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 not 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 <u>after</u> 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 <u>Phytophthora citricola</u> 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:

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

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

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

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.

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