Understanding Soil, Leaf and Water Analyses

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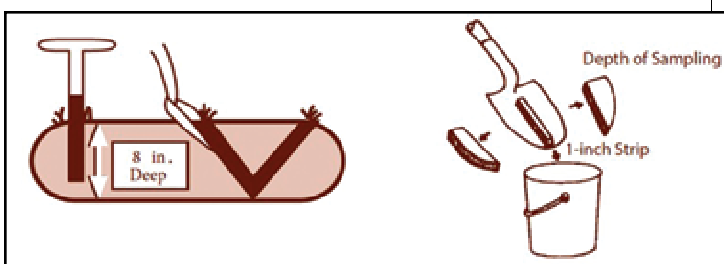
Avocado growers should collect leaves every year, from mid-August to mid-October, for leaf nutrient analysis. Soil samples should be taken prior to planting a new block/grove and at least every couple of years thereafter. The timing of soil sample collection is not as critical as it is for leaf analysis and can be done in the spring or in late summer with the leaf sampling. Water samples should be taken annually, regardless of water source. In general, most growers are pretty good about collecting these samples and sending them off to the lab for analysis. But do you read the reports that come back? More importantly, do you know what the reports mean? This article will help demystify those reports and help you understand what they mean.



An illustration showing proper soil sampling technique for avocados using a soil probe or a shovel. Illustration adapted from: H.J. Savoy. 2017. Soil Testing (PB1061), University of Tennessee Cooperative Extension.

Soil Sampling Basics

When collecting soil samples, it's important to know how to collect a proper sample, including where in the grove to sample, how many samples to collect, and how to actually collect the sample. If you are taking samples before planting a new grove, you should sample based on variability – soil textures/types, slope, aspect (N, S, E, W). If you are not familiar with the ground you are planting and don't know what soil textures or types are present, the United States Department of Agriculture's Web Soil Survey (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm) is an excellent, free tool you can use to learn what soil types exist on your property. The American Farmland Trust has produced an excellent tutorial video to help you learn how to use the WSS (https://www.youtube.com/watch?v=ifAmQybESUM). If you are sampling an existing grove, your sampling should be done based on management blocks, which in most cases will be an irrigation block.

Samples should be collected from the rootzone where most water and nutrients are taken up. For avocados this is the top 6 to 8 inches of soil. The samples should be collected about halfway between the trunk of the tree and the edge of the canopy, which should also equate to the wetted area from your irrigation. You will want to collect a composite sample from each sampling area. How many individual samples you need to collect to make up the composite sample will be based on variability, but typically 10-20 individual samples will give a representative sample of an area up to about 10 acres. Individual samples should be placed in a clean 5-gallon bucket and mixed thoroughly. You will then take a sample from this composite to send to the lab of your choice according to their instructions.

Leaf Sampling Basics

As mentioned previously, leaf samples should be collected in late summer to early fall because this is when the nutrients in the tree are most stable. Leaf samples, like soil samples, should be collected based on a management block. To collect a leaf sample, select healthy, mature, spring flush leaves (4 to 6 months old) from non-fruiting, non-flushing branches. Do not sample terminal leaves or the worst looking leaf on a branch. Collect 30 to 40 leaves from across a block, being sure to collect samples from all four quadrants of the trees (N, S, E, W). Criss-crossing a block on several diagonals is a good way to ensure you collect a representative sample of the block. Leaf samples should be stored in paper bags, not plastic, and kept at room temperature until they are delivered to the lab.

Water Analysis Basics

Water samples should be collected based on your chosen lab's recommendations. Beyond basic chemical analysis, the Food Safety Modernization Act has specific requirements for routine biological contaminant testing. These samples require special handling, such as wearing gloves and being refrigerated and shipped with ice packs, so following your lab's specific instructions is critical.

Analysis Results

Depending on the lab you use the layout of your reports may or may not look like the examples shown, but should contain the same basic information: soil, water and leaf nutrient values and optimum ranges; pH; soil cation exchange capacity and percent base saturation; salinity and sodium adsorption ratio. Typically soil physical properties — textural classification and percentages of sand, silt, and clay — will not be part of a standard soil test. Depending on your lab, soil salinity and SAR may not be included as part of a standard analysis either but given the sensitivity of avocado to salinity these parameters are critical information to have and should be requested if not included in the basic analysis.

There are numerous terms that you will find on soil, leaf and water analyses that are important to understand in order to interpret your test results. Below are the key terms and basic information about each one. As you read through these definitions, refer to the accompanying sample reports for examples.

PPM: this stands for parts per million and is a concentration value. You will commonly find PPM on soil, leaf, and water reports. If you have a bowl of 1 million candies (wishful thinking, I know) and there are five blue candies in that bowl, the concentration of blue candies is 5 PPM.

mg/L: this stands for milligrams per liter and is a concentration value equivalent to PPM.

meq/L: this stands for milliequivalents per liter and is a measure of the charge concentration of a particular element per liter. You will find meq/L on both soil and water test results. Each element exists in a solution as an ion, which has an electrical charge, either positive or negative. Calcium for example exists in soil solution with a positive charge of two, which is usually written as Ca^{2+} or Ca^{++}. An equivalent of an ion is the atomic mass of the ion divided by its charge. Sticking with the calcium example, the atomic mass of calcium is 40.08. Thus, an equivalent of calcium is: 40 ÷ 2 = 20. PPM and meq/L are convertible since they are both concentration values.

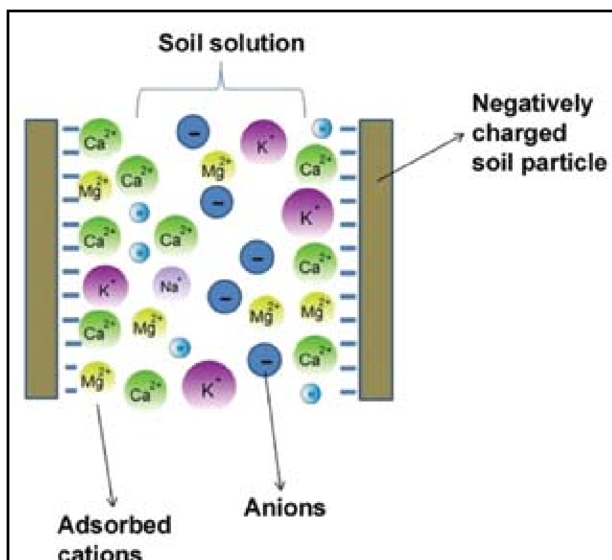
PPM = equivalent weight × meq/L
meq/L = PPM ÷ equivalent weight

Looking at the accompanying sample soil analysis, we can see this soil has 28.6 meq/L Ca. To convert this to PPM we multiply the equivalent weight of calcium by the meq/L concentration: 20 × 28.6 = 572 PPM. For future reference, the equivalent weights of the most common soil ions are shown in the accompanying table.

Ion Type	Ion Name	Symbol	Atomic Mass	Equivalent Weight
Cations	Calcium	Ca^{2+}	40	20
	Magnesium	Mg^{2+}	24	12
	Sodium	Na^{+}	23	23
	Potassium	K^{+}	39	39
Anions	Bicarbonate	HCO_3^-	61	61
	Carbonate	CO_3^{2-}	60	30
	Chloride	Cl^-	35.5	35.5
	Nitrate	NO_3^-	62	62
	Sulfate	SO_4^{2-}	96	48

Common soil nutrient ions, their chemical symbols, and equivalent weights.

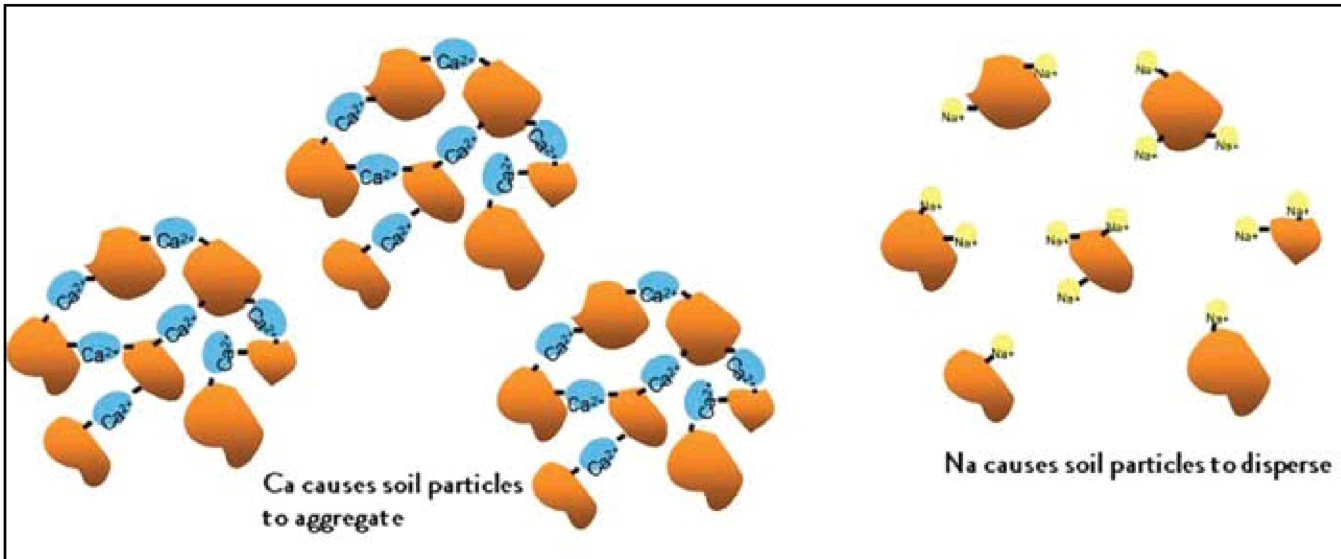
CEC: this stands for cation exchange capacity and is a measure of the quantity of cations (positively charged ions) that can be held by a soil. It is usually reported as milliequivalents per 100 grams of soil (meq/100 g). Since opposites attract, cations are held (adsorbed) by the negative charges on clay particles and organic matter. A high CEC value means the soil has a higher nutrient holding capacity (lower risk of leaching). The cations in soil solution — that is, those nutrients that can be taken up by plant roots — are in dynamic equilibrium with the cations adsorbed on the soil particles.



An illustration showing the Cation Exchange Capacity (CEC) of a soil. The calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}) and sodium (Na^+) ions are held by the negative charges on the soil particles. The ions in excess of the soil's CEC are free in the soil solution and can be taken up by plant roots or leached below the plant's root zone.

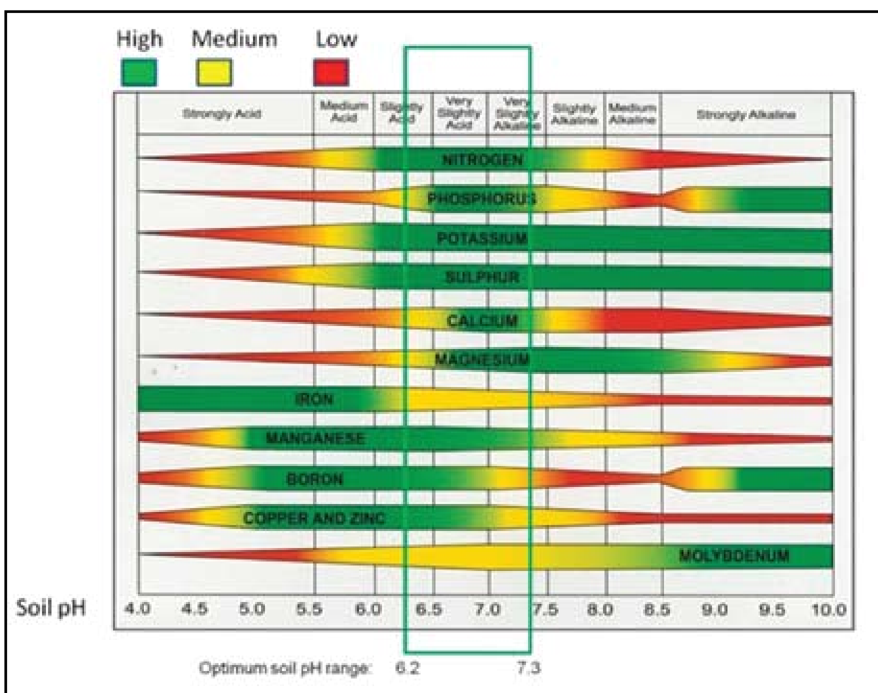
Exchangeable nutrients: nutrient ions held on the soil complex (by the CEC capacity of the soil) that may be replaced by other ions of like charge. Exchangeable nutrients are not leachable.

Soluble nutrients: nutrient ions in the soil solution (those in excess of the soil's CEC) that can be readily absorbed by plant roots. Soluble nutrients are leachable.



An illustration showing how calcium (or magnesium) ions help build soil structure. The double positive charge of calcium and magnesium ions binds soil particles together into aggregates, which give soil structure and allow for better water infiltration. In contrast, sodium ions only have a single positive charge and cannot bind soil particles together. In high sodium soils, the soil particles are dispersed, the soil has poor structure, and water infiltration is reduced. The sodium adsorption ration (SAR) of your soil tells you the balance of calcium and magnesium to sodium ions. To avoid water infiltration issues, the SAR should be less than 3.

pH: a unitless measure of acidity or alkalinity, which is a measure of the hydrogen ion concentration of a substance. pH is based on a logarithmic scale from 0 to 14. That is, for every unit change on the pH scale, the acidity or alkalinity changes by a factor of 10. For example, a pH of 6 is 10-times more acidic than a pH of 7. A pH of 7 is neutral; below neutral a substance is considered acidic and above neutral it is alkaline or basic. Soil pH is important because it affects the availability of nutrients for plant uptake. pH issues cannot be overcome simply by adding more fertilizer.

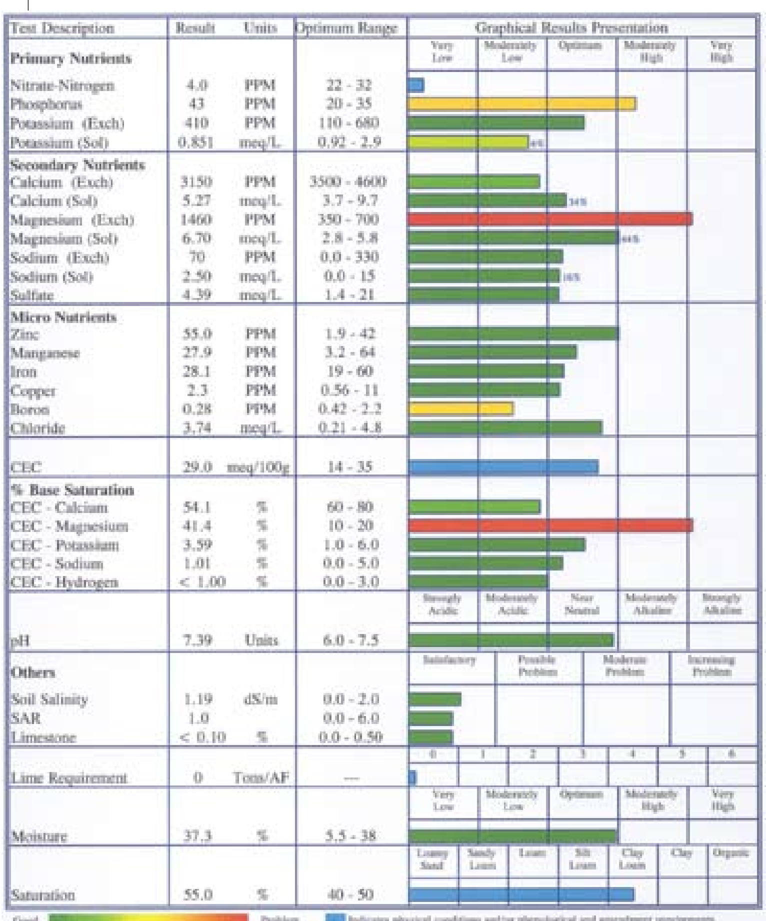


An illustration of how the availability of the different plant nutrients is affected by soil pH. In general, plants do best at a soil pH centered around 7 or neutral. Avocados prefer a slightly more acid soil, doing best at a pH of 6 to 6.5.

EC: stands for electrical conductivity and is a measure of the salinity of a solution. Pure water does not conduct electricity, but water with salts dissolved in it does. Chemically speaking, a salt is any substance that, when dissolved in water, dissociates (separates) into a cation and anion. Table salt, sodium chloride (NaCl), when dissolved in water dissociates into Na^+ and Cl^-. Most fertilizers are chemically classified as salts. For example, calcium nitrate [$Ca(NO_3)_2$] becomes Ca^{2+} and $2NO_3^-$ when dissolved in water. The more salts dissolved in a solution, the better it conducts electricity. EC is reported in units of decisiemens per meter (dS/m). EC can be divided into various components, most commonly EC_e and EC_w. EC_e is the EC of the extract of the soil solution and is a measure of the salinity your tree roots are exposed to. EC_w is the EC of water and represents the EC of your irrigation water.

SAR: this is the sodium adsorption ratio, which describes the relative activity of sodium ions (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) in soil solution or water. For avocados, an SAR below 3 is desirable and should not exceed 4. As the SAR increases, the permeability of the soil decreases and the risk of sodium toxicity increases. The mathematical formula to calculate SAR is:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$



Test Description	Result	Units	Optimum Range
Primary Nutrients			
Nitrate-Nitrogen	4.0	PPM	22 - 32
Phosphorus	43	PPM	20 - 35
Potassium (Exch)	410	PPM	110 - 680
Potassium (Sol)	0.851	meq/L	0.92 - 2.9
Secondary Nutrients			
Calcium (Exch)	3150	PPM	3500 - 4600
Calcium (Sol)	5.27	meq/L	3.7 - 9.7
Magnesium (Exch)	1460	PPM	350 - 700
Magnesium (Sol)	6.70	meq/L	2.8 - 5.8
Sodium (Exch)	70	PPM	0.0 - 330
Sodium (Sol)	2.50	meq/L	0.0 - 15
Sulfate	4.39	meq/L	1.4 - 21
Micro Nutrients			
Zinc	55.0	PPM	1.9 - 42
Manganese	27.9	PPM	3.2 - 64
Iron	28.1	PPM	19 - 60
Copper	2.3	PPM	0.56 - 11
Boron	0.28	PPM	0.42 - 2.2
Chloride	3.74	meq/L	0.21 - 4.8
CEC	29.0	meq/100g	14 - 35
% Base Saturation			
CEC - Calcium	54.1	%	60 - 80
CEC - Magnesium	41.4	%	10 - 20
CEC - Potassium	3.59	%	1.0 - 6.0
CEC - Sodium	1.01	%	0.0 - 5.0
CEC - Hydrogen	< 1.00	%	0.0 - 3.0
pH	7.39	Units	6.0 - 7.5
Others			
Soil Salinity	1.19	dS/m	0.0 - 2.0
SAR	1.0		0.0 - 6.0
Limestone	< 0.10	%	0.0 - 0.50
Lime Requirement	0	Tons/AF	---
Moisture	37.3	%	5.5 - 38
Saturation	55.0	%	40 - 50

A sample soil analysis showing soil nutrient content values as well as various soil chemical properties.

What Does a Soil Analysis Tell You?

Soil analyses tell you the nutrient content of your soil, which includes both the nutrients you've applied through fertilizer as well as those naturally available in the soil. Knowing how much of a nutrient is available in your soil on an acre basis requires some basic calculations. Average soils weigh 4 million pounds per acre-foot (1 foot depth over an area of 1 acre). Since avocados are shallow rooted, we'll assume most nutrient uptake occurs in the top 6 inches of soil. Six inches of soil over 1 acre (half an acre-foot) weighs approximately 2 million pounds. Thus, we can multiply a soil PPM value for a nutrient by two to get pounds per acre. In the sample soil analysis, the concentration of nitrate nitrogen is 4 PPM or approximately 8 pounds per acre.

A soil analysis will tell you the capacity of your soil to act as a reservoir of nutrients. With a high CEC, the soil can hold a lot of nutrients that will be released into solution over time. In low CEC soils (e.g., sands or low organic matter soils), there is little nutrient holding capacity and fertilizers should be applied at lower rates more frequently to prevent leaching, which wastes money and can cause pollution.

From your soil analysis you will know your soil pH. As mentioned previously, pH greatly influences the availability of nutrients for plant uptake. If your soil pH is out of the optimum range, ideally 6 to 6.5 for avocado, your trees can show nutrient deficiency or toxicity symptoms that you will not be able to correct simply by adding or reducing fertilizer.

A soil test also will alert you to potential salinity and water infiltration issues. It is very important to have a soil analysis done at least every couple of years so you can track your SAR and soil salinity. Much of the irrigation water used for avocados in California is relatively high in salinity. Couple that with California's generally low rainfall — which means trees are almost exclusively watered with poor quality water and there is little natural leaching to wash salts from the soil — and it doesn't take long for salts to build up to damaging levels in the soil.

What Does a Leaf Analysis Tell You?

Leaf analyses are snapshots in time that tell you how well your nutrition program is working. Comparing leaf analyses over time can be very revealing. When reviewing leaf analysis results, you should have prior years' analyses at hand for comparison (if available), and it's important to consider what is happening in your grove. Do you have a heavy crop on your trees for next year? When did you harvest or do you still have the current year's crop on the tree for late season harvest? Did your trees produce a strong summer growth flush to have good bloom potential next spring or was the summer flush weak?

The answers to these questions will all factor into interpreting your results. For example, if you harvested early, have a light crop on the trees for next year and had a poor summer flush, then your trees have a relatively low nutrient demand. In this case, you may see values in the high or excessive range if you've been fertilizing based on the needs of a large crop. So, as you review your leaf tissue analysis consider where you've been and where you're going and talk with your farm adviser, grove manager, crop consultant or more experienced growers to develop a game plan to get where you want to be.

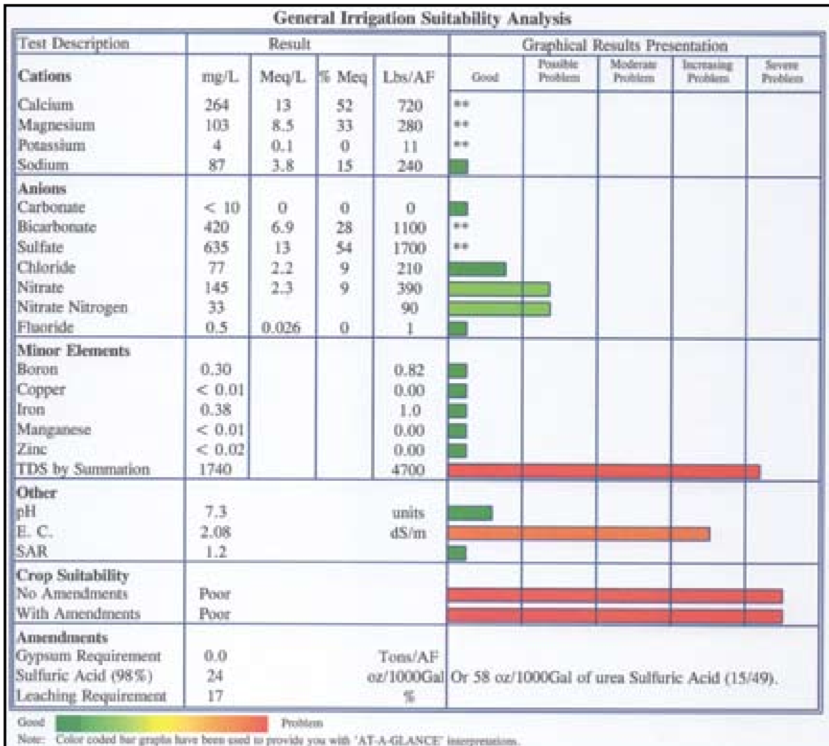
For a review of avocado leaf nutrient optimum values please refer to "Optimum Leaf Nutrient Concentration Ranges for the 'Hass' Avocado in California" in the summer 2020 issue of *From the Grove*. These optimum ranges may not necessarily align with those of the lab that did your analysis, but they are based on the latest science from an extensive analysis of nearly 30 years' worth of data.

HASS PLANT TISSUE ANALYSIS

Test Description	Result	Units	Optimum Range	Graphical Results Presentation				
				Deficient	Low	Ample	High	Excessive
Macro Nutrients								
Total Nitrogen (Leaf)	2.31	%	2.2 - 2.4					
Phosphorus (Leaf)	0.19	%	0.080 - 0.44					
Potassium (Leaf)	0.675	%	1.0 - 3.0					
Calcium (Leaf)	1.45	%	1.0 - 4.5					
Magnesium (Leaf)	0.96	%	0.25 - 1.0					
Micro Nutrients								
Zinc (Leaf)	22.5	ppm	30 - 250					
Manganese (Leaf)	34	ppm	30 - 700					
Iron (Leaf)	51	ppm	50 - 300					
Copper (Leaf)	11	ppm	5.0 - 65					
Boron (Leaf)	14.4	ppm	12 - 100					
Sodium (Leaf)	0.011	%	0.0 - 0.25					
Chloride (Leaf)	0.111	%	0.0 - 0.25					
Nutrient Ratios								
Nitrogen:Potassium	3.42		1.7 - 2.2					
Nitrogen:Phosphorus	12.2		11 - 23					
Phosphorus:Zinc	84.4		20 - 50					
Potassium:Magnesium	0.702		1.5 - 3.5					
Nitrogen:Calcium	1.59		0.90 - 2.0					

Good — Problem

A sample avocado leaf tissue analysis showing the various essential plant nutrients, their concentration in the leaves, and the suggested optimum range for each nutrient.



General Irrigation Suitability Analysis

Test Description	Result				Graphical Results Presentation				
Cations	mg/L	Meq/L	% Meq	Lbs/AF	Good	Possible Problem	Moderate Problem	Increasing Problem	Severe Problem
Calcium	264	13	52	720	**				
Magnesium	103	8.5	33	280	**				
Potassium	4	0.1	0	11	**				
Sodium	87	3.8	15	240					
Anions									
Carbonate	< 10	0	0	0					
Bicarbonate	420	6.9	28	1100	**				
Sulfate	635	13	54	1700	**				
Chloride	77	2.2	9	210					
Nitrate	145	2.3	9	390					
Nitrate Nitrogen	33			90					
Fluoride	0.5	0.026	0	1					
Minor Elements									
Boron	0.30			0.82					
Copper	< 0.01			0.00					
Iron	0.38			1.0					
Manganese	< 0.01			0.00					
Zinc	< 0.02			0.00					
TDS by Summation	1740			4700					
Other									
pH	7.3			units					
E. C.	2.08			dS/m					
SAR	1.2								
Crop Suitability									
No Amendments	Poor								
With Amendments	Poor								
Amendments									
Gypsum Requirement	0.0			Tons/AF					
Sulfuric Acid (98%)	24			oz/1000Gal	Or 58 oz/1000Gal of urea Sulfuric Acid (15/49).				
Leaching Requirement	17			%					

Good — Problem

Note: Color coded bar graphs have been used to provide you with 'AT-A-GLANCE' interpretations.

A sample irrigation water analysis of some very poor quality irrigation water that would cause significant injury to avocado trees.

What Does an Irrigation Water Analysis Tell You?

Like leaf and soil analyses, your water analysis will tell you what nutrients are in your irrigation water. Depending on your lab, this information may be provided to you in PPM (mg/L), meq/L, pounds per acre-foot or some combination thereof. An acre-foot of water, that is water covering an acre of land 1-foot deep, weighs about 2.7 million pounds. Thus, to convert from PPM (or mg/L) to pounds of nutrient per acre-foot simply multiply PPM by 2.7. It's important to consider what your irrigation water is contributing to your trees' nutrient needs and deduct this amount from any fertilizer you plan to apply, especially nitrogen. In the accompanying sample water analysis, you can see this water is providing a lot of nutrients, even to the point of potentially being problematic (nitrogen). If you did not have an analysis of this water and just blindly fertilized your trees you would have major issues.

An irrigation water analysis also will tell you the water's pH, in the accompanying example 7.3. A water pH over 7 is problematic since we would like to grow avocados at a soil pH of 6 to 6.5. In this case, this water would best be treated with acid prior to use to adjust the pH. Adjusting the pH also would help neutralize the high levels of bicarbonates, which will cause sprinkler and dripper clogging. This lab provides acid recommendations along with what you can expect your water chemistry to be after treatment at the recommended rate.

Perhaps most importantly for avocado production is the water's EC and SAR. Recall that all fertilizers are salts. If your irrigation water has a high EC to begin with (2.08 dS/m in this example, which is already problematic) by the time you add fertilizer to the mix your EC will be very high and cause major issues. An analysis by Jim Oster and Mary Lu Arpaia some years ago revealed that avocado yield begins to decline when the EC_e (EC of the soil water extract) exceeds 0.4 dS/m. Beginning with an irrigation water EC of 2.08 dS/m means this water is essentially useless for avocado irrigation unless it can be run through a reverse osmosis system.

The final thing an irrigation water analysis should tell you is the leaching fraction (LF) or leaching requirement (LR). This will be expressed as a percentage, and it is the percent of irrigation water that needs to be applied in excess of the trees' needs to maintain an acceptable EC_e. The leaching fraction or requirement is based on the target EC_e and the EC_w using the following formula:

$$LF = \frac{EC_w}{(5 \times Ec_e) - EC_w}$$

In our example, calculating from the recommended leaching fraction of 17% would result in an EC_e of 3 dS/m. The trees may survive, but they will be unproductive.

Soil, leaf, and water analyses each tell you a part of the story about what is happening in your avocado grove. Taken together and viewed over time they can be of great help to managing your avocados, but they also can reveal potentially insurmountable problems that may make avocado production on a particular soil and water combination near impossible.