from avocado trees before bloom. Prune and harvest only during dry conditions and minimize fruit contamination and injury.

Postharvest treatments should not be needed if fruit is properly handled. Keep fruit dry and cool until sold. Postharvest temperature is especially critical to anthracnose development. Cool fruit to 41°F as soon as possible after harvest. Delays of longer than 6 hours before cooling and higher pulp (air) temperatures during these delays will result in increased postharvest fruit decay. Cooling fruit promptly is of increasing importance as the season progresses because fruit ripens faster as it increases in maturity. Avoid storage temperatures below 41°F because chilling injury may occur. Market fruit rapidly.

Chemical Control: Anthracnose is rarely significant enough in California avocado groves to warrant fungicide application. Copper compounds thoroughly sprayed on healthy tissue can prevent infection.

Common name (trade name)	**Amount/Acre**	**R.E.I.+ (hours)**	**P.H.I.+ (days)**

When choosing a pesticide, consider information relating to environmental impact. Not all registered pesticides are listed. Always read label of product being used.

A. COPPER HYDROXIDE
(BlueShield, Champ, Kocide, etc.) Label rates 24 0
MODE OF ACTION GROUP NAME (NUMBER[1]): Multi-site contact (M1)
COMMENTS: Apply as a trunk spray. Make the first application at the start of the growing season and repeat every 60 days. Repeat applications at 60 days are important; a single trunk spray is not sufficient to arrest the disease. Do not exceed 20 lb/acre/year.

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment until harvest. In some cases the REI exceeds the PHI. The longer of these two intervals is the minimum time that must elapse before harvest.

1 Group numbers are assigned by the Fungicide Resistance Action Committee (FRAC) according to different modes of actions (for more information, see http://www.frac.info/). Fungicides with a different group number are suitable to

alternate in a resistance management program. In California, make no more than one application of fungicides with mode of action Group numbers 1, 4, 9, 11, or 17 before rotating to a fungicide with a different mode of action Group number; for fungicides with other Group numbers, make no more than two consecutive applications before rotating to fungicide with a different mode of action Group number.

PRECAUTIONS (see last page of this chapter)

ARMILLARIA ROOT ROT (Oak Root Fungus)

Pathogen*: Armillaria mellea*

SYMPTOMS AND SIGNS

Armillaria is a soil-borne fungus that causes a root and trunk rot of avocado. The fungus can become well established in roots and the root crown before any symptoms become visible above ground. Infected trees usually die prematurely, and young trees often die quickly after infection. Mature trees may die quickly or slowly, or may recover at least temporarily if conditions become good for tree growth and poor for disease development.

Wilted, downward-hanging foliage is often the first obvious symptom of Armillaria root rot. Other symptoms include foliage yellowing, leaf drop, and dieback of upper limbs. During the rainy fall and winter, groups of short-lived mushrooms often grow around the base of *Armillaria*-infected trees.

The most reliable sign of Armillaria root rot is fungal growth in cambial tissue. If trees exhibit aboveground symptoms of infection, cut off bark at the base of the tree and crown to diagnose the presence of *Armillaria* mycelium. Fungal mycelia are whitish and have a strong mushroom odor. Growth typically occurs in patches in the cambium and inner bark. Large roots can be infected throughout their diameter.

COMMENTS ON THE DISEASE

Armillaria root rot infects many crops and native and ornamental plants. Common hosts include avocado, cherimoya, citrus, and oaks. The fungus persists in infested roots and wood in soil, infecting new plantings and spreading to infect nearby plants.

Armillaria mycelium persist for years under the bark of diseased roots or the root crown. The fungus spreads from tree to tree mainly by rhizomorphs growing along or out from diseased roots and eventually contacting and infecting the healthy roots of adjacent trees. *Armillaria* also spreads by any activity that moves soil containing infested wood fragments, such as during cultivation.

Long after the aerial parts of a tree are gone, *Armillaria* can remain alive in roots and stumps. When avocado trees are planted, new roots grow into contact with *Armillaria*-infected roots or infested wood pieces, and the new tree becomes infected. *Armillaria* can also be introduced on infected nursery stock.

Armillaria can spread by root-to-root grafts and by cordlike rhizomorphs, which resemble small dark roots. In contrast, healthy avocado roots are lighter-colored, usually light brown to whitish. When pulled apart, rhizomorphs have a cottony interior, while the center of a healthy root is solid and woody. Rhizomorphs grow on buried wood, the surface of diseased roots and root crowns, and short distances on or through soil. Infection occurs when rhizomorphs contact and directly penetrate the root bark.

MANAGEMENT

Look for diseases and disease-promoting conditions regularly throughout the grove (see MONITORING DISEASES AND DISEASE-PROMOTING CONDITIONS). Provide a good growing environment and proper cultural practices and use good sanitation to manage Armillaria root rot. Providing good drainage and avoiding excess irrigation are important. *Armillaria* fungus is very susceptible to drying. Excavating soil around the trunk to temporarily air-dry the root crown can prolong the life of citrus trees and may also be effective on avocado, but apparently has not been tested on avocado. Shade any exposed root crowns from sunburn. Once trees die, remove them and any immediately adjacent trees that may also be infected. Remove the stumps and as many root pieces from the soil as possible. Thoroughly clean all soil from equipment and leave soil on-site before removing equipment. Consider replanting only with crops not susceptible to *Armillaria.*

AVOCADO BLACK STREAK

Pathogen: unknown

SYMPTOMS AND SIGNS

Black streak appears as an elongated dark discoloration on bark. Small cankers can develop in a direction that parallels the direction of limb or trunk growth but sometimes cankers encircle limbs or the trunk. On green shoots and young trees, lesions look like black blotches with distinct margins. Cankered bark develops shallow cracks that ooze sap, which dries as a brownish or white powder on the bark surface. This exudate is readily washed off by rain or sprinklers, and in the absence of the powder the canker can be difficult to see externally on bark. Black streak lesions can be very small or encompass the greater part of the trunk. Cankers often first appear on the lower trunk and the underside of lower limbs and then later appear higher in the tree. Scraping off bark over the canker reveals shallow reddish brown to black areas. This discoloring forms mottled areas of dead and live tissue or merges into one large necrotic area. It rarely extends into the wood and can be removed easily by inserting a knife blade under the canker and prying upwards. Because trees can die with very few lesions, the lesions appear to be a symptom of the disease and not the cause of tree death.

COMMENTS ON THE DISEASE

Black streak develops under adverse growing conditions and is a serious disease that can kill avocado trees. The specific cause of the disease is unknown and apparently is not a viroid as was previously believed.

Many symptoms of avocado black streak are similar to those from other causes; the appearance of the cankers is the most diagnostic characteristic of this disease. Avocado black streak appears after prolonged periods of environmental or cultural stress, especially conditions of high salinity and insufficient water. An affected tree can decline gradually and may eventually die, or it may collapse and die rapidly. Conversely, with improved cultural practices trees can recover and symptoms can virtually disappear.

Avocado black streak may occur wherever Guatemalan cultivars are grown in California. All ages of trees are affected, and symptoms have been observed on trees ranging from 1 year to over 35 years old. Many groves are apparently free of the disease, and disease incidence varies considerably within affected groves. Avocado black streak symptoms typically are most severe on trees that appear to be the most stressed.

MANAGEMENT

Current management of avocado black streak consists of maintaining plant health with good fertilizer and irrigation practices, and preventing stress. Adequate irrigation with high quality water is believed to be especially important.

AVOCADO ROOT ROT (Phytophthroa Root Rot)

Pathogen: *Phytophthora cinnamomi*

SYMPTOMS AND SIGNS

Foliar symptoms of avocado root rot include small, pale green or yellowish leaves. Leaves often wilt and have brown, necrotic tips. Foliage is sparse and new growth is rare. There may be little leaf litter under infected trees. Small branches die back in the tree top, exposing other branches and fruit to sunburn because of the lack of shading foliage. Fruit production declines, but diseased trees frequently set a heavy crop of small fruit.

Small, fibrous feeder roots are scarce at advanced stages of this disease. Where present, small roots are black, brittle, and dead from infection. Foliage is wilted even when soil under diseased trees is wet. Affected trees will decline and often die either rapidly or slowly.

COMMENTS ON THE DISEASE

Phytophthora root rot is the most serious and important disease of avocado worldwide. The causal agent, *Phytophthora cinnamomi,* has over 1,000 hosts, including many species of annual flower crops, berries, deciduous fruit trees, ornamentals, and vegetables.

Root rot thrives in areas of excess soil moisture and poor drainage. Trees of any size and age may be affected. The pathogen is easily spread through movement of contaminated nursery stock of avocado and other plants, on equipment and shoes, in seed from fruit lying on infested soil, or by any activity by people or animals that moves moist soil from one place to another. *Phytophthora* produces four different spore stages that are involved in disease development and survival: sporangia, zoospores, chlamydospores, and oospores. They spread easily and rapidly in water moving over or through the soil. Entire areas can readily become infested. *Phytophthora* species are not true fungi but have many fungal-like attributes.

MANAGEMENT

Look for diseases and disease-promoting conditions regularly throughout the grove by MONITORING DISEASES AND DISEASE-PROMOTING CONDITIONS. Use an integrated approach that emphasizes prevention. Purchase certified disease-free nursery stock (if available) and root rot-resistant cultivars. Inspect roots before planting and if their health appears questionable seek advice from a farm advisor or private consultant before planting trees. Employ stringent sanitation measures, good cultural practices, and appropriate chemical controls. The most important control of this disease is good irrigation management. For example, where new trees are interplanted among older trees, separate irrigation lines are needed to insure appropriate irrigation timing and amounts for the different aged trees.

Cultural Controls Use cultural practices that promote growth of the tree while discouraging growth of the pathogen.

Provide favorable soil conditions. In new plantings, avoid soils favorable to root rot

development, including poorly drained, saline, or pathogen-infested soils. Plant on well-drained soil, or improve drainage by planting on a soil berm, deep-ripping impervious subsoils, or installing subsurface drains. In established plantings, manage soils carefully so that excess moisture does not accumulate.

Use certified disease-free nursery stock. Request certified, disease-free plants, especially when planting new areas, because disease is especially damaging to young trees. Nurseries should disinfest propagation material, such as by immersing seed in water at 120 to 122°F for 30 minutes and then quickly cooling it. Nurseries should also use pasteurized soil mix, clean irrigation water from deep wells or disinfested surface water, and stringent sanitation to prevent pathogen introduction and spread. Nurseries that rely only on fungicides for disease prevention can promote fungicide resistance and produce symptomless plants with infections that develop after planting.

Plant resistant rootstocks. Certain rootstock cultivars are more tolerant of root rot, including Dusa, Latas, and others. Newer recommended cultivars such as Uzi and Zentmyer may also be available. Barr Duke, Duke 7, and Duke 9 can also be good rootstocks but have less *Phytophthora*-resistance than some newer cultivars. To obtain rootstocks with maximum resistance to avocado root rot, choose rootstocks produced by a nursery using the clonal method because clones of recommended cultivars are more resistant than seedlings. Be aware that resistant rootstocks are not immune to root rot; if they are planted or maintained under adverse conditions, they may be killed by the combination of adverse conditions and the pathogen.

Prevent soil or water movement from infested areas. Excluding *P. cinnamomi* from an uninfested grove is the most economical control method. Install water-tight drains to divert surface runoff if a diseased area lies above a healthy grove. Control gophers, as their burrows can provide means of moving the fungus in water. Do not work in infested groves when the soil surface is wet; *Phytophthora* is readily spread by activities such as walking or driving on infested wet soil. Bring only clean bins and equipment into groves. Begin harvesting and other activities in healthy areas of the grove; work in diseased areas last to minimize pathogen movement.

Soil solarization. Soil solarization can be effective for treating infested soil following tree removal in warm inland areas of California through a process in which radiant heat from the sun is trapped under clear polythene sheets laid on the surface of the soil. Solarization is effective when soil temperatures in the top 2 inches of soil reach between 108° to 131°F.

Establish a barrier. If the fungus occurs in only one area of the grove and cannot spread downhill in surface runoff or drainage water, erect a physical barrier and post warning signs to prevent people and activities from spreading the fungus into protected areas. Establish the barrier around healthy sections of the grove, at least two tree rows beyond where tests indicate the fungus is present.

Irrigate carefully. Appropriate irrigation is the single most critical practice for improving tree health and managing root rot. Schedule irrigation frequency and amount using

sophisticated methods, such as based on local evapotranspiration or by installing soil moisture monitoring devices, such as tensiometers. Good irrigation management is especially important where trees are diseased, near the margins of diseased areas of groves, and beneath thick mulch. It may be necessary to replace irrigation emitters around unhealthy trees by installing lower output sprinklers to avoid saturating the soil. Do not water soil that is already wet because it will become waterlogged and accelerate disease.

Use high-quality irrigation water. Irrigation water with high overall salinity or an excess of boron, chloride, or sodium promotes infection of roots by *Phytophthora. Phytophthora* can contaminate irrigation water, such as surface water that is runoff from infested soil. The extra cost of purchasing high quality water can often be justified by reduced disease and increased crop quality and yield.

Apply gypsum and mulch. Create soil conditions that suppress development of Phytophthora root rot. Apply gypsum under the canopy of each tree, perhaps 25 lb beneath a medium-size tree. Apply at least 4 to 6 inches of coarse organic mulch onto soil beneath canopies, but keep mulch several inches away from the trunk. Use coarse organic mulch such as avocado trimmings, composted greenwaste (yard trimmings), or hardwood chips. Mulching promotes development of beneficial microorganisms antagonistic to *Phytophthora cinnamomi* and reduces the adverse effects of saline soil and water. Gypsum supplies calcium, which suppresses the formation of *Phytophthora* spores. Apply mulch and gypsum when the orchard is being established. Consider periodically applying additional mulch containing mostly ground wood, which provides better *Phytophthora* control than naturally dropped leaves. Reapply gypsum as the old material dissolves from view.

Provide appropriate nutrition. Moderate amounts of nitrogen promote good growth that helps avocado better tolerate root rot. Avoid excess amounts of fertilizer, especially avoid large amounts of animal manures or other products high in ammonia or salts. Avocado roots are sensitive to ammonia and salts.

Rotate crops. Replanting infested soil to resistant crops for at least several years reduces avocado root rot propagules in soil. The fungus has a wide host range, but plants such as cherimoya, citrus, and persimmon are highly resistant to the *Phytophthora* sp. causing *Phytophthora* root rot in avocado.

Chemical control. Certain phosphonate fungicides (phosphorous acid and phosphonate compounds) can markedly improve trees' ability to tolerate, resist, or recover from infection by *Phytophthora cinnamomi.* Good control requires using fungicides in combination with other recommended practices, such as careful irrigation practices and applying wood chip mulch. Phosphonates cannot eradicate *Phytophthora* from the grove and avocado root rot requires ongoing management throughout the life of the trees.

If only a few trees are affected, and the disease is detected early, trees can be cut off at ground level and the soil fumigated with the maximum rate of fumigant. However, eradication of *P. cinnamomi* from infested field soil is extremely difficult and fumigation is not recommended. Often *P. cinnamomi* re-invades fumigated soil and the avocado root rot

becomes worse than before because the soil microbial community and competing microorganisms have been reduced by the fumigation.

Application methods. Varying with the product label, phosphite fungicides may be sprayed onto bark or foliage, injected into soil with irrigation water (chemigation), or injected into trunk vascular tissue. If permitted on the product label, proper trunk injection is generally the most effective application method when treating severely diseased trees. Proper application timing is critical. Phosphites can move both up and down within plants. To induce phosphites to move to roots, apply phosphites prior to initiation of new root growth. This effective application time is when about three-fourths of leaf flush is complete or just as new leaves harden, usually in late spring (May) and summer (August). Optimal application dates vary according to local conditions. If applied during early flush or when many new leaves are flushing, most of the phosphite will move to leaves and provide little *Phytophthora* control. If injected when new leaves are hardening, phosphites will move upward in the xylem stream, then move downward in the phloem where they can encourage healthy new root growth.

Inject trunks using proper equipment, such as spring powered or gas powered (CO_2) injectors. Drill relatively small diameter holes to the depth of the drill bit, at a slightly downward and sidewise angle so that more of the phosphonate material is deposited in the outer wood. Larger holes do not heal properly and continuous weeping and bacterial infection in the holes often occurs. Drill holes into smooth sections of the trunk or main limbs, avoiding knots and side branches. Where feasible, locate holes above any trunk area that is wetted by mini-sprinklers to facilitate injection wound closure.

Application (spraying) directly onto bark is usually not effective for managing avocado root rot. Bark application may be more effective in managing the trunk canker fungus *Phytophthora citricola.* Application through the irrigation system is more effective in slowing down the spread of avocado root rot disease than it is in controlling disease in already infected trees.

Common name (trade name)	**Amount/Acre**	**R.E.I.+ (hours)**	**P.H.I.+ (days)**

When choosing a pesticide, consider information relating to environmental impact.

NONBEARING TREES

A. ALUMINUM TRIS PHOSPHONATE

(Aliette) WDG	Drench: 5 oz/10 gal	12	365
(Aliette) WDG	Foliar: 5 lb/100 gal	12	365

COMMENTS: For drench application: apply 1 qt per pot or sleeve of each tree 2-3 days before transplanting. For foliar application: begin application at transplanting or the start of the growing season and continue for up to 4 applications/year at 60-day intervals.

BEARING TREES

A. PHOSPHOROUS ACID

(Agri-fos, Fosphite)	1–2 qt	4	0

MODE OF ACTION GROUP NAME (NUMBER[1]): Phosphonate (33)
COMMENTS: Do not apply with copper-based fungicides or fertilizers; allow 10 days before applying copper-based compound after phosphorous acid treatment or 20 days before applying phosphorous acid after copper treatment. Do not apply to dormant or heat- or moisture-stressed trees.

B. ALUMINUM TRIS PHOSPHONATE

(Aliette) WDG	5 lb	12	12 hours

COMMENTS: Begin application at the start of the growing season and repeat every 60 days. Do not exceed 20 lb/acre/year.

C. MEFENOXAM

(Ridomil Gold) EC	Label rates	48	0 - drench;
		48	28 - chemigation

MODE OF ACTION GROUP NAME (NUMBER[1]): Phenylamide (4)
COMMENTS: Apply as a drench or by chemigation. Trials indicate this material is less effective on older trees, but is effective for a few years on young trees that have been replanted into *Phytophthora*-infested soil.

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

1 Group numbers are assigned by the Fungicide Resistance Action Committee (FRAC) according to different modes of actions (for more information, see http://www.frac.info/). Fungicides with a different group number are suitable to alternate in a resistance management program. In California, make no more than one application of fungicides with mode of action Group numbers 1, 4, 9, 11, or 17 before rotating to a fungicide with a different mode of action Group number; for fungicides with other Group numbers, make no more than two consecutive applications before rotating to fungicide with a different mode of action Group number.

PRECAUTIONS (see last page of this chapter)

BACTERIAL CANKER

Pathogen: *Xanthomonas*

SYMPTOMS AND SIGNS

Bacterial cankers appear as slightly sunken, dark areas on the bark and vary in size from about 1 to 4 inches in diameter. Bark around cankers may crack. Fluid often oozes and dries, leaving a white powder around or over the lesion. Usually cankers appear and spread upward in a line on one side of the trunk or branch. Cutting under the bark surface reveals a decayed, reddish brown necrotic pocket, which may contain liquid. Dark streaks in the wood radiate out both above and below from the lesions. These necrotic streaks are usually in the bark cortex or xylem, but sometimes extend deeper into the center of branches or trunks. Often the disease will become inactive and canker wounds will close, except that a bark flap over the wound will remain.

Severely affected trees may have pale, sparse foliage and low yields on one branch or on the entire tree, but this is rare. Sometimes newly planted trees become stunted with many lesions; new branches may grow from buds below the affected part.

COMMENTS ON THE DISEASE

Bacterial canker is widespread but is a relatively unimportant disease. In some groves the bacterium infects over 60% of the trees, but most of these trees will perform well if otherwise cared for appropriately. The pathogen can also be introduced through nursery practices.

Xanthomonas campestris is a common bacterium on avocado leaves and green twigs, where it apparently is harmless. Its reproduction and spread is favored by wet plants and humid conditions. It can infect through wounds and branch stubs and spread within the plant's vascular system. Drought stress and boron deficiency may promote development of disease symptoms. The disease most typically shows up in drought years, at the end of irrigation lines, or at points where irrigation system water pressure is lowest.

MANAGEMENT

Normally the disease is a minor problem. Usually no control is necessary on established trees. If the disease is severe and yield is affected, remove the tree. Keep trees healthy and provide good cultural care. Provide appropriate amounts and frequency of irrigation and good uniformity of water distribution among trees. Use certified, disease-free nursery stock if available. Regularly inspect young trees and remove and dispose of young trees if they are infected. Nurseries should use stringent sanitation, regularly screen stock for disease, and dispose of affected trees so they are not planted.

DEMATOPHORA OR ROSELLINIA ROOT ROT

Pathogen: *Dematophora necatrix*

SYMPTOMS AND SIGNS

Yellow foliage, shriveled fruit, and little or no new growth are symptoms of Dematophora root rot. Cottony, white mycelia cover small feeder roots, and roots decay. Mycelia grow into soil and upward in the tree, forming small, pale patches under or in bark of major roots, the root crown, and lower trunk, which eventually decay. Older mycelium become gray or black. The fungus can also cause a purple canker in wood at the root crown of young trees. Diseased trees will defoliate and always die prematurely, usually within 1 to 3 years of initial infection.

COMMENTS ON THE DISEASE

Dematophora root rot is not common in avocado in the United States. Although uncommon, when present, it is a very serious disease and requires prompt action to prevent its spread to other trees.

Dematophora root rot is also called white root rot in reference to its pale mycelium, or Rosellinia root rot because the fungus is named *Rosellinia necatrix* during another stage of development. The fungus persists for years in buried wood and organic matter in soil. It spreads to nearby trees through root grafts and can also be moved longer distances in infected soil or wood. Spores apparently are not important in causing disease.

The whitish mycelial patches of *Rosellinia* resemble those of *Armillaria,* but *Rosellinia* mycelia lack the characteristic mushroomlike odor produced by *Armillaria.* One method to diagnose *Rosellinia* is to seal infected wood, roots, or soil in a moist container. Extensive white mycelium will grow within a few days. However, because of its severity and persistence, seek expert assistance if Dematophora root rot is suspected.

MANAGEMENT

The biology and management are much the same as described for *Armillaria.* Uproot and dispose of infected trees. Remove immediately adjacent trees that may also be infected. Remove as many root pieces from soil as possible and trench around the infected site to break root grafts. Establish a dry zone and prevent soil movement or water runoff from that site. Fumigate or solarize the ground well before replanting.

DOTHIORELLA CANKER

Pathogen: *Botryosphaeria* and *Fusicoccum* spp.

SYMPTOMS AND SIGNS

Dothiorella cankers exude reddish sap that dries to a brown and white powder. Bark may be cracked, darkly discolored, or slightly sunken. With older cankers, bark may shed or can be easily removed from the damaged area. Under the canker, inner bark and wood is brown, orangish, or red, instead of the normal pale color. Brown dead leaves remain attached if much of the xylem becomes infected and rapidly kills the entire limb.

Dothiorella canker can be a serious problem in new plantings; stock sometimes arrives from the nursery with latent infections in the graft union. Where infection kills the graft union, the dead scion retains a dry brown canopy, while shoots and green leaves sprout up from the rootstock. The graft union may be unusually swollen and rough before the young tree dies. Cutting inside at the graft union reveals dark, discolored wood that can extend through the entire width of the small trunk.

Dothiorella canker is usually of minor importance in established, older trees. Scattered small branches and sometimes large limbs can die back. Usually the entire tree is not affected and the tree remains productive. In severe cases, the main trunk may be girdled, killing the tree.

COMMENTS ON THE DISEASE

Several pathogens cause Dothiorella canker on trunks and large limbs. This disease was formerly attributed to a *Botryosphaeria* anamorph, *Dothiorella gregaria* (teleomorph *B. ribis),* and the disease was known as Dothiorella canker. *Neofusicoccum luteum* is now known to be the most common cause of Dothiorella canker disease on avocados in California. *Botryosphaeria dothidea* also causes Dothiorella canker in California. Several other *Botryosphaeria, Diplodia,* or *Fusicoccum* spp. cause DOTHIORELLA FRUIT ROT, DOTHIORELLA LEAF AND STEM BLIGHT, and cankers and these fungi can not be reliably distinguished during certain stages of their growth, except with molecular tests such as PCR (polymerase chain reaction).

Dothiorella cankers closely resemble Phytophthora canker. Dothiorella cankers usually occur higher above the ground, beginning around the first main branch crotch or higher. *Dothiorella* can infect much smaller limbs, such as twigs and small branches, as well as the upper trunk and large limbs. When cut into with a knife, Dothiorella cankers sometimes extend deep into wood, while Phytophthora canker discolors only a shallow layer of outer wood. Except when trees are young, Dothiorella canker is usually not as serious as diseases caused by *Phytophthora* spp.

Botryosphaeria spp. can infect only through wounds. Heavy rainfall causes increased spore production and infection. Spores spread in air and water. Trees that are stressed are much more susceptible to this disease. Common stresses include poor irrigation, low quality irrigation water, nutritional deficiencies, or severe insect and mite feeding. Drought stress especially promotes symptom development and triggers latent infections to develop into

disease. Mexican rootstocks are generally much more resistant to this disease than are Guatemalan cultivars.

MANAGEMENT

Look for diseases and disease-promoting conditions regularly throughout the grove using recommended monitoring methods. Consider planting rootstock cultivars that have some resistance to this disease. Where Dothiorella canker is a problem, rely primarily on sanitation and good cultural practices to control it. Prune out dead limbs and twigs, where the pathogen pycnidia (spore-forming structures) and spores persist. Dispose of dead wood and old fruit well away from avocado trees. Prune and harvest only during dry conditions. Correct environmental and nutritional stresses, and minimize other pest problems. Appropriate amount and frequency of irrigation is especially important. Leach soil periodically and use low salinity water if salt toxicity is a problem. Nurseries should use stringent sanitation measures, disinfest propagation material, and consider treating graft unions with fungicide.

DOTHIORELLA FRUIT ROT

Pathogens: *Botryosphaeria* and *Fusicoccum* spp.

SYMPTOMS AND SIGNS

Dothiorella fruit rot is usually not obvious while fruit is on the tree. Small, superficial lesions can develop on fruit in the grove, but the disease usually is apparent only on fruit that is very overmature, hanging on dead limbs, or dropped on the ground.

Infections usually become active after the fruit is picked and starts to soften. Initially lesions are small, irregular brown to reddish discolorations on the peel. Under the peel, brown streaks running lengthwise in flesh may be observed because decay initially spreads along vascular bundles in the fruit. Small, purplish brown spots may appear on any part of the fruit, most often at the stem end. As fruit ages, the surface lesions gradually enlarge and become sunken and black. Fruit shrivels, and the black surface can become covered with grayish brown fungal mycelium and spores. Decay then spreads throughout the entire fruit, causing the flesh to turn brown and watery with an offensive odor.

COMMENTS ON THE DISEASE

Postharvest rots are a relatively minor problem of avocados in California. Dothiorella fruit rot is caused by several *Botryosphaeria* and *Fusicoccum* species. *Neofusicoccum luteum* and *Botryosphaeria dothidea* are common causes.Disease was formerly attributed to *Dothiorella gregaria,* hence the name Dothiorella fruit rot. Several *Botryosphaeria, Diplodia,* and *Fusicoccum* spp. fungi can cause Dothiorella fruit rot, canker, or leaf and stem blight.

These pathogens spread by wind blown or water splashed spores produced in or on cankers, dead twigs, and dying fruit and leaves. Spores infect through wounds and lenticels (tiny natural openings) on fruit. Infection occurs in the grove, but disease usually is not obvious until after fruit is picked and starts to ripen.

Damage from Dothiorella fruit rot closely resembles that from anthracnose and stem end rot, and fruit damaged by these pathogens are usually culled and lumped together in the packing house. During its early stages, Dothiorella fruit rot lesions can occur anywhere on the avocado skin, while stem end rot initially occurs only near the narrow end of fruit, where decay begins under the button. Anthracnose produces pink sporulation on the fruit surface, in contrast with the grayish mycelium from Dothiorella fruit rot.

MANAGEMENT

Use good sanitation and optimal cultural practices to minimize fruit rots. Prune out dead limbs and twigs. Dispose of dead wood and old fruit away from avocado trees. Prune and harvest only during dry conditions. Correct environmental and nutritional stresses, and minimize other diseases and disorders that injure bark, fruit, or leaves. For example, anything that causes a large number of leaves to develop necrosis will cause fruit decay spores to become abundant on those leaves and spread to infect nearby fruit. Provide sufficient irrigation with appropriate placement of high quality water to minimize this and many other avocado problems. Follow the same postharvest handling instructions for fruit as discussed in the ANTHRACNOSE section.

DOTHIORELLA LEAF AND STEM BLIGHT

Pathogens: *Botryosphaeria* and *Fusicoccum* spp.

SYMPTOMS AND SIGNS

Small branches and leaves can be killed, leaving entirely brown dry leaves that usually remain on dead limbs for months. Dead branches may retain fruit, which blackens and shrivels. When leaves are infected but are attached to healthy stems, leaves often are mostly green with necrosis only in brown patches along leaf margins and at tips. When stems are healthy, typically only some of the leaves on that stem have necrotic patches. Within a tree, usually only one or a few scattered stems have necrotic leaves, and all leaves on most branches will show no symptoms of infection.

COMMENTS ON THE DISEASE

Dothiorella leaf and stem blight is caused by several similar fungal species named in DOTHIORELLA CANKER. Dothiorella leaf and stem blight is a common disease of minor importance to the health of established trees. Stem and leaf blight commonly develops during hot weather and where irrigation is not adequately managed. Otherwise healthy trees tolerate scattered necrotic leaves and a few branches killed by Dothiorella disease. The primary concern is fruit and nursery stock health. Copious spores are produced on dead limbs and leaves. Spores inoculate fruit on the tree, sometimes causing significant fruit rot and stem end rot after harvest. Contamination of plant parts used for propagation can kill young trees because of infection of the graft between rootstock and scion.

MANAGEMENT

Prune off dead limbs and twigs during dry conditions and dispose of dead wood and old fruit away from avocado trees. Knock down groups of dead leaves stuck in trees. Maintain a thick layer of mulch to hasten decomposition of fungi on the ground. Use good sanitation and optimal cultural practices to minimize disease as discussed in DOTHIORELLA CANKER and DOTHIORELLA FRUIT ROT. When weather changes from cool to warm, appropriately modify the irrigation program, and pay special attention to irrigation needs during periods of hot weather.

PHYTOPHTHORA CANKER AND CROWN ROT
(Citricola Canker)
Pathogen: *Phytophthora citricola*

Phytophthora cankers usually originate at or below ground level but can occur higher above ground, especially where trunks or lower limbs have been wounded. The canker appears as a region of dark bark that often exudes red resin, which becomes brownish to white and powdery as it dries. Cutting away the superficial canker reveals an orange-tan to brown lesion, instead of the normal white or cream-colored tissues. The lesion may have a fruity odor when exposed. The lesion infects the inner bark and outer layer of wood, killing cambium and phloem. Discoloring rarely extends deeper into wood than the outer woody layer. Depending on the local conditions and rootstock, the tree may ward off the disease and the lesions may heal.

Affected trees show a gradual loss of vigor and decline of the top. With advanced disease, foliar symptoms of Phytophthora canker differ some from symptoms caused by avocado root rot *(Phytophthora cinnamomi)*. With Phytophthora canker, leaves retain their normal size, there is a gradual loss of canopy, and branch dieback (staghorning) is less typical. Unlike root rot, canker and collar rot affects the major tree roots and the smaller feeder roots are usually still present. Occasionally, in advanced stages, trees will die suddenly, with leaves turning brown within a short period of time. Confirmation of *P. citricola* is achieved by laboratory tissue isolations onto selective media for *Phytophthora.*

COMMENTS ON THE DISEASE
Phytophthora canker is the most important of several canker diseases infecting avocado and is second only to root rot in severity among diseases of avocado. *Phytophthora citricola* infects the root crown and lower trunk and limbs of older trees, causing diseases called Phytophthora canker, Citricola, Citricola canker, Phytophthora canker and collar rot, or Phytophthora canker and crown rot. *Phytophthora citricola* also causes PHYTOPHTHORA FRUIT ROT. It has a wide host range, including cherimoya, cherry, fir, and walnut.

Phytophthora citricola damages trunks and limbs and only the larger roots, while *P. cinnamomi,* which cause avocado (Phytophthora) root rot damages small roots. *P. citricola* occurs innocuously on the feeder roots of many or most avocados, but disease occurs on only some of these trees. Disease develops after crowns, limbs, or trunks become infected through wounds, such as injuries from equipment, pruning, vertebrate chewing, and wind damage. Spore spread and disease development are favored by excess soil moisture and wet conditions. Cankers often occur on the side of trunks wetted by irrigation sprinklers. *Phytophthora citricola* produces oospores, which ooze from wounds and spread in splashing water or anything that contacts ooze. Contaminated equipment and tools that wound healthy trees can cause a new infection.

MANAGEMENT
Look for diseases and disease-promoting conditions regularly throughout the grove by MONITORING DISEASES AND DISEASE-PROMOTING CONDITIONS. In California, the diseases caused by *Phytophthora* spp. (root rot and canker) are increasingly found

together. Hence, integrated approaches to the control of both need to be followed including sanitation, selection of tolerant rootstocks, good water management, and wound prevention.

Phytophthora citricola can easily be spread in contaminated nursery stock and on irrigation equipment, vehicles, and people. Follow the same sanitation procedures as described in the section AVOCADO ROOT ROT.

Certain rootstock cultivars are more resistant to or tolerant of Phytophthora canker or Phytophthora root rot. Consider planting more than one rootstock in a grove with a history of *Phytophthora.* Seedling rootstocks are much more sensitive than most of the clonal cultivars to trunk cankers. In University of California field trials, Toro Canyon, Duke 7, Duke 9, and Barr Duke have shown moderate tolerance, as compared to other, more susceptible rootstocks such G1033, G6, and G755B. Thomas rootstock has tolerance to root rot, but is quite susceptible to canker and collar rot and other problems such as excess salinity.

Do not keep the lower trunks wet for long periods, as this increases the chances of infection. Place drippers away from trunks, aim sprinklers to avoid wetting trunks, or switch from sprinkler to drip irrigation where feasible. Avoid wounding major roots and trunks, especially avoid pulling suckers so the bark below ground is injured. Do not stack cut wood against trunks. Rake mulch several inches back from the trunk.

Chemical Control: Consider promptly treating fresh wounds with fungicide, such as wounds from pruning. Remove suckers only by cutting them above ground, then treat the wound. Periodically disinfect pruning tools, such as after finishing work on each tree. If cankers are detected in an early stage before much of the trunk is invaded, they can sometimes be controlled by cutting out the infected tissue and spraying the wound with an effective fungicide. Where cankers extend below ground, a combination of aboveground application and soil drench with fungicide may be warranted. There is little documentation of fungicide efficacy for managing Phytophthora canker and crown rot in avocado. See AVOCADO ROOT ROT for discussion of *Phytophthora* fungicide application.

Common name (trade name)	**Amount/Acre**	**R.E.I.+ (hours)**	**P.H.I.+ (days)**

When choosing a pesticide, consider information relating to environmental impact. Not all registered pesticides are listed. Always read label of product being used.

A. ALUMINUM TRIS PHOSPHONATE
(Aliette) WDG — 2.5–5 lb — 12 — 0.5
COMMENTS: Apply as a trunk spray. Make the first application at the start of the growing season and repeat every 60 days. Repeat applications at 60 days are important (up to 4 applications/year); a single trunk spray is not sufficient to arrest the disease. Do not exceed 20 lb/acre/year.

B. PHOSPHOROUS ACID
(Agri-fos, Fosphite) — 1–2 qt — 4 — 0
MODE OF ACTION GROUP NAME (NUMBER[1]): Phosphonate (33)
COMMENTS: Do not apply with copper-based fungicides or fertilizers; allow 10 days before applying copper-based compound after phosphorous acid treatment or 20 days before applying phosphorous acid after copper treatment. Do

not apply to dormant or heat- or moisture-stressed trees.

+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

1 Group numbers are assigned by the Fungicide Resistance Action Committee (FRAC) according to different modes of actions (for more information, see http://www.frac.info/). Fungicides with a different group number are suitable to alternate in a resistance management program. In California, make no more than one application of fungicides with mode of action Group numbers 1, 4, 9, 11, or 17 before rotating to a fungicide with a different mode of action Group number; for fungicides with other Group numbers, make no more than two consecutive applications before rotating to fungicide with a different mode of action Group number.

PRECAUTIONS (see last page of this chapter)

PHYTOPHTHORA FRUIT ROT

Pathogen: *Phytophthora citricola*

SYMPTOMS AND SIGNS

Diseased fruit have a distinct circular black area that usually occurs near the bottom or lowest spot on the fruit. Internally, the rot extends into the flesh, darkening it in the same pattern as on the affected surface. Affected fruit are often touching the soil or are hanging on low branches. Most damage occurs within 3 feet of the ground.

COMMENTS ON THE DISEASE

Phytophthora fruit rot is caused by *Phytophthora* spp., usually *P. citricola,* the same fungus that causes Phytophthora canker and collar rot. Phytophthora fruit rot is usually of minor importance in California. Most damage occurs after prolonged wet conditions, the same situation that favors anthracnose. In contrast to anthracnose, which is primarily a postharvest problem, Phytophthora fruit rot infections often become obvious while fruit is still hanging on the tree, as well as causing decay after harvest.

MANAGEMENT

The most common cause of infection is believed to be the splashing of *Phytophthora* propagules from the soil surface to the fruit during heavy rain or sprinkler irrigation. Prune lower limbs so they are 2 to 3 feet from the ground. Maintain a thick layer of mulch to hasten decomposition of fungi on soil. Consider removing and disposing of fruit lying on the ground because the fungus sporulates on dropped fruit. Prune out dead limbs and twigs and dispose of dead wood and old fruit away from avocado trees.

SOOTY MOLD

Pathogen: *Capnodium* spp. and related fungi.

SYMPTOMS AND SIGNS

Sooty mold consists of hyphae and spores of *Capnodium* spp. and related fungi. Sooty mold is black, somewhat felty fungal growth on the surface of fruit, leaves, or stems. Sooty molds grow on honeydew excreted by juice-sucking insects, including soft scales and whiteflies.

COMMENTS ON THE DISEASE

Sooty molds do not infect avocado and generally cause no damage. Exceptions are if leaves become so heavily covered that photosynthesis is significantly reduced, causing chlorosis and possible premature leaf drop. If fruit is noticeably fouled, it may be downgraded at the packing house.

MANAGEMENT

Manage sooty mold by controlling the insects that produce honeydew. Honeydew-producing insects in avocado are usually well-controlled by natural enemies. Control ants, minimize dust, and avoid broad-spectrum insecticides to conserve these beneficial parasites and predators. If direct insect control is required, use selective insecticides whenever possible.

STEM END ROT

Pathogen: *Lasiodiplodia theobromae (Botryodiplodia theobromae* and others)

SYMPTOMS AND SIGNS

Decay from stem end rot begins as slight shriveling around the stem button. Fungal mycelium are often visible on fruit if the button is removed. Conspicuous dark decay with a well-defined margin develops at the stem end. As fruit ripens, decay spreads and rots the entire fruit, which becomes dark and shriveled. Depending on the causal organisms, flesh may be watery and soft, or initially dry and corky, becoming watery later as secondary organisms colonize tissue.

COMMENTS ON THE DISEASE

Decay at the stem end of fruit is caused by the several species of bacteria and fungi. Causes include the fungus *Lasiodiplodia theobromae* and other fungi discussed in ANTHRACNOSE and DOTHIORELLA FRUIT ROT, as well as *Alternaria* and *Phomopsis* spp. These stem end rotting species are saprophytes (decay organisms) or weak pathogens, which are present in soil and most any dead or dying avocado tissue, including senescing flowers and injured bark, fruit, and leaves. Spores spread in wind and splashing water.

Stem end rot infection typically occurs in the grove during harvest, but does not develop into disease until after fruit is shipped to the packinghouse. Harvesting injures fruit around the button, and bacteria and fungi can enter the freshly cut stem, causing decay as fruit ripens.

MANAGEMENT

Use good sanitation and optimal cultural practices to minimize fruit rots. Prune out dead limbs and twigs. Dispose of dead wood and old fruit away from trees. Prune and harvest only during dry conditions. Correct environmental and nutritional stresses. Minimize other diseases and disorders that injure bark, fruit, or leaves. Provide sufficient irrigation with appropriate placement of high quality water. Maintain a thick layer of mulch under canopies to hasten decomposition of pathogen propagules. Do not harvest during or soon after rain; allow trees and fruit to dry before harvesting. Minimize the interval from harvest until fruit is placed into cold storage at the packing house; prompt cold storage reduces disease incidence. Follow the same postharvest handling instructions discussed in ANTHRACNOSE.

SUNBLOTCH

Pathogen: Avocado Sunblotch Viroid (ASBVD)

SYPTOMS AND SIGNS

Sunblotch causes a wide variety of symptoms or may exhibit no symptoms in some hosts. Symptoms of sunblotch include necrotic, red, yellow, or white discolorations on fruit, often in depressions or scars in the fruit surface. Twigs can develop narrow, necrotic, red or yellow streaks on their surface or in shallow lengthwise indentations along the twig. Leaves may have white or yellowish variegated areas and be deformed, but leaf symptoms are uncommon. Rectangular cracking and checking of the bark, called "alligator bark," often occurs on the trunk and larger branches. Infected trees may be stunted and have a disproportionate amount of horizontal growth or sprawling lateral low limbs. Trees with visible sunblotch symptoms often have reduced yields. Infected trees can also be symptomless, although large reductions in yield of previously vigorous trees may indicate the presence of the viroid in otherwise symptomless carriers.

COMMENTS ON THE DISEASE

Sunblotch is caused by dozens of variants of submicroscopic particles of genetic material (viroids) that alter development and growth of infected plants. Sunblotch viroid can move systemically within avocado, and it persists in host tissues. Trees that do not show symptoms even though the viroid is present are known as "symptomless carriers." Nearly all cuttings and seed from symptomless carriers will be infected with viroid. However, seedlings from symptomless carriers do not show symptoms of sunblotch when they are used as rootstocks, but the disease often appears on scions grafted to them. Conversely, most seed from trees with symptoms are not infected, and budwood and shoot cuttings from symptomatic trees often do not contain viroid. The viroid transmits in pollen, but pollen only infects the fruit and seed produced from it. Unless a tree is infected by grafting or some way other than through pollen, there will be no viroid in budwood, root grafts, and shoot cuttings from that tree.

Transmission of the viroid most often occurs during grafting by using infected budwood or rootstock seedlings from infected trees with or without symptoms. Natural root-to-root grafts are important in transmitting sunblotch in groves. Mechanical transmission through wounds caused by contaminated harvest clippers, pruning tools, and injection equipment can also be important if infected trees are in the grove. Spread via pollen from an infected tree to the flower ovule of a noninfected avocado, resulting in infected seed, can cause fruit to be culled, but does not further spread the disease unless seed is propagated. There is no evidence of insect transmission.

MANAGEMENT

Careful propagation of nursery stock to eliminate viroid has greatly reduced sunblotch to a relatively minor disease. However, ongoing monitoring and management is required in nurseries and established groves. Sunblotch can be easily overlooked, and there are many ways that trees can become infected. Look for diseases and disease-promoting conditions regularly throughout the grove by MONITORING DISEASES AND DISEASE-PROMOTING CONDITIONS.

In the nursery, carefully select disease-free scions and seed sources. Use stringent sanitation and frequent disinfection to avoid spreading pathogens. Periodically confirm that propagation sources are disease-free (indexing) by grafting propagative source material to young Mexican seedlings and observing leaves and twigs for sunblotch symptoms, or by performing a genetic test.

Plant only indexed nursery stock that is registered as disease-free. Promptly remove symptomatic trees from the grove and chemically kill the stumps. Do not retain infected, symptomless trees just because yield does not seem to be affected; symptomless carriers are a highly infective source that can dramatically reduce yield on other trees. If only fruit and seed are infected (from infected pollen), it may not be necessary to remove that tree if indexing indicates the rest of the tree is not infected. However, trees with only fruit and seed infection indicate that other infected (possibly symptomless) trees nearby need to be indexed or removed.

The danger of spreading viroid increases in established orchards where mature trees are pruned to reduce tree size and restimulate or maintain fruit production. Severe pruning of symptomless carriers, and perhaps other severe causes of tree stress, are suspected of causing viroid to become active in the new growth, inducing previously symptomless trees to exhibit symptoms. Disinfect pruning tools, harvest clippers, and injection equipment before beginning work on a new tree. Scrubbing tools clean and then soaking them in a 1.5% sodium hypochlorite solution is effective. Growers must use a registered disinfectant and follow label directions.

SUNBURN

SYMPTOMS AND SIGNS

Bark, fruit, and leaves exposed to direct sunlight can be injured by heating and drying of tissue. Damage typically is most severe on the south and southwest sides of trees. Sunburn initially causes a pale yellowish area on the exposed side of fruit. The center of discoloration may turn black, brown, or red, then necrotic or withered. Sunburned leaves develop chlorotic then necrotic blotches, which initially form between veins. Sunburned twigs become cracked, discolored, purplish, or roughened on their exposed (usually upper) side. When severe, sunburned trunk and limb bark and the cambium underneath can discolor and die, causing cankers that can girdle and possibly kill limbs.

COMMENTS ON THE DISEASE

Sunburn, sometimes called sunscald, typically occurs when trees defoliate, exposing fruit or previously shaded bark. Newly planted trees that grew with bark shaded in the nursery, and trees that are unable to take up enough water because of unhealthy roots or inappropriate irrigation, are highly susceptible to sunburn.

Prevent sunburn by providing trees with good growing conditions and proper cultural care, especially appropriate amount and frequency of irrigation. Where feasible, prevent conditions that cause foliage to drop prematurely, including Phytophthora root rot and high persea mite populations. If trees defoliate, do not irrigate until soil in the root zone approaches dryness. Defoliation reduces tree use of water, so soil will remain wet longer than with unaffected trees. Examine soil carefully and frequently and modify irrigation to prevent excess moisture in the root zone.

MANAGEMENT

Whitewash young trees routinely at planting. Whitewash the trunk and major limbs of older trees if they develop sparse canopies or are severely pruned, such as when cut back to trunks and grafted with new scion (stumped). Special whitewash products are available, or white interior latex paint diluted 50% with water can be applied. An inexpensive whitewash formula is 50 lbs hydrated lime and 4 lbs zinc sulfate to each 100 gallons of water. Certain white film kaolin clay particle products can be sprayed onto foliage to reduce sunburn and tree heat stress, apparently without interfering with leaf photosynthesis.

VERTICILLIUM WILT

Pathogen: *Verticillium dahliae*

SYMPTOMS AND SIGNS

The entire tree or only one or several branches wilt suddenly when infected with *Verticillium.* Leaves turn brown and die, but the dead leaves usually remain on the tree for several months. Brown to gray-brown streaks are visible in the xylem of the branches or roots when the bark is removed. Trees with Verticillium wilt often send out new, vigorous shoots within a few months after the initial wilting. If well cared for, affected trees often recover completely with no reoccurrence of the disease. However, not all trees survive an infection and disease symptoms sometimes reoccur after an apparent recovery.

COMMENTS ON THE DISEASE

Verticillium dahliae fungus infects many hosts, including various berry and flower crops, cotton, eggplant, olive, pepper, stone fruit trees, strawberry, and tomato. Verticillium wilt is present throughout the state but is less common in avocado than root rot and canker diseases. *Verticillium dahliae* persists for years as microsclerotia in soil. Microsclerotia spread in infested organic matter and soil that is moved. The fungus infects through feeder roots, and then moves up in the water-conducting xylem system, retarding or preventing water movement to foliage from the roots.

MANAGEMENT

No known methods are effective in curing infected trees. Trees often recover completely and display no further symptoms, even though they are still infected. After dieback ceases and new growth begins, prune off dead branches. Provide optimal irrigation and modest fertilization to promote new growth. If a tree dies from *Verticillium,* remove it.

In areas where *V. dahliae* is known to occur, plant Mexican rootstocks instead of the more *Verticillium*- susceptible Guatemalan rootstocks. Do not plant avocado on land where crops susceptible to Verticillium wilt have previously grown. Do not interplant avocado with other hosts of *Verticillium,* which are listed in publications such as *Plants Resistant or Susceptible to Verticillium Wilt* (UC ANR Publication 2703). Even if they have recovered, do not use trees that have been affected with Verticillium wilt as a source of budwood or seed.

PRECAUTIONS FOR USING PESTICIDES

Pesticides are poisonous and must be used with caution. **READ THE LABEL BEFORE OPENING A PESTICIDE CONTAINER**. Follow all label precautions and directions, including requirements for protective equipment. Apply pesticides only on the crops or in the situations listed on the label. Apply pesticides at the rates specified on the label or at lower rates if suggested in this publication. In California, all agricultural uses of pesticides must be reported. Contact your county agricultural commissioner for further details. Laws, regulations, and information concerning pesticides change frequently. This publication reflects legal restrictions current on the date next to each pest's name.

Legal Responsibility. The user is legally responsible for any damage due to misuse of pesticides. Responsibility extends to effects caused by drift, runoff, or residues.

Transportation. Do not ship or carry pesticides together with food or feed in a way that allows contamination of the edible items. Never transport pesticides in a closed passenger vehicle or in a closed cab.

Storage. Keep pesticides in original containers until used. Store them in a locked cabinet, building, or fenced area where they are not accessible to children, unauthorized persons, pets, or livestock. DO NOT store pesticides with foods, feed, fertilizers, or other materials that may become contaminated by the pesticides.

Container Disposal. Dispose of empty containers carefully. Never reuse them. Make sure empty containers are not accessible to children or animals. Never dispose of containers where they may contaminate water supplies or natural waterways. Consult your county agricultural commissioner for correct procedures for handling and disposal of large quantities of empty containers.

Protection of Nonpest Animals and Plants. Many pesticides are toxic to useful or desirable animals, including honey bees, natural enemies, fish, domestic animals, and birds. Crops and other plants may also be damaged by misapplied pesticides. Take precautions to protect nonpest species from direct exposure to pesticides and from contamination due to drift, runoff, or residues. Certain rodenticides may pose a special hazard to animals that eat poisoned rodents.

Posting Treated Fields. For some materials, restricted entry intervals are established to protect field workers. Keep workers out of the field for the required time after application and, when required by regulations, post the treated areas with signs indicating the safe re-entry date. Check with your county agricultural commissioner for latest restricted entry interval.

Preharvest Intervals. Some materials or rates cannot be used in certain crops within a specified time before harvest. Follow pesticide label instructions and allow the required time between application and harvest.

Permit Requirements. Many pesticides require a permit from the county agricultural commissioner before possession or use. When such materials are recommended, they are marked with an asterisk (*) in the treatment tables or chemical sections of this publication.

Processed Crops. Some processors will not accept a crop treated with certain chemicals. If your crop is going to a processor, be sure to check with the processor before applying a pesticide.

Crop Injury. Certain chemicals may cause injury to crops (phytotoxicity) under certain conditions. Always consult the label for limitations. Before applying any pesticide, take into account the stage of plant development, the soil type and condition, the temperature, moisture, and wind. Injury may also result from the use of incompatible materials.

Personal Safety. Follow label directions carefully. Avoid splashing, spilling, leaks, spray drift, and contamination of clothing. NEVER eat, smoke, drink, or chew while using pesticides. Provide for emergency medical care IN ADVANCE as required by regulation.

Diseases I

Fig. 1 Avocado fruit with black specks or lesions of anthracnose, caused by *Colletotrichum gloeosporioides*

Fig. 2 Clusters of *Armillaria* mushrooms

Fig. 3 Trunk canker and discoloration, symptoms of avocado black streak disease.

Fig. 4 Avocado with dead twigs, leafless branches, and sparse foliage from Phytophthora root rot, caused by *Phytophthora cinnamomi.*

Fig. 5 A close-up of a bacterial canker

Fig. 6 White patches of Dematophora root rot

Fig. 7 White exudate and dark bark on an avocado trunk with Dothiorella canker, caused by *Dothiorella gregaria.*

Fig. 8 Avocado decayed by Dothiorella fruit rot, caused by *Dothiorella gregaria.* Note fungal spores visible as a brown discoloration on the fruit.

Diseases II

Fig. 9 Browning of leaf margins and tips on an avocado branch with Dothiorella canker, caused by *Dothiorella gregaria.*

Fig. 10 Tree trunk with symptoms of *Phytophthora citricola*

Fig. 11 Phytophthora fruit rot: black circular area on an avocado fruit caused by *Phytophthora cinnamomi,* identical to symptoms commonly caused by *P. citricola*

Fig. 12 Citricola scale-infested leaves showing sooty mold growth.

Fig. 13 Avocado fruit showing dark decay with a well-defined margin, damage from stem end rot, caused by *Dothiorella gregaria* and *Alternaria* spp.

Fig. 15 Avocado fruit with a black and yellow lesion from wildland fire (left) and fruit with black, red, and yellow discoloration from sunburn (right)

Fig. 14 Avocado fruit deformed and streaked from avocado sunblotch viroid

Fig. 16 Verticillium wilt symptoms.

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Book 2

Chapter 4

Strategies for Control of Avocado Root Rot

Author: John A. Menge

Summary

Integrated management of avocado root rot includes planting clean avocado nursery stock, selecting low hazard sites, planting on mounds in more hazardous sites, preventing the introduction of *Phytophthora cinnamomi,* using resistant rootstocks, preventing over- or under-irrigation, applying systemic chemicals, treating with gypsum and adding organic mulches. It appears that avocados can survive and grow in the presence of *P. cinnamomi* if this management scheme is practiced.

Introduction

P. cinnamomi, the casual agent of avocado root rot, is the limiting factor in avocado production in most avocado-producing countries. It attacks all varieties of avocado by rotting the feeder roots, which can result in death of the tree. In California it has been estimated to affect between 60% and 75% of the orchards and it caused an annual loss of approximately $44 million in 1989 (Coffey, 1992). Although the disease has been studied for more than 60 years, definitive control measures have not been found and losses continue to mount. However, many control strategies have been discovered that will reduce the impact of avocado root rot. When all of these control measures are packaged into a single strategy called the "integrated management of avocado root rot", they allow the continued economical production of avocados in the presence of *P. cinnamomi* (Coffey, 1987). The following is an attempt to enumerate the various components of the "integrated management of avocado root rot".

Clean Nursery Practices

The best control for avocado root rot is to prevent introduction of the fungus into the orchard. Diseased nursery stock has undoubtedly been mainly responsible for the wide distribution of avocado root rot throughout the avocado producing areas of the world. The fungus can be readily transmitted in balled or container grown trees.

It can also be spread via infected seed that has been gathered from the ground. Clean nursery practices which will prevent avocado root rot from infesting nursery stock include heat treatment of seeds, fumigation or heat treatment of soil used to grow the avocados, use of clean water and good sanitation (Zentmyer and Ohr, 1978). A certification program

run by the local government or growers to make sure that nurseries are producing clean stock is a safeguard against importing pests into clean orchards via nursery stock.

Clean Seed. Because *P. cinnamomi* can infect avocado seed through fruit which has dropped on the ground, seed used to propagate avocados should be picked from the tree or treated with hot water to kill *P. cinnamomi*. Seed, which is immersed in water at 49° to 50° C for 30 min. and then quickly cooled, will be free of *P. cinnamomi* (Zentmyer and Ohr, 1978). Care must be taken because treatment at 52° C will damage the seed.

Disinfested Soil. Soil or soil mixes used to propagate avocado should be disinfested to make sure they are not contaminated with *P. cinnamomi*. Fumigating with methyl bromide at 2 lbs/11 cu. M of soil for 24 hr. will free the soil of *P. cinnamomi* (Zentmyer and Ohr, 1978). Heat treatment with steam at 100° C for 30 min. or with aerated steam at 60° C for 30 min. is also effective at disinfesting soil or soil mix with *P. cinnamomi* (Coffey, 1992).

Clean Water. Water should come from deep wells which are devoid of *P. cinnamomi* propagules. Surface water from rivers, canals and reservoirs are often contaminated with *P. cinnamomi* and should not be used to irrigate nurseries. This water could be disinfested by treating with 20 ppm copper sulfate or 0.5 ppm chlorine (Coffey, 1992).

Sanitation. Sanitation is the single most important tool for preventing avocado root rot in the nursery. Nurseries should be fenced and protected from excessive human and animal traffic. Phytophthora is frequently tracked into the nurseries in soil or mud. Many nurseries place boxes of copper sulfate at their entrance and ask all workers and visitors to dust their shoes with this material before entering. Vehicles must pass through a shallow, chlorinated or copper sulfate-treated water bath before entering the premises. Vehicles should be washed and disinfested as necessary, especially if they have been in Phytophthora-infested avocado groves. These precautions not only serve to protect the nursery from unwanted Phytophthora introduction, but they also create a psychological mindset among workers that bringing avocado soil into the nursery is unacceptable. Benches in greenhouses should be at least 45 cm above the ground to prevent soil from splashing into pots and to provide air circulation under benches. In container nurseries, containers should always be placed on blocks or kept from contact with the ground. Containers should never be placed on tarps or cement slabs, which are impenetrable to water, since Phytophthora spreads rapidly in the water film on these surfaces after irrigation or rain. Potting media and fertilizer should never be stored on the ground, but on benches or a dry concrete pad. All pots and liners should be sterilized before use. Vigorous monitoring for Phytophthora in seedbeds or nurseries should be practiced. Avocados contaminated with Phytophthora the seedbed, nursery or containers must be destroyed, since Phytophthora often spreads rapidly through a nursery if left unchecked. Although fungicides, which are effective in the control of avocado root rot, are available, neither phosphorous acid nor metalaxyl will kill 100% of the Phytophthora propagules. Some Phytophthora will survive these fungicide treatments and will be spread from the nursery to a grower's field. Because many nurserymen repeatedly treat nursery stock with fungicides, resistant Phytophthora isolates may appear.

The spread of resistant isolates of *P. cinnamomi* would be disastrous to the avocado industry. If sanitation is practiced correctly, the use of fungicides in avocado nurseries should be unnecessary.

Site Selection and Preparation

Soil with poor drainage, high clay content, high water tables, hard pans, and clay pans or where water pools after irrigation or rainfall have historically been associated with sites where avocado root rot is severe (Zentmyer and Ohr, 1978; Zentmyer, 1980). Soils in California were classified by Zentmyer and Ohr, 1978 according to their hazard to root rot. Severe hazard soils have a slow to very slow subsoil permeability, are poorly to very poorly drained, are less than 91 cm deep and have clay textures. Moderate hazard soils are those with a moderately slow permeability, are somewhat poorly drained, are 91 to 152 cm deep and have clay loam textures. Soils with only a slight hazard for root rot development have a rapid to moderate subsoil permeability, are well drained, are over 152 cm deep and have sand to loam textures. Soil with a high hazard for avocado root rot or soils which already have *P. cinnamomi* present, should be avoided when planting an avocado orchard. Soils with high salinity levels should also be avoided since, not only does salinity weaken avocado grow and yields, but salinity severely exacerbates avocado root rot (Borst, 1970). Alternative crops such as citrus would be a better choice for planting under these conditions. For soils with moderate hazard, soil preparation prior to planting may pay huge dividends in the future. Soils with impervious subsoil layers may be improved by deep ripping and inserting subsurface tile drains. On sloped land, the construction of interception and diversion drainage canals or water-tight drain pipes which drain rain water away from the orchard may prevent the introduction of *P. cinnamomi*. In heavy clay soils, planting trees on soil mounds (1-1.5 M in diameter and 0.5 to 1 M high) or ridges has been shown to increase survival and improve growth of avocado in California by as much as 1800% during the first three years in *P. cinnamomi*-infested soil. Mounding breaks up the soil and provides a well-drained soil for young trees to become established in before they encounter the more hazardous surrounding soil. Soil solarization, which consists of heating the soil to above 45° C with clear polyethylene sheets that have been placed on the soil surface to trap the sun's radiant energy, has been found to be effective for reducing Phytophthora inoculum following tree removal in infested soil in Israel (Erwin and Ribeiro, 1996). This method is particularly effective where summers are hot and most days are cloudless. Fumigation of infested soil and replanting is not recommended because complete eradication of *P. cinnamomi* from soil once it has been infested is extremely difficult. Often *P. cinnamomi* re-invades fumigated soil and the avocado root rot becomes worse than during the initial infestation because the soil microbial community and competing microorganisms have been reduced by the fumigation.

Grove Sanitation

Excluding *P. cinnamomi* from a clean avocado grove is the most economical method of controlling the disease. Groves should be fenced to protect them from human and animal

traffic. All soil or water should be prevented from movement into diseased groves from healthy ones. The fungus is readily moved from grove to grove in moist soil on cultivation equipment, trucks, cars, shovels, soil augers, picking boxes, shoes, etc. Boxes of copper sulfate may be placed at the property entrance and all workers and visitors are asked to dust their shoes with this material before entering. Shallow, chlorinated or copper sulfate-treated water baths may also be placed at the entrance to the property for vehicles to drive through before entering the premises. Small pieces of equipment such as shovels, augers and towels should be washed and dipped in 70% ethanol or rubbing alcohol. Always use equipment in the healthy groves before using it in a diseased grove. Thoroughly wash and dry equipment after using it in a diseased grove. Remember that *P. cinnamomi* has an extremely wide host range and can attack many other woody plants. Use care when planting ornamental plants into an avocado orchard, since they could be infected with *P. cinnamomi*. If diseased trees exist near healthy trees, a dry barrier of at least two rows of trees should be established between the diseased and healthy trees. Diversion furrows should be dug to divert rainwater, which passes through the diseased grove, away from the healthy grove and also to isolate healthy groves from diseased ones. Fences should be erected separating diseased and healthy trees. Once isolated, the diseased trees should be removed and the soil fumigated to reduce the chance of spread from inoculum in the diseased area. Methyl bromide, VorlexR, or VapamR are fumigants which can be used to reduce *P. cinnamomi* inoculum in infested soil (Zentmyer and Ohr, 1978). Irrigation water must be kept free of *P. cinnamomi* inoculum. Water from deep wells is preferred. Water from canals and reservoirs should be treated with chlorine or copper sulfate to eliminate Phytophthora inoculum.

Resistant Rootstocks

Resistant rootstocks have the greatest possibility of successfully controlling avocado root rot in the long run. Several breeding and selection programs around the world have identified rootstocks with a high degree of tolerance to *P. cinnamomi*. In order to use resistant rootstocks, they must be clonally propagated so that they all contain the same genetic identity, which results in resistance to *P. cinnamomi*. Heritability of resistance traits in avocado is generally low, less than 1%. Therefore seedlings produced from seeds gathered from resistant trees usually show little resistance. In most cases the mechanisms for the resistance are not yet fully understood, although several resistant rootstocks appear to simply produce new roots faster than susceptible rootstocks in the presence of *P. cinnamomi*. None of the rootstocks identified so far is able to withstand infections by *P. cinnamomi* under hazardous disease conditions. That is why several other methods of control must be used in conjunction with resistant rootstocks in order to control the disease. Duke 7 was discovered by Zentmyer and in 1975 it became the first commercial rootstock which was resistant to *P. cinnamomi*. It was highly successful, and it is now being used worldwide to combat avocado root rot (Zentmyer, 1980). Several newer varieties are now available which are even more resistant to avocado root rot than Duke 7. These include Dusa Thomas, D9, Barr Duke and Evstro. These rootstocks may not perform well under all avocado growing conditions, and some like Thomas may not yield as well as other

rootstocks when Phytophthora is not present (Menge et al.1992). However, it appears that when these rootstocks are used in conjunction with other control methods, the trees will survive and even thrive in the presence of *P. cinnamomi*. However, with older, highly susceptible seedling rootstocks such as Topa Topa, spending money on other control measures only postpones the inevitable death of the trees. Newer, even more resistant rootstocks are currently being tested and provide hope that one day avocado root rot will be fully controlled.

Irrigation Management

It is difficult to manage irrigation of avocado to benefit the avocado and not *P. cinnamomi* because avocado roots are very shallow and sensitive to drying. Tensiometers should be installed at depths of 15 and 30 cm near the dripline of one or two representative trees. These should be used as a guide to identify when trees are receiving too much or too little water. Trees must not be over watered (several days at 0 to -10 cb) or under-watered (several days at -50 to -70 cb). As little as three days under saturated conditions can predispose roots to attack by *P. cinnamomi*. Over-watering or drought conditions apparently injure the roots so that root exudates are produced, which attract more zoospores of *P. cinnamomi* (Erwin and Ribeiro, 1996). For correct irrigation growers should vary water applications depending on the local evapotranspiration demands. In hot, summer weather more water should be scheduled; while in cooler, winter conditions less water should be scheduled. Constant monitoring of the tensiometers will alert growers to any over- or under-watering. In saline soils periodic leaching irrigations should be scheduled, which will force salt below the root zone, thus ameliorating the predisposing effect of salt on avocado root rot. Remember that root rot itself results in fewer roots and thus less water uptake. Adding more water to wilting, root-rotted trees will only exacerbate the situation. Use the tensiometers to maintain adequate soil moisture under root-rotted trees, but use care not to over-water.

Systemic Fungicides

Two fungicides have been very successful at reducing avocado root rot in many areas of the world (Coffey, 1987, 1992; Erwin and Ribeiro, 1996). Metalaxyl (Ridomil) is highly soluble, moves readily in soil and is absorbed readily by avocado roots. It may be applied as a granular, a drench or injected into the irrigation water. A single application of metalaxyl will provide 3 months of control. Some resistance to metalaxyl has been found in some Phytophthora spp. and rapid soil degradation may occur in some soils, although uptake of the material by roots should occur well before degradation begins. Metalaxyl will kill active Phytophthora in the soil, but it is not capable of destroying all the Phytophthora inoculum. The other fungicide is fosetyl-AL (Aliette) or potassium phosphonate which breaks down into the active ingredient phosphorous acid. They appear to be superior to metalaxyl when applied to mature trees in California (Coffey, 1992). This fungicide is translocated both upward and downward in the plant, although the upward movement is much stronger. Fosetyl-AL or potassium phosphonate can be applied as soil drenches, foliar sprays, trunk

paints, trunk injections or injected into the irrigation water. All methods are effective if used properly, but local preferences indicate some methods work better than others under certain growing conditions. Foliar sprays require more chemical be applied and this method may not be practical on steep slopes. Soil applications require that roots be available for uptake of the material, so trees in advanced stages of root rot are difficult to rejuvenate using soil applications. Heavy clay soils may also impede the uptake of this material from soil. Trunk paints are more effective for treating trunk lesions, and it is often difficult for enough fungicide to be absorbed through the bark to effectively rejuvenate the roots. Injections are often the best way to rejuvenate root-rotted trees, but there is concern in many countries that wood decay organisms may invade the injection holes; or that the intense, brown stain in the avocado wood surrounding injection holes may damage the trees. There is little evidence to support either of these concerns. Fosetyl-AL should be buffered with potassium hydroxide before it is injected into trees. The correct timing for treatment is during active root growth since the material moves toward areas in the tree with active growth. Since root flushes generally follow foliage flushes, these fungicides should be added when the foliage flush is three-quarters complete. There are generally two root flushes per year—one in the spring and the other in the late summer or fall. Fosetyl-AL has little direct effect on soil populations of Phytophthora, but rather it seems to function mainly by increasing the resistance of avocado roots to infection, which indirectly lowers the soil populations of *P. cinnamomi*. A single application of Fosetyl-AL or potassium phosphonate will provide 3 - 4 months of control. For both fungicides, growers should heed label directions because rates, products, and methods of application may vary for each country in which avocados are grown.

Cultural Practices

To best combat avocado root rot, fertilizer nutrients should be applied so that trees are vigorous and healthy. Use leaf analysis to determine if deficiencies exist. Ammonium nitrogen fertilizers are thought to be less conducive to avocado root rot than nitrate fertilizers (Pegg, et al. 1982). Calcium is a particularly important nutrient that may be utilized in the control of avocado root rot. Applications of calcium as calcium carbonate, calcium nitrate and calcium sulfate have also been shown repeatedly to reduce avocado root rot (Broadbent and Baker, 1974; Messenger-Routh, 1996; Pegg et al. 1982). Calcium may reduce avocado root rot by:

1) Stimulating avocado root growth;
2) Increasing disease resistance in avocado roots;
3) Impairing activity of *P. cinnamomi* by reducing sporangial formation;
4) Interfering with zoospore motility or inducing premature encystment;
5) Improving soil drainage; and
6) Stimulating antagonistic microorganisms.

Messenger-Routh (1996) studied all of these mechanisms in California soils and determined that calcium primarily acted as a weak fungicide by reducing the size and

number of sporangia produced by *P. cinnamomi*. It is recommended that applications of between 1500 and 3000 kg/ha of gypsum be made under the tree canopies, depending on the size of the trees. Animal manures are known to reduce populations of *P. cinnamomi*, probably because they frequently release ammonia which is very toxic to *P. cinnamomi* (Tsao and Oster, 1981). However, avocado roots are also very sensitive to ammonia and the damaged roots may even be more susceptible to avocado root rot. Therefore, animal manures should be broadcast sparingly and not used as mulch directly on top of avocado roots. If animal mulches are used, they could be spread over other organic mulches with a high C:N ratio (Pegg, et al. 1982). Soil pH should be maintained above 6.0, ostensibly to maintain high populations of antagonistic bacteria, which may reduce populations of *P. cinnamomi* (Broadbent and Baker, 1974).

Mulches

The use of mulches to control avocado root rot originated with Broadbent and Baker (1974) in Australia. They found that certain Queensland rainforest soils were often free of *P. cinnamomi*. They attributed this effect to the high microbial populations, high levels of organic matter (>7%), and high exchangeable magnesium, calcium and nitrogen. They labeled these soils suppressive to *P. cinnamomi*. They found that a complex scheme called the Ashburner method using bulky, organic mulches such as wheat straw, barley straw, or sorghum stubble together with fowl manure and dolomite to encourage breakdown of the mulch simulated the natural suppressiveness of soils. Today the practice has been modified to add only the key ingredients which are organic mulches and gypsum. High populations of bacteria and actinomycetes, according to Broadbent and Baker (1974); or cellulose and lignin-degrading microorganisms, according to Downer (1998); are naturally stimulated to create the suppressive soils. Organic material in soil can reduce avocado root rot by:

1) Increasing the activity of the indigenous microflora resulting in suppression of the pathogen population through competition or specific inhibition;
2) Releasing degradation compounds such as carbon dioxide, ammonia, nitrites, saponins or enzymes which are generally toxic to *P. cinnamomi*;
3) Acting as a trap, since Phytophthora will be attracted and encyst on organic matter; 4) inducing plant defense mechanisms;
5) Improving soil drainage; and
6) creating an environment that stimulates root development but physically inhibits Phytophthora (Turney and Menge, 1994).

Downer (1998) has shown that enzymes such as cellulase or glucanase are extremely disruptive to the life cycle of *P. cinnamomi* because its cell wall, unlike that of most other fungi, is composed of cellulose and glucans. He found that cellulases and gluconases are prevalent at high concentrations in organic matter as a result of the breakdown of cellulose and lignin compounds by microorganisms. It is recommended to layer organic matter in the form of yard trimmings, avocado trimmings, corn stubble, sorghum stubble, wheat straw, alfalfa straw, and pine bark with a C:N ratio between 25:1 and 100:1 under the canopy at

the base of trees in layers 15-30 cm thick. It is important to keep the mulch away from the trunk because animals, which frequent the mulch, may occasionally damage the trunk. Tensiometers should be used to carefully monitor soil moisture under the mulch. Since the mulch reduces water loss, it is easy to over-water mulched trees and thus eliminate much of the beneficial effects that the mulch produces. Avocado roots that proliferate abundantly in the mulch and at the mulch/soil interface are relatively free of *P. cinnamomi*. Unfortunately the beneficial effects of mulch do not extend very far into the soil, probably because enzymes detrimental to *P. cinnamomi* that are produced in the mulch are adsorbed and inactivated on soil particles. Therefore roots in the soil below the much are often rotted; however, mulches have provided substantial growth stimulation of up to 43% in some California soils infested with *P. cinnamomi*.

Biological Control

Broadbent and Baker (1974) maintain that high levels of active microorganisms can reduce avocado root rot. Since then many soil-borne microorganisms such as *Myrothecium roridum, Trichoderma harzianum, Epiccocum purpurascens, Catenaria anguillae, Humicola fuscoatra, Anguillospora pseudolongissma, Hypochytrium catenoides, Myrothecium verrucaria, Streptomyces griseoalbus, Micromonospora carbonacea, Streptomyces violascens* and *Ceraceomyces tessulatus* have been shown to be inhibitory to *P. cinnamomi* via competition, antibiosis or parasitism (Downer, 1998; Erwin and Ribeiro, 1996). Today there are several commercial biocontrol products available with Trichoderma or Gliocladium as the active biocontrol agent. However, these products are mostly experimental at this time. Evidence indicates these biocontrol microorganisms do not always survive when used in avocado groves. It may be that biocontrol microorganisms, such as these, may add little benefit if mulches with large populations of antagonistic microorganisms are already present. Research is continuing in the search for specific biocontrol microorganisms which target and kill *P. cinnamomi*. Another interesting biocontrol approach is the field production of antagonistic bacteria in field fermentors and their continuous application in irrigation water.

LITERATURE CITED

Borst, G. 1970. Selection and Management of Avocado Soils. Calif. Citrograph 55:263-265.

Broadbent, P. and K. F. Baker. 1974. Behavior of Phytophthora Cinnamomi in Soils Suppressive and Conducive to Root Rot. Aust. J. Agric. Res. 25:121-137.

Broadly, R. H. 1992. Protect Your Avocados. Information Series Q191031, Dept. Primary Indust. Queensland, Brisbane.140p.

Coffey, M. D. 1992. Phytophthora Root Rot of Avocado.pp. 423-444. In Plant Diseases of International Importance, Volume III. Diseases of Fruit Crops. J. Kumar, H. S. Chaube, U. S. Singh and A. N. Mukhopadhyay (eds.) Prentice Hall, Englewood Cliffs.

Coffey, M. D. 1987. Phytophthora Root Rot of Avocado: An Integrated Approach to Control in California. Plant Dis. 71:1046-1052.

Downer, A. J. 1998. Control of Avocado Root Rot and *Phytophthora Cinnamomi* Rands in Mulched Soils. Ph. D. Dissertation., University of California, Riverside. 210p.

Erwin, D. C. and O. K. Ribeiro. 1996. Phytophthora Diseases Worldwide. APS Press, St Paul. 562p.

Menge, J. A., F. B. Guillemet, S. Campbell, E. Johnson, and E. Pond. 1992 The Performance of Rootstocks Tolerant to Root Rot Caused by *Phytophthora Cinnamomi* under Field Conditions in Southern California. Proc. 2nd World Avocado Congress, Pp. 53-59.

Messenger-Routh, B. J. 1996. The Effects of Gypsum Soil Amendments on Phytophthora Root Rot of avocado. Ph. D. Dissertation, University of California, Riverside, 106p.

Pegg, K. G., L. I. Forsberg, and A. W. Whiley. 1982. Avocado Root Rot. Queensland Agric. J. 108: 162-168.

Turney, J. and J. Menge. 1994. Root Health--Mulching to Control Root Disease in Avocado and Citrus. The California Avocado Society. Circ. No. CAS-94/2.

Tsao, P. H. and J. J. Oster. 1981. Relation of Ammonia and Nitrous Acid to Suppression of Phytophthora in Soils Amended with Nitrogenous Substances. Phytopathology 71:53-59.

Zentmyer, G. A. 1980. *Phytophthora Cinnamomi* and The Diseases It Causes. Monograph # 10, Amer. Phytopath. Soc., St Paul. 96p.

Zentmyer, G. A., and H. D. Ohr. 1978. Avocado Root Rot. Div. Agric. Serv., University of California, Leaflet # 2440.

Book 2

Chapter 5

Insect and Mite Control

Authors: B. A. Faber, J. G. Morse, & M. S. Hoddle

Editor's note: This chapter is from the University of California's IPM website at http://www.ipm.ucdavis.edu/index.html
Please refer to this website for current information as this website is updated quite often.

AMORBIA (Western Avocado Leafroller)

Scientific name: *Amorbia cuneana*

DESCRIPTION OF THE PEST

Western avocado leafroller (family Tortricidae), is primarily a pest of avocado. It occurs in most California groves and occasionally increases dramatically, causing severe fruit damage. This caterpillar also damages citrus, where it is called amorbia, its official common name. Amorbia is often called just "leafroller." However, amorbia, avocado looper, and orange tortrix all roll avocado leaves and web plant parts together with silk.

Amorbia (and orange tortrix) adults are bell-shaped when their wings are folded at rest. Their variably colored forewings are typically orangish to tan with dark markings. Adult amorbia are about 1 inch (2.5 cm) long, about twice the size of orange tortrix adults.

Each amorbia female lays about 150 to 200 eggs during her 2 to 3 week life. These light green, oval-shaped eggs occur mostly on the upper side of leaves close to the midrib. Amorbia (and orange tortrix) eggs are laid overlapping or shinglelike in a flat mass. Amorbia lays about 5 to 100 eggs per mass, with an average of 25 eggs per mass. Eggs darken and larvae emerge about 2 weeks after oviposition. Hatched egg masses resemble whitish patches on leaves.

Amorbia larvae develop through five instars. At maturity they are 0.75 to 1 inch long. Caterpillars are yellowish green when young, and mostly darker green when mature. Older larvae have one short dark horizontal line on their side on their thorax just behind the head and above the first pair of legs. Other avocado caterpillars lack these distinct black marks. Amorbia feed in nests of leaves and fruit tied together with silk. When disturbed, amorbia and orange tortrix larvae often wriggle violently and drop to the ground.

Amorbia pupate for 2 to 3 weeks in rolled leaves. The 0.5 to 0.75 inch long pupae initially are pale green, gradually turn tan, and become brown when mature.

Egg to adult development time is about 1.5 months at an average temperature of 75°F. Amorbia typically has three generations per year at warmer growing areas. From inland Ventura to San Diego Counties, most adults fly and females oviposit during January through April, May through June, and during September through October. Two generations a year

occur on average in coastal groves. In Santa Barbara County most moths emerge and lay eggs during March through June, and August through November.

DAMAGE
Young amorbia larvae chew the leaf surface, leaving a thin brown membrane or skeleton of leaf veins. Mature caterpillars consume the whole leaf, starting in the center or at the leaf edge. Young larvae often web terminal leaves together and feed within them. This damage becomes apparent when terminals grow and unfold. Mature avocado trees can tolerate considerable larval chewing without severe effects on tree growth or fruit yield.

Healthy trees tolerate some loss of chewed foliage and blossoms. Extensive defoliation can result in sunburned fruit and twigs. Economic damage occurs primarily when caterpillars damage fruit. When larvae web leaves to fruit or feed among touching fruit in a cluster, in these protected sites larvae feed on fruit skin. This scarring causes downgrading or culling of fruit.

MANAGEMENT
Conserve natural enemies, which usually keep caterpillars below damaging levels. Modify cultural practices to reduce pest reproduction and survival. Avoid applying broad-spectrum or persistent insecticides for any pests. Caterpillar outbreaks commonly occur after spraying malathion, which poisons parasites and predators. When pesticides are warranted, limit application to the most infested spots to provide refuges from which natural enemies can recolonize after treatment.

Biological Control: Birds, predaceous insects, and spiders commonly prey on caterpillars. Predators include assassin bugs, damsel bugs, lacewings, and pirate bugs. A naturally occurring nuclear polyhedrosis virus often kills many amorbia when caterpillar populations become high. The caterpillar pathogen *Bacillus thuringiensis* is commercially available as a selective insecticide.

Parasites, especially flies (family Tachinidae) are the most important natural enemies that usually keep amorbia populations below economically damaging levels. Tachinids attacking amorbia include *Eumea* (=*Aplomya) caesar, Nilea* (=*Pseudoperichaeta) erecta,* and at least 5 other species. Their black to dark grayish adults are about 0.25 to 0.33 inch (6–8 mm) long and resemble a common house fly, but have more prominent stout hairs. White tachinid eggs may be observed on or near a caterpillar's head. Brown to reddish, parchmentlike tachinid pupal cases are often found near the larger pupal cases of dead caterpillars.

At least 8 wasps species parasitize amorbia, including the external larval parasite *Habrobracon* (=*Bracon) xanthonotus* (Braconidae) and the internal pupal parasite *Brachymeria ovata* (Braconidae). *Trichogramma* spp., 0.04 inch (1 mm) long or smaller wasps, lay one to several eggs in each caterpillar egg. Black amorbia eggs are probably parasitized by *Trichogramma.*

Where naturally occurring parasitism is inadequate, amorbia has been controlled by releasing *Trichogramma platneri* during peak moth egg laying in late spring as determined by monitoring adults using commercially available pheromone-baited or black light traps.

Commercial suppliers typically provide *Trichogramma* as parasitized moth eggs glued to cardboard. The adult wasps should emerge soon after the shipment arrives. Protect cards from Argentine ants and other predatory insects. Keep a small portion from any purchase in a shady location in a clear container covered with tightly woven cloth. Observe wasp emergence to assess product quality.

Cultural Control: Prune to reduce foliage touching among adjacent trees and to minimize dead twig and plant debris accumulation in canopies. Thin or selectively harvest fruit in clusters. Pruning and thinning reduce protected sites and canopy bridges that facilitate insect movement between trees, thereby reducing the abundance of caterpillars, greenhouse thrips, and mealybugs. Remove abandoned citrus to reduce the likelihood that amorbia and orange tortrix will move from citrus to nearby avocado. Control weeds near avocado that host these caterpillars. Reduce dust in groves by driving slowly and oiling or watering dirt roads. Dusty conditions reduce the effectiveness of parasites and predators that attack caterpillars and other pests including mites and scales.

Organically Acceptable Methods: Biological and cultural controls are organically acceptable.

Monitoring and Treatment Decisions: Where problems may occur, monitor during at least spring and summer, especially after peaks in moth flights. Good places to monitor include where bright lights such as security lights are used outdoors because the nocturnal moths are attracted by lights to lay eggs nearby. Be sure to correctly distinguish the cause of any damage as other insects and certain abiotic disorders cause leaf holes resembling caterpillar chewing. Correctly identify the species of caterpillars. Alternate host plants, damage potential, monitoring methods, and natural enemies vary depending on the species of caterpillar. Look for caterpillar predators and larval diseases and parasitism. Natural enemy prevalence affects treatment decision-making. See MONITORING CATERPILLARS AND THEIR NATURAL ENEMIES for details on identification and monitoring methods including inspecting foliage for caterpillars and their damage (timed counts), trapping adults, shaking foliage to dislodge larvae (primarily for avocado looper), or a combination of these methods.

There are no established amorbia thresholds for pesticide application. Monitor parasites and other natural enemies several times to determine if their populations are increasing. If they are, the amorbia population will decrease. Spraying with malathion often leads to outbreaks of other pests and is not recommended. Bt sprays are the least disruptive to beneficials.

Treatment

Comon name (trade name)	**Amount to use**	**R.E.I.+ (hours)**	**P.H.I.+ (days)**

When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact. Not all registered pesticides are listed. Always read label of product being used.

A.	TRICHOGRAMMA PLATNERI PARASITES#	100,000 parasites/acre/season	—	—

COMMENTS: Make at least 2 releases a week apart during the period of peak egg laying (as determined by pheromone traps and visual inspection). Place parasite egg cards on at least 4 trees/acre for a total minimum release of 100,000 parasites/acre/season.

B.	BACILLUS THURINGIENSIS spp. AIZAWAI# (various products)	Label rates	4	0

MODE OF ACTION GROUP NUMBER[1]: 11

COMMENTS: Effective when used to control early instars of the caterpillar.

C.	BACILLUS THURINGIENSIS ssp. KURSTAKI# (various products)	Label rates	4	0

MODE OF ACTION GROUP NUMBER[1]: 11

COMMENTS: Effective when used to control early instars of the caterpillar.

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

\# Acceptable for use on organically grown produce.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

— Not applicable.

PRECAUTIONS (see last page of this chapter)

ANTS

Scientific names:
Argentine ant: *Linepithema humile*
Native gray ant: *Formica aerata*
Southern fire ant: *Solenopsis xyloni*

DESCRIPTION OF THE PEST

Most ants (family Formicidae) are wingless workers (sterile females). Workers search for food outside the nest, dig tunnels, and care for the tiny, pale, grublike ant larvae in the nest. Adult ants can also be winged males that die soon after mating or reproductive females (queens) that lay tiny elliptical eggs in underground nests. Queens and males are usually observed only during their brief mating season when they develop wings and swarm outside of the nest.

Ants have a narrow constriction between the thorax and abdomen. Their antennae are distinctly elbowed. Winged ants have hind wings that are much shorter than the forewings. It can be very helpful to identify the species present as ant biology and management often differ among species. An illustrated key is available.

The most prevalent species is the Argentine ant, which travels in characteristic trails with numerous individuals. Workers are about 0.13 inch (3 mm) long, uniformly deep brown to light black and do not sting and rarely bite. The Argentine ant has one petiole node (hump) between the thorax and the abdomen.

Native gray ants, also called field ants, are larger than the other ants. Native gray ants are up to 0.3 inch (7.5 mm) long and have one petiole node. Gray ants nest in topsoil or under rocks and debris. Individuals move in an irregular jerky manner and generally do not travel in trails or sting.

The southern fire ant, also called the California or native fire ant, is light reddish brown with a black abdomen. The entire body is covered with golden hairs. It has two nodes (humps) between the thorax and the abdomen. Workers size is variable range from 0.1 to 0.018 inch (2.5–4.5 mm) long. Southern fire ants nest beneath loose mounds or craters and do not aggregate in colonies as large as those of the Argentine ant. Southern fire ants may swarm over the ground and may sting when disturbed. They forage mostly in the morning and early evening and usually do not travel in conspicuous trails.

Be especially alert for the highly aggressive red imported fire ant *(Solenopsis invicta =S. wagneri)*. Red imported fire ants run up any objects they encounter and have a venomous sting, which can seriously injure people. Red imported fire ants can be recognized in part by their size, which varies greatly among workers. Large and small ants, 0.08 to 0.25 inches (2–6 mm) long occur together in the same clump or trail. Except for southern fire ants, which also range in size, workers outside the nest are about the same size for all other ants likely to be found in California groves. Report suspected red imported fire ant infestations to agricultural officials. Contacts include telephoning 1-888-4FIREANT toll free and the http://www.fireant.ca.gov Web site.

DAMAGE

Ants are important natural enemies of many insect pests and provide benefits such as improving soil. However, ants sometimes chew crop twigs and tender bark, damage irrigation tubing, or annoy workers. In avocado, ants are pests primarily because they disrupt biological control of other pests. Ants are primarily a problem in young avocado trees where mealybugs and other honeydew-producers are occasional pests. Ants protect these food sources from natural enemies, causing phloem-sucking insects to become more abundant. When honeydew-producers are present, ants also increase populations of armored scales and some other pests that do not excrete honeydew. Ants are general predators that attack most any other predator or parasite they encounter, regardless of what host that natural enemy is seeking.

MANAGEMENT

Periodically inspect for ants and bark damage under trunk wraps of young trees. Check for ants on trees of any age if honeydew-producing insects are a problem. If ants have swollen, almost translucent abdomens, this can indicate they are honeydew−collecting species.

Ants do not have effective natural enemies, except for competition with other ants. Cultivation controls ants, but creates dust and disturbing soil near trees damages roots. Insecticide mixed with bait is the preferred chemical control. Baits are slow acting, but effective over the long-term because they take advantage of ants' food-sharing behavior. Ants spread insecticide bait throughout the colony, including to nest-bound immatures and queens underground. The best time to bait is late winter to early spring when ant numbers are relatively low. Bait effectiveness varies with ant species, availability of alternative food, active ingredient, type of bait, and the time of year. To determine which bait to use, offer a small quantity of each of several baits and observe which is preferred by the ants.

Solid baits are applied for fire ants. Argentine ant and other honeydew-feeding species are most effectively controlled by liquid baits, which must be applied in registered bait stations. Check for the registration and availability of new liquid baits and baits stations to control honeydew-feeding ants. Apply an effective bait in spots near nests or on trails. Spot treating takes advantage of ants' trailing behavior, which leads nest mates to locations where food is concentrated. Spot treatment minimizes toxicity to non-pest ant species, which compete with pest ants and help to limit their populations. Broadcasting baits or widespread spraying with insecticide is expensive, and may not reach many ants within nests underground.

Treatment

Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)
When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact. Not all registered pesticides are listed. Always read label of product being used.			
A. STICKY POLYBUTENE MATERIALS# (Tanglefoot)	Label rates	—	—

COMMENTS: For use on all varieties. Use polybutene-based products only. Do not apply sticky materials directly on the trunk; use a 6- to 18-inch wrap under the sticky material to protect the tree from sunburn. Exercise caution in applying multiple applications (more than 3 or 4); watch for symptoms of bark cracking. Apply the sticky band high enough to avoid sprinklers, dust, and direct sunlight. Reactivate periodically by rubbing with a stick to remove dust. Skirt- and canopy-prune trees so that ants have access only via the trunk. Check to ensure that low hanging branches, sticks, weeds, etc., are not allowing ants access to trees.

B. BORIC ACID#
(Gourmet) Label rates — 0
MODE OF ACTION GROUP NUMBER[1]: —
COMMENTS: Available only for organically grown fruit under a Special Local Need (SLN) registration. Liquid boric acid formulation with sweet bait for use only in approved bait stations that meet EPA ChemSAC criteria. For use against honeydew-feeding ant species, including Argentine ant and native gray ant.

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

\# Acceptable for use on organically grown produce.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of Action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

— Not applicable.

PRECAUTIONS (see last page of this chapter)

AVOCADO BROWN MITE

Scientific name: *Oligonychus punicae*

MITE PESTS OF AVOCADO – GENERAL INFORMATION

Spider mites (family Tetranychidae) and predatory mites (Phytoseiidae) are tiny 8-legged arthropods. Persea mite is a key pest of California-grown avocados. Avocado brown mite and sixspotted mite are sporadic pests. Several beneficial mites are important predators of pest mites and certain insects. Natural enemies and certain management strategies vary among pest mites. Identify the pest and natural enemy species in your grove and learn their biology so you can manage these pests appropriately as needed. For details about sampling techniques, see MONITORING PERSEA AND SIXSPOTTED MITES.

DESCRIPTION OF THE PEST

Avocado brown mite (family Tetranychidae) is dark brown, oval, and tiny (about 0.01 inch or 0.3 mm long). Its tiny amber-colored eggs have a short projecting stalk. At low populations most eggs are laid singly along the midrib. Eggs are increasingly found throughout the upper leaf surface as populations increase. In summer there may be two complete generations per month. Temperatures of 90° to 95°F or higher usually kill these mites and their eggs, as does the first cold weather in fall or early winter.

DAMAGE

Avocado brown mite is a sporadic pest, mostly in coastal growing areas. Bronzing of leaves, mite cast skins, and partial defoliation of some trees by avocado brown mite is most noticeable from about July to September. Severe infestations tend to occur in border row trees along dirt roads, where road dust is detrimental to mite predators. Ash deposited on leaves from wildfires reportedly also causes brown mite outbreaks.

Avocado brown mite feeds almost entirely on upper leaf surfaces. It causes no significant damage when population densities are low to moderate (about 10 to 20 adult females per leaf). If the spider mite destroyer lady beetle *(Stethorus picipes)* is present and reproducing well at this time, brown mite does not become a problem. Damage occurs if avocado brown mite averages about 50 to 70 adult females per leaf (about 100-200 motile stages, adults and nymphs combined). At these higher densities mites also colonize the lower leaf surface and sometimes fruit, and partial defoliation can occur. These higher populations cause leaf bronzing along the midrib, then along smaller veins, and finally the entire leaf turns brown.

MANAGEMENT

Natural enemies and temperature (hot or cold weather) usually maintain this mite at innocuous levels. Maintain good biological control by conserving natural enemies. Control dust and avoid applying broad-spectrum pesticides for any pests. When treating any pests, including avocado brown mite during late summer or fall, spot treat individual trees where possible.

Biological Control: Naturally occurring populations of the spider mite destroyer *(Stethorus picipes)* provide the majority of brown mite biocontrol. Predaceous mites (especially *Euseius hibisci* and *Galendromus helveolus)* are also helpful, but predatory mites

are primarily effective against sixspotted mite. Most other natural enemies listed as attacking persea mite also feed on avocado brown mite.

Cultural Control: Controlling dust, which improves predator activity, is critical for maintaining biological control. Oil or pave main orchard roads to reduce dust drift onto trees. When it is necessary to use dirt roads, drive slowly. Use a water truck or trailer to wet unpaved roads and prevent airborne dust, especially during summer months when heat convection currents carry dust well up into tree canopies.

Organically Acceptable Methods: Biological and cultural controls along with sulfur and some oil sprays are acceptable control methods in an organically certified crop.

Monitoring and Treatment Decisions: Look for bronzed leaves and brown mites during summer through fall monitoring for other pests such as caterpillars and persea mite, especially when monitoring in coastal groves. Consider monitoring specifically for brown mite in border rows along dirt roads during summer through fall where trees are dusty, were sprayed earlier in the season with a broad-spectrum insecticide, and after wildfires. Major outbreaks have occurred after spraying a broad-spectrum insecticide to control greenhouse thrips or omnivorous looper. To locate avocado brown mite and its webbing, use a hand lens (10X) to inspect along the midrib on the upper leaf surface. There is no suggested threshold for when treatment is warranted. Pesticide applications for avocado brown mite are rarely needed.

Common name (trade name)		Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)
When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact.				
A.	NARROW RANGE OIL#	Label rates	4	0
	MODE OF ACTION: Contact including smothering and barrier effects. COMMENTS: Requires good coverage to be effective. Check with certifier to determine which products are organically acceptable.			
B.	WETTABLE SULFUR#	Label rates	1 day	0
	MODE OF ACTION: Unknown. An inorganic miticide. COMMENTS: Do not treat with sulfur when temperatures exceed 90°F to avoid leaf damage. Sulfur sprays are often not effective in coastal areas where temperatures do not promote fuming action.			

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment until harvest. In some cases the REI exceeds the PHI. The longer of these two intervals is the minimum time that must elapse before harvest.

\# Certain products are acceptable for organically grown produce.

PRECAUTIONS (see last page of this chapter)

AVOCADO LACE BUG

Scientific name: *Pseudacysta perseae*

DESCRIPTION OF THE PEST

Avocado lace bug (family Tingidae) occurs in parts of the Caribbean, Mexico, and southeastern United States. As of 2006, in California it occurs only in San Diego County. Also known as the camphor lace bug, it's only known hosts are various *Persea* species and the camphor tree *(Cinnamomum camphora)*, which is grown as a landscape ornamental and commercially for its aromatic extracts.

Lace bugs do not feed on fruit. Adults and nymphs feed in groups on the underside of leaves. This sucking pest causes chlorotic blotches on foliage, which become necrotic. Severely damaged leaves may drop prematurely. Defoliation can result in sunburned fruit and wood and stressed trees, reducing subsequent yield.

Adults are about 0.08 inch (2 mm) long oval shaped insects with a dark (black or brownish) head and thorax. Their abdomen, antennae, legs, and wing covers have both dark and light (orangish, yellowish, or white) areas. Nymphs are mostly dark and orangish, resembling the adults without wings. Eggs are laid on leaves within shiny black globs of excrement. Insects develop from egg to adult in about 1 month during warm weather and have several generations a year. All stages can be present throughout the year.

DAMAGE

Relatively little is known about this insect in California. Populations increase during summer, and high populations and severe foliage damage occur in California on some untreated avocado trees. Avocado lace bug is an intermittent pest in Florida on avocado.

MANAGEMENT

An important component of managing avocado lace bug is preventing its spread into uninfested areas. Do not move uncertified host material or dirty bins from infested areas. Clean bins and other potentially infested equipment and materials before bringing them into groves, as lace bugs may survive and spread on leaf debris. Conserve resident natural enemies that prey on lace bugs, including lacewing larvae and predatory thrips. The introduction of natural enemy species is being researched in an effort to provide classical biological control. At least two species of parasitic wasps kill avocado lace bug eggs in Florida, an unidentified species in the family Mymaridae and an *Oligosita* sp. (Trichogrammatidae).

Do not treat low populations of lace bugs. If populations are increasing and are anticipated to cause extensive foliage damage or premature leaf drop, where feasible make a foliar spray of short-persistence contact materials such as oil or pyrethrin. Avoid persistent, broad-spectrum insecticides, which can disrupt biological control of other pests in avocado. Certain systemic insecticides can be very effective and may be available for application through irrigation systems.

Organically Acceptable Methods Sprays of pyrethrin (PyGanic) and certain oils are

acceptable for use in an organically certified crop.

Treatment

Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)

When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact. Not all registered pesticides are listed. Always read label of product being used.

A. NARROW RANGE OIL# — Label rates — 4 — 0
MODE OF ACTION: Contact including smothering and barrier effects.
COMMENTS: Requires good coverage to be effective. Check with certifier to determine which products are organically acceptable.

B. IMIDACLOPRID (Admire Pro) — 14 fl oz/acre — 12 — 6
MODE OF ACTION GROUP NUMBER[1]: 4A
COMMENTS: Do not exceed 14 fl oz/acre per season. Apply by chemigation through low-pressure drip, trickle, microsprinkler or equivalent equipment. Application may only occur pre-bloom or during bloom period. Post bloom applications are not allowed. Bees shall not be used in avocado treated while avocado is in bloom. Remove bee hives from avocado orchards prior to application. Hives may be returned only after the avocado bloom period has ended.

C. PYRETHRIN# (PyGanic) — Label rates — 12 — 0
MODE OF ACTION GROUP NUMBER[1]: 3
COMMENTS: Because there is little residual activity, repeat application may be needed in 2-3 weeks and control may be only partial.

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

\# Acceptable for use on organically grown produce.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

PRECAUTIONS (see last page of this chapter)

AVOCADO THRIPS

Scientific name: *Scirtothrips perseae*

DESCRIPTION OF THE PEST

Avocado thrips (order Thysanoptera) is a key pest that scars fruit. Adults lay eggs hidden inside the underside of leaves, in young fruit, and in fruit petioles. The thrips then develop through two larval and two pupal stages. The first instar is white to pale yellow. The second instar is larger, more robust, and bright yellow. Larvae are typically found along major veins on the underside of younger leaves and anywhere on the surface of young fruit. Although some pupation occurs on the tree in cracks and in crevices, about three-fourths of avocado thrips drop from trees to pupate in the upper layer of dry, undecomposed leaf litter. Pupae are rarely seen and they do not feed. Adults are 0.03 inch (0.7 mm) long and have fringed-tipped wings. Adults are orange-yellow with distinct thin brown bands between segments of their abdomen and three small red dots (ocelli) on top of the head.

Neohydatothrips burungae, a new species of unknown importance, closely resembles avocado thrips, and may reliably be distinguished only by an expert. *Neohydatothrips burungae* often is darker brownish and has bands only on upperside of its abdomen. Adult avocado thrips can closely resemble citrus thrips and to a lesser degree, western flower thrips, which occur on, but do not damage, avocado. Citrus thrips has no abdominal bands on its light orangish yellow to white body. Western flower thrips color is highly variable and some individuals have abdominal banding. Western flower thrips are most often found in flowers. Western flower thrips adults have thick, bristlelike hairs at the tip of the abdomen, which the other species lack. When at rest, avocado thrips' wing tips extend beyond its abdomen, while the abdomen of western flower thrips extends beyond the tips of its wings. Avocado thrips larvae resemble those of several other species, including certain beneficial predaceous thrips. Predatory thrips are seldom seen at high levels as can be common with avocado thrips larvae.

Avocado thrips develops well under cool temperatures. Populations typically begin increasing in late winter and spring, when avocado thrips feed on young leaves. Abundance peaks in late spring and early summer, when most fruit are young and after the growth flush when hardening of leaves induces thrips to move from foliage to feed on young fruit. Populations are suppressed by warm, dry conditions, but this weather usually occurs later in the season, when most fruit are larger and no longer susceptible to new damage.

Avocado thrips has 6 or more generations a year. Egg to adult development occurs in about 20 to 30 days when temperatures average 65° to 75°F. Actual development time can be predicted by monitoring temperature using degree-days.

DAMAGE

Although it has little effect on tree health, avocado thrips feed directly on immature fruit. Internal fruit quality is not affected, but obvious feeding scars cause severe downgrading or culling of damaged fruit. Severe scarring when fruit are young can slow or stunt fruit growth. As fruit grow, this early feeding becomes apparent as scabby or leathery brown scars that expand across the skin. Thrips scarring is sometimes called "alligator skin."

Mechanical injury or abrasion, such as from strong winds, also causes fruit scarring that can be confused with injury from thrips.

Avocado thrips prefer to feed and lay eggs in succulent leaves. Feeding on young leaves causes irregular bronzing or scarring on both sides of the leaf. Discoloration is typically concentrated along the midrib and lateral leaf veins, and then appears in scattered patches between veins as populations increase. Foliar feeding is usually unimportant, except when very high populations cause premature leaf drop.

Thrips move to young fruit when leaves harden after the growth flush has finished. Almost all damage occurs when fruit are 0.2 to 0.6 inches (5–15 mm) long. Although Hass fruit are susceptible to feeding until they reach about 2 inches, thrips feeding rarely causes scars on fruit larger than about 0.75 inches. This scarring on young fruit may not become obvious until fruit enlarge.

MANAGEMENT

Importation of new species of natural enemies and modifications of cultural practices are being investigated for controlling avocado thrips. If insecticides are applied, choose selective materials whenever possible to minimize adverse impacts on the natural enemies that usually provide good control of other avocado pests, including caterpillars, certain mites, scales, whiteflies, and other thrips.

Biological Control: Natural enemies may suppress avocado thrips, but sometimes do not reduce populations below damaging levels. Predatory thrips are the most important natural enemies, especially *Franklinothrips orizabensis.* At mild temperatures, about 77°F, *F. orizabensis* populations can increase readily if avocado thrips populations are increasing. This predator also eats other thrips, mites, and whiteflies, and feeds on avocado pollen and leaf juices. The adult *F. orizabensis* is mostly black with white or pale bands on its body, especially near its thin waist. Females lay eggs into plant tissue. Immatures develop through two larval and two pupal stages. First instars are yellowish with relatively long legs. Second instars have a distinctly swollen, bright orangish or red abdominal area. Pupation occurs in a silken cocoon.

Franklinothrips vespiformis, black hunter thrips *(Leptothrips mali)*, and several banded-wing thrips *(Aeolothrips* spp.) also feed on avocado thrips, other pest thrips, and mites. Banded-wing thrips supplement their diet with pollen and plant juice, and can complete their life cycle and persist even when their prey are uncommon. Other general predators (especially green lacewings) and at least one parasitoid *(Ceranisus menes)* also attack avocado thrips.

Cultural Control: Avocado thrips damage is affected by practices that increase or decrease the abundance of succulent foliage during set and growth of young fruit. Modifying fertilization (amount, application method, formulation, and timing) and pruning (the extent and time of branch removal) alters the extent to which trees continue to produce tender foliage during about May and June. Research indicates that in comparison with pruning during February through April, pruning during January does not affect yield. January

pruning may also induce additional growth flush during fruit set, which may reduce thrips tendency to move from hardening leaves to young fruit.

Adding coarse organic mulch beneath trees and maintaining a mulch layer 6 inches thick may reduce survival of avocado thrips that drop from trees to pupate. The effectiveness of mulching to control thrips is uncertain and labor costs of adding mulch may not be justified solely for thrips control. However, applying coarse organic material such as composted yard waste beneath trees helps control *Phytophthora* root rot and weeds, and thrips reduction might be an additional benefit.

Organically Acceptable Methods: Biological and cultural controls along with sprays of the Entrust formulation of spinosad are acceptable for use in an organically certified crop.

Monitoring and Treatment Decisions: Adults and second instars can be found anywhere on fruit or leaves, including on the upper leaf surface. Avocado thrips most often occur on the underside of tender, reddish foliage before or soon after leaves reach full expansion. Examine newly flushed leaves during February and March to get an indication of whether thrips are abundant enough to be a likely problem later when young fruit occur.

Monitor regularly every 7 to 10 days beginning as early as April, looking for both mites and thrips. Begin regular thrips monitoring before young fruit are present and continue monitoring until most fruit exceed 0.75 inch in diameter. Look for thrips on 10 young leaves on at least 10 trees per grove. Use a magnifying lens to inspect the underside these leaves and count the number seen. (Avoid leaves that are fully hardened and dark green, that touch fruit or other leaves, or are very close to flowers and fruit. Thrips on hardened leaves, touching leaves and fruit, and in flowers are often other species.) Calculate the average number of thrips per leaf: divide the total number of thrips counted by the number of leaves sampled (100). Young fruit can be monitored by clipping or pinching stems and examining the entire fruit surface for thrips, especially under the calyx. Be sure to correctly identify the thrips present, and record the results on a monitoring form (70 KB, PDF).

Depending on thrips densities, treatment decisions are sometimes made based on thrips abundance on succulent leaves. A treatment decision generally should be made before most new fruit are set or before most thrips move from leaves to young fruit. Before making a treatment decision, consider factors that influence the likelihood of thrips damage. These include thrips damage history, natural enemy abundance, weather, fruit load, and age or size of fruit. If extensive leaf flush continues through fruit set, treatment need may be reduced because more of the thrips population will remain on tender foliage. Conversely, little or no succulent foliage during fruit set increases the extent to which thrips will feed on and damage young fruit. Treatment decision-making is also influenced by grower tolerance for scarring, treatment feasibility and equipment availability, and the possibility that treatments will disrupt natural enemies or promote the development of pesticide resistance. A general guideline is that an average of three to five thrips per leaf at fruit set warrants treatment.

Coordinate treatment decision-making with any persea mite management. Certain materials applied to control avocado thrips (usually earlier in the season) can reduce the need for persea mite treatment (which usually is applied later in the season). Only one application per season may be permitted or recommended for certain materials (e.g., abamectin) to reduce the development of pesticide resistance. Rotate among chemical classes when making multiple applications to reduce the development of pesticide resistance.

Treatment

Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)

When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact. Not all registered pesticides are listed. Always read label of product being used.

A. SABADILLA

(Veratran-D) 10–15 lb PLUS up to 10 lb sugar-based spray adjuvant in 50-200 gal water — 24 — when dry

MODE OF ACTION: Stomach poison

COMMENTS: Must be ingested to be effective. Thrips feed more actively and are killed to a greater degree in warm weather. Acidify water in the spray tank to a pH of 4.5 before adding sabadilla; use a registered citric acid adjuvant or other approved acidifying agents. Re-treat when thrips populations reappear, usually every 2-3 weeks or so. Resistance to sabadilla has been detected in some avocado thrips populations.

B. ABAMECTIN*

(Agri-Mek 0.15 EC and others) Label rates — 12 — 14

MODE OF ACTION GROUP NUMBER[1]: 6

. . . PLUS . . .

NARROW RANGE OIL

(415) 1% — see label — see label

MODE OF ACTION: Improves translaminar movement and persistence of insecticide.

COMMENTS: Use with 1-2% narrow range (415) oil in a minimum of 50 gal water/acre for aerial applications and 100 gal water/acre for ground applications. On large trees aerial applications may require larger volumes of water to achieve desired efficacy. Control may last 4 or more weeks. Only use in an alkaline or slightly acidic solution. Do not tank mix with nutrients. To avoid promoting pesticide resistance, do not make more than one application of any abamectin product per year.

C. SPINETORAM

(Delegate) WG 4–7 oz — 4 — 1

MODE OF ACTION GROUP NUMBER[1]: 5

. . . PLUS . . .

NARROW RANGE OIL

(415) 1% — see label — see label

MODE OF ACTION: Improves translaminar movement and persistence of insecticide.

COMMENTS: To delay resistance, do not apply Group 5 insecticides (spinetoram, spinosad) more than twice per year. Trials against avocado thrips have shown that spinetoram provides more persistent control than spinosad. Choose a lower rate for light infestations and/or small trees and a higher rate for heavy infestations and/or large trees. Toxic against some natural enemies (e.g., *Franklinothrips orizabensis* predatory thrips) when sprayed and for 8-24 hours after. The short residual persistence of this pesticide, however, allows most populations of natural enemies to survive quite well. Apply in a minimum of 50 gal

water/acre. On larger trees, aerial applications may require larger volumes of water to achieve desired efficacy. Control may last 3 or more weeks. Only use in an alkaline or slightly acidic solution. Do not tank mix with nutrients.

D. FENPROPATHRIN*

(Danitol) 2.4 EC	16–21.33 fl oz	24	1

MODE OF ACTION GROUP NUMBER[1]: 3

E. SPINOSAD

(Entrust)#	1.25-3 oz	4	1
(Success)	5-10 fl oz	4	1

MODE OF ACTION GROUP NUMBER[1]: 5

. . . PLUS . . .

NARROW RANGE OIL

(415)	1%	see label	see label

MODE OF ACTION: Improves translaminar movement and persistence of insecticide.

COMMENTS: To delay resistance, do not apply Group 5 insecticides (spinetoram, spinosad) more than twice per year. Trials against avocado thrips have shown that spinetoram provides more persistent control than spinosad. Choose a lower rate for light infestations and/or small trees and a higher rate for heavy infestations and/or large trees. Toxic against some natural enemies (e.g., *Franklinothrips orizabensis* predatory thrips) when sprayed and for 8-24 hours after. The short residual persistence of this pesticide, however, allows most populations of natural enemies to survive quite well. When applying to organically grown produce, be sure that the oil used is also organically acceptable. Apply in a minimum of 50 gal water/acre. On larger trees, aerial applications may require larger volumes of water to achieve desired efficacy. Control may last 3 or more weeks. Only use in an alkaline or slightly acidic solution. Do not tank mix with nutrients.

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

\# Acceptable for use on organically grown produce.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

PRECAUTIONS (see last page of this chapter)

GREENHOUSE THRIPS

Scientific name: *Heliothrips haemorrhoidalis*

DESCRIPTION OF THE PEST

Greenhouse thrips (order Thysanoptera) occurs primarily on broadleaved evergreen plants including avocado, citrus, and many ornamentals. Adult greenhouse thrips are black with white legs and white wings. Adults seldom fly, and all stages of this tiny insect are sluggish. Males are not found in California, where each parthenogenic female can lay up to 60 eggs during her life. Eggs are inserted singly into fruit or the upper or lower leaf surface. Eggs hatch in about 4 to 5 weeks during summer, longer during the winter. Unhatched eggs gradually increase in size, causing a swelling (egg blister) in the leaf cuticle that can be seen with a hand lens.

Greenhouse thrips larvae and pupae are pale yellow to whitish with red eyes. Larvae carry a greenish red to black globule of liquid feces on the tip of their abdomen. They periodically drop this excrement, leaving dark specks on fruit and foliage that help to locate infestations during monitoring. Most greenhouse thrips occur in fruit clusters and where leaves and fruit touch.

Greenhouse thrips has about five to six generations a year. All life stages are usually present throughout the year. In some colder areas, overwintering is primarily as eggs, with newly hatched larvae appearing about mid-February. Greenhouse thrips populations are lowest during winter and spring, but can become abundant enough to damage fruit during early summer or fall. On Hass, where most greenhouse thrips reside on fruit, much of the population is removed annually at harvest.

DAMAGE

Greenhouse thrips occasionally is a serious pest in coastal avocado groves. Feeding on fruit skin causes scarring and the downgrading and culling of fruit at the packing house. Damage to leaves, although unsightly, is of no significance to tree health. Thrips injury on foliage begins to show in June as small, white-gray patches on upper leaf surfaces where thrips are found in the greatest numbers. The pale discoloration of foliage and fruit caused by early infestations turns brownish later in the season. The epidermis of injured leaves and fruit become thick, hard, and cracked. Black specks of thrips excrement may be noticeable.

Most economic damage occurs when fruit are 2 to 7 months old. Economic damage occurs when thrips cause scars or blemishes larger than 0.75 inches in diameter on fruit. Damage usually is most severe on fruit in clusters or where fruit touch leaves, as thrips are protected where fruit touch. Mexican seedling avocados and Hass are extremely susceptible. Least susceptible varieties include Anaheim, Dickinson, Fuerte, and Nabal, which are not widely planted. On green fruit avocado varieties like Bacon and Zutano, greenhouse thrips are not a pest as they feed primarily on foliage.

MANAGEMENT

Biological control, cultural practices, grove microclimate, and weather influence whether greenhouse thrips will be a problem on susceptible (Hass and Mexican seedling) avocado.

Conserve natural enemies of thrips and other pests. Consider modifying harvest and pruning practices to control greenhouse thrips. If pesticide application is warranted, spot treat infested areas and avoid spraying the entire grove. Use selective materials for thrips and other pests whenever possible. Application of broad-spectrum pesticides often leads to outbreaks of pests such as caterpillars and mites.

Biological Control: An important egg parasite, *Megaphragma mymaripenne* (family Trichogrammatidae), often kills about 25 to 50% of greenhouse thrips eggs in coastal avocado. Parasitized eggs develop a relatively large round hole, usually in the middle of the egg blister, where the adult parasite emerges. When a greenhouse thrips emerges, part of the egg shell is often visible at the side of the egg blister.

Thripobius semiluteus (family Eulophidae) attacks second-instar larvae. The normally yellow to whitish thrips larvae turn black and swell around the head when a larva of this parasitic wasp matures inside. *Thripobius* egg to adult development time is about 3 weeks when temperatures average 70°F. Thrips populations decline when about 60% of larvae are parasitized. Natural control due to *Thripobius semiluteus* is inconsistent. Release of several thousand *Thripobius* per acre per week has controlled greenhouse thrips in coastal avocado, but *Thripobius* may not currently be commercially available.

Predaceous thrips including black hunter thrips and vespiform thrips *(Franklinothrips* spp., family Aeolothripidae), prey on greenhouse thrips. However, many predators apparently avoid greenhouse thrips because of their fecal excrement. Beneficial thrips and thrips-feeding general predators are discussed in AVOCADO THRIPS.

Cultural Control: The earlier the harvest, the less thrips damage on harvested fruit. Early harvest (about June or July) of all mature fruit on infested trees also reduces damage to next season's crop. Especially on Hass, where a large proportion of the greenhouse thrips feed and breed on fruit, early harvest minimizes the crop-to-crop overlap period, reducing the number of thrips that can move from old to new fruit.

When fruit prices are low, making early harvest less economical, selectively size-pick the larger fruit in clusters and where fruit and leaves touch. Size-picking reduces greenhouse thrips populations by removing some thrips. Thinning clustered fruit and pruning dense canopies eliminates harborage, which reduces the density of greenhouse thrips, as well as caterpillars and mealybugs.

Organically Acceptable Methods: Biological and cultural controls and sprays of pyrethrin (PyGanic) are acceptable for use on an organically certified crop.

Monitoring and Treatment Decisions: Map or record the locations of infestations and check these areas each year. Greenhouse thrips problems tend to reoccur at the same sites within groves, typically where the microclimate is moderate. From late March through July, monitor for greenhouse thrips about every 10 to 14 days, at least in coastal groves. Concentrate in less exposed and interior grove areas where temperature and humidity are moderate and where your records document greenhouse thrips were most abundant during previous seasons. If greenhouse thrips are present, also monitor trees where

mature fruit was held the longest before harvest.

Monitor on the inside and the north side of trees, away from direct sun exposure. Examine where older fruit touch in clusters and the upper surface of older leaves. Look for colonies of greenhouse thrips, bleached tissue, and black excrement specks. Be sure to correctly distinguish the species of any thrips you find.

Record on a monitoring form the number of greenhouse thrips (adults and larvae combined) per fruit on 10 fruit from each of at least 10 trees per grove. Calculate the average number of thrips per fruit: divide the total number of greenhouse thrips by the total number of fruit sampled (100).

One study indicates greehouse thrips damage can be predicted based on "thrips-weeks" (the number of thrips present x number of weeks they feed). When a colony of thrips are feeding in a group on a fruit, about 25 thrips-weeks (e.g., one thrips feeding for 25 weeks, or five thrips feeding for 5 weeks) may produce a 0.75 inch (19 mm) diameter, economically important scar. There are no more specific guidelines for when treatment is warranted.

Treatment

Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)

When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact. Not all registered pesticides are listed. Always read label of product being used.

A. PYRETHRIN/PIPERONYL BUTOXIDE
(Pyrenone Crop Spray) — Label rates — 12 — 0
MODE OF ACTION GROUP NUMBER[1]: 3/unknown
COMMENTS: Because there is little residual activity, repeat application may be needed in 2-3 weeks and control may be only partial.

B. PYRETHRIN#
(PyGanic Crop Protection, etc.) — Label rates — 12 — 0
MODE OF ACTION GROUP NUMBER[1]: 3
COMMENTS: Because there is little residual activity, repeat application may be needed in 2-3 weeks and control may be only partial.

C. SABADILLA
(Veratran-D) — 10–15 lb — 24 — when dry
MODE OF ACTION: unknown
COMMENTS: Acidify water in the spray tank to a pH of 4.5 before adding sabadilla; use a registered citric acid adjuvant or other approved acidifying agents. Less effective than pyrethrin. Wet, cool weather conditions limit the use of this material because thrips feeding is reduced under these conditions.

D. MALATHION 8 — 1.5 pt/100 gal — 12 — 7
MODE OF ACTION GROUP NUMBER[1]: 1B
COMMENTS: Treat only infested trees to avoid destroying natural enemies of mites, loopers, scales, and other potential secondary pests.

+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

Acceptable for use on organically grown produce.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

PRECAUTIONS (see last page of this chapter)

NEOHYDATOTHRIPS

Scientific name: *Neohydatothrips burungae*

DESCRIPTION OF THE PEST

Neohydatothrips burungae was discovered in San Diego County in 2004. It has previously been reported throughout Central America. In Mexico it is relatively common on avocado and mango. Little is known about its biology.

Neohydatothrips burungae closely resembles avocado thrips. In comparison with avocado thrips, *N. burungae* often has darker brown shading on the thorax, darker abdominal stripes (brownish rings around the top front of each abdominal segment), and brown bands occur only on top of its abdomen, not underneath. However, coloration is variable and may not reliably distinguish these species. These thrips can be separated by differences in the position and size of setae (stout hairs) on their thorax and wings. For example, *Neohydatothrips burungae* has a continuous or complete row of short stout hairs on both midveins within its forewings. Avocado thrips has relatively few hairs along these midveins on its front wings; there are sizable gaps in both these rows of hairs on avocado thrips. Careful preparation of several specimens and a good microscope are needed to recognize these characters.

DAMAGE

The importance of *N. burungae* in California is unknown.

MANAGEMENT

No specific monitoring or management methods are recommended for *N. burungae.* Whether any management is warranted is unknown.

OMNIVOROUS LOOPER

Scientific name: *Sabulodes aegrotata*

DESCRIPTION OF THE PEST

The omnivorous looper (family Geometridae), also called looper or avocado looper, feeds on several dozen plant species. Omnivorous looper occurs in most avocado groves, generally in low numbers, unless natural enemies are disrupted by application of broad-spectrum insecticides.

Adults are mostly tan to orangish on top, with a narrow black band across the middle of the wings. They are white on the underside and have a wingspan of about 1.75 to 2 inches. Females live 2 to 3 weeks, laying eggs in clusters of 3 to 80 on the underside of leaves. Each barrel-shaped egg has a ring of tiny projections around one end. Eggs initially are pale green, then turn shiny reddish to brown. Eggs hatch about 8 or 9 days after oviposition, leaving transparent shells.

Young larvae are pale yellow and about 0.06 inch long. Mature larvae are 2 to 2.5 inches long and mostly yellow to pale green or pink, with a gold-colored head. Older larvae have variable dark brown, black, green, or orangish lines along their sides. In addition to three pairs of true legs behind the head, avocado looper has two pairs of appendages (prolegs) near its rear on abdominal segments 6 and 10. Larvae travel in a characteristic looping manner, where they extend their body forward, then draw their rear forward to meet their forelegs. This arches their body up into a loop. When disturbed, omnivorous loopers often drop and hang from leaves on a silken thread.

Larvae feed about 6 weeks, then pupate within rolled or webbed leaves. Pupae are 1 to 1.25 inches long and white when first formed. The case darkens as a moth with brownish wings develops and can be seen through the pupal case. Pupation lasts 1 to 4 weeks.

Populations increase with increasing temperatures in spring. Omnivorous looper typically has four (and perhaps five) generations per year at warmer growing areas. From inland Ventura to San Diego Counties, most adults fly and oviposit during January through March, May through June, August through September, and October through November. Three generations a year are typical in coastal Santa Barbara County, where moths typically emerge and lay eggs during March through April, June through July, and August through September. Depending on temperature, egg to adult development takes 2 to 5 months.

DAMAGE

Leaf damage is especially evident on terminal shoots. Very young larvae feed only on the leaf surface, leaving a characteristic brown membrane. Older larvae chew all the way through the leaf, often leaving only the midrib and large veins. Full-grown larvae can consume an entire leaf in 1 day. Healthy avocado trees tolerate considerable leaf damage without severe effects on growth or yield. Extensive feeding can result in sunburn and may reduce yield the following year.

Economic damage occurs primarily when caterpillars damage fruit. Both young and old

larvae can chew fruit. If young fruit is fed on, it sometimes becomes misshapen. Chewing typically scars the fruit surface, which may cause fruit to be culled or downgraded.

MANAGEMENT
Conserve natural enemies, which usually keep caterpillars below damaging levels. Modify cultural practices to reduce pest reproduction and survival. Avoid applying broad-spectrum or persistent insecticides for any pests. Caterpillar outbreaks commonly occur after spraying malathion, which poison parasites and predators. When pesticides are warranted, limit application to the most infested spots to provide refuges from which natural enemies can recolonize after treatment.

Biological Control: Spiders are important looper predators, especially in orchards that have not been sprayed with pesticide or recently subject to a freeze. Assassin bugs, birds, damsel bugs, lacewings, and pirate bugs and predatory insects also prey on caterpillars.

Granulosis virus frequently infects and kills larvae when they become abundant. A virus epidemic can cause the looper population to rapidly decline within 1 to 2 weeks. Virus-killed caterpillars are immobile and range in appearance from white and swollen to brownish and shriveled. Diseased larvae cease feeding, become lethargic, and eventually liquefy and then dry up.

Wasps, especially *Trichogramma* egg parasites and three larval parasites (family Braconidae), are the most important natural enemies. *Apanteles caberatae* and *Meteorus tersus* are solitary internal parasites of larvae. The *Apanteles caberatae* larva pupates in a 0.1 inch, whitish silken cocoon near its dead host. The *Meteorus tersus* larva pupates in a brown or yellowish parchmentlike cocoon, which often hangs suspended beneath leaves or twigs on a 1 to 2 inch long thread. One to several pale *Habrobracon* (=*Bracon) xanthonotus* larvae feed externally on each looper, then each pupates in a 0.12 inch long white silken cocoon near the shriveled dead caterpillar.

At least 5 fly species (family Tachinidae) attack omnivorous looper, including *Eumea caesar, Hyphantrophaga* (=*Eusisyropa) virilis,* and *Nilea erecta.* Their black to dark grayish adults are about 0.25 to 0.33 inch long and resemble a common house fly, but have more prominent stout hairs. White tachinid eggs may be observed on or near a caterpillars' head. Brown to reddish, parchmentlike tachinid pupal cases are often found near the larger pupal cases of dead caterpillars.

Trichogramma platneri naturally parasitizes looper eggs, which turn black when parasitized. Where natural biological control is inadequate, omnivorous looper has been controlled by releasing *T. platneri* in late spring or early summer during peak moth egg laying, as determined by monitoring using commercially available pheromone-baited or black light traps. Until all *T. platneri* have emerged, protect cards from Argentine ants and other predatory insects. Keep a small portion from any purchase in a shady location in a clear container covered with tightly woven cloth. Observe wasp emergence to assess product quality.

Organically Acceptable Methods: Biological controls and sprays of *Bacillus thuringiensis*

are acceptable for use on an organically certified crop.

Monitoring and Treatment Decisions: Where caterpillar problems may occur, monitor during at least spring and summer, especially after peaks in moth flights. Good places to monitor include where bright lights such as security lights are used outdoors because the nocturnal moths are attracted by lights to lay eggs nearby. Be sure to correctly distinguish the cause of any damage as other insects and certain abiotic disorders cause leaf holes resembling caterpillar chewing. Correctly identify the species of caterpillars. Alternate host plants, damage potential, monitoring methods, and natural enemies vary depending on the species of caterpillar. Look for caterpillar predators and larval diseases and parasitism. Natural enemy prevalence affects treatment decision making.

MONITORING CATERPILLARS AND THEIR NATURAL ENEMIES methods include shaking foliage to dislodge larvae, inspecting foliage for caterpillars and their damage (timed counts), trapping adults, or a combination of these methods.

When inspecting foliage, if 15 healthy omnivorous looper larvae are found per hour of search, treatment may be warranted. Modify this guideline based on orchard history and the extent of biological control. If caterpillar damage has previously been a problem or broad-spectrum pesticides have been applied it is more likely that treatment will be needed. If natural enemies are increasing, this may indicate treatment can be delayed or avoided. If looper populations are near the guideline, monitor parasites and other natural enemies several times. With higher levels of larvae, watch for evidence of viral disease. When a nuclear polyhedrosis virus is present, looper populations will often crash within 2 weeks. Diseased larvae cease feeding, become lethargic, and eventually liquefy and then dry up in their nests. Spraying with malathion often leads to outbreaks of other pests and is not recommended. Bt sprays are the least disruptive to beneficials.

Treatment

	Common name (trade name)	**Amount to use**	**R.E.I.+ (hours)**	**P.H.I.+ (days)**
	When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact. Not all registered pesticides are listed. Always read label of product being used.			
A.	TRICHOGRAMMA PLATNERI PARASITES#	100,000 parasites/acre/season	—	—
	COMMENTS: Make at least 2 releases a week apart during the period of peak egg laying (as determined by pheromone traps and visual inspection). Place parasite egg cards on at least 4 trees/acre for a total minimum release of 100,000 parasites/acre/season.			
B.	BACILLUS THURINGIENSIS spp. AIZAWAI#			
	(various products)	Label rates	4	0
	MODE OF ACTION GROUP NUMBER[1]: 11			
	COMMENTS: Effective when used to control early instars of the caterpillar.			
C.	BACILLUS THURINGIENSIS ssp. KURSTAKI#			
	(various products)	Label rates	4	0
	MODE OF ACTION GROUP NUMBER[1]: 11			

COMMENTS: Effective when used to control early instars of the caterpillar.

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment until harvest. In some cases the REI exceeds the PHI. The longer of these two intervals is the minimum time that must elapse before harvest.

\# Acceptable for use on organically grown produce.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

— Not applicable.

PRECAUTIONS (see last page of this chapter)

PERSEA MITE

Scientific name: *Oligonychus perseae*

MITE PESTS OF AVOCADO—GENERAL INFORMATION

Spider mites (family Tetranychidae) and predatory mites (Phytoseiidae) are tiny 8-legged arthropods. Persea mite is a key pest of California-grown avocados. Avocado brown mite and sixspotted mite are sporadic pests. Several beneficial mites are important predators of pest mites and certain insects. Natural enemies and certain management strategies vary among pest mites. Identify the pest and natural enemy species in your grove and learn their biology so you can manage these pests appropriately as needed. For details about sampling techniques, see MONITORING PERSEA AND SIXSPOTTED MITES.

DESCRIPTION OF THE PEST

Persea mite (family Tetranychidae) is a key pest that occurs in most avocado-growing areas of California except the Central Valley. It is most damaging to Hass, Gwen, and a few other varieties. Esther, Pinkerton, and Reed are of intermediate susceptibility. The Bacon, Fuerte, Lamb Hass, and Zutano varieties are much less affected. Many ornamentals and weeds also host persea mite. When persea mites were first introduced into California in the early 1990s, individual mites from heavy populations on avocado trees were seen drifting onto leaves of adjacent stone fruit trees, although they did not feed. Since that time, however, populations have been reduced and persea mites have not been observed on stone fruit trees or fruit, and *Prunus* species are not known to be a host of this mite.

Persea mite develops from an egg through a six-legged larval stage and two eight-legged nymphal stages before becoming an eight-legged adult. Adult females have an oval-shaped body that is slightly flattened and elongated. Females and immatures are yellowish or greenish with two or more small dark blotches on their abdomen. Old females that have ceased oviposition turn darker green and become somewhat smaller and inactive. Males are smaller than reproductive females. Males are somewhat pear-shaped, slightly flattened, and yellowish with or without small dark spots. Persea mites feed and reproduce mostly beneath webbed patches or silk-covered "nests."

Each female lays about 2 to 4 dozen eggs during her life. Eggs are round, pale yellow, and develop red eye spots as they mature. Egg to adult female development time is about 2 to 3 weeks when temperatures average 77° to 63°F. Generation time can be accurately estimated by monitoring degree-days.

Cool winter temperatures slow persea mite population growth. Mite densities are lowest about March and gradually increase through spring feeding on new leaf flush. Populations generally peak in July and August. Persea mite populations are suppressed, and populations may decline rapidly, when the daily high temperature is 100°F or more on several consecutive days and humidity is low.

DAMAGE

High persea mite populations cause premature leaf drop and defoliation. Defoliation leads to sunburned bark and fruit, aborted or dropped fruit, and severely stressed trees, which

later reduces yields.

Persea mite feeding on the underside of leaves causes discrete circular chlorotic to brown spots on the lower leaf surface. These spots become visible on the upper leaf surface. Persea mite colonies are small and can become very numerous. Each colony can produce dense webbing, which resembles a silvery spot on the underside of the leaf. High persea mite populations can often be recognized by numerous brown-spotted, green leaves hanging from trees and on the ground beneath infested trees. Heavily infested canopies can appear lighter colored overall when viewed from a distance.

Persea mite damage early in the season can be confused with sixspotted mite damage. Sixspotted mite webbing is less dense and usually does not occur in small circular patches. Sixspotted mite feeding causes brown to purplish irregularly shaped blotches, in comparison with the roundish, mostly scattered spots created by persea mite. Damage from sixspotted mites is generally confined to areas immediately adjacent to veins, while persea mite often feeds throughout the lower leaf surface. Persea mite also sometimes feeds on the upper leaf surface, but mite feeding on the upper leaf surface is usually caused by avocado brown mite. Avocado brown mite feeding causes the upper leaf surface to appear bronzed or scorched and damage does not occur in discrete circular spots.

MANAGEMENT

Minimize tree stress to reduce the effect of persea mite feeding on trees. Appropriate irrigation frequency and amounts, good management of avocado root rot and other key pathogens, and harvesting fruit early will reduce the adverse impact of mite feeding. If treating, whenever possible choose pesticides that have low residual toxicity or are non-toxic to natural enemies.

In the early stages of a significant infestation, highly refined or narrow-range petroleum oils or certain other materials can be applied. Treat only where necessary and leave unsprayed areas to conserve beneficials and provide refuges from which natural enemies and pesticide-susceptible pests can recolonize treated trees. Maximize the interval between treatments and alternate applications among pesticides with a different mode of action to reduce the rate at which pesticide resistance develops.

Biological Control: Numerous predators feed on persea mite. Predaceous mites include *Amblyseius* (=*Neoseiulus) californicus, Euseius hibisci, Galendromus annectens,* and *G. helveolus.* Black hunter thrips *(Leptothrips mali)*, sixspotted thrips *(Scolothrips sexmaculatus)*, brown lacewings *(Hemerobius* spp.) and green lacewings *(Chrysopa* and *Chrysoperla* spp.), dustywings (family Coniopterygidae), a predatory midge *(Feltiella* sp., Cecidomyiidae), a rove beetle *(Oligota oviformis,* Staphylinidae), and the spider mite destroyer lady beetle *(Stethorus picipes)* are other common predators. Most predators are not highly effective because of persea mites' protective webbed nests. However, conserve natural enemies because they can reduce persea mite populations, and predators often provide good biological control of avocado brown mite and sixspotted mite.

Commercially available predators include predatory mites *(Amblyseius californicus,*

Galendromus annectens, and *G. helveolus,* family Phytoseiidae) and green lacewing larvae *(Chrysoperla* spp.). Often relatively few predaceous mites are present through the winter because populations of their persea mite prey have been suppressed by hot summer weather. Introducing *Galendromus helveolus* helps to control persea mite if sufficient numbers of predators are introduced and releases are well-timed. If predator releases are planned, monitor persea mites regularly in late February through summer and release predaceous mites when about 50% of leaves have one or more active-stage pest mites. To check the viability of purchased predaceous mites, gently pour some mites and any shipping substrate into a clear jar and look for an abundance of fast-moving mites, which indicates predators arrived in good condition.

Cultural Control: Eliminate or reduce persea mite alternate host plants growing near avocado, including mite-susceptible ornamentals, non-commercial fruit trees, and weeds. Provide trees with appropriate irrigation and other good cultural care to maintain the flush of new growth and compensate for mite-induced leaf drop. However, be careful not to overfertilize. Excess fertilization, especially with quick-release formulations, may increase persea mite populations and damage during late spring and summer due to increased foliar nitrogen. Spraying the underside of leaves with a forceful stream of water can reduce mite populations on a few small trees where this is feasible. Whitewash trunks and major limbs to protect bark and wood from sunburn after premature leaf drop

Organically Acceptable Methods: Biological and cultural controls and sprays of certain oils are acceptable for use on an organically certified crop.

Monitoring and Treatment Decisions: Inspect leaves for mites, mite damage, and natural enemies about every 7 to 10 days from mid-March through at least August, and perhaps through October. Coordinate monitoring and treatment decision-making for persea mite and avocado thrips, which are usually the key invertebrate pests feeding on leaves. Mite monitoring frequency, and the need for treatment and choice of material, can be affected by thrips management decisions. Certain materials applied (usually earlier in the season) to control avocado thrips can also control or suppress mite populations (which are usually treated later in the season if needed). Some materials can adversely impact natural enemies, so applying a less selective material early for thrips may increase the need to later treat mites. Only one application per season may be permitted or recommended for certain materials (e.g., abamectin) to reduce the development of pesticide resistance. Rotate among chemical classes when making multiple applications to reduce the development of pesticide resistance.

Consider the effect of weather on treatment decision-making. Heavy winter rains and high winds can substantially reduce subsequent mite populations and damage. Persea mite populations are suppressed or may crash when the daily high temperature is 100°F or more on several consecutive days and humidity is low.

There are no research-based thresholds for when persea mite treatment is warranted. Develop treatment guidelines satisfactory for your situation by keeping good records and adapting your monitoring and management methods as appropriate. Regularly monitor

and record mite densities and compare these numbers from year-to-year with records of your control actions and their effectiveness. See MONITORING PERSEA AND SIXSPOTTED MITES for additional information.

Treatment

	Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)
	When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact. Not all registered pesticides are listed. Always read label of product being used.			
A.	GALENDROMUS MITES#	2,000/tree	—	—
	. . . or . . .			
	NEOSEIULUS CALIFORNICUS#	2,000/tree	—	—
	COMMENTS: Make a single release of 2,000 mites/tree, or two releases each of 1,000 mites/tree, when regular monitoring of leaves for mite presence-absence shows that about 50% of leaves have one or more active-stage pest mites, typically in spring or early summer. The most effective release strategy is to dispense predator mites and carrier (e.g., corn grits) in small paper cups attached to branches. Attach 4 cups per tree evenly distributed around the canopy on avocado branches that are shaded from the sun. Add about 250 to 500 predators per cup depending on the release rate. The predators will disperse from the cups.			
B.	ABAMECTIN*			
	(Agri-Mek 0.15 EC and others)	Label rates	12	14
	MODE OF ACTION GROUP NUMBER[1]: 6			
	COMMENTS: Use with 1-2% narrow range (415) oil in a minimum of 50 gal water/acre for aerial applications and 100 gal water/acre for ground applications. On large trees aerial applications may require larger volumes of water to achieve desired efficacy. Control may last 3 or more weeks. Only use in an alkaline or slightly acidic solution. Do not tank mix with nutrients. To avoid promoting pesticide resistance, do not make more than one application of any abamectin product per year in each grove.			
C.	SPIRODICLOFEN			
	(Envidor 2 SC)	18–20 fl oz	12	2
	MODE OF ACTION GROUP NUMBER[1]: 23			
	COMMENTS: Only one application is allowable per crop season.			
D.	FENPROPATHRIN*			
	(Danitol 2.4 EC)	16–21.33 fl oz	24	1
	MODE OF ACTION GROUP NUMBER[1]: 3			
E.	NARROW RANGE OIL#	Label rates	see label	see label
	MODE OF ACTION: Contact including smothering and barrier effects.			
	COMMENTS: Requires good coverage to be effective. Check with certifier to determine which products are organically acceptable.			

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

\# Acceptable for use on organically grown produce.

* Permit required from county agricultural commissioner for purchase or use.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional

information, see their Web site at http://www.irac-online.org/.

— Not applicable.

PRECAUTIONS (see last page of this chapter)

SIXSPOTTED MITE

Scientific name: *Eotetranychus sexmaculatus*

MITE PESTS OF AVOCADO—GENERAL INFORMATION

Spider mites (family Tetranychidae) and predatory mites (Phytoseiidae) are tiny 8-legged arthropods. Persea mite is a key pest of California-grown avocados. Avocado brown mite and sixspotted mite are sporadic pests. Several beneficial mites are important predators of pest mites and certain insects. Natural enemies and certain management strategies vary among pest mites. Identify the pest and natural enemy species in your grove and learn their biology so you can manage these pests appropriately as needed. For details about sampling techniques, see MONITORING PERSEA AND SIXSPOTTED MITES.

DESCRIPTION OF THE PEST

The oval adults are about 0.01 inch (0.3 mm) long. Their body is lemon yellow, often with about six dark blotches on the abdomen, although some individuals have no distinct spots. Females lay tiny, globular, pale greenish yellow to translucent or pearly white eggs, which have a slender projecting stalk. About 25 to 40 eggs are laid over 10 to 20 days. Eggs hatch in 5 days to 3 weeks, depending on temperature. In summer, mites reach maturity in 8 to 12 days. Populations are heaviest in spring and early summer.

DAMAGE

Sixspotted mite is an occasional pest, mostly near the coast in foggy areas of San Luis Obispo and Santa Barbara counties. It generally is under good control in the interior growing areas (Riverside and San Diego counties) because of predators and warm weather. Sixspotted mite can become a problem anywhere if trees are drought-stressed or pesticides used to control other pests disrupt mite biological control.

Sixspotted mite feeds only on the lower avocado leaf surface. It causes irregular brown to purplish discoloring, mostly along the midrib and larger veins. Sixspotted mite produces webbing, but not the dense roundish silk patches formed by persea mite.

MANAGEMENT

Enhance biological control by conserving natural enemies. Minimize dust. Avoid applying non-selective pesticides that are toxic to predaceous insects and beneficial mites that control plant-feeding mites and other pest insects. Limit any needed applications to spots where pests are most abundant.

Biological Control: Sixspotted mite is controlled primarily by predatory mites (family Phytoseiidae). These phytoseiids include *Amblyseius*(=*Typhlodromalus) limonicus* and *Galendromus helveolus. Euseius hibisci,* a shiny pear-shaped predator, is important in part because it can maintain and increase its populations on avocado pollen when pest mites are scarce. *Typhlodromus rickeri* also preys on sixspotted mite around Santa Barbara County. The spider mite destroyer lady beetle *(Stethorus picipes)* and sixspotted thrips *(Scolothrips sexmaculatus)* are other important natural enemies.

Cultural Control: Encourage predators by oiling or paving main orchard roads to control

road dust. Drive slowly when it is necessary to use dirt roads. Consider using a water truck or trailer to wet dirt roads, especially before travel during summer months when heat convection currents carry dust well up into the tree canopies. Individual backyard trees can be hosed down in early to mid-summer to remove dust and enhance biological controls.

Organically Acceptable Methods: Biological and cultural controls and sulfur and certain oil sprays are acceptable for use on an organically certified crop.

Monitoring and Treatment Decisions : Look for sixspotted mite when monitoring persea mite (see MONITORING PERSEA AND SIXSPOTTED MITES). Be sure to distinguish the mite species present. When specifically monitoring for sixspotted mite, select trees in dusty and more humid locations of groves. Use a hand lens to examine along the midrib and lateral veins on the underside of interior canopy leaves. Look for brown to purplish discoloring, mite webbing, and mites.

Sixspotted spider mite can severely stress trees at relatively low densities by causing premature leaf drop. However, populations rarely exceed an average of 2 to 3 mites per leaf. At this low abundance sixspotted mite is not damaging, does not warrant treatment, and is easily overlooked.

Treatment

	Common name (trade name)	**Amount to use**	**R.E.I.+ (hours)**	**P.H.I.+ (days)**
	When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact.			
A.	NARROW RANGE OIL# MODE OF ACTION: Contact including smothering and barrier effects. COMMENTS: Requires good coverage to be effective. Check with certifier to determine which products are organically acceptable.	Label rates	4	0
B.	WETTABLE SULFUR# MODE OF ACTION: Unknown. An inorganic miticide. COMMENTS: Do not treat with sulfur when temperatures exceed 90°F to avoid leaf damage. Sulfur sprays are often not effective in coastal areas where temperatures do not promote fuming action.	Label rates	1 day	0

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

\# Certain products are acceptable for organically grown produce.

PRECAUTIONS (see last page of this chapter)

BROWN GARDEN SNAIL

Scientific name: *Cantareus aspersus (=Helix aspersa)*

DESCRIPTION OF THE PEST

The brown garden snail (Phylum Mollusca, family Helicidae) has a soft, slime-covered brown body. Its body and a pair of antennalike sensory appendages can be withdrawn into its shell. The hard spiraling shell grows up to about 1.25 inches in diameter. The shell is brown, tan, and yellow patterned in bands, flecks, and swirls.

Snails are hermaphroditic; they contain both male and female organs. After mating, snails drop eggs in a scattered group in a sheltered spot on topsoil. Mature snails lay eggs up to six times during a year, depending on climate and moisture.

Snails are most active during the night and early morning when surfaces are damp. In southern California, particularly along the coast, young snails are active throughout the year. Mature snails hibernate in topsoil during cold weather.

DAMAGE

Extensive chewing of blossoms, leaves, and shoots stunts the growth of young trees and trees that have been topworked. The brown garden snail can especially be a problem following wet winters and springs. Brown garden snail feeding is not a problem in mature groves. Thick, dry leaf mulch suppresses snail numbers and large trees tolerate any modest chewing.

MANAGEMENT

Inspect young and topworked trees regularly for chewing damage, especially during and after wet conditions. Be sure to distinguish the cause of damage. Caterpillars, earwigs, Fuller rose beetle, grasshoppers, and June beetles also chew tree foliage. Inspect surfaces for slimy or dry silvery trails characteristic of snails and slugs. Look for snails hidden under trunk wraps or other shelters near trunks.

Modify cultural practices, encourage biological control, and exclude snails from canopies to provide good control. Control weeds in young groves and groves where tree canopies are sparse as low vegetation favors snails. Retain dropped leaves and apply coarse organic mulch around trunks to retard snail populations and to suppress root rot and weeds. Frequent microsprinkling encourages snail problems. Increase the interval between irrigations to the extent compatible with good tree growth. Trim branches that touch soil to restrict snail access to canopies and expose the soil surface to drying.

Birds and other small vertebrates, parasitic flies, and several types of predatory beetles commonly prey on snails. The predatory decollate snail *(Rumina decollata,* family Subulinidae) is widely distributed in southern California. Decollate snail is commercially available and legal for introduction only in southern California counties. Decollate introductions are not recommended in avocado. Establishment of significant decollate populations usually requires several years after introduction, and brown garden snail primarily is a pest when avocado trees are young.

Snails and slugs are repelled by copper. Commercially available bands of copper foil wrapped around trunks exclude snails. Certain snail baits are available for spot applications. Molluscicides also kill predatory decollate snails. Pesticides are rarely warranted for mollusk control in avocado.

Treatment

	Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)
	When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact. Not all registered pesticides are listed. Always read label of product being used.			
A.	METALDEHYDE G COMMENTS: Use the higher rate for heavy infestations.	20–40 lb/acre	12	0
B.	COPPER BANDS# COMMENTS: Place copper foil band around the tree trunk at a height of 1-2 feet above the ground. Overlap the copper foil on the tree trunk about 8 inches so it will slip and allow for trunk growth.	Label rates	—	—
C.	BORDEAUX MIXTURE# (10:10:100) MODE OF ACTION: An inorganic insecticide. COMMENTS: A slurry containing tribasic copper sulfate can be sprayed on trunks to act as a barrier. Not all copper compounds are approved for use in organic production; be sure to check individual products. Be sure to follow label directions for products used. For information on making a Bordeaux mixture, see UC IPM Pest Note: Bordeaux Mixture, ANR Publication 7451.	Label rates	see label	see label
D.	IRON PHOSPHATE (Sluggo) COMMENTS: Apply using standard fertilizer spreader. If ground is dry, wet it before applying bait. Reapply as bait is consumed or at least every 2 weeks. Check with your organic certifier to determine if this product is acceptable for use on organically certified produce.	Label rates	0	0

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

\# Acceptable for use on organically grown produce.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

— Not applicable.

PRECAUTIONS (see last page of this chapter)

BRANCH AND TWIG BORER

Scientific name: *Melalgus (=Polycaon) confertus*

DESCRIPTION OF THE PEST

The adult branch and twig borer (family Cerambycidae) is a slender brown beetle about 0.5 to 0.75 inches long. Its body is cylindrical, and the head and prothorax are narrower than the body. Females lay eggs in the dead wood of many different species of native and cultivated trees and shrubs. Larvae bore into heartwood and feed there for a year or more. Pupation occurs within the tree and adults emerge in early summer. There is one generation per year.

DAMAGE

When present, borers cause a recognizable hole in branches. This entrance to a larval feeding tunnel often exudes sugary sap that turns white and flaky. Infested branches with tunnels can be easily broken by wind. Branch and twig borer is not common in avocado and seldom causes economic injury.

MANAGEMENT

Borers prefer injured, dying wood and stressed, slow-growing trees. Protect trees from sunburn and injuries, such as by whitewashing exposed bark. Provide appropriate irrigation to keep trees healthy. Remove badly diseased or borer-infested trees and branches from the orchard. Promptly destroy brush piles. Branch and twig borers can emerge from cut limbs of many species and attack nearby trees. Spraying insecticides does not kill borer larvae. Pesticides are not recommended for this insect.

EUROPEAN EARWIG

Scientific name: *Forficula auricularia*

DESCRIPTION OF THE PEST

The introduced European earwig (family Forficulidae) is the most common of several earwig species that can occur in avocado. Adults are about 0.75 inch long, reddish brown, and have a pair of prominent tail appendages that resemble forceps. Most species have wings under short, hard wing covers, but earwigs seldom fly. Immature earwigs resemble small, wingless adults.

Earwigs feed mostly at night and hide during the day. Common hiding places include bark crevices, mulch, topsoil, protected (touching) plant parts, and under trunk wraps. Females lay masses of 30 or more eggs in soil. Nymphs are whitish and remain in soil until their first molt, after which they darken and begin searching for food. Earwigs generally have one or two generations a year. They can be active year round.

DAMAGE: Earwigs feed on dead and living insects and insect eggs, other organisms, and on succulent plant parts. Earwigs occasionally damage buds and leaves on young or newly grafted trees. They can be especially problematic on trees with trunk wrappers or cardboard guards. The cause of damage can be difficult to distinguish from that of other chewing pests that hide during day and feed at night, including brown garden snail, Fuller rose beetle, and June beetles.

MANAGEMENT

If you suspect that earwigs are causing damage, lift and shake or sharply tap any trunk wrappers and look for earwigs dropping to the ground, where they quickly scurry for cover. Alternatively, place a folded newspaper or burlap bag near the base of several trees with chewed foliage. Check these traps or earwig hiding places the next morning. Cans with sardine or tuna fish oil are highly attractive to earwigs, which will climb into containers and drown. It may be necessary to cover liquid traps with heavy screening to exclude feeding by domestic and wild animals drawn to the fish odor. Remove trunk wrappers where pests hide when wraps are no longer needed, thereby reducing earwig populations. Earwigs rarely are abundant enough to warrant chemical treatment, except on young trees bordering uncultivated areas. Check with your farm advisor or County Agricultural Commissioner about registration status of baits for treating earwigs.

FALSE CHINCH BUG

Scientific name: *Nysius raphanus*

DESCRIPTION OF THE PEST

The false chinch bug (family Lygaeidae) adult is mostly light to dark gray, elongate, and about 0.12 inch (3 mm) long. Females lay eggs on host plants or in cracks in soil. The mostly pale gray nymphs have inconspicuous reddish to brown abdominal markings. There are from four to seven generations per year. All stages can be present throughout the year.

During winter and early spring, false chinch bug primarily feeds on foliage, stems, and seeds of wild grasses and cruciferous weeds. When vegetation dries or is cut, bugs move to feed on virtually any nearby green plants, including irrigated fruit and nut trees, grains, and vegetable crops.

DAMAGE

False chinch bug occasionally causes severe injury on young trees by sucking sap from shoots and young stems. Infested shoots wither and die suddenly after attack, which typically occurs in May and June. Economic damage occurs in groves away from the coast only on young trees in border rows adjacent to uncultivated areas or grasslands. Otherwise healthy mature trees tolerate bug feeding.

MANAGEMENT

Monitor during late winter and early spring if young avocado trees are growing inland near unmanaged areas most susceptible to false chinch bug migrations. Before winter weeds dry or are cut, look for bugs on fences and weedy areas adjacent to young trees. If false chinch bugs are abundant, consider treating weedy borders to kill bugs before they migrate.

Treatment

	Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)
	When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact.			
A.	MALATHION 8 MODE OF ACTION GROUP NUMBER[1]: 1B COMMENTS: Apply as a foliar spray. Use of this material will disrupt biological control of other pests such as scales, thrips, mites, and whiteflies.	4–9 pt/acre	12	7

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

PRECAUTIONS (see last page of this chapter)

FULLER ROSE BEETLE

Scientific name: *Pantomorus cervinus*

DESCRIPTION OF THE PEST

Adult Fuller rose beetles are brown to grayish snout beetles (weevils, family Curculionidae), about 0.36 inch (9 mm) long. Adults are all females, which lay eggs in clusters of several dozen in crevices on the tree or under loose bark. Larvae drop to the ground and feed on weed or tree roots, but larval feeding does not damage trees. Overwintering is as grubs that pupate beginning about May to July. Adults emerge during about June through September. They feed for 2 weeks before laying their first eggs. Feeding and egg-laying can continue into winter. There is one generation each year.

DAMAGE

Fuller rose beetle is an occasional problem in young avocado plantings and replantings. It can also damage top-worked, recently grafted, or severely pruned trees that have relatively little foliage. Fuller rose beetle usually is abundant only on avocado growing near citrus or other preferred hosts.

Fuller rose beetle adults chew leaf margins, causing a ragged, notched, or serrated appearance. Most chewed leaves are on lower branches because adults cannot fly and must climb trunks and branches to reach foliage. Leaf chewing on older, well-foliated trees is not economically important.

MANAGEMENT

During late winter or early spring, apply a sticky barrier to trunks to exclude weevils if they may be a problem. Encircle a smooth section of trunk with a flexible wrap or tape and apply the sticky material on top to prevent direct contact with, and injury to, bark. A parasitic wasp *(Fidiobia citri,* family Platygastridae) parasitizes up to 50% of Fuller rose beetle eggs in citrus. Parasitized eggs darken and may persist long after unparasitized eggs have hatched. This parasite's importance in avocado is unknown.

Starting in June, inspect susceptible young or top-worked trees for leaf notching made by newly emerged adults. Be aware that caterpillars, earwigs, June beetles, grasshoppers, and snails also chew avocado leaves. Larvae and pupae of the exotic Diaprepes root weevil *(Diaprepes abbreviatus)* resemble Fuller rose beetle and adults of both species chew leaves. Be certain to identify the cause of problems before taking action. If suspected Diaprepes root weevils are found, notify agricultural officials as prompt management action may be warranted.

Treatment

Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)

When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact.

A. STICKY POLYBUTENE MATERIALS#

(Tanglefoot) Label rates — —
COMMENTS: For use on all varieties. Use polybutene-based products only. Do not apply sticky materials directly on the trunk; use a 6- to 18-inch wrap under the sticky material to protect the tree from sunburn. Exercise caution in applying multiple applications (more than 3 or 4); watch for symptoms of bark cracking. Apply the sticky band high enough to avoid sprinklers, dust, and direct sunlight. Reactivate periodically by rubbing with a stick to remove dust. Check to ensure that low hanging branches, sticks, weeds, etc., are not allowing ants access to trees.

B. MALATHION 8 4–9 pt/acre 12 7
MODE OF ACTION GROUP NUMBER[1]: 1B
COMMENTS: Apply as a foliar spray. Use of this material will disrupt biological control of other pests such as scales, thrips, mites, and whiteflies and is not very effective against Fuller rose beetle.

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

\# Acceptable for use on organically grown produce.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

— Not applicable.

PRECAUTIONS (see last page of this chapter)

GRASSHOPPERS

Scientific name:
Devastating grasshopper: *Melanoplus devastator*
Valley grasshopper: *Oedaleonotus enigma*

DESCRIPTION OF THE PEST

Grasshoppers (order Orthoptera) are robust, elongate insects with winged adults that are good flyers. Commonly they are brown, gray, green, or yellowish insects with greatly enlarged hind-leg femurs adapted for jumping. Grasshoppers have relatively short antennae, which distinguishes them from crickets, katydids, and other Orthoptera, which have long antennae.

Most species of grasshopper overwinter as eggs and have only one generation a year. Adults live and feed for 2 to 3 months, during which females typically deposit elongate pods of about 20 to 100 eggs in the topsoil of undisturbed areas. Eggs hatch when soil warms in spring. The nymphs feed on most any species of nearby green plant, molting five or six times before becoming adults.

Nymphs and adults readily move. Each individual typically feeds on several different plants. As vegetation is consumed or dries when the rainy season ends, grasshoppers migrate to succulent plants. Adults, sometimes in a large swarm, can fly several miles a day. Nymphs readily jump, walk, or are carried by wind.

Grasshopper populations vary from year to year. Grasshoppers become more numerous after warm, moist springs produce abundant vegetation in uncultivated areas, favoring grasshopper survival. Conversely, parasites and bacterial, fungal, and protozoan diseases can cause grasshopper populations to crash. Many grasshoppers are eaten by arboreal predators such as birds and robber flies (family Asilidae) and soil-dwelling egg predators such as blister beetles (Meloidae).

DAMAGE

Grasshoppers become economic pests when young tree foliage is extensively chewed by large numbers of insects migrating from unmanaged vegetation. Mature trees are not harmed by grasshopper feeding.

MANAGEMENT

Do not take control action based solely on damage. Caterpillars, earwigs, Fuller rose beetle, June beetles, and snails also chew leaves. Some management methods vary depending on the cause. Where abundant, grasshoppers can be observed during the day feeding openly and flying or jumping among plants.

Grasshoppers can be difficult to manage once large numbers move onto young trees. If you believe grasshoppers may become a problem, monitor for them in uncultivated areas near young trees. Before adjacent vegetation dries or is cut, consider applying insecticide combined with bait or spraying border areas to kill grasshoppers before they migrate and start to damage crops.

Treatment

Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)

When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact. Not all registered pesticides are listed. Always read label of product being used.

A.	MALATHION 8 MODE OF ACTION GROUP NUMBER[1]: 1B COMMENTS: Only treat infested trees to avoid destroying natural enemies of mites, loopers, scales, and other potential secondary pests.	4–9 pt/acre	12	7

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

PRECAUTIONS (see last page of this chapter)

JUNE BEETLES

Scientific name: *Coenonycha testacea, Serica fimbriata,* and *Serica alternata.*

DESCRIPTION OF THE PEST

June beetles (sometimes called Junebugs) and May beetles include various species in the family Scarabaeidae. Adult beetles fly into avocado from untilled fields and brushland during late spring or early summer. Adults chew tree foliage at night and when present night-after-night can completely defoliate a large number of young trees in a single grove. During the day, adults hide under litter or burrow into the upper 2 inches of soil, reappearing the following night to resume feeding.

Serica spp. are the most common and widely distributed scarabs in avocado. The adult *Serica fimbriata* is 0.6 inch long and velvety brown with faintly striated wing covers. *Serica alternata* and *Coenonycha testacea* adults are 0.4 inch long and uniformly shiny brown. Adult scarabs are robust beetles, although *C. testacea* is almost rectangular and is distinctly more narrow than the *Serica* spp. Scarab larvae are C-shaped, cream colored, soil-dwelling grubs. June beetles have one generation per year.

DAMAGE

During spring they sometimes injure young, newly planted trees, typically near uncultivated land away from the coast. Chewing on mature trees with a well-developed canopy is generally of no economic importance.

MANAGEMENT

Determine whether chewing is actually caused by June beetles and not other nocturnal pests, including earwigs, Fuller rose beetles, and snails. Caterpillars and grasshoppers also cause similar damage. June beetles can be detected, and perhaps controlled somewhat in small plantings, by deploying blacklight traps at night during late winter and spring. It may be best to deploy any blacklight traps somewhat away from the young or topworked trees. Placing traps in mature trees near new plantings and along grove edges bordering unmanaged vegetation reduces the risk that traps placed among susceptible hosts might attract adult beetles to those plants.

Treatment

	Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)
	When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact.			
A.	MALATHION 8 MODE OF ACTION GROUP NUMBER[1]: 1B COMMENTS: Apply as a foliar spray at night when beetles are feeding in trees. Use of this material will disrupt biological control of other pests such as scales, thrips, mites, and whiteflies.	4–9 pt/acre	7	12

+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment to harvest. In some cases the REI exceeds the PHI. The longer of two intervals is the minimum time that must elapse before harvest.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

PRECAUTIONS (see last page of this chapter)

ARMORED SCALES

Scientific name:
Latania scale: *Hemiberlesia lataniae*
California red scale: *Aonidiella aurantii*
Dictyospermum scale: *Chrysomphalus dictyospermi*
Greedy scale: *Hemiberlesia rapax*

DESCRIPTION OF THE PEST

Armored scales are rarely a problem on avocados in California.

Armored scales (family Diaspididae) have a flattened, slightly convex cover that at maturity is about 0.06 inch (3 mm) in diameter. This platelike cover usually can be removed to reveal the actual scale body underneath. Armored scale covers typically have a different colored, slight protuberance (exuviae or "nipple") and concentric rings, which form as each nymphal stage enlarges its cover. Females develop roundish covers. For species with males, their covers are elongate in late instars.

Latania and greedy scale can reliably be distinguished only by an expert. Their covers are gray, tan, or white. Dictyospermum scale has a yellowish brown cover that is somewhat darker than the similar-looking, orange to reddish California red scale cover. California red scale and latania scale occur throughout the plant, with relatively even distribution among fruit, leaves, and wood. Dictyospermum scale infests mostly fruit and leaves. Greedy scale is usually limited to twigs and branches.

Latania scale and greedy scale females lay eggs beneath their cover, from which crawlers hatch. California red scale and dictyospermum scale give live birth to young crawlers. Greedy scale and latania scale reproduce without males, at least in California. Both California red scale and dictyospermum scale produce males, which as immatures develop under elongate covers.

DAMAGE

Scales in avocado are usually under good biological control. Latania scale occasionally damages avocado. High latania scale populations on bark can kill twigs, especially on young trees. Unlike many plant-sucking insects, armored scales do not secrete any noticeable liquid. Economic damage is from scale covers on the fruit skin, which appear as tiny dimples or light-colored spots. Feeding may also cause small discolored spots in the skin. Internal fruit quality is not impaired, but infested or spotted fruit may be culled. California red scale is a rare problem, and only on avocado near citrus. Dictyospermum scale and greedy scale occur in avocado only at innocuous densities.

MANAGEMENT

Biological control is the primary scale control method. Conserve natural enemies by controlling ants, minimizing dust, and avoiding application of broad-spectrum, persistent insecticides. If certain areas of a grove have high armored scale populations, determine whether encrusted fruit can be selectively harvested and sent to a packing house that uses brushes or pressure-washing equipment that can remove scale covers from fruit. In the

infrequent event that direct control may be justified, oil spray has little long-term adverse impact on natural enemies. Time any scale treatments to occur soon after most scale crawlers have emerged.

Biological Control: Predatory insects and parasitic wasps control most scales. Armored scale parasites include species of tiny *Aphytis* and *Aspidiotiphagus* (family Aphelinidae), and *Comperiella* and *Signiphora* (family Encyrtidae). Most scale predators feed on both armored and soft scales and often on other pests. Predators include brown and green lacewings, pirate bugs, predaceous mites such as *Cheletomimus berlesei* and *Hemisarcoptes malus,* and sixspotted thrips.

Predaceous Coccinellidae include the spotless lady beetle *(Cycloneda sanguinea)*, steelblue lady beetle *(Halmus chalybeus)*, and twicestabbed lady beetle *(Chilocorus orbus =C. stigma)*. As adults, these lady beetles are about 0.16 to 0.2 inch (4–5 mm) long. Spotless lady beetle has a black and white head and thorax and orangish wing covers without markings. Steelblue lady beetle is metallic bluish. Twicestabbed lady beetle is shiny black with two large orangish spots on its wing covers. Its larvae are black to brownish with a yellowish transverse band and are covered with branched spines.

Organically Acceptable Methods: Biological control and some oil sprays are acceptable for use on an organically certified crop.

Monitoring and Treatment Decisions: In the rare situation where treatment is warranted, spray oil after the end of maximum crawler emergence. To time an application, monitor scale crawlers by trapping them with transparent tape that is sticky on both sides. Wrap tape traps tightly to encircle each of several twigs near female scales. Replace traps weekly when crawlers are expected. Preserve traps sandwiched between clear plastic and light blue paper, and label papers with the trap date and location. Visually compare crawler abundance in traps among monitoring dates. Treat when it is obvious that more crawlers per trap were caught during previous weeks and catches have definitely declined. If persistent populations of California red scale are present, consider releasing a small number (perhaps 10,000) of *Aphytis melinus* near the scale infested trees after purchasing them from an insectary.

Treatment

Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)

When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact. Not all registered pesticides are listed. Always read label of product being used.

A.	NARROW RANGE OIL#	Label rates	4	0

MODE OF ACTION: Contact including smothering and barrier effects.
COMMENTS: Requires good coverage to be effective. Oil does kill some beneficial wasps and suppresses beneficial mite populations, however the residue does not persist and parasitic wasps can emerge from parasitized scale or be commercially released soon after treatment. Check with certifier to determine which products are organically acceptable.

B.	APHYTIS MELINUS#	About 10,000 per infested site	—	—

COMMENTS: For release against California red scale only. Make a single release, or several smaller release at about 2 week intervals, totaling approximately 10,000 parasites per infested site. Time release so that the parasites can attack unmated female scales. Visually monitor scales and release parasites when a significant proportion of the scale population is at or approaching the virgin female stage. Alternatively, monitor using pheromone-baited sticky traps and release parasites at or just before a male flight, which is approximately 800 degree-days after the peak of the previous generation male scales.

Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment until harvest. In some cases the REI exceeds the PHI. The longer of these two intervals is the minimum time that must elapse before harvest.

Certain products are acceptable for organically grown produce.

— Not applicable.

PRECAUTIONS (see last page of this chapter)

ORANGE TORTRIX

Scientific name: *Argyrotaenia citrana*

DESCRIPTION OF THE PEST

Orange tortrix (family Tortricidae) is an uncommon problem on avocados grown in coastal areas. It rarely is injurious at inland growing areas. Orange tortrix feeds on various weeds and crops including citrus, grape, and strawberry.

Orange tortrix and amorbia adults resemble each other. They are orangish to tan moths with dark shading across their folded wings. At rest, their folded wings flare out at the tip so their overall shape resembles a bell. Orange tortrix adults are about 0.4 inch long, about one half the size of amorbia adults.

Orange tortrix and amorbia females lay eggs overlapping in a mass. Orange tortrix oviposits on the surface of young leaves, green twigs, or green fruit. Each egg is pale green, flat, oval, and has a finely reticulated surface. Females lay several clusters that range from a few eggs to over 150 eggs per mass. Eggs hatch in about 9 days.

Larvae usually feed singly on shoot tips or on succulent leaves in nests they web together with silk. Larvae develop through 5 to 7 instars over about 40 days. They are about 0.08 inch (2 mm) long at hatching and about 0.5 inch long when mature. Larvae have a brownish or straw-colored head and prothoracic plate (the top of first segment behind the head). The variable body color is dark gray, greenish, straw-colored, or tan. Orange tortrix and amorbia larvae typically wriggle vigorously backwards or sideways when disturbed. Orange tortrix may drop to the ground or remain suspended from the leaf on a silken thread.

Larvae form a dense silken cocoon where they pupate within webbed foliage. Adults emerge in about 1 to 3 weeks, depending on temperature. Orange tortrix has two to four generations per year, with all stages present throughout the year.

DAMAGE

Most larval chewing occurs within silken webs on outer-canopy shoots. During bloom, tiny larvae sometimes feed among flowers. Larvae also feed on green bark, girdling some twigs. White exudate may cover wounds on larger twigs. Least common is fruit feeding, but this is the economic damage. Fruit injury closely resembles damage from other avocado caterpillars, except that orange tortrix tends to chew deeper holes. Feeding near the stem end of fruit and on the stem may cause fruit to drop.

MANAGEMENT

Conserve natural enemies, which usually keep caterpillars below damaging levels. Modify cultural practices to reduce pest reproduction and survival. Avoid applying broad-spectrum or persistent insecticides for any pests. Caterpillar outbreaks commonly occur after spraying carbamate or organophosphate insecticides, which poison parasites and predators. When pesticides are warranted, limit application to the most infested spots to provide refuges from which natural enemies can recolonize after treatment.

Biological Control: More than one dozen parasite species and various predators attack orange tortrix, including assassin bugs, birds, damsel bugs, lacewings, and pirate bugs. These usually provide excellent biological control. Parasites include *Trichogramma platneri* and several tachinid flies as described in the section AMORBIA. Common internal larval parasitic wasps are *Apanteles aristoteliae* (family Braconidae) and *Exochus* spp. (Ichneumonidae).

Organically Acceptable Methods: Biological controls and sprays of *Bacillus thuringiensis* are acceptable for use on an organically certified crop.

Monitoring and Treatment Decisions: Where caterpillar problems may occur, monitor during at least spring and summer. Good places to monitor include where bright lights such as security lights are used outdoors because the nocturnal moths are attracted by lights to lay eggs nearby. Be sure to correctly distinguish the cause of any damage as other insects and certain abiotic disorders cause leaf holes resembling caterpillar chewing. Correctly identify the species of caterpillars. Alternate host plants, damage potential, monitoring methods, and natural enemies vary depending on the species of caterpillar. Look for caterpillar predators and larval diseases and parasitism. Natural enemy prevalence affects treatment decision making. See MONITORING CATERPILLARS AND THEIR NATURAL ENEMIES for details on identification and monitoring methods including inspecting foliage for caterpillars and their damage (timed counts), trapping adults, shaking foliage to dislodge larvae (primarily for avocado looper), or a combination of these methods.

There are no established thresholds, and treatment for orange tortrix is rarely warranted. If sprays are needed, use *Bacillus thuringiensis* when larvae are small. Spraying with malathion often leads to outbreaks of other pests and is not recommended.

Treatment

Common name (trade name)	Amount to use	R.E.I.+ (hours)	P.H.I.+ (days)
When choosing a pesticide, consider information relating to the impact on natural enemies and honey bees and environmental impact. Not all registered pesticides are listed. Always read label of product being used.			
A. BACILLUS THURINGIENSIS spp. AIZAWAI#			
(various products)	Label rates	4	0
MODE OF ACTION GROUP NUMBER[1]: 11			
COMMENTS: Effective when used to control early instars of the caterpillar.			
B. BACILLUS THURINGIENSIS ssp. KURSTAKI#			
(various products)	Label rates	4	0
MODE OF ACTION GROUP NUMBER[1]: 11			
COMMENTS: Effective when used to control early instars of the caterpillar.			

\+ Restricted entry interval (R.E.I.) is the number of hours (unless otherwise noted) from treatment until the treated area can be safely entered without protective clothing. Preharvest interval (P.H.I.) is the number of days from treatment until harvest. In some cases the REI exceeds the PHI. The longer of these two intervals is the minimum time that must elapse before harvest.

\# Acceptable for use on organically grown produce.

1 Rotate chemicals with a different mode-of-action Group number, and do not use products with the

same mode-of-action Group number more than twice per season to help prevent the development of resistance. For example, the organophosphates have a Group number of 1B; chemicals with a 1B Group number should be alternated with chemicals that have a Group number other than 1B. Mode of action Group numbers are assigned by IRAC (Insecticide Resistance Action Committee). For additional information, see their Web site at http://www.irac-online.org/.

PRECAUTIONS (see last page of this chapter)

GLASSY-WINGED SHARPSHOOTER

Scientific name: *Homalodisca vitripennis (=H. coagulata)*

DESCRIPTION OF THE PEST

Glassy-winged sharpshooter (family Cicadellidae) sucks leaf and stem xylem tissue, and vectors *Xylella fastidiosa* bacteria lethal to certain crops. While feeding, adults and nymphs excrete large amounts of liquid, which gives fruit and foliage a whitewashed appearance. Glassy-winged sharpshooter adults feed on over 300 plant species and can reproduce (lay eggs) in about 100 species.

Sharpshooters are active insects that walk rapidly sideways or readily jump when disturbed. The glassy-winged sharpshooter is a larger than most other leafhoppers. Adults are about 1/2 inch (13 mm) long and dark brownish with white and yellowish patches and spots. Pale head spots help to distinguish glassy-winged sharpshooter from the native smoke-tree sharpshooter *(Homalodisca lacerta)*, which has light-colored wavy lines on the head.

Females lay eggs in a cluster of about one dozen eggs within the lower surface of leaves. Eggs initially resemble a greenish blister on the leaf, which females cover with a white chalky secretion. Eggs turn brown as they mature and leave a permanent brown to gray scar in leaf tissue after nymphs emerge.

Immature glassy-winged sharpshooters develop through several stages (instars) and resemble small adults, except the immatures are wingless, uniformly olive gray, and have prominent bulging red eyes. Smoke-tree sharpshooter nymphs appear very similar but have blue eyes.

The glassy-winged sharpshooter has two generations per year in California. Although all life stages can be found year-round, reproduction and immature stages occur mostly from late winter through fall. Overwintering adults oviposit in late winter and early spring. Nymphs mature into first generation adults during about April through early June. Most second generation adults appear during later summer through fall, and can survive overwinter until the following season.

DAMAGE

Glassy-winged sharpshooter is not currently damaging in avocado. Quarantines may require treatment of nursery stock before young avocado trees can be shipped.

Glassy-winged sharpshooter is a serious pest of certain other crops because it vectors lethal *Xylella fastidiosa* diseases such as almond leaf scorch, oleander leaf scorch, and Pierce's disease of grapes. No leafhopper-vectored avocado diseases have been observed in the United States. However, strains of *Xylella* in other parts of the world, such as one reportedly damaging avocado in Costa Rica, could be damaging if introduced into California.

MANAGEMENT
Avocado nurseries may be required to treat stock and meet other requirements when producing and shipping young avocado trees. Contact the county department of agriculture for current quarantine compliance rules.

In established avocado groves, glassy-winged sharpshooter generally requires no management. However, monitoring may be warranted if avocado are grown near untreated citrus or other favored hosts. Yellow sticky traps are useful for monitoring adults of glassy-winged sharpshooter and their primary parasites *(Gonatocerus* spp.) Mid-summer through fall are the best times to deploy and inspect traps. Glassy-winged sharpshooters become most abundant during their second generation, when they move into avocado from nearby citrus.

If abundant in avocado, consider removing or replacing nearby alternate hosts such as favored ornamentals and abandoned citrus. Because glassy-winged sharpshooters reproduce in great numbers on citrus, consult with nearby citrus growers regarding any plans to promote biological control (e.g., conserve egg parasites) or treat sharpshooters in citrus.

Biological Control: Several *Gonatocerus* spp. wasps parasitize glassy-winged sharpshooter eggs. Parasitized eggs are easily recognized by a tiny, round hole at one end of the glassy-winged sharpshooter egg through which the adult parasite emerged. *Gonatocerus ashmeadi* is commonly found wherever glassy-winged sharpshooter occurs in California. In southern and coastal areas of California, *Gonatocerus morrilli,* can be very effective in the late summer, when the second generation of eggs are deposited. *Gonatocerus fasciatus, G. novifasciatus,* and *G. triguttatus* also occur at low levels in California.

Organically Acceptable Methods: Biological controls are organically acceptable.

LONGTAILED MEALYBUG

Scientific name: *Pseudococcus longispinus*

DESCRIPTION OF THE PEST

Nymphs and adult female mealybugs (order Pseudococcidae) are soft, oval, white powder- or wax-covered insects. Adult males are tiny, two winged insects with two long tail filaments, but are rarely seen. In many mealybug species the female lays tiny yellow eggs in an ovisac, a mass of eggs intermixed with white wax. Longtailed mealybug produces no external egg sacs; it gives live birth to nymphs. Longtailed has two to four overlapping generations a year. All stages can occur throughout the year.

Longtailed mealybug is the only species common in California avocado. Other species to look out for because they infest avocado elsewhere include citrus mealybug *(Planococcus citri)*, pink hibiscus mealybug *(Maconellicoccus hirsutus)*, and vine mealybug *(Planococcus ficus)*, none of which are reported pests of avocado in California.

The citrus, longtailed, and vine mealybugs have distinct, well-developed wax filaments around their body margin. Female longtailed mealybugs have tail filaments almost as long as the body length. Citrus and vine mealybug filaments are relatively short. Pink hibiscus mealybug lacks distinct waxy filaments.

Have unfamiliar mealybug species identified by an expert. For example, the introduced vine mealybug has not been found in California groves, but it infests avocado elsewhere. Pink hibiscus mealybug in California has been limited to Imperial county. Introduced parasites, especially *Anagyrus kamali* (Encyrtidae), are providing good biological control. If pink hibiscus mealybug is discovered elsewhere in California, notify agricultural officials as prompt management action may be warranted.

DAMAGE

Mealybugs suck phloem sap. When abundant, they can reduce tree vigor, foul plants with sticky honeydew, and promote growth of blackish sooty mold that fouls fruit. Mealybug populations are usually very low. They occasionally are pests of young trees. New scion grafts on old (top-worked) trees have sometimes been damaged by longtailed mealybugs abundant during late winter to early spring.

MANAGEMENT

Conserve natural enemies that control most mealybug populations. Selectively controlling ants causes longtailed mealybug populations to decline and can prevent outbreaks. Reduce dust, which interferes with natural enemies. Whenever possible, apply only selective or short-residual pesticides when treating other pests. Pesticide application is not recommended for mealybugs in avocado.

Biological Control: Mealybug predators include green lacewing *(Chrysoperla* spp.) larvae, pirate bugs, predaceous fly larvae, and lady beetles, such as the mealybug destroyer *(Cryptolaemus montrouzieri)*. Parasitic wasps are especially important in controlling outbreaks because the wasps specialize on mealybugs and reproduce rapidly. *Acerophagus*

notativentris, Arhopoideus peregrinus, and *Anarhopus sydneyensis* (family Encyrtidae) parasitize longtailed mealybug.

Organically Acceptable Methods: Biological control is organically acceptable.

SOFT SCALES

Scientific names:
Black scale: *Saissetia oleae*
Brown soft scale: *Coccus hesperidum*
European fruit lecanium: *Parthenolecanium corni*
Hemispherical scale: *Saissetia coffeae*

DESCRIPTION OF THE PEST

Black scale is the most common soft scale (family Coccidae) in California avocado. Other species occasionally present include brown soft scale, European fruit lecanium, and hemispherical scale. Pyriform scale occurs on avocado in landscapes, but is absent or rare in commercial groves.

Soft scales at maturity are 0.08 to 0.2 inch (2–5 mm) in diameter. The soft scale's surface is the actual body wall of the insect and, unlike armored scales, cannot be removed. Adults are black, brown, or orangish with a hemispherical, humped, or round shape. The exception is pyriform scale, which is flattened and somewhat deltoid (pointed at one end and rounded at the other). White wax projects from beneath the margin of female pyriform scales.

Mobile first instars (crawlers) emerge from eggs laid under the female's body. First instars settle to feed within a day or two of emergence. These nymphs are oval and yellow, pale orange, or reddish. Soft scales retain barely visible legs and are able to move slowly, as they molt through three instars. On evergreen hosts such as avocado, after the crawler stage scales usually spend the rest of their life in one spot.

DAMAGE

Soft scales rarely are pests in avocado. They suck phloem sap from foliage and twigs. Rarely do they feed on fruit. Where soft scales are abundant, the large quantities of sticky honeydew they excrete promotes growth of blackish sooty mold, which can foul fruit.

MANAGEMENT

Soft scales usually are controlled by predators and parasites. Conserve natural enemies by reducing dust and selectively controlling ants. Whenever possible, apply only selective or short-residual pesticides to control other pests. Treating scales is rarely warranted.

Parasitic wasps are especially important in controlling scales. Parasites include *Coccophagus* spp. (family Aphelinidae) and *Metaphycus* and *Microterys* spp. (Encyrtidae). Scale-feeding lady beetles include *Chilocorus*, *Hyperaspis,* and *Rhyzobius* species and along the south coast, the steelblue lady beetle *(Halmus chalybeus)*. Lady beetles can easily be overlooked because many are tiny, colored and shaped like scales, or (as small larvae) feed hidden beneath scales' body. Lacewings, predaceous bugs, and predatory mites are among the other invertebrates that at least occasionally feed on scales.

WHITEFLIES

Scientific names:
Giant whitefly: *Aleurodicus dugesii*
Greenhouse whitefly: *Trialeurodes vaporariorum*
Mulberry whitefly: *Tetraleurodes mori*
Nesting whitefly: *Paraleyrodes minei*
Redbanded whitefly: *Tetraleurodes perseae*

DESCRIPTION OF THE PEST

Whiteflies (order Aleyrodidae) are named for the appearance of the small (0.12 inch, 3 mm or less) pale powdery adults. Females lay tiny oblong eggs on foliage. The first-instar nymphs that hatch from eggs are initially mobile and called crawlers. Crawlers soon settle to feed and lose their legs. The subsequent three nymphal stages are inactive. Nymphs are generally flattened and oval and may resemble certain soft scales. Whiteflies are identified to species primarily by the color, shape, and waxiness of the fourth-instar nymph or pupa. In approximate order of their abundance, the species in California avocado are redbanded whitefly, nesting whitefly, greenhouse whitefly, mulberry whitefly, and giant whitefly.

All whiteflies have similar life cycles. All life stages can be present at any time, with several generations each year. For example, one redbanded whitefly generation from egg to adult takes about 6 weeks when temperatures average 77°F.

DAMAGE

Whiteflies suck phloem sap. They excrete honeydew, which collects dust and supports growth of blackish sooty mold fungi that can foul fruit. Honeydew attracts ants, which interfere with the biological control of whiteflies and other pests. Giant whitefly, greenhouse whitefly, and mulberry whitefly each have hosts in over a dozen plant families. Nesting whitefly prefers citrus, but also infests avocado and some ornamental broadleaf evergreens. Redbanded whitefly in California has been found only on avocado. Whiteflies have many natural enemies and usually are under good biological control.

MANAGEMENT

Conserve natural enemies, which provide partial to complete biological control of most whitefly species unless disturbed by ants, dust, or insecticides. Control dust by oiling or paving main orchard roads. Use a water truck or trailer to wet unpaved roads, especially during summer months when dust moving up into the tree canopies can especially disrupt natural enemies. Where ants are abundant on trees, consider applying barriers or insecticide baits to control them. Apply selective materials for other pests, such as *Bacillus thuringiensis* (Bt) for caterpillars, to conserve natural enemies.

No pesticide applications are recommended for whiteflies in avocado. Chemical treatment of whiteflies often is not effective; temporary suppression may be achieved only to be followed by a resurgence of the pest, especially after applying certain broad-spectrum insecticides. Have any unfamiliar whiteflies identified by an expert. New species periodically are introduced into California.

Biological Control: Parasitic wasps are the most important natural enemies. These include many *Cales*, *Encarsia*, and *Eretmocerus* spp. (family Aphelinidae). Parasitized immature whiteflies often change color and have round parasite exit holes. Predators of whitefly nymphs include bigeyed bugs (*Geocoris* spp.), green lacewings (*Chrysoperla* spp.), lady beetles (*Delphastus* spp.), and pirate bugs (*Orius* spp.). Spiders feed on adult whiteflies.

Cultural Control: Avoid moving uncertified or infested plant material from one orchard to another to minimize pest spread. Make sure bins are clean when transporting bins from giant whitefly infested areas to clean groves. Do not bring plant materials into California from other states or out of the country because they may be infested. Control dust.

Organically Acceptable Methods: Biological and cultural controls are organically acceptable.

PRECAUTIONS FOR USING PESTICIDES

Pesticides are poisonous and must be used with caution. **READ THE LABEL BEFORE OPENING A PESTICIDE CONTAINER**. Follow all label precautions and directions, including requirements for protective equipment. Apply pesticides only on the crops or in the situations listed on the label. Apply pesticides at the rates specified on the label or at lower rates if suggested in this publication. In California, all agricultural uses of pesticides must be reported. Contact your county agricultural commissioner for further details. Laws, regulations, and information concerning pesticides change frequently. This publication reflects legal restrictions current on the date next to each pest's name.

Legal Responsibility. The user is legally responsible for any damage due to misuse of pesticides. Responsibility extends to effects caused by drift, runoff, or residues.

Transportation. Do not ship or carry pesticides together with food or feed in a way that allows contamination of the edible items. Never transport pesticides in a closed passenger vehicle or in a closed cab.

Storage. Keep pesticides in original containers until used. Store them in a locked cabinet, building, or fenced area where they are not accessible to children, unauthorized persons, pets, or livestock. DO NOT store pesticides with foods, feed, fertilizers, or other materials that may become contaminated by the pesticides.

Container Disposal. Dispose of empty containers carefully. Never reuse them. Make sure empty containers are not accessible to children or animals. Never dispose of containers where they may contaminate water supplies or natural waterways. Consult your county agricultural commissioner for correct procedures for handling and disposal of large quantities of empty containers.

Protection of Nonpest Animals and Plants. Many pesticides are toxic to useful or desirable animals, including honey bees, natural enemies, fish, domestic animals, and birds. Crops and other plants may also be damaged by misapplied pesticides. Take precautions to protect nonpest species from direct exposure to pesticides and from contamination due to drift, runoff, or residues. Certain rodenticides may pose a special hazard to animals that eat poisoned rodents.

Posting Treated Fields. For some materials, restricted entry intervals are established to protect field workers. Keep workers out of the field for the required time after application and, when required by regulations, post the treated areas with signs indicating the safe re-entry date. Check with your county agricultural commissioner for latest restricted entry interval.

Preharvest Intervals. Some materials or rates cannot be used in certain crops within a specified time before harvest. Follow pesticide label instructions and allow the required time between application and harvest.

Permit Requirements. Many pesticides require a permit from the county agricultural commissioner before possession or use. When such materials are recommended, they are marked with an asterisk (*) in the treatment tables or chemical sections of this publication.

Processed Crops. Some processors will not accept a crop treated with certain chemicals. If your crop is going to a processor, be sure to check with the processor before applying a pesticide.

Crop Injury. Certain chemicals may cause injury to crops (phytotoxicity) under certain conditions. Always consult the label for limitations. Before applying any pesticide, take into account the stage of plant development, the soil type and condition, the temperature, moisture, and wind. Injury may also result from the use of incompatible materials.

Personal Safety. Follow label directions carefully. Avoid splashing, spilling, leaks, spray drift, and contamination of clothing. NEVER eat, smoke, drink, or chew while using pesticides. Provide for emergency medical care IN ADVANCE as required by regulation.

Insects and Mites I

Pests of Primary Concern

Fig.1 Western avocado leafroller larva

Fig.2 Adult Argentine ant tending brown soft scale

Fig.3 Brown leaves caused by avocado brown mites

Fig.4 Avocado lace bug, *Pseudacysta perseae,* colony on the underside of a leaf and damage on the upper side of adjacent infested leaves

Fig.5 Avocado fruit scarred by avocado thrips, *Scirtothrips perseae*

Fig.6 Fruit scar caused by greenhouse thrips

Fig.7 Adult *Neohydatothrips burungae* closely resembles avocado thrips. Like avocado thrips, it has three red head spots but is often darker than avocado thrips and the brown bands occur only on the top of the abdomen and not underneath

Fig.8 Omnivorous looper larva

Fig.9 Persea mite colony

Fig.10 Sixspotted mite damage

Insects and Mites II

Young Tree Pests

Fig.1 Removing cardboard wrap from around a young avocado trunk to reveal brown garden snails, *Helix aspersa,* hiding underneath

Fig.2 Adult branch and twig borer, *Melalgus (=Polycaon) confertus,* on grape shoot

Fig.3 European earwig

Fig.4 Adult false chinch bug, *Nysius raphanus*.

Fig.5 Adult Fuller rose beetle (weevil)

Fig.6 Adult devastating grasshopper

Fig.7 Adult masked chafer, *Cyclocephala pasadenae,* digging in soil

Insects and Mites III

Uncommon or Rarely Managed Pests

Fig.1 Greedy scale colony

Fig.2 Adults and an egg mass of the orange tortrix, *Argyrotaenia franciscana*

Fig.3 Glassy-winged sharpshooter leafhopper adult on wine grape leaf

Fig.4 Female longtailed mealybug, *Pseudococcus longispinus*

Fig.5 Adult black scale and a black scale nymph in the 'rubber' stage

Fig.6 Two adult greenhouse whiteflies, *Trialeurodes vaporariorum,* with nymphs

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Book 2

Chapter 6

Vertebrate Pest Management

Authors: Rex E. Marsh and Terrell P. Salmon and Gary S. Bender

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Mammal pests of one kind or another are found in and around virtually every avocado grove in the state, although they may not always present a significant problem. Damage caused by birds is generally very limited and is usually seen only where crows and ravens peck open graft covers on top-worked trees, or break off the young grafts by landing on them. Tree injury by rodents, rabbits, or deer is often more serious, killing the tree outright or causing permanent damage that lowers yields for years following the initial feeding. Coyotes, especially the pups, may chew on irrigation tubing and sprinklers.

Several rodents and rabbits eat roots, fruit, or bark and can kill young trees outright. Rodent burrows and mounds (such as those of pocket gophers and ground squirrels) interfere with grove maintenance and harvesting operations and inflict structural damage by gnawing on drip irrigation lines. Deer strip young trees of foliage and can stunt or even kill saplings. Damage to irrigation systems by coyotes has been especially frustrating to growers because the animals may come back to the same irrigation line (after the grower has repaired the line) and chew it full of holes repeatedly. Occasionally bears (especially in the Goleta area of Santa Barbara County) have been known to break young avocado trees by rubbing on them.

A program incorporating the points that follow will not only result in fewer vertebrate pest problems, but make control more economical.

- Correctly identify the species causing the problem.
- Alter the habitat, when feasible, to make the area less favorable to the pest species.
- Take early action and use the control methods appropriate for the grove and time of year, with due consideration for the environment.
- Establish a monitoring system to detect reinfestation so you can determine when additional corrective measures or controls are necessary.

Vertebrate control equipment and supplies (baits, fumigants, propane exploders, traps and the like) are available at local retail outlets such as farm supply and hardware stores. In addition, many County Agricultural Commissioners make certain rodent pesticides available to growers. For further information or sources of special control materials, consult your local County Farm Advisor or Agricultural Commissioner.

GROUND SQUIRRELS

A California ground squirrel, *Spermophilus beecheyi,* is a medium-sized rodent 14 to 20 inches long from its head to the tip of its long, slightly bushy tail. This species is responsible for major damage in avocado groves throughout the state. California ground squirrels live in underground burrows and form colonies of 2 to 20 or more animals. Ground squirrels live in a variety of natural habitats. They adapt well to human activities and are found along road or ditch banks, fence rows, around buildings, and within or bordering many agricultural crops. They tend to avoid thick chaparral, dense woods, and very moist areas. Ground squirrels are active during the daytime and are easy to spot. During winter months most hibernate, but squirrels less than a year old may be active on warm sunny winter days. Many adults go into a temporary summer sleep called estivation during the hottest parts of the year. Squirrels reproduce once yearly, in the early spring, and have an average litter of 7 or 8 young. The young are nursed in the burrow for about 6 weeks before they come above ground to forage. Ground squirrels are primarily herbivorous. During early spring they consume a variety of green grasses and forbs. When these begin to dry and form seeds, the squirrels switch to seeds, grains, and nuts.

Damage

Ground squirrels often infest avocado groves, especially cut banks of grove roads and around the banks of reservoirs. They have been seen to climb trees but they do not seem to feed on avocado fruit. Damage by squirrels in avocado groves is mostly related to increased erosion due to rainwater channeling down through burrows and eventually collapsing a bank, sometime taking out trees if they slide into a ravine. Burrows are also dangerous to the pickers if they happen to step in one and twist an ankle.

When digging burrows, squirrels bring soil and rock to the surface and deposit it in mounds near burrow openings. They enlarge burrow systems each year by constructing new interconnecting tunnels, so the longer the squirrels occupy the burrow, the more extensive and complex it becomes. They create more entrances to serve a growing population. Large and numerous burrow openings and soil mounds are dangerous to pickers during the harvesting operation. Ground squirrels frequently burrow around trees and damage the root systems; they can even kill trees. Bark gnawing on the trunks of young trees and on limbs of older trees is relatively rare but sometimes occurs. Squirrels gnaw on surface-type drip irrigation pipes also. They are not intimidated by people, and squirrel burrows are common beneath buildings and other structures made by humans. They are particularly fond of burrowing beneath concrete slabs.

Monitoring Guidelines

Establish a plan for periodic monitoring of areas where ground squirrels are likely to invade, such as along ditch or road banks or in crops adjacent to the orchard. To monitor, simply observe squirrel haunts in mid morning, when squirrels feed most actively. Where ground squirrels are a major problem, keep annual records of the dates squirrels emerge

from hibernation and when the first young are seen above ground; changes in the general number of squirrels; and the controls used, dates of use, and their effect. Use these records as the basis for future management decisions.

Management Guidelines

When even one or two ground squirrels are present in or immediately adjacent to an avocado grove, control them; otherwise, damage is inevitable. Fencing is practically useless against squirrels, and no feasible habitat modification within the grove expels established animals. Unfortunately, ground squirrels are not responsive to chemical or physical repellent methods. Burrow fumigants, poison baits, and traps are the current means of control.

Habitat modification. In natural habitat, ground squirrels generally feed in open areas where visibility is good (presumably to avoid their natural enemies), although they adapt to other situations. In groves, ground squirrels often burrow beneath longstanding piles of prunings, stacked firewood, or rocks, or use them as harborage. Removing such piles may make the area somewhat less desirable to them, but the base of trees, fence lines, and ditch banks still offer burrowing sites. Peripheral grove cleanup may somewhat reduce the potential for squirrels. In addition, it makes burrow detection and population monitoring easier and improves access to burrows during control operations.

Predation. Animals that prey on squirrels include coyotes, foxes, badgers, and other mammalian carnivores, and several hawk species. Predation, however, is not a significant factor in keeping ground squirrel populations below the level that causes damage.

Trapping. Because trapping is time-consuming, it is most practical for small infestations. Several types of kill traps, including a modified pocket gopher box (fig. 1) and conibear traps, are effective.

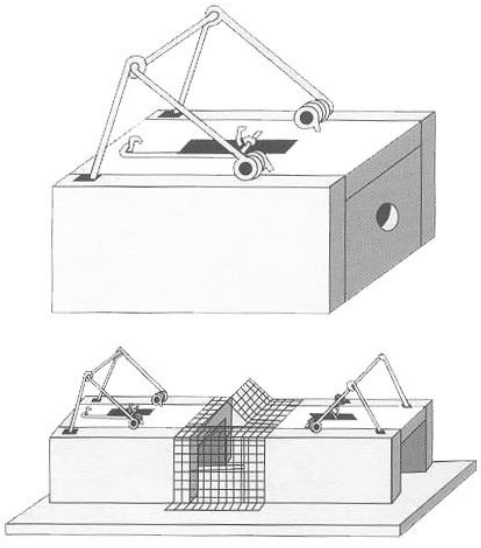


Figure 1. Box-type pocket gopher traps modified by reversal of the trigger mechanism make effective kill traps for ground squirrels (top). They can be used in pairs by removing the backs, securing them to a board at the base, and connecting the two with wire mesh (bottom).

Place box-type traps on the ground near squirrel burrows or runways. For several days bait them but do not set them, so the squirrels become accustomed to them. After the squirrels are taking the bait, rebait and set the trap. Walnuts, almonds, oats, barley, and melon rinds are effective trap baits. Set unbaited Conibear -110 traps in burrow openings so squirrels will pass through them and trip the trigger (fig. 2). Specially designed boxes are sometimes used with baited conibear traps—the boxes permit the traps to be placed anywhere squirrels are active (fig. 3). As with all traps, take precautions to minimize trapping of nontarget wildlife and pets.

Fumigation. Treating ground squirrel burrows with toxic gases (including smoke-generating cartridges) is an effective control method when used according to directions. It is most effective and selective in the spring or when the soil contains enough moisture to retain the toxic gas in high concentrations within the burrow. Fumigants are ineffective when animals are hibernating or estivating, because ground squirrels use a soil plug to seal themselves in their nest chamber. For safety reasons, do not use fumigants in burrows that extend beneath occupied buildings.

Poison baits. Poison grain baits have been developed for ground squirrel control. They tend to be ineffective after squirrels emerge from hibernation through late spring, however. During this period ground squirrels feed extensively on green vegetation and may not accept grain baits. Hence, the time of baiting is critical. Ground squirrels switch from eating vegetation to eating seeds, grains, and nuts in the latter part of May. Therefore, May and June are usually the best months for baiting. When a percentage of the adult population goes into estivation during the hottest part of the summer, suspend baiting until September 15. Continue baiting through the end of October. During this time many squirrels again feed on grain baits until they go into winter hibernation. Various grain baits with one of several poisons are available from commercial distributors or the County Agricultural Commissioner's office.

Single-dose poison baits are the most cost-effective for ground squirrels and generally produce results within 48 hours. Distribute bait by spot-baiting (scattering bait by hand on bare ground to cover 2 to 3 square feet at the side or behind each active burrow) or by broadcasting (scattering bait relatively uniformly over the entire infested area). Broadcasting can be done by hand with a belly grinder-type seeder or with a vehicle equipped with a tailgate-type seeder. Consult the product label for recommended application methods and rates.

Multiple-dose baits (anticoagulant rodenticides) provide effective control when squirrels ingest them in multiple feedings for 6 days or more. Death generally occurs from 6 to 14

days following the first feeding. Eating anticoagulant bait does not immediately affect the squirrel's feeding or activity. To be effective, multiple-dose baits must remain available; effectiveness is greatly reduced if 48 hours pass between feedings. The multiple feedings usually required for a fatal dose, the slow action of the anticoagulants, and the availability of an antidote (vitamin K_1) make anticoagulant rodenticides safer to livestock, pets, and children than are some other rodenticides.

Use anticoagulant baits in bait boxes or, if the label permits, spread it by repeated spot or broadcast baiting. Bait boxes or stations are small structures designed to hold enough bait to provide multiple feedings and to allow the squirrel to enter and feed (fig. 4). Bait boxes, or stations, safeguard larger nontarget species by excluding them from the bait (fig. 5).

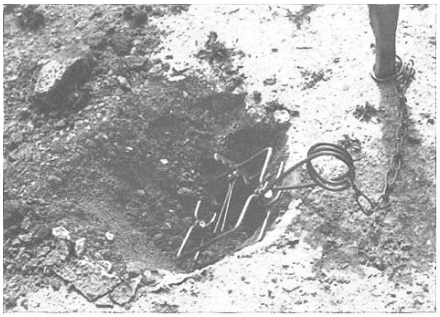


Figure 2. A Conibear — 110 trap set over a squirrel burrow entrance. The trap chain is secured to a stake.

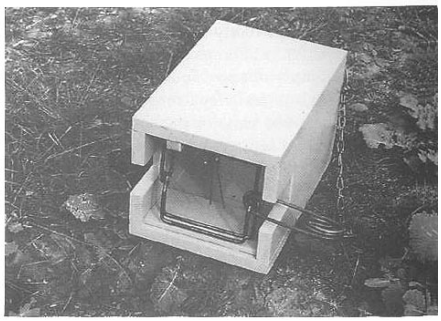


Figure 3. Conibear traps can be set in specially constructed boxes to make them more versatile.

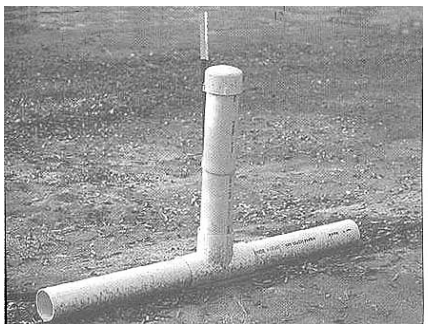


Figure 4. An inverted “T” ground squirrel bait station constructed of 4-inch plastic pipe.

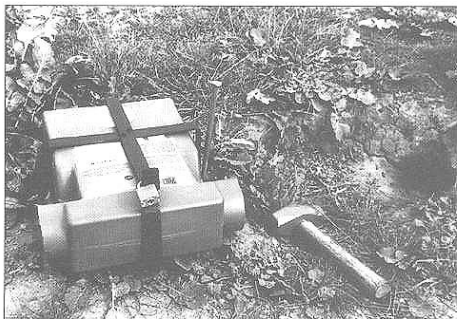


Figure 5. A commercial bait station considered tamper-resistant if properly anchored to the ground.

RABBITS

Young trees are particularly susceptible to debarking and limb clipping by rabbits. Jackrabbits (*Lepus californicus*) are the major rabbit pest, although cottontails *(Sylvilagus*

spp.) may cause problems in some areas. Jackrabbits breed from early spring to late summer. Females may produce more than one litter a year, especially where irrigated crops are available. The litter contains four young. Rabbits are active from early evening to early morning year-round. Rabbit populations sometimes fluctuate dramatically and often reach high levels every 5 to 10 years.

Damage

Rabbit damage to avocado trees is almost always limited to groves fewer than 4 years old. Rabbits may debark trunks during the first winter following planting, and clipping of small branches and leaves may be evident. Rabbits tend to partially girdle tree trunks rather than completely girdle them. Girdling caused by rabbits is usually higher on the trunk than that caused by meadow voles.

Monitoring Guidelines

Rabbits usually breed, bear young, and live outside avocado groves. If they move into the grove only to feed, you may not see them during daylight hours. Inspect young trees periodically for debarking to catch a rabbit problem early. Tour the grove in early morning, late evening, or at night using a spotlight to look for rabbits.

Management Guidelines

Rabbit control in avocado groves includes exclusion, repellents, shooting, and poisoning. The choice of method should depend on the urgency of the problem and the situation. Manage rabbit populations before severe damage occurs. Habitat modification to reduce damage within the grove is rarely practical.

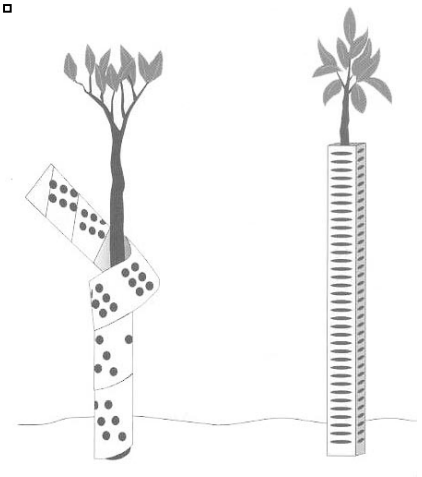


Figure 6. Various types of cardboard and plastic tree guards are available commercially for protecting the trunks of trees from rabbits.

Exclusion. Where jackrabbits or cottontails are a constant and continuing threat to young trees, fencing the entire grove may be the best management approach. To make an effective barrier, build a fence 36 inches high of woven wire or poultry netting, using 1½-inch diameter mesh. After digging a trench 6 inches deep and 6 inches wide along the fence line, bury 48-inch wide wire 6 inches deep, leaving a 6-inch lip turned outward at a right angle at the bottom. When backfilled with soil this will leave a 36-inch high fence, which rabbits will normally not jump; burying the bottom prevents their digging beneath it. If you are constructing a deer-proof fence, the additional expense of a bottom roll of the smaller-mesh wire, properly buried to also exclude rabbits, may be worthwhile.

Repellents. Chemical repellents may provide temporary relief from rabbits. Spray or paint the repellent you choose on the trunks or foliage, following label instructions. Repeat applications may be required to renew repellency lost through rain or sprinkler irrigation or to protect new growth.

Shooting. Under certain conditions shooting can be an effective control. Patrol systematically in early morning and late evening.

Poison baits. Poison baits offer a practical and economical way to control large numbers of rabbits in large areas, although results are sometimes erratic. Grains such as rolled barley, crimped oat groats, or alfalfa hay make effective baits.

Only multiple-dose poisons are registered for use against rabbits. Place multiple-dose anticoagulant baits in open self-dispensing feeders, shallow trays, or nursery flats. Position the feeders in areas frequented by rabbits, such as trails and resting and feeding areas. If rabbits fail to feed after a few days, move feeders to where bait are readily accepted. Keep bait available until all feeding ceases, which may be from 1 to 4 weeks.

Place poisoned bait where livestock and humans- especially children-cannot pick it up. Be aware of all wildlife in the area, such as doves or pheasants, and take precautions to protect them from poisoning. Protect diurnal seed-eating birds by removing or covering the bait during daylight hours, exposing it only at night.

Habitat modification. Rabbits usually invade groves from adjacent fields and unless the land is under the grower's direct management, modification of the outlying habitat is usually impractical. The removal of grove cover crops and weeds that serve as rabbit food may decrease the number of rabbits that routinely visit the grove. Removing vegetative cover may temporarily increase tree damage, however, because trees are all the rabbits have left to feed on. In any case, cover removal does make rabbit detection easier.

MEADOW VOLES

Meadow voles *(Microtus* spp.) — also called meadow mice, or field mice — can cause severe damage in avocado groves by feeding on the bark at the base of trees. Vole populations often develop in groves or on grove borders, roadsides, and fence lines — places where grass or other permanent vegetative cover remains year-round. Dense grass

is their preferred habitat. Most susceptible to damage are groves that have cover crops or those in which grass and herbaceous plants are left to grow next to tree trunks.

Meadow voles are small, blunt-nosed, stocky rodents with small ears and eyes, short legs, and short tails. Their coarse fur is usually dark gray or grayish brown. When full grown they are larger than a house mouse but smaller than a rat. Females may produce from 5 to 10 litters a year. A few females breed year-round, but the principal breeding time is during late winter and spring. Because voles mature rapidly and can bear multiple litters yearly, vole populations can increase quickly. Typically, the numbers peak every 6 to 8 years when a population can be as high as hundreds of voles per acre. Meadow voles' home ranges are relatively small; in search of food a vole usually travels less than 10 feet from its nest.

Damage

Characteristic damage by meadow voles is complete or partial girdling of tree trunks from just below the soil line to as far as they can reach on the trunk, usually no more, than 5 inches. In rare situations voles climb higher on young trees. The animals attack young trees more readily than older ones, and young trees sustain greater damage.

Monitoring Guidelines

Meadow voles are usually found first in localized areas marked by numerous 1- to 2-inch wide surface runways through dense or matted grass, and silver dollar-sized holes to their burrows. They are active all year, irrespective of weather, but do most damage to trees in winter or early spring, when many plants are more dormant than almond. Meadow voles feed night and day. Deposits of small, soft, brownish feces and short 1- to2-inch pieces of grass stems along the runways are evidence of their presence. Burrows frequently have numerous openings to the surface. They are relatively shallow and contain food and nesting chambers.

Starting in midwinter, inspect groves and surrounding fields for vole activity and population increases. Especially check areas with heavy vegetation; look for new vole runways, fresh droppings, burrow openings, and evidence of bark or grass feeding.

Management Guidelines

Vegetative cover provides food and protection from predators, so management of cover is important to meadow vole control. Fence rows or properties adjacent to the grove may harbor voles. As the vole population increases, young adults begin to disperse into new areas where the habitat is favorable. Eliminating vegetative cover in adjacent areas or providing a 30- to 40-foot wide buffer between it and the grove reduces the number of voles invading the orchard. Once you detect voles in the grove, clean cultivation of the entire grove, removal of all vegetation from immediately around the trees, or poison baits are generally the three most effective ways to deal with the problem.

Habitat modification. Cultural practices can significantly affect meadow vole populations. Clean cultivation or band weed control kills vegetation next to the tree, making the immediate habitat unsuitable and thus preventing damage. Maintaining weed-free fence rows, roadsides, and ditch banks is also an important preventive measure. Because voles do not travel more than a few feet from their burrows to obtain food, any significant destruction of their food and cover causes them to abandon their burrows or die away from them.

Predation. Predators such as coyotes, foxes, badgers, weasels, owls, and hawks feed on meadow voles; however, predation is rarely, if ever, a major factor in controlling a rapidly increasing vole population.

Trunk guards. Cylindrical wire or plastic trunk guards can protect young trees from voles. To hinder burrowing, guards must extend at least 6 inches below the soil surface but even then voles may dig beneath them. Meadow voles rarely climb over guards. On the other hand, some believe that trunk guards can encourage voles by giving them a sense of security. The voles often work beneath them or gnaw in seclusion behind them, where early damage goes undetected.

Chemical controls. Chemical repellents have been tested, but no repellents have been effective in protecting grove trees from voles. Poison grain baits, in contrast, are very effective in reducing meadow vole populations. For most effective control, apply bait in the voles' runways, where most feeding occurs. Spotbait or broadcast bait over the entire infested area. For broadcasting, use a belly grinder-type seeder; a vehicle with a tailgate seeder; or, in some situations, an airplane or helicopter. Broadcast application rates vary, depending upon estimated density of the vole population and type of toxicant. Both single- and multiple-dose poisons are used for meadow vole control. Consult the product label for application methods and rates.

POCKET GOPHERS

Pocket gophers *(Thomomys* spp.) are stout-bodied, short-legged rodents. External fur-lined cheek pouches open outside the lips, on each side of the mouth, and are used extensively for carrying food. The head and body measure 6 to 8 inches. They have a short scantily haired tail. In groves and other irrigated lands, females may produce two litters in a single year, with litters averaging about five young.

Pocket gophers are most common in areas of abundant plant growth. They feed primarily on succulent underground parts of herbaceous plants, but they are capable of pulling a 2-foot-tall plant underground to consume it.

This species lives almost entirely underground. Pocket gophers are antisocial and solitary except during breeding and when the young are being raised. Burrow systems may be extensive and include deep main burrows, shallow feeding tunnels, and side tunnels to push out dirt (fig. 7). They create characteristic soil mounds above ground (fig. 8). Main tunnels are normally 10 to 12 inches under the surface but are frequently deeper. Some

lead to deeper nests or food storage chambers. The animals plug burrow openings with soil so the tunnel system is completely enclosed. As a result the temperature and humidity in the burrow are stable and close to optimal.

Damage

Pocket gophers frequently live in groves. They are active throughout the year and, if uncontrolled and food is plentiful, a population can increase to 30 to 40 gophers per acre. (Pocket gophers are relatively slow reproducers, however, and population buildups are gradual year after year.) They cause tree damage or death by girdling roots or crown at or below the soil level.

Monitoring Guidelines

Because pocket gopher damage is frequently invisible, it often goes undetected until a tree exhibits stress. By that time the tree may be beyond saving. Gopher activity is readily detected, however: Just look for fresh mounds of soil. The animals produce these in greatest numbers in the spring and fall, when the soil is amply moist.

Management Guidelines

Persistent efforts can control pocket gophers and even eliminate them. The preferred control methods are baiting, trapping, and fumigation. No chemical or mechanical repellents have been effective against pocket gophers.

Baits. Single-feeding poison baits placed in the burrow tunnels are widely used and effective for controlling gophers in large groves. Follow bait label directions for application methods and amounts. The two methods of bait application are hand baiting and mechanical baiting.

Hand-baiting usually requires a metal probe, which is used to locate one of the gopher's tunnels. With a pointed ¼-inch steel rod, probe near the fresh mounds or between two recent mounds to find the burrow. Then enlarge the probe opening with a larger rod or broomstick, and place a small amount of grain-type bait in the burrow.

Hand-operated mechanical bait dispensers have a bait reservoir and bait release mechanism. They permit probing and bait dispensing in one operation. These devices are substantially faster than hand-baiting. Mechanical bait applicators are tractor drawn and offer an excellent way of controlling gophers over large areas. The device constructs an artificial burrow beneath the soil and deposits poison grain bait within it at preset intervals and quantities. The machine is driven between the tree rows, where pocket gopher activity is seen. The artificial burrow intercepts some of the gopher's natural burrows or the gopher will soon discover an artificial one and consume the bait. When using the mechanical applicator, use a shovel to occasionally open a small section of the artificial burrow and inspect its depth and condition. Soil moisture must be right to produce a well-formed, smooth, artificial burrow.

Trapping. Traps, either pincher or box type, are effective. But because trapping is labor-intensive, they are most commonly used where only a few pocket gophers are present. To locate the main runway or tunnel, probe with a steel rod a short distance in front of the low side of a fresh mound or between two fresh mounds (fig. 9A). After you find the main tunnel, dig a hole to intercept it (the hole will probably be 10 to 12 inches deep). Then clean out the burrow and set two traps in the runway, one facing each direction. Whether you use Macabee traps or traps similar to them, wire each pair to a stake so the captured gopher cannot drag them down the tunnel (fig. 9B). Replace the soil.

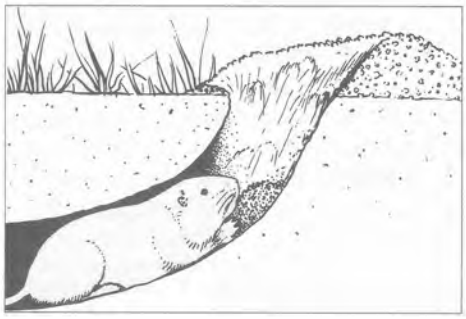


Figure 7. Pocket gophers push loose soil from main tunnels and dispose of it through lateral tunnels, creating surface mounds.

Figure 8. Mounds of fresh soil indicate recent gopher activity.

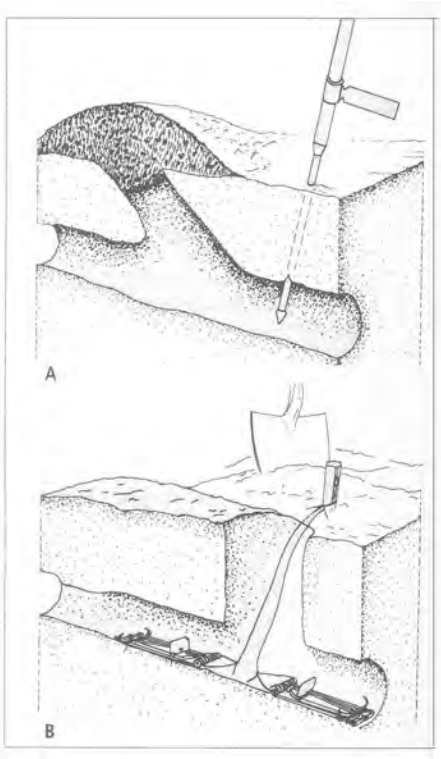


Figure 9. Use a steel probe to locate a main tunnel (A). With a shovel, excavate the soil to expose the tunnel and then insert two traps (B). Stake them and replace the soil.

Fumigation. The burrows of pocket gophers are extensive. Portions of these are relatively near the surface; therefore, maintaining a lethal concentration of most burrow fumigants (poison gases) is difficult. Plus, pocket gophers can escape detectable fumigants quickly by plugging their burrows. In recent years, however, one registered fumigant, aluminum phosphide, has produced very acceptable results and more growers are using it. Repeat treatments if the initial treatment is ineffective.

Habitat modification. Permanent ground covers of herbaceous and certain grassy plant species favor gophers. Removal of the permanent ground cover will do much to reduce their numbers, because food is generally the factor that limits population. Deep discing destroys some burrows, making the grove less habitable; clean cultivation removes cover for gophers and allows growers to detect new mounds easily. Controlling gophers along fence rows and roadways adjacent to groves is important because young gophers will disperse from there into the grove.

When groves were flood-irrigated (before the advent of drip and mini-sprinkler irrigation in the 1970's), very young pocket gophers were usually drowned and adults would be forced to the surface where their natural avian predators or the irrigator's dog could kill them. By comparison, sprinklers or drip irrigation systems generally favor pocket gophers by creating a soil moisture that is beneficial to burrowing, but not wet enough to drown the gopher.

Predation. A variety of predators feed on pocket gophers; however, their presence does not usually keep pocket gopher populations in groves low enough to prevent economic damage.

DEER

Where habitat adjacent to an avocado grove supports moderate to high populations of deer *(Odocoileus hemlonus),* deer can cause significant damage to young trees. Foothill and coastal districts with brush or woodlands that provide cover for deer usually experience the most frequent depredation. Some valley groves near stream bottoms may also suffer. State game-management laws limit the control methods available to growers and make combating deer damage expensive.

Damage

Deer can completely defoliate young trees. They can distort, or kill a tree by repetitive browsing. Buck deer, when they rub their antlers on trunks and lower limbs, can severely scar the bark of young trees. (This is relatively rare.) Deer may browse on older trees, but the damage to them is usually less severe than that caused to young trees.

Monitoring Guidelines

In bushy areas deer usually stay out of sight during the daytime. They move into groves at night to browse. Feeding evidence and hoofprints in the orchard indicate their presence. Evening or early morning sightings are possible where deer are numerous.

Management Guidelines

Exclusion. Fencing is the most effective method of excluding deer from an orchard. A 7-foot high wire fence usually works. A 6-foot high mesh fence can be heightened to 7 feet by

adding two or three strands of barbed or smooth wire on top. Deer may occasionally clear a 7-foot fence when being chased or if the fence is on steep, sloping ground. Electric fences have been used successfully in some areas. Check deer fences periodically to be sure they remain intact: Damaged wire, broken gates, soil washout beneath fences, and the like permit access and must be repaired immediately. Deer that manage to circumvent the fence and get inside may have to be removed by shooting if they cannot be driven out.

Shooting. In some circumstances depredation permits may be obtained from the Department of Fish and Game, but shooting is rarely a satisfactory solution to a significant deer problem. Encouraging deer hunting in the area can lower the overall deer population and thus reduce deer depredation.

Repellents. Growers have tried many odor repellents, but deer usually adjust to them rapidly, especially when hungry. When deer populations increase, they compete fiercely for food and repellents become totally ineffective. Taste or odor repellents can be somewhat effective, however, if applied to the foliage and retreated as new foliage develops or after rain or irrigation washes the repellent away. Noise-making devices, such as propane exploders and electronic alarms, have not been effective for more than a day or so because deer rapidly habituate to scaring devices.

Habitat modification. Eliminating suitable cover for bedding and other survival needs is rarely a feasible solution. Deer are highly mobile and many travel ½ mile or more to reach a grove, especially when they have become accustomed to feeding there.

COYOTES

Coyotes are medium-sized members of the dog family, larger than foxes but smaller than wolves. Native to western North America, they are extremely adaptable. Coyotes have increased in numbers and have increased their geographical range during the past fifty years, due in part to human modification of the landscape. Coyotes now are found almost everywhere in North America. Coyotes can be particularly troublesome in avocado groves because they may chew irrigation lines and sprinklers and the damage may go undetected unless the grower is looking at the lines during every irrigation event. Avocado fruit fallen on the ground are a favorite food of coyotes.

Identification and Biology

Males are larger and heavier than females, typically weighing 20 to 35 lbs when full-grown, while females are about 18 to 25 lbs. They stand approximately 18 inches high at the shoulders. Coloration is usually a blend of rust-colored to brown to gray. The coyote resembles a small German shepherd dog, but with a longer, narrower snout and a bushy black-tipped tail.

Breeding occurs once annually, typically in late January and in February, with pups born in March and April. Parents and offspring continue to remain in a family group for about six months. Before giving birth, the adults excavate one or more dens in the soil, occasionally

expanding the burrows of other animals, but sometimes using hollow logs, rock piles, or culverts. Typically, even when denning in suburban areas, they choose sites where human activity is minimal. If disturbed, the parents may move the litter to an alternate den site. Litter size is normally 4 to 7 pups and may depend on the female's nutritional status, which is a function of food availability and coyote population density.
Pups emerge from the natal den at about 3 weeks of age and grow quickly, relying primarily on their parents to provide them with food for the first few months. By late fall, juveniles may disperse to live independently, although if food resources are adequate, they can remain with their parents through the next year. Coyotes can be heard vocalizing (barking and howling) in the evening and night throughout most of the year, but they vocalize less when in the early stages of pup-rearing.

Space Use and Food Habits
Coyotes can live in almost any habitat in California, from arid deserts in the south to wet meadows and foggy coastal regions in the north. They are not as common in densely forested regions or in agricultural environments planted mainly to annual crops, because they find few food resources in these situations. In recent decades, they have become more numerous in many suburban environments where an ample food supply is available. Some of the highest population densities on record occur in suburban Southern California.

While some coyotes may be nomadic or transient and travel over wide areas, others occupy distinct territories that they defend, particularly during breeding and pup rearing. Where food is abundant, territories are smaller than where food is scarce. Coyote territories can be greater than 15 square miles in arid areas where food is scarce, to 1 to 3 square miles in oak woodland livestock rangelands typical of California's Coast Range, to as small as one quarter of a square mile in the suburbs of Los Angeles. Dominant, territorial pairs may share their space with their juvenile offspring or other related coyotes when food resources are sufficient to support these expanded family groups. Coyotes are generally regarded as less social with each other than are wolves. While they can live successfully as solitary individuals or pairs, and often do so, they can form packs of up to 10 individuals in environments where abundant food is present. Therefore, dense populations of suburban coyotes may not appear to be highly territorial.

Coyote diets are diverse and adaptable, varying according to local or seasonal availability of resources. Rodents or rabbits are often a major portion of their diet, when available. However, at times coyotes will rely on insects (such as grasshoppers), fruits (including avocados), berries, songbirds, and carrion. They readily scavenge on carcasses of large wild or domestic animals and also are capable predators, able to attack and kill full-grown deer and other large prey. Because domestic animals such as poultry, sheep, goats, and calves lack effective natural defenses against wild predators, they are easy prey for coyotes. Some coyotes learn to kill livestock and pets and will do so repeatedly unless corrective action is taken. When preying on poultry and livestock, coyotes often kill more than they can consume.

Behavior around Humans

Normally, coyotes are elusive animals that avoid contact with humans. Most active after dusk and before daylight, they are typically seen only at a distance. This trait may be a response to hunting, trapping, and other efforts to control coyote predation. Indeed, coyotes have been harassed and killed ever since settlers first arrived in western North America with their livestock. In most areas of California, coyotes continue to behave in ways that minimize their contact with humans.

In areas where predator control activities are practiced, coyotes are particularly wary of humans and of changes in their environment. Similarly, they are also wary of humans in places where sport hunters pursue or shoot at coyotes. Their excellent sense of smell and their tendency to avoid new objects makes it very difficult to capture or even to study them, as they often recognize and evade traps, snares, and cameras.

Within urban and suburban areas in California, however, some coyotes have adapted to residential neighborhoods, parks, and open spaces, and seemingly have lost their fear of humans. This may be a result of behavioral changes that have occurred over several generations of coyotes, in localities where predator control is no longer practiced. Coyotes thrive in such areas because food, water, and shelter are abundant, and coyotes living in these environments may come to associate humans with food and protection. Once attracted to suburban areas, they prey on the abundant rodents, rabbits, birds, house cats, and small dogs that live in residential habitats. They also will feed on household garbage, pet food, and seeds and fruits of many garden and landscape plants. In some localities, this has resulted in the development of local coyote populations that seemingly ignore people, while a few coyotes have become increasingly aggressive toward humans. They will stalk and even attack children or adults, or attack pets being walked on a leash by their owners. More than 160 such attacks have occurred in California since the 1970s, and they are becoming more frequent, particularly in suburban areas of Southern California. While only one attack has been fatal (to a 3-year-old girl, attacked in her front yard in 1981), a number of attacks have resulted in serious injuries.

Recognizing Problem Coyote Behavior

As coyote numbers increase in cities, they become accustomed to the presence of people, especially if the people do not harass them. Studies of coyote attacks on pets and on humans have revealed a predictable pattern of change in coyote behavior in these environments (Table 1). This progression is accelerated when coyotes are provided abundant food, either unintentionally or intentionally, in residential areas. When it reaches the point where pets are being attacked or coyotes are seen in neighborhoods in early morning or late afternoon, area-wide corrective actions are recommended to prevent an escalation to attacks on humans. If coyotes are seen near your home, teach your children to identify them, recognize the potential for danger, and know what to do if they come in contact with a coyote. (See Responding to Coyote Aggression and Attack.)

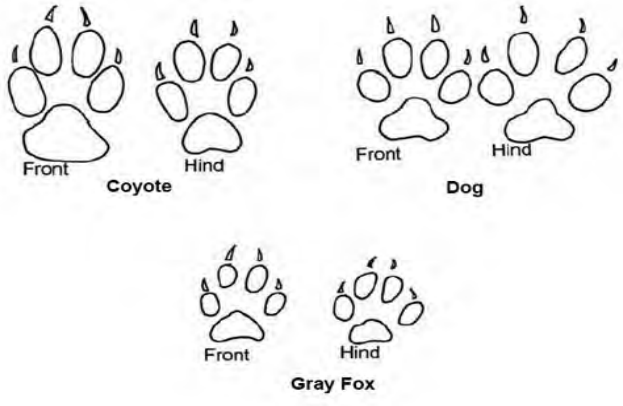
Table 1. Sequence of increasingly aggressive coyote behaviors

1. Increase in coyotes on streets and in yards at night
2. Increase in coyotes approaching adults and/or taking pets at night
3. Coyotes on streets, and in parks and yards, in early morning/late afternoon
4. Coyotes chasing or taking pets in daytime
5. Coyotes attacking and taking pets on leash or near owners; chasing joggers, bicyclists, other adults
6. Coyotes seen in and around children's play areas, school grounds, and parks in midday
7. Coyotes acting aggressively toward adults in midday

Identifying Coyote Damage

Coyotes come into conflict with humans in a variety of ways, from chasing and attacking pets in suburban and agricultural areas, to chewing plastic drip irrigation systems in groves, killing livestock on rangelands, or killing other valued wild animals. The first step in solving any conflict with wildlife is to identify the wildlife species causing the problem. Because coyote damage often is not seen by humans as it is happening, heavy reliance must be placed on indirect evidence at the damage site. Inspect the area for "coyote sign" such as tracks, hair, droppings, or tooth marks on irrigation pipe.

Tracks. Coyote tracks can often be distinguished from those of dogs by their shape and appearance. Coyote tracks tend to be more oval-shaped and compact than those of common dog breeds. Nail marks of coyotes are less prominent, and the tracks tend to follow a straight line more closely than those of dogs. Tracks of large coyotes can be up to 3 by 1-3/4 inches.



Hair. Coyote hair may be found in fence wire, particularly at locations where coyotes have dug a "slide" to crawl under a chain-link or woven-wire fence. A close look at the hair will reveal bands of color on individual hairs (but many other animals also have hair with bands of color). Hairs from a coyote's back are often black-tipped.

Droppings. Coyote droppings or "scats" are typically about the diameter of a cigar, sometimes tapering at one end. Scats are deposited along trails and roadsides and will vary in appearance depending on the animal's diet and on the age of the scat. The scat may contain hair, feathers, bones or other animal parts, as well as plant materials such as grass or seeds. Scats are typically black to light gray in color, becoming bleached out as they remain exposed to sunlight and the elements.

Tooth Marks. Drip irrigation pipe and other such materials, when chewed by coyotes, have the appearance of having been compressed and shredded as if chewed by dogs. This is in contrast to chewing damage done by rodents or rabbits, where the pipe is scraped or gnawed repeatedly and often shows evidence of the presence of paired incisor tooth marks.

Drip irrigation pipe and other such materials, when chewed by coyotes, have the appearance of having been compressed and shredded as if chewed by dogs. *Photo by Craig Coolahan*

Holes chewed in a microsprinkler drip line by California ground squirrel, *Spermophilus beecheyi.*
Photo by Jack Kelly Clark.

Prey Remains. When prey killed by coyotes is found and examined before it can be consumed or scavenged by other species, the appearance of the carcass may give clear evidence that coyotes were responsible. Coyotes usually kill small mammalian prey such as rabbits, young kid goats, and small lambs by biting them through the head or neck. The size and spacing of puncture wounds from the coyotes' canine teeth is sometimes apparent; the spacing between a coyote's canine teeth is typically 1 to 1-3/8 inches. A coyote's carnassial ("cheek") teeth are capable of making clean, knifelike cuts through carcasses, as coyotes sometimes dismember prey in order to transport portions to their den to feed pups. Municipal authorities and homeowners have sometimes found remains of dead house cats and mistakenly assumed they were mutilated by people practicing animal sacrifices, when in fact they were killed by coyotes.

Larger prey such as large lambs, large kid goats, and adult sheep and goats are usually attacked at the throat and may show puncture wounds on the side of the head or on the lower part of the neck. Skinning the neck may reveal substantial hemorrhaging in the area of the attack that is not visible externally. In contrast, dogs usually kill such prey by attacking the hindquarters, flanks, and head, often mutilating prey and leaving a "messy" kill. Because inexperienced or young coyotes sometimes do not make typical or "clean" kills, and some dogs may kill in a manner resembling coyotes, it is important to seek additional evidence at the site before reaching a conclusion.

Because coyotes will scavenge carcasses, it is important not to assume coyotes have killed every animal they might feed on. Livestock and other prey can die from a variety of causes. However, the presence of hemorrhaging and bruising on the skin around tooth punctures or bites indicates the animal was alive when it was attacked by a predator.

Predator Damage Management, Past and Present

During the twentieth century, livestock producers and government predator control agents often were able to control losses by suppressing coyote numbers, at least locally, through use of toxicants, traps, shooting, and other techniques. Population models reveal that to control coyote numbers through removal, more than three-quarters of all coyotes must be killed annually, and even then, their elimination would take decades of effort. As regulations on predator control tools and materials increased and society's attitudes toward predators changed, it has become increasingly difficult to control coyote numbers or slow their range expansion into new areas. Today, toxicants are highly restricted for use in controlling coyotes, leghold traps are banned in some states including California, and shooting is not safe or legal in many situations, especially in suburban areas. Modern strategies to manage coyote damage integrate a number of nonlethal and preventive techniques, relying on lethal removal only when other techniques are ineffective or impractical.

While coyote removal often results in a void that is quickly filled by coyotes moving in from surrounding areas, this does not mean that coyote removal is ineffective in reducing or

stopping damage. Coyotes moving in to fill a void may have different travel patterns and preferences for prey, thus reducing conflicts with humans, pets, or livestock. Recent research, as well as decades of practical field experience, suggests that removal of dominant coyote pairs at the beginning of breeding season may substantially reduce predation on livestock for up to a year. Removal of coyotes from a population may result in more resources being available to remaining coyotes, thus increasing litter sizes and pup survival. However, coyote removal does not result in higher coyote populations over the long term, as numbers are largely regulated by food availability.

Legal Status. Coyotes have no special protection in California and may be killed by any method that is not prohibited by federal, state, or local statutes. Since the passage of a state ballot initiative measure in November 1998, leghold traps cannot be used to capture coyotes except in situations where a human health and safety emergency has been declared by designated officials, or in selected situations where the existence of an endangered species is threatened by predation. Toxicants or poisons used to control coyotes are illegal, with the exception of fumigant cartridges available only to predator control specialists to asphyxiate coyote pups in their dens. No chemical repellents are registered for use in repelling coyotes from property or from livestock.

The situations in which coyotes cause damage are quite variable, and therefore strategies and solutions to resolve these problems also must be tailored to individual situations. Professional wildlife damage management specialists who are employed by federal, state, or county agencies can be very helpful in evaluating coyote damage and in assisting landowners to develop appropriate management strategies for specific situations. Contact your county agricultural commissioner or county Cooperative Extension office to obtain information about professionals who can control coyotes, or telephone the United States Department of Agriculture, California Wildlife Services state office at 916-979-2675, or see their website at *www.aphis.usda.gov/ws/ca/*

Exclusion. Coyotes have the physical ability to go under, through, or over many types of fences. While coyotes generally prefer to dig under fences or go through fence gaps at gates or washouts, some coyotes have the inclination to jump or climb fences, particularly at corners or where cross-braces provide a foothold.

While it is expensive and difficult to construct a completely coyote-proof fence, a fence that discourages coyotes will have the following design characteristics. Fence height should be a minimum of 5-1/2 feet and should be built higher on sloping terrain. Net wire-mesh should be no larger than 6 inches between stays. To deter digging under, bury a galvanized wire-mesh apron, attached securely to the bottom of the fence, 4 to 6 inches below the soil and extending outward at least 15 inches. An extra degree of protection against coyotes scaling a fence can be obtained by installing a wire-mesh overhang of at least 18 inches, slanted outward, or roller-type devices designed to be attached to the top of a fence, which prevent coyotes from getting a foothold in their attempts to climb or jump over. In general, truly coyote-proof fences are so expensive to build and maintain that they are economically viable only to protect very valuable commodities.

Electric fences of various designs have been effective in excluding coyotes. Retrofitting existing fences by adding electrified wires may provide an added degree of effectiveness. Electric fencing can be less expensive to construct than conventional woven-wire fence, but it requires substantially more maintenance to keep it in working condition. Additionally, electrical fencing may be inappropriate for use or illegal in residential or suburban areas.

Close off crawl spaces under mobile homes, porches, decks, and garden sheds, as coyotes can use these areas to rest and to rear their young. While quality fencing may not prevent all coyotes from entering an area, it will often result in coyotes leaving evidence of where and how they penetrated the fence, which will enable you to determine what other methods of management will be most effective to stop the damage.

Hazing and Behavior Modification. Using sound or visual stimuli to keep coyotes away from livestock or other resources will provide only temporary effectiveness, if any. Such efforts are likely to work best in localities where coyotes are wary as a result of continuing predator control efforts and where the stimuli can be frequently varied in type and location. In the absence of any real threat, coyotes quickly adapt or habituate to sounds, flashing lights, propane cannons, scarecrows, and so on. A strobe-siren device, developed by researchers to keep coyotes away from sheep flocks at night, was effective only for several weeks to a few months at most locations where it was tested. Because of the disturbance such devices cause, they are impractical for use in suburban areas.
When coyotes first venture into a suburban area, they likely have some degree of wariness toward humans. In this situation, certain hazing techniques may, when combined with modifications to make the environment less attractive, reduce the chance that coyotes will lose their wariness of humans. Suburban residents who see a coyote in their neighborhood should attempt to frighten it away by shouting, throwing rocks, squirting it with a water hose, blowing portable air horns, or otherwise acting aggressively in order to reinforce its fear of people. Motion-sensitive lights on houses or outbuildings may deter coyotes from approaching.
Certain breeds of guard dogs, as well as llamas and donkeys, may effectively exclude coyotes from pastures. Livestock operators who have had the best success with guard animals typically place them in small, flat, fenced pastures where the guard animal can see and challenge any intruding coyotes. Guard animals are most effective when they are behaviorally bonded to the sheep or goats they are protecting. However, there are occasions when guard animals are of limited effectiveness, and multiple coyotes or mountain lions may even attack guard animals. In suburban areas, there have been instances of groups of coyotes attacking large dogs such as Labrador retrievers, even in the presence of their owners.

Habitat Management in Suburban Areas. Areas with lush landscaping provide ample food, water, and shelter for coyotes. Suburban coyotes can reach densities far greater than they do on rangeland or undeveloped wildlands. Homeowners can reduce the attractiveness of their property to coyotes by clearing or thinning thick vegetation and by removing brush and dense weeds from the landscape, thereby depriving coyotes and their prey of shelter and cover. In particular, prune back the lower limbs and branches of shrubs and small trees to a height of 2 feet, to deprive coyotes of cover where they can easily hide.

Avoid using landscape plants that produce fruits and seeds, and pick fruit from trees before it falls to the ground to avoid attracting coyotes. Coyotes are attracted to ripening fruits of many kinds, and they will also readily consume the fruits of some plants commonly used for landscaping (Table 2). Install quality fencing around garden plots to exclude coyotes, as they will eat many common garden fruits and vegetables. Compost piles should be managed carefully so they will not encourage rodents or other prey attractive to coyotes, and they should be fenced or contained to exclude coyotes from foraging for grubs and worms. Eliminate available water sources for coyotes and other wildlife; for example, remove ponds or fountains, or install net wire fences around their perimeter. Manage bird feeders carefully to avoid spillage that attracts rodents and rabbits, which are attractive coyote prey.

Table 2. Landscape plants having fruits or seeds often preferred by coyotes

Common name	**Scientific name**
Indian laurel fig	*Ficus microcarpa* var. *nitida*
Ornamental strawberry	*Fragaria chiloensi*
Date palm	*Phoenix dactylifera*
Passion fruit, Passion vine	*Passiflora* spp.
Lychee	*Litchi chinensis*
Sugar bush	*Rhus ovata*
Strawberry bush	*Euonymus americanus*
Strawberry tree	*Arbutus unedo*
Jujube, or Chinese date	*Ziziphus jujuba*
Brush cherries	*Eugenia* spp.
Elderberry	*Sambucus* spp.
Avocado	*Persea americana*
Fig	*Ficus carica*
Guava	*Psidium guajava*
Loquat	*Eriobotrya japonica*

Habitat Management in Semi-rural Areas. In areas where residential dwellings are on small acreages or where homeowners may keep livestock as hobby animals, consider installation of quality fencing to deter coyotes. Confine livestock and poultry from dusk to dawn, and use lights above corrals. Control rodents, especially any that are living in and around your livestock facilities or residence. Be particularly attentive when lambs or kid goats are present, as well as during the coyotes' pup rearing season (March through August), when their food needs are highest.

Pet Management. Cats and dogs should be fed indoors, or if fed outdoors, food dishes should be promptly emptied and removed after pets have eaten. Store pet food indoors or in sealed heavy-duty containers. Use refuse containers that have tight-fitting lids to prevent raccoons, dogs, or coyotes from having access to household garbage. Keep small pets such as cats, rabbits, and small dogs, indoors, or if outdoors, keep them within enclosed kennels. Large dogs should be brought inside after dark. Never allow cats or dogs to run free at any time, as they are easy prey. Because coyotes that come in contact with domestic animals may transmit diseases, vaccinate all pets for rabies, distemper, parvovirus, and other diseases, as recommended by a veterinarian.

When exercising your dog, always use a leash, and walk only in populated areas of high pedestrian traffic. You may want to carry a walking stick or cane that you can use to fend off an attack. Try not to establish a regular routine in terms of route or time of day, as coyotes can learn your schedule and have been known to lie in wait to attack. Avoid walking pets at dawn or dusk, and avoid areas of dense vegetation or cover. Coyotes are more likely to attack dogs during the pup-rearing season, if dogs come too near the den site. If coyotes establish a den site near a residential area, attempts should be made to harass the coyotes so that they move their pups to an alternative, more remote den site. Never intentionally feed or provide water to coyotes, as this causes them to quickly lose their fear of people and become aggressive. Anyone who intentionally feeds coyotes is putting the entire neighborhood's pets and children at risk of coyote attack and serious injury.

In addition, ask your neighbors to also follow the described methods in order to reduce the potential for conflicts with coyotes.

Responding to Coyote Aggression and Attack. If you or your pets are approached by an aggressive or fearless coyote, try to frighten it away by shouting in a deep voice, waving your arms, throwing objects at the animal, and looking it directly in the eyes. Stand up if you are seated. If you are wearing a coat or vest, spread it open like a cape so that you appear larger. Retreat from the situation by walking slowly backward so that you do not turn your back on the coyote.

If you are bitten or scratched by a coyote, wash the affected area thoroughly with soap and water and then seek immediate medical attention. Although most problem coyotes are healthy, the risk of rabies is always present. Rabies can occur from a bite or scrape from an infected coyote, or if you handle your pet after it has been attacked and the coyote's saliva comes into contact with broken skin or mucous membranes. Because rabies infections in humans are nearly always fatal, medical authorities typically recommend post-exposure immunization whenever a person comes into contact with a wild coyote during an attack.

Report any incidents of coyote aggression or attack to local authorities including your local animal control agency and the California Department of Fish & Game. Report any attacks on livestock to your county agricultural commissioner.

Coyote Removal in Suburban Areas. Once coyotes have lost their fear of humans or have started behaving aggressively, a health and safety hazard exists. Usually it can be remedied only by removal of one or more of the coyotes. Typically, coyote removal in urban or suburban areas is conducted by predator control professionals who shoot coyotes or capture them in padded leghold traps or snares. Captured coyotes must be destroyed, as relocating problem coyotes would incur unacceptable liability and risk on the part of the agency involved, and relocation is illegal without prior approval of the California Department of Fish & Game. Management experience has shown that removal of only a few problem coyotes from a population will reinstill fear of humans in the remaining population, often solving coyote problems in that locality for months or even years. Because other coyotes quickly move in to occupy vacant territories, removal of several animals has no long-term impact on coyote numbers.

Following coyote removal, local agencies or authorities should evaluate the entire neighborhood and recommend preventive measures that homeowners should take in order to make the area less attractive to coyotes, thus preventing recurrence of the problem.

Coyote Removal in Rural Areas. In semi-rural settings or in agricultural lands, coyote damage to livestock, drip irrigation systems, and other resources often cannot be solved by habitat management or livestock management efforts alone. Professional assistance is usually required to remove the responsible coyotes as selectively and as efficiently as possible.

Wildlife management specialists employed by United States Department of Agriculture Wildlife Services or by individual counties are available to assist landowners in most areas within California. Contact your county agricultural commissioner to obtain a referral, telephone the United States Department of Agriculture, California branch of Wildlife Services at 916-979-2675, or see their website at www.aphis.usda.gov.ws/ca/ . Wildlife Services professionals have experience in dealing with problem coyotes, which can be wary and difficult to capture. They can also use certain tools and methods that are not generally available to the public. There are also private “nuisance” wildlife control firms in some areas that specialize in dealing with suburban wildlife problems.

OTHER MAMMAL PESTS

Roof Rats

Avocado trees may be a food source for roof rats, or black rats *(Rattus rattus),* which inhabit and nest is some branches. Roof rat damage to fruit is relatively minor, rarely is there more than one or two fruit per bin that show typical chewing damage from roof rats. Damage is not considered severe enough to warrant control measures.

Birds

Birds are generally not a problem in avocado groves. However, there is one exception where bird damage can be substantial. Crows and ravens have caused the death of many young grafts on top-worked trees by knocking off the paper graft covers and exposing the young buds to sun, or by pecking out the young buds and breaking off the tender new grafts. If birds are a serious problem, and there are just a few young grafts to protect, the grafter may have to erect chicken wire netting over the grafts supported by stakes nailed to the stumps. If there are a considerable number of trees to protect, the grafter may have to try some sort of frightening technique.

Frightening Birds

Not surprisingly, shooting to produce noise is the most frequently used frightening technique because it uses commonly available equipment and is immediate. What is not commonly known, however, is that shooting-with live ammunition, cracker shells, or whistle bombs-consists of two elements of harassment: periodic loud blasts and the presence of humans and, if used, their vehicle. After the shooting technique has been employed for a while, some birds, like crows, often disperse as soon as they see the shooter or the shooter's vehicle approach. They may return as soon as they see the human and the vehicle leave.

The major problem with all frightening techniques is that, when used day in and day out, most birds habituate, or become accustomed, to them. Thus, their effectiveness diminishes with time. Their effectiveness diminishes also as more growers in the same general area use the same techniques. The grower with the most innovative frightening strategies has the advantage.

To prolong the effectiveness of the frightening methods you choose, introduce as many variations as are practical. For example, if a shooter normally rides around the orchard on an ATV, he or she should occasionally abandon the vehicle and walk through the orchard shooting. Instead of using normal shotgun ammunition, occasionally use cracker shells, which produce a second blast above the birds.

Employ variations intermittently. Rather than using exploders and an Av-Alarm system simultaneously, employ them in a rotational scheme. Use the Av-Alarm system for 5 to 7 days, and then use the gas exploders for the next 5 to 7 days. Compared to simultaneous use, rotation usually results in superior and longer-lasting bird dispersal, reduced operating costs, and extended equipment life. Determine the number of days in each sequence by observing the birds' response. In, terms of the preceding example, some type of visual stimulus along with the Av-Alarm might improve control. The grower might suspend large, bright balloons above the treetops, for example. This combination would only be used with the Av-Alarm system and taken down when the propane exploders were in operation. In general, reports show, Av-Alarm systems are less effective than propane exploders.

Legal Status and Restrictions

Crows are considered migratory nongame birds; however, a federal permit is not required to kill them when birds depredate or are about to depredate a crop, but check first with your local Fish and Game officer because regulations change frequently. When crows cause crop depredations, the California Fish and Game Code allows them to be taken (killed) by landowners, tenants, or persons authorized in writing by landowners or tenants.

LITERATURE CITED

Bekoff, M., and E. M. Gese. 2003. Coyote. In G. A. Feldhamer, B. C. Thompson, and J. A. Chapman, eds. *Wild Mammals of North America: Biology, Management, and Conservation.* Johns Hopkins University Press, Baltimore. pp. 467-481.

Clark, J. P. 1986. *Vertebrate pest control handbook.* Sacramento: California Department of Food and Agriculture Division of Plant Industry.

Cummings, M. W., and R. E. Marsh. 1978. Vertebrate pests of citrus. In W. Reuther, E. C. Calavan, and G. E. Carman (eds.), *The Citrus Industry,* volume IV, 237-73.,. Berkeley: University of California Division of Agricultural Sciences Publication 4088.

Green, J. S., F. R. Henderson, and M. D. Collinge. 1994. Coyotes. In S. E. Hygnstrom, R. M. Timm, and G. E. Larson, eds. *Prevention and Control of Wildlife Damage.* Univ. of NE Cooperative Extension, Lincoln. pp. C51-C76.

Marsh, R. E., and M. W. Cummings. 1976. *Pocket gopher control with mechanical bait applicator.* University of California Agricultural Extension Service Leaflet 2699.

Salmon, T. P., A. C. Crabb, and R. E. Marsh. 1986. Bird damage to pistachios. *Calif. Ag.* 40(5,6):5-8.

Salmon, T. P., and R. E, Lickliter. 1984. *Wildlife pest control around gardens and homes.* Oakland: University of California Division of Agriculture and Natural Resources Publication 21385.

Timm, R. M., R. O. Baker, J. R. Bennett, and C. C. Coolahan. 2004. Coyote attacks: an increasing suburban problem. *Trans. No. Amer. Wildlife & Natural Resources. Conf.* 69:67-88.

UC Statewide IPM Project. 1985. *Integrated pest management for almonds.* Oakland: University of California Division of Agriculture and Natural Resources Publication 3308.

Book 2

Chapter 7

Pruning/Canopy Management

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Most mature avocado groves in Southern California are over-crowded. Crowding leads to a situation where there is little light penetration into the lower canopy; leaves in low light conditions drop and are not replaced as the tree shifts to growth in the upper canopy where there is more light. This in turn has led to poor flowering and fruit set in the lower canopy and (we believe) a general reduction in fruit production per acre overall. In addition, our most common cultivar 'Hass' is well known for flowering on the outside of the canopy, the most abundant flowering is always where the outside of the canopy is exposed to full light. Therefore, removal of the outside of the canopy (as part of a pruning program) has generally not led to increased yields. Researchers at the University of California in the 1960's remarked- "experience has shown that heavy pruning does not increase production but reduces it by stimulating new vegetative growth at the expense of fruit production" (McCarty et al. 1962).

A review of the literature on avocado pruning reveals that there have been few scientific evaluations of pruning and the costs and yield returns that are related. More information needs to be developed on the proper time for pruning, and the best methods (and the most economical methods) of canopy management.

However, the desire to increase yield per acre is only one factor involved in the decision whether to maintain a pruning program; other factors such as reduced picking costs, improved safety for pickers working in shorter trees, and better spray coverage when applying pesticides are all good reasons for pruning avocado trees. The latter point has become more important in recent years with the infestations of thrips and persea mites in the California avocado groves.

This chapter will examine the reasons why canopy management in avocado is one of the most difficult cultural operations. Solutions to the problem will be discussed, and yield results from a pruning trial in California will be presented.

Figure 1.
A recently thinned grove (every other row removed) showing lack of canopy on the lower trunk.

Issues in Canopy Management

An understanding of the reasons behind the difficulties in canopy management is essential. The following six points on this subject were presented in the Australian Extension avocado handbook (Newitt and Vock, 2001):

1. "The avocado is a rainforest species, which has evolved to compete for light in that situation. Growth is rapid and, if left unchecked, the tree may reach 15 to 20 m tall and 12 to 15 m in diameter within 15 to 20 years. Under Australian conditions, trees of these dimensions are uneconomical to manage because of the extra costs of spraying and harvesting large trees. Good spray penetration of the canopy and coverage often is more difficult to obtain and they also pose a higher risk of injury to pickers."

2. "The combination of terminal flowering and the long cropping cycle in the avocado present a unique problem for canopy management. As fruit form on the perimeter of the tree and are carried for considerable time (in some cases, over 12 months from fruit set to final harvest), there are few opportunities for pruning that do not risk damage to fruit."

3. "One option for reducing tree size that has been used successfully in other tree crops is dwarfing rootstocks. However, no dwarfing rootstocks suitable for commercial avocado orchards have yet been found."

4. "When establishing an orchard, land is generally the highest value input and growers need to maximize the return per hectare in as short a time as possible. The standard approach is to plant trees at a higher than normal density (up to 400 trees per hectare). Densities of up to 2000 trees/ha are being tried in California, but these are not considered suitable for Australian conditions. When planted at higher densities, trees will soon grow into each other unless canopy management is practiced. Once the side canopies meet, light penetration into the orchard is significantly reduced and, as a result, the fruiting surface migrates to the tops of trees. This reduces fruit yield, size and quality, makes pest and disease control more difficult and increases the costs of harvesting. Poor light penetration also reduces growth of the inter-row grasses, increasing the risk of soil erosion between the tree rows."

5. "Avocado branches are highly susceptible to sunburn. Heavy pruning exposes large limbs to the sun, and these limbs need to be protected by applying whitewash or a white plastic paint (not mineral-based paint)."

6. "One of the most effective ways to minimize canopy growth is to maximize fruit load because a tree carrying a heavy crop has fewer resources to put into vegetative growth. Careful management of nitrogen is the key to maintaining a good balance between fruit production and vegetative growth."

Methods of Canopy Management

Canopy management methods for the mature grove fall into three categories: 1) thinning, 2) drastic pruning (stumping or staghorning), and 3) gradual pruning. Methods to develop the young grove are similar to methods used after an older grove is stumped. These include pruning to a vase shape or pruning to a central leader. Doing no pruning at all, but adjusting the tree spacing according to the variety of avocado, could also be a legitimate strategy. However since Hass is the only variety with good returns to the grower, we don't really have this opportunity.

1. Tree thinning (removal of every other tree) has traditionally been the method for dealing with the crowding problem and was promoted by University of California extension specialists and farm advisors in the 1970's (Platt et.al 1975). Even though thinning relieved crowding in the grove, growers often balked at removing mature trees, and the remaining trees continued to grow upward (albeit at a slower rate).

Thinning is advantageous in that the operation opens up the grove and allows light to reach the lower limbs. Light on the lower limbs initiates vegetative growth from dormant buds, and eventually flowering and fruit-set occurs. The thinning operation increases yield on the remaining trees, but does not solve the problem of picking fruit high up in the trees.

The question remains as to whether thinning can increase yield per acre. Surprisingly, there is little data from California to answer this question. Platt et.al presented yield data from a Fuerte grove that averaged 8760 lbs/ac during years 10-14 when the grove was not crowded, 7675 lbs/ac during years 15-19 when the grove was crowded, and 11,033 lbs/ac during years 20-22 after the grove was thinned. In this example, they showed that yield per acre increased after thinning, with half the number of trees per acre.

Using small plots in a pruning trial conducted from 1999-2004 in a high yielding grove, Bender and Faber (unpublished) have shown that thinning a Hass grove did not increase yield per acre over the non-thinned control block, but yields in the thinned block were good. The yield in the non-pruned control block averaged 20,583 lbs/acre over the six-year period, in contrast to 14,252 lbs/acre in the thinned block. In this trial, data from the control block was considered to be exceptional and not representative of an average crowded grove.

Thinning Methods. The first step is to map the grove and mark weak trees. Plan the tree removal to remove as many of the weak trees as possible. If a tree is missing, leave a nearby tree in and train it to fill into the empty space. Ideally, the grove should be thinned before crowding occurs. If crowding has already occurred and trunks look like telephone poles after the thinning, foliage will grow and fill in the lower branches and trunk in about two years.

Thinning is usually accomplished by removing every other row on the diagonal (Figures 2-5). This allows light to reach all sides of each of the remaining trees. If the grower wishes to remove every other row to leave a hedgerow, crowding will be eliminated in one direction, but not along the row. A comparison of long-term yields from the two types of thinning programs has not been made.

Platt et al. suggested that the grove may have to be thinned a second time as the trees start to crowd again, and perhaps even a third time if the soil is deep and the variety has a spreading habit (Figures 6-12). Due to the shallow soils on the hillsides in California, most groves that are thinned are only thinned once, followed up by some topping and selective limb pruning.

Figures 2-12 are from Platt et al. 1975.

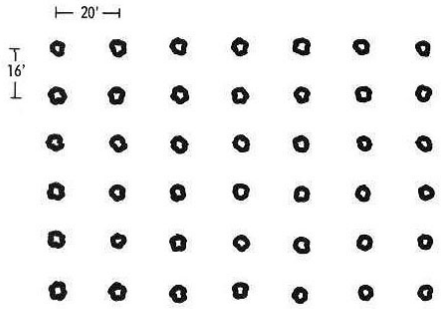

FIGURE 2. Original planting—136 trees per acre.

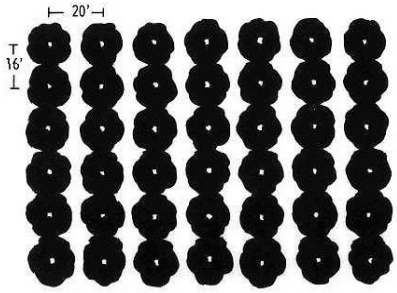

FIGURE 3. Trees starting to crowd.

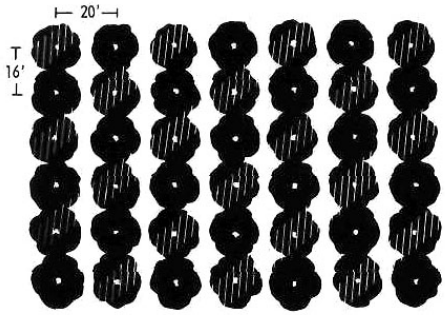

FIGURE 4. Every other diagonal row (temporary trees) removed.

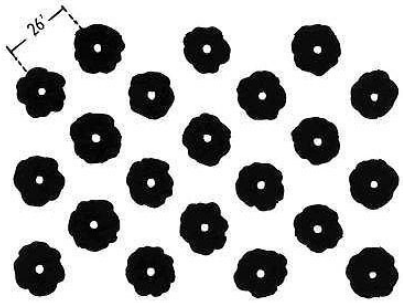

FIGURE 5. Orchard after first thinning—68 trees per acre.

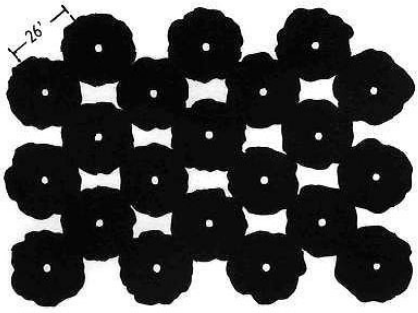

FIGURE 6. Trees crowding again.

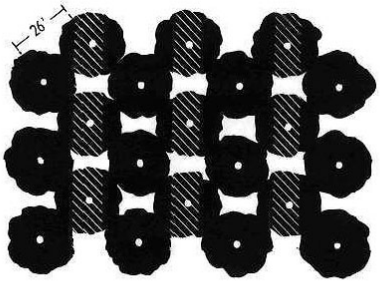

FIGURE 7. Removal of every other row. (semitemporary trees)

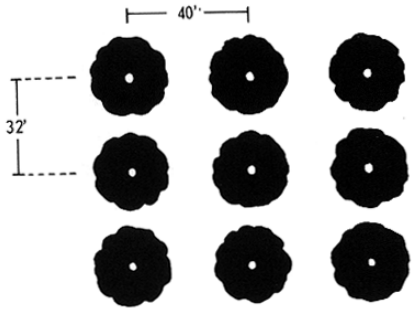

FIGURE 8. Orchard after second thinning—34 trees per acre.

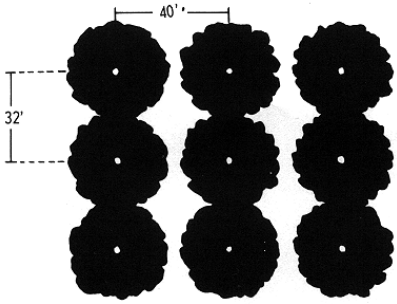

FIGURE 9. Trees crowding again.

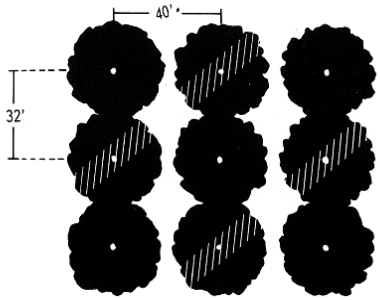

FIGURE 10. Every other diagonal row (semipermanent trees) removed.

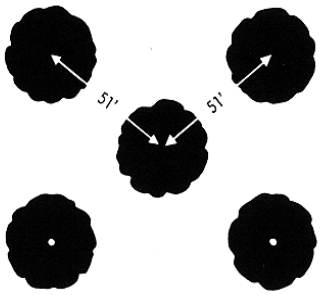

FIGURE 11. Orchard after third thinning—17 trees per acre.

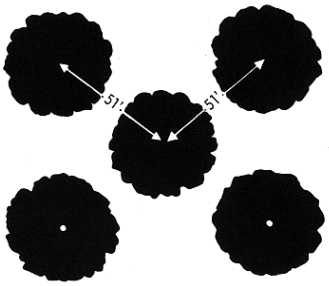

FIGURE 12. Mature orchard—17 trees per acre.

A question remains as to how to handle the irrigation system. Some growers cap the sprinkler where the tree has been removed, but other growers keep the sprinkler running with the belief that roots from the remaining trees have grown into this space. In our opinion, a "pig-tail" should be attached to the riser and the sprinkler relocated to the opposite side of a nearby remaining tree. This arrangement would give each remaining tree two sprinklers.

Figure 13. A stumped grove due to water cutbacks in San Diego County. Stumps have been painted with white water-based paint for sunburn protection. The firewood should be removed in order to reduce the fire hazard and to increase the efficiency of harvesting the trees after they grow back.

2. Stumping. When trees are just too tall, the grove may have to be stumped. In stumping, the tree is cut down to 4 or 5 feet in height leaving 2 ft-long stubs of the large scaffold limbs. Some growers take off all of the stubs to leave just the stump. Stumps should immediately be white-washed or painted with a white water-based paint to reduce sunburn damage to the bark. The main horizontal cut should be sloped slightly to avoid water puddling on the cut surface during a rain. It is not necessary to paint a tree sealant on the cut surfaces as a boundary layer of protective cells develops about ½ to 1 inch below the cut. This boundary layer reduces the invasion of fungi into the large cut, reducing the incidence of trunk rot. Applications of tree sealant often increase trunk rot because the sealant keeps the freshly-cut wood too moist. It is best to stump as early in the year as possible, but after the threat of rain has passed in order to reduce fungal infections in the wood.

It is best to stump an entire irrigation block at the same time. Irrigation can be discontinued until the trees begin to grow foliage. It is important to keep the soil moist when the tree starts to grow, but not over-watered. Water use by the trees as they start to

grow will gradually increase and the use of a tensiometer or soil probe is necessary to guide the irrigation frequency and amount.

Stumping alternate rows has been tried with the thought that the grove could remain productive during the removal process; after the stumped trees grow and start to crowd, the taller trees are then stumped. It was discovered that the stumped rows were too shaded and would not flower, instead they grew vegetative upward and by the time they started to flower and fruit they were 2/3 of their original size. Also, it is difficult to irrigate this type of grove, and difficult to stump the remaining rows and not have branches crashing into the smaller trees.

Canopy Management after Stumping. Stumped avocados, if healthy, grow back very vigorously. Platt recommended that a progressive thinning program be practiced once the stumped trees began to crowd again. However, due to the high cost of picking fruit from extension ladders, others began to question if stumped trees could be maintained at a lower height and still remain productive. Greg Partida, professor at California State University at Pomona (Cal Poly Pomona) began a pruning program in which stumped trees were pruned to a modified vase shape by pruning lightly on the outside along with pruning in the center to create an opening for light penetration (Partida, 1996). Partida worked with a Hass grove that was interplanted with Zutano and Bacon for pollenizer trees. He pruned his trees in the spring, with light pruning in the summer to maintain the shape. During the spring pruning he reduced the height of the trees to 12 feet. He presented yield data on only 8 trees, but he showed that trees maintained at less than 15 feet tall had the potential to equal or exceed yield on trees that were 50 feet tall. Given the alternate bearing habit of avocado, several years of yield data with more replications would be necessary to convince the industry to enter into a pruning program after stumping, but this paper did create interest.

Gray Martin (working for the University of California Avocado Breeding Program) expressed the opinion that Hass trees should be pruned to a central leader shape after stumping or grafting, maintaining that increased light distribution to the tree canopy would eventually result in increased production (Martin 1991). Under his system, trees would more or less maintain a shape like a fat Christmas tree; this would require periodic pinching or bending down of lateral branches to decrease competition for growth with the central leader. No data was presented as to yield from this type of canopy management system.

Bender and Faber included the stumped-to-vase shape and the stumped -to-central leader pruning systems along with a stumped (with no follow-up pruning) control block, in their pruning trial that began in 1998. As of the last harvest in 2004, the stumped block with no follow-up pruning had the best production, followed by the stumped-central leader system. The stumped-vase shape system did poorly, but yields may have been suppressed by shade from nearby trees, and by the fact that they were pruned late in the year (October). From experience it appears that avocados should <u>not</u> be pruned after the summer flush, and it is best to prune in the spring. Yields from this pruning trial are listed in *Table 1*.

Table 1. Yield (calculated in lbs/acre) from an avocado (Hass) pruning trial in San Diego County. All trees were stumped in May, 1998. Central leader trees were pruned in June, vase-shaped trees were pruned in October of each year. Eighteen data trees per treatment.

Pruning Style	1999	2000	2001	2002	2003	2004	Average yield (lbs per acre)/yr
Stumped, vase shape	0	0	5,004	4,578	1,713	623	
Stumped, central leader	0	6	4,657	11,881	1,968	10,810	4,888
Stumped, no follow-up pruning	0	0	8,857	23,937	2,503	9,421	7,453

As can be seen, stumping takes a grove out of production for two years. When the trees were stumped and not pruned, a very high yield was attained in the fourth year, but then crowding set in and yields were reduced again. In this trial, pruning to a central leader with yearly maintenance pruning in June, and topping at 14 feet, gave good yields in the fourth and sixth year (the fifth year was an off year), and all of the fruit could be harvested from the ground with picking poles. The vase shape pruning was done in October due to labor availability, but this was too late to prune; most of the fruiting wood was cut off and did not have a chance to re-grow before the spring.

Experimentation is still in progress to find the best method to handle the canopies of stumped trees, and optimum time for pruning.

Staghorning. In other avocado-growing countries, the word "staghorning" includes stumping (the most drastic form of staghorning). In California, the word "staghorning" refers to trees that have been cut back to approximately 15 to 20 feet in height, leaving bare branches without foliage. "Stumping" (as described above) refers to a tree that has been cut back to 4-5 ft in height.

When staghorn pruning is finished, the general shape of the tree should be like a pyramid, narrow at the top and wider at the base. This allows for better light penetration into the lower canopy, with better flowering and fruit set.

Staghorning is done with the belief that trees will be back in production 1 year earlier than stumping. This is likely, especially if the trees are pruned early in the year (February or March). However, staghorning is not very popular in California for the following reasons:

- The pruning operation is difficult and dangerous. Chainsaw work is done mostly from a ladder, and branches do not always fall away from the person doing the pruning. Avocado branches are notorious for being out of balance, when pruned they often twist around and fall the wrong direction. It is better for the worker to have his/her feet on the ground so that he/she can move out of the way if the branch begins to fall the wrong direction.
- Bare branches high off the ground are still susceptible to sunburn and should be painted with white water-based paint after pruning is finished. This is difficult to do with high branches, and is usually not done.
- Abundant vegetative growth occurs just below the pruning cut. This growth is high in the tree and is difficult to keep in check with follow-up pruning.

Although it would seem that staghorning might be more beneficial than stumping, it is not generally recommended in California.

3. Gradual Pruning. The concept behind a gradual pruning program is to keep the height of the trees down to a reasonable height, and to keep the tree canopy within it's allocated space. The idea is to keep the grove in production with as high a yield as possible. Several ideas have been advanced as to how to accomplish this goal, and some were incorporated into the Bender/Faber pruning trials.

Selective Limb Removal.

a. Israeli Method. This method was suggested to the author by some visiting Israeli farm advisors. In this method, the tree is divided into five main branches. (Some branches may be low in the canopy and some may be higher, but almost all trees can be divided into five main branches somewhere in the canopy.) Starting on the southwest side of the tree (the side facing the setting sun), a branch is removed the first year (cut to a two foot long stub). This allows light to penetrate into the lower canopy initiating vegetative growth. The next year a branch is removed on the opposite side of the tree. The third year a branch is removed in the middle of the tree, and in the fourth and fifth year the last two remaining branches are removed. This method is simple, most of the chainsaw work is done from the ground, and the tree never goes out of production.

b. Two-Cut Method. Each year one vertical branch is removed (cut at about the 20 ft height) and one side branch is removed. The side branch chosen is the one encroaching most into the neighboring tree. In the case of the vertical branch, it should be cut back to a horizontal branch to reduce the amount of vegetative re-growth around the cut surface. In the case of the side branch, it should be cut back to a branch to avoid leaving a stub. After the pruning is finished, there should be about 20% dappled light hitting the ground (if the grove floor was completely shaded prior to the pruning). In our experience, "two cut" pruning continued for four years before we reduced it to "one cut" pruning to avoid removing too much canopy. This method allows the grower to gradually reduce the height of the trees and to gradually bring the canopy back into its space.

c. Low Branches. In any type of canopy management system, low branches along the ground should be removed. They interfere with water distribution from the sprinklers and fruit are often lying on the ground, resulting in poor coloration of the peel.

1. **Pruning to the Pyramid Shape.** Stassen and colleagues from South Africa believed that the pyramid shape is the only shape that could allow enough light to all parts of the tree to achieve maximum sustained production of the tree unit (Stassen et.al, 1997). They stated "plant parts differ in their sunlight requirement, but need between 30 to 50% of the available sunlight to function normally. When the minimum requirement is not met then inefficiency, retardation and ultimately die-back will occur."

The attempt to achieve the pyramid shape was the purpose behind stumping and pruning to a central leader system in the Bender/Faber trials (described above). Alternatively, pruning to a pyramid can be partially achieved (on two sides of each tree) by hedgerow pruning with machinery, or it can be achieved on all sides of each tree by hand pruning. The need to prune hedgerow trees can be reduced if the trees are grown like a pyramid in the nursery.

Figure 14. A grove that has been machine-pruned. Trees are machine-pruned in every other row each year, leaving the non-pruned row to develop fruiting wood and set a crop. The non-pruned row is harvested before pruning, usually in April. These trees are about 6 m (20 ft) in height.

a. Hedgerow Pruning using Machinery.

Hedgerow pruning is done in some avocado regions of the world where the ground is flatter and pruning machinery can be driven down the row. The method is seldom used in California due to the hilly terrain. Hedgerow pruning shapes the trees into

the pyramid shape with a wall of foliage on two sides, separating the rows and allowing light into the lower branches. According to the Australian Avocado Extension Handbook, the best yields are achieved when the rows run north to south (the sun passes over the row illuminating both sides of the row equally).

Other characteristics of the hedgerow pruning system in Australia include:

- shape of the trees should be an A shape in cross section, narrow at the top and broad at the bottom, pruned to an angle of 22° to the vertical to achieve good light penetration down the face of the "wall".
- tree height should be up to 6 m (18-20 ft).
- tree canopy diameter at the base should be 5 m (15-16 ft).
- spacing between rows should be 7.5-8 m (24 ft) plus 3 m (9-10 ft) for a laneway.
- tree spacing within the rows should be as close as 4 m (12-13 ft).

b. Pyramid Pruning by Hand. As suggested by Stassen et. al 1997, the goal is to develop trees that are narrow at the top and wider at the base, with the tree width restricted and the inner branches and foliage thinned to keep the canopy from becoming too dense.

- This tree form is easier to achieve when the trees are shaped early, starting at the nursery.
- A central leader, or two or three leaders that are growing vertically are utilized.
- Branches on these leaders should be not more than one-third to one-half of the thickness of the leader. Branches or shoots at the top of the tree must be weaker than those at the base. Very strong branches and those in the wrong position must be cut away at the point of attachment. (Note that this recommendation differs from hedgerow pruning by machinery where all branches are sheared off along the outer wall, not the point of attachment to the central leader).
- Strong water shoots should be removed in June, August and October.

The "goal of pyramid pruning" as outlined by Stassen can be daunting for the grower when faced with an over-crowded orchard. Further suggestions to the practice were outlined by South African researchers Snijder, Mathumbu and Stassen in 2000.

1. **Time of pruning.** Initial severe pruning should be done after harvesting.
   - During **post harvest** pruning, individual branches are removed that cause overshadowing. The pyramid shape of the tree after pruning prevents the treetops from becoming too wide and too tall.
   - During **spring pruning** watershoots (upright-growing shoots) are either removed or headed back when they reach a length of about 10 inches. Terminal growth should be tipped back where excessive flowering occurs. Only small amounts of nitrogen should be applied during the spring to reduce growth.

- During **summer pruning** a light skimming of the shoots tops is done to increase side branching in the trees. Special attention is made to the treetops to keep the trees from becoming too wide.

2. **Strategies for Pruning.**
   - **Little or no overcrowding.** In this case the trees have not grown together and leaf canopy is to the ground, but some die-back has begun on the inside of the trees. Trees should be pruned so that treetops are made narrower and branches do not over-shadow the base. Upright shoots are removed, leaving more branches on a horizontal plane. Sides of the tree should be cut at a 10^{o} angle, and the tree height should not be greater than 80% of the row width; this is done by cutting the top of the tree at a 25^{o} angle.
   - **Medium overcrowding.** Die-back at the base of the trees has commenced. Prune one side of the trees at a 10 angle and the tree tops at a 25 angle to get light into the lower branches. The other side of the trees will be pruned in the second year. Starting in the third year a light annual pruning maintenance pruning is begun.
   - **Serious overcrowding.** In this case the tree trunks are visible with no foliage for 6-10 ft (or more) above the ground. Drastic pruning is required, the yield for at least one year will be sacrificed. A leader is cut at about 15 feet in height, and side scaffold pruning is done to create the pyramid shape as described above. The branches are painted with a water-based paint to reduce sunburn. The new growth is shaved at three months and six months after pruning to increase side branching and to maintain the pyramid shape.

Conclusion

Avocado pruning trials have thus far not been shown to increase yield per acre, but other factors important to production have benefited from pruning. These include lower picking costs, better safety for pickers and better spray coverage for pesticides. This is an area of active research in many avocado-producing countries. Hopefully, with research, we will soon reach a conclusion as to the best method of pruning, the best timing for pruning and the most economical method for maintaining a reasonable tree canopy.

LITERATURE CITED

Martin, G. 1991. Avocado tree structuring. Calif. Avocado Soc. Yrbk. 75:51-56.

McCarty, C.D., R.G. Platt and L.N. Lewis. 1962. Pruning avocado trees. Calif. Avocado Soc. Yrbk. 46:42-43.

Newett, S. and N. Vock. 2001. Avocado Information Kit. Dept. of Primary Industries, Queensland Horticulture Institute Agrilink Series QAL9906 Section 4:58-64.

Partida, G. J. 1996. Avocado canopy management for greater yields and orchard efficiency. Calif. Avocado Soc. Yrbk. 80:117-131.

Platt, R.G., G.E. Goodall, C.D. Gustafson, B.W. Lee., 1975. Thinning avocado orchards. University of California Leaflet 2799: pp. 1-8.

Snijder, B., J.M. Mathumbu and P.J.C. Stassen. 2000. Pruning and managing existing avocado orchards. S. African Avocado Growers Association Yearbook 23:36-38.

Stassen, P.J.C., S.J. Davie and B. Snijder. 1997. Guidelines for planning future avocado orchards. Neltropika (October, 1997). 39-50.

Book 2

Chapter 8

Frost Management -
Treatment of Cold-Injured Avocado Trees

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Normal grower reaction after a freeze is to immediately do something for his/her trees. This, however, is contrary to what experience has shown to be most effective in treating cold-injured avocado trees.

A full assessment of cold damage is difficult until several months following a freeze. While light damage may he apparent within a week or so, the extent of severe damage is often impossible to determine for several months.

The avocado tree has a remarkable ability to recover from cold damage. Observations following previous freezes have shown that wood, which appeared discolored and severely damaged, put out vigorous new growth later in the season. It is best, therefore, to wait and let the tree indicate the extent of damage.

Recommendations for the treatment of cold-injured avocado trees are as follows:

1. **Protection from Sunburn**
   Protection of the trunk and large limbs from sunburn is advisable in warmer areas if regrowth has not occurred before hot weather arrives. It is only necessary to cover that part of the trunk and large limbs which 'see' south and southwest. A cold water white paint or a whitewash made of 50 pounds hydrated lime and 4 pounds zinc sulfate per 100 gallons may be sprayed or painted on the exposed wood.

2. **Pruning and Training**
   Don't prune until the full extent of the injury has been determined by re-growth on the tree. This may be at least six months after the freeze. By pruning too soon good wood may be unnecessarily removed, or, in the case of severe injury, not enough wood will be removed and successive pruning will be required.

Lightly Damaged Trees
Trees on which only the leaves and small twigs are damaged require no special pruning treatment. Recovery is usually rapid.

Moderately Damaged Trees
Trees on which injury extends to and into the large scaffold branches will require some rebuilding of framework branches. But again, no pruning should be done until the full extent of the damage is known, usually in about six months after the freeze.

Regrowth from the uninjured limbs is usually vigorous and selection of some shoots and removal of others will be necessary to rebuild the framework of the tree. This should be done when the new shoots are two to three feet long. At the same time the injured wood should be cut back to good strong shoots.

Severely Damaged Trees
On trees in which the scaffold limbs as well as part or the entire trunk has been killed, a complete tree rebuilding is necessary. The only new shoots may be those coming from low on the trunk. If these originate above the bud union, one strong shoot on small trees and up to three strong shoots on large trees should be selected to form the new tree. Other shoots should be allowed to remain but suppressed by pinching out the terminals. These suppressed shoots act as temporary nurse limbs and are finally removed when the permanent shoots are well developed.

When more than one shoot is selected on larger trees, it is best to also cut the injured trunk off as close to the selected shoots as possible at that time. If left until the new selected shoots grow and enlarge it is difficult to remove the damaged wood without injury to the new shoots.

Trees that are killed back below the budunion may be handled in the same manner as above. Shoots originating below the budunion however, will require budding or grafting to the desired variety. If, on young trees particularly, the re-growth is weak, the tree should be removed and replaced with a new tree.
Some staking may be necessary in windy locations to prevent the new selected shoots from breaking out.

Treatment of Wounds
All large pruning cuts should be disinfected soon after the cuts are made to prevent wood rots. After disinfecting, allow the wound to dry and then cover with an asphalt emulsion. Dissolving one teaspoon of potassium permanganate crystals in one pint of water makes a simple and effective disinfectant.

3. Irrigation

Irrigate cautiously after a freeze. Water removed from the soil by the tree is lost through the leaves. When the leaves are destroyed by a freeze the water use is less than normal until a new crop of leaves has been developed. Since the root rot fungus thrives in waterlogged soils, it is doubly important to avoid over irrigation while the tree is recovering.

Irrigate only when soil conditions indicate a need. Follow the readings of tensiometers or determine moisture by examination of the soil. Irrigations should be less frequent and smaller amounts of water should be applied until the trees have regained their ability to use normal amounts of water. In the case of severely damaged trees this reduced water requirement may last the entire growing season.

4. Fertilization

The application of fertilizer should be carefully considered and the amount will depend largely upon the extent of injury. It is best to withhold any fertilizers until the extent of damage is determined. Freeze-damaged trees will not respond better if heavily fertilized. In fact, more harm than good may occur.

Slightly injured trees will recover most rapidly and will usually set crops in the spring following a freeze. These trees will need normal fertilizer applications.

Severely damaged trees will usually put forth a good deal of sucker or shoot growth which, through selection, will be used to rebuild the tree. Until the tree regains its full top, an imbalance exists between the root system and top. Trees which have received regular fertilization or are growing on fertile soils should have ample nutrients to satisfy their needs. Fertilizer applied before the top has been reestablished will only force additional sucker growth which will be more difficult and costly to control.

Reduce or omit fertilization during the first season on severely damaged trees.

5. Micro-nutrients

The imbalance between the root system and top, together with the very vigorous sucker growth following a freeze, often results in micro-nutrient deficiencies. Zinc is the element most likely to be deficient. It should be applied as a spray when the symptoms appear. With the rapid growth of new shoots, two or three applications may be necessary during the first season.

Zinc sprays are:
3 pounds zinc sulfate (36% metallic zinc)
2½ pounds hydrated lime
100 gallons water
-or-
2 pounds zinc oxide
100 gallons water
-or
Pre-neutralized package zinc sprays

Iron deficient symptoms sometimes appear. These are often the result of excess soil moisture and can best be corrected by reducing irrigation.

6. Other considerations

In orchards where tree crowding has become a problem, the period of rebuilding after a freeze is a good time to consider orchard thinning. The removal of trees is not an easy task for a grower— either physically or mentally—but after a freeze it presents less problems.

Thinning the orchard will provide more room for normal development of the remaining trees and will make harvesting easier. It will also provide better air drainage through the orchard, thereby reducing the frost hazard.

No **LITERATURE CITED** for this Chapter

Appendix 1

Avocado Irrigation Calculator using CIMIS (California Irrigation Management Information System)

Updated February, 2013

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The irrigation requirement can be calculated each week by using CIMIS (California Irrigation Management Information System). CIMIS is a network of weather stations throughout California that take daily information on evapotranspiration (ETo) of eight-inch tall grass and send this ETo to a computer in Sacramento. ETo is basically the amount of water lost each day from this grass; it is calculated in inches of water. You can download this information when you want to irrigate your avocados and put it into an "irrigation calculator". This information will be multiplied by the crop coefficient developed for avocados by UC Cooperative Extension farm advisors and specialists . This will give you the amount of water lost each day by avocados through transpiration and evaporation from the soil surface. Then, **assuming the weather doesn't change**, you can replace that amount of water when you irrigate.

Follow these steps to use the irrigation calculator:

1. Go the website http://www.avocadosource.com/
2. Click on Tools
3. Click on Irrigation Scheduling Calculator
4. Follow the calculator inputs. For the Kc source you can use "California New Values" which is 0.86. Some growers find that this is too high and they prefer the values from Chile. The Chilean Kc is 0.72 to 0.75 depending on the month. Click on Chile in the dropdown box and this will be done automatically. **For our example we will use the Chilean values.**
5. Nest to 'Data Source': select CIMIS from the dropdown box. Then click on Data Source.
6. Then click on www.ipm.ucdavis.edu/WEATHER/wxretrieve.html. This will send you to the IPM website (weather, models and degree days).
7. Scroll down and select "stations" in San Diego. Click "Submit".
8. Scroll down to "Escondido" for our example.
9. Click on "Daily Data"
10. Select a time period. For this example try January 29- February 4, 2013.
11. Leave everything checked, scroll down to "Retrieve Data" and click.
12. Write down the daily ETo data and add the numbers. For this example it was:
    a. 0.06, 0.09, 0.10, 0.11, 0.07, 010, 0.10. Calculate the total = 0.63.
    b. Use this space for **your** calculation each week:
    c.

13. Close this website by clicking the back arrows. You will go back to the Irrigation Scheduling Calculator website page.
14. Under "Reference Evapotranspiration" (ETo), put in 0.60.
15. Under "Crop Coefficient (Kc)", Click on February (for this example).
16. Under "Distribution Uniformity" put in 85 (for 85% uniformity). **Caution….a common mistake here is to put in 0.85. Make sure you put in 85 to indicate 85%.**
17. Under "Leaching Requirement" put in 10. **This means that you are irrigating with 10% extra water to leach the salts below the root-zone.**
18. Under "Trees per Acre" put in 105 (there are actually 109 on a 20' x 20' spacing, but there are grove roads with no trees).
19. Under "Number of emitters per tree" put in 1. **This means that you have one mini-sprinkler per tree.**
20. Under "Emitter Output" put in your gallons per hr. For this example use 17.
21. Under "Grove Size", for this example leave the number at 1 (for one acre).
22. Click "Calculate".

You should get (for this example):

Water per tree per day or **period**: 158 gallons. **Since we used a 7 day period in our example, this means that one tree in this grove used 151 gallons during this 7 day period.**

Watering time per day or **period**: **9 hrs and 18 minutes**

Total water requirements for this one acre grove: **16,603 gallons**

Appendix 2

Historical Water Use-Doing Your Own Calculations

The Historical Water Use Table (Table 1) is an example of a table developed by the Mission Resource Conservation District in Fallbrook to help growers understand water use by avocados. Table 1 is based on the evapotranspiration (Eto) measured by the CIMIS station in Escondido. Table 1 was calculated by multiplying Eto in inches per acre by the avocado crop coefficient for a given month to give the evapotranspiration of the crop in question (Etc). This is divided by the number of days in the month, converting inches per day to gallons per day, dividing by the number of trees per acre, and dividing by the distribution uniformity.

You can do your own calculations using any CIMIS station in California, or by using the historical tables from selected stations (Table A and Table B at the end of this Appendix). The calculations are simple if one follows the simple formula below with the conversion factor of 0.623:

a. Monthly Eto x Kc (crop coefficient) = Etc (see Tables 2 or 3 for avocado Kc by month)

_____ x _____ = _____

b. Monthly Etc/days in the month = Etc per day

_____/_____ = _____

c. Etc per day x tree spacing (in sq. ft.) x 0.623 = Gallons per day used by avocados

_____ x _____ x 0.623 = _____

Note*: if your tree spacing is 20' x 20', the factor used is 400. If your tree spacing is 15' x 20', the factor used is 300.*

d. Adjust the "gallons per day" by dividing by efficiency of irrigation system (eu) (see section below on irrigation evaluations, 0.81 is used in Table 1)

gallons per day/eu = adjusted gallons per day

_____/__ = _____

Note: *with a low distribution uniformity, you will be watering more to keep all trees receiving the minimum irrigation requirement.*

e. The <u>leaching fraction</u> has not been well-defined, but we know if we apply just the right amount of water to meet the trees' requirement, salts will eventually build up

in the rootzone, be absorbed into the roots and cause "tip-burn" in the leaves late in the season. Traditionally we have added 10% extra water with each irrigation to help leach the salts below the rootzone.

[adjusted gallons per day (from d) x 0.10] + adjusted gallons per day = daily water use

(_____ x 0.10) + _____ = _____

f. Let's say in this case you have not watered in seven days. You want to replace the amount of water that the trees have used in the last seven days. From the

historical tables you have calculated how much water the trees are using on a daily basis (adjusted for distribution uniformity and leaching fraction).

days x daily water use (from e) = amount of water per tree during an irrigation

___ x _____ __ = _____

g. For the run time, you have to know the application rate of your mini-sprinklers in gallons per hour:

Amount of water (from f) = run time for irrigation system (hr)

gallons/hr (application rate)

_____ = _____

Table A. Average monthly evapotranspiration in inches (Eto) from selected CIMIS stations in Ventura and Santa Barbara Counties (historical)

	El Rio	Fillmore	Goleta	Hueneme	Ojai	Santa Paula
Jan	2.20	1.89	1.95	2.32	1.89	1.95
Feb	2.93	2.93	2.56	2.81	2.50	2.93
Mar	3.17	3.42	3.11	3.17	3.17	3.30
Apr	3.97	4.64	3.66	3.66	4.27	4.27
May	4.64	5.25	4.58	4.40	4.88	5.01
Jun	4.88	6.10	4.88	4.52	5.80	5.98
Jul	5.49	6.72	5.49	5.19	6.41	6.59
Aug	4.88	6.84	5.19	4.76	6.72	6.71
Sep	4.58	5.15	4.58	4.15	5.49	5.49
Oct	3.42	3.60	3.36	3.30	3.42	3.78
Nov	2.56	2.68	2.38	2.44	2.44	2.68
Dec	1.95	1.71	1.83	1.95	1.53	1.95
Total	44.67	50.93	43.57	42.67	48.52	50.64

Table B. Average monthly evapotranspiration in inches (ETo) from selected CIMIS stations in Riverside and San Diego Counties (historical)