Soil and Water Quality for Trees and Vines

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Introduction

Declines in row crop commodity prices, increases in water and land costs have fueled rapid conversion of older farms into housing developments and pushed growers to consider more marginal soils for permanent crop plantings. A basic understanding of soil and water quality parameters, tolerance limits and amendment strategies is important to achieve a profitable result.

Evaluating soil physical characteristics

Orchards with soils that vary from sands to clay texture are subject to variable water stress across the orchard because of different water-holding capacities of the soils. Layers of different soils in the rootzone can cause water logging by slowing water movement through the root zone and creating temporarily saturated soil layers. These injure roots by depriving them of oxygen and enhancing conditions that favor root diseases. Some subsoil layers can form physical barriers to roots that simply cannot grow through hard, dense, or compacted layers. The result is non-uniform orchard growth and production, especially under surface irrigation where infiltration rates can vary considerably from one area to the next. Evaluation and appropriate modification of orchard soils provides the following benefits:

1) Reduced physical barriers to drainage and root development.
2) Increased uniformity of water infiltration and water-holding characteristics.
3) Improved leaching of excess salts.
4) More uniform and increased vigor resulting in less time to achieve full production.

Soil survey data

The best place to begin your evaluation is with the **USDA Natural Resource Conservation Service soil surveys**. There are 170 published surveys for California alone – starting with the first Fresno County survey in 1900 to the most recent Western Tulare County survey in 2003. Many of these surveys are revisions of earlier surveys, changing and adding to earlier soil series descriptions. The surveys published since 1970 have the best maps (Plate 1.) and soil series detail.

On-line access: Unfortunately, only a small number of these surveys are available online. Use the following links to obtain information:

List of all California soil surveys:

http://www.soils.usda.gov/survey/printed_surveys/california.html

Full surveys published online:

http://www.ca.nrcs.usda.gov/mlra02/

Colusa County, Intermountain Area, Mendocino County (Western), Napa County, Santa Cruz County, Stanislaus County (Western), Tulare County (Western), Yolo County

For georeferenced spatial and tabular data available for California (more difficult to access and requires use of GIS software):

https://soildatamart.nrcs.usda.gov/County.aspx?State=CA

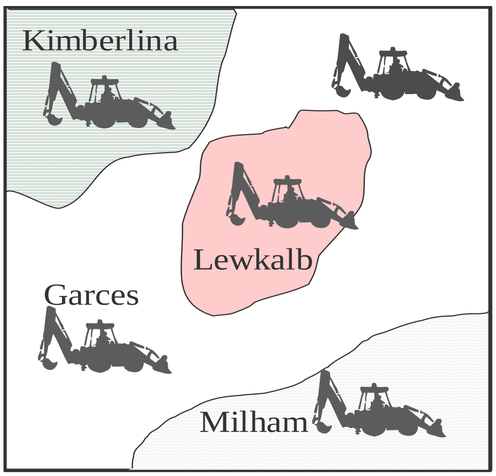
For locating NRCS offices in the US:

http://offices.sc.egov.usda.gov/locator/app

For most areas it may be necessary to contact the local NRCS office and consult the area conservationist and a paper hard copy of the survey. Most current surveys are supposed to be online by 2008.

Identifying physical limitations

The soil survey, along with aerial images and personal observation of row crops previously grown in the field is very useful for identifying “zones” that should be sampled and viewed separately. Commercially available equipment (i.e. EM-38 and VERIS equipment) that use electromagnetic or conductivity sensors and global positioning systems technology can also map soil variability. When properly calibrated, the sensors detect changes in soil salinity and major differences in water holding capacity. The diagram illustrates the potential variation one might find in a possible 160 acre orchard development in Western Kern County.



A thorough site evaluation uses a series of backhoe pits in the different zones. Observation pits clearly show the number and types of soil layers, the depth of the layers, and the variability of the subsoil throughout the orchard site. This information can help determine the most economical method of soil modification, how to properly set up and use deep-tillage equipment, and to what depth tillage is required. One alternative to backhoe pits is the use of a soil probe to pull undisturbed soil cores for evaluation. Special equipment is required for this option if you want to examine the profile down to six feet and it must be done by an experienced agronomist/soil scientist who knows what to look for. Using your farm backhoe or even renting one may be cheaper in the end and will be more revealing as the entire profile can be viewed at once. As a rule of thumb, it is advisable to dig at least one backhoe pit per 20 acres. Where possible, locate backhoe pits in areas of the prospective orchard site that have a history of desirable as well as poor growth, for comparison.

Evaluating soil and water salinity/chemical characteristics

There are two basic philosophies for sampling soils and water to diagnose and manage salinity/quality problems

(1) **Preplant sampling followed by annual or biannual sampling required:** This approach is usually required if marginal soil/water quality is often found in the area being developed.

(2) **Trouble-shooting or infrequent analysis only:** In areas where soils and water are mostly uniform, of good quality and previous crops show no toxicity symptoms, soil and water sampling is only necessary to troubleshoot problems that may appear after planting or when forced to switch water supply.

Regardless of which approach you chose, soil and water sampling must reasonably represent the average condition for the area of concern for the analytical results to be of value. Results from unrepresentative sampling (i.e. soil pulled from just one or two backhoe pits) may be misleading and costly. Although obtaining representative, composite samples involves some effort and expense, it should not require more than 8 hours of labor and $550 ($7/acre) in lab fees every one or two years for an 80-acre orchard or vineyard. The Table 1 describes the salts and ranges typical for ag.

Table 1. LABORATORY DETERMINATIONS NEEDED TO EVALUATE COMMON IRRIGATION WATER QUALITY PROBLEMS

. Ayers, R.S., D.W. Westcot. *Water Quality for Agriculture.* FAO Irrigation and Drainage Paper 29 Rev. 1, Reprinted 1989, 1994 . http://www.fao.org/DOCREP/003/T0234E/T0234E00.htm
(This publication is one of the most extensive references on water quality and can be downloaded for free at the above website.)

Water parameter	Symbol	Unit[1]	Usual range in irrigation water	
SALINITY				
Salt Content: Electrical Conductivity	EC_w	dS/m	0 – 3	dS/m
(or) Total Dissolved Solids	TDS	mg/l	0 – 2000	mg/l
Cations and Anions				
Calcium	Ca^{++}	meq/l	0 – 20	meq/l
Magnesium	Mg^{++}	meq/l	0 – 5	meq/l
Sodium	Na^{+}	meq/l	0 – 40	meq/l
Carbonate	CO^{--}_3	meq/l	0 – .1	meq/l
Bicarbonate	HCO_3^-	meq/l	0 – 10	meq/l
Chloride	Cl^-	meq/l	0 – 30	meq/l
Sulphate	SO_4^{--}	meq/l	0 – 20	meq/l
NUTRIENTS[2]				
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2	mg/l
Potassium	K^+	mg/l	0 – 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 – 2	mg/l
Acid/Basicity	pH	1–14	6.0 – 8.5	
Sodium Adsorption Ratio[3]	SAR	(meq/l)[1], [2]	0 – 15	

[1] dS/m = deciSiemen/meter in S.I. units (equivalent to 1 mmho/cm = 1 millimmho/centi-metre)

mg/l = milligram per litre ≃ parts per million (ppm).

meq/l = milliequivalent per litre (mg/l ÷ equivalent weight = meq/l); in SI units, 1 me/l= 1 millimol/litre adjusted for electron charge.

[2] NO_3 -N means the laboratory will analyse for NO_3 but will report the NO_3 in terms of chemically equivalent nitrogen. Similarly, for NH_4-N, the laboratory will analyse for NH_4 but report in terms of chemically equivalent elemental nitrogen. The total nitrogen available to the plant will be the sum of the equivalent elemental nitrogen. The same reporting method is used for phosphorus.

[3] SAR is calculated from the Na, Ca and Mg reported in meq/l ($SAR = Na/((Ca+Mg)/2)^{0.5}$).

Table 2. Guidelines for water quality for irrigation[1]
(Adapted from FAO Irrigation and Drainage Paper 29)

Potential Irrigation Problem		Units	Degree of Restriction on Use		
			None	Slight to Moderate	Severe
Salinity *(affects crop water availability)*					
	EC_w	dS/m	< 0.7	0.7 – 3.0	> 3.0
	TDS	mg/l	< 450	450 – 2000	> 2000
Infiltration *(affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)*					
Ratio of SAR/EC_w			< 5	5 – 10	> 10
Specific Ion Toxicity *(sensitive trees/vines, surface irrigation limits)*					
	Sodium (Na)[2]	meq/l	< 3	3 – 9	> 9
	Chloride (Cl)[2]	meq/l	< 4	4 – 10	> 10
	Boron (B)	mg/l	< 0.7	0.7 – 3.0	> 3.0

[1] Adapted from University of California Committee of Consultants 1974.

[2] For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown. Most annual crops are not sensitive; use the salinity tolerance only. With overhead sprinkler irrigation and low humidity (< 30 percent), sodium and chloride may be absorbed through the leaves of sensitive crops.

Water/Soil toxicity ranges

Your irrigation water quality is always the place to begin as this will be the long-term constraint on where your final soil salinity ends up. **In general, the average rootzone soil salinity will be about double the irrigation water salinity with a 15% leaching fraction.** Table 2 to the left gives the general range of no restriction to severe problems for most permanent crops. As a general rule of thumb you can double these numbers for guidelines when checking soil saturation extract analyses.

Pistachios have proven to be the winner for permanent crops when it comes to salt tolerance. Studies in NW Kern County, UC Riverside and Iran have shown that this tree is as salt tolerant as cotton. Most row crops, except for some sensitive veg crops, have no problem tolerating irrigation water at the "Severe" restriction limit in Table 2.

Figure 1 shows almond and pistachio relative yield as a function of salinity ($EC_{soil\ ex}$) in comparison to alfalfa and cotton. (The curve shown is for the UCB1 rootstock, Pioneer Gold was the same or possibly greater tolerance. Symbols on lines are for legend identification and do not represent specific data points.)

Water can only move into plant roots by osmosis, which means that the xylem sap in the plant must have a much higher concentration of solutes than the soil water in the rootzone. As salinity in the rootzone increases the plant must work harder to generate the sugars and other solutes in the root tips in order to keep water moving into the plant to satisfy the transpiration demand. Plants have differing abilities to generate these solutes to maintain crop growth and yield. In general, the plant is good to a certain threshold. As salinity increases above this threshold, crop water use begins to decrease and eventually will cause a decline in yield.

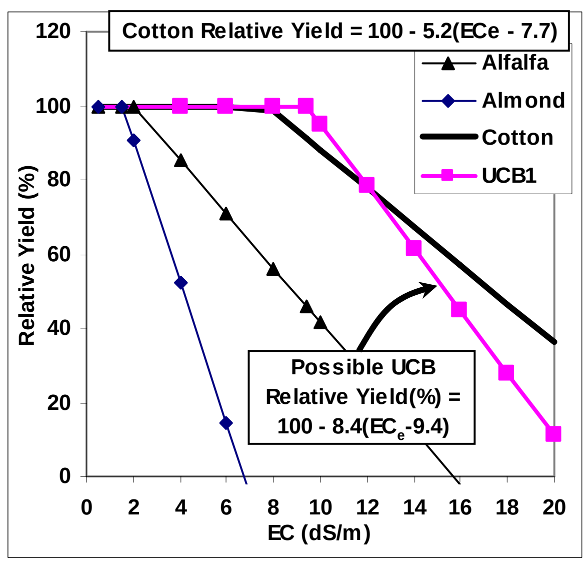


Fig. 1. Relative yield (RY) of various crops as a function of soil EC_e (Sanden, B.L., L. Ferguson, H.C. Reyes, and S.C. Grattan. 2004. Effect of salinity on evapotranspiration and yield of San Joaquin Valley pistachios. Proceedings of the IVth International Symposium on Irrigation of Horticultural Crops, Acta Horticulturae 664:583-589)

Table 3. Summary of published tolerance limits for various permanent crops. S = sensitive, <5-10 meq/l. MT = moderately tolerant, <20-30 meq/l (Ayers and Westcott, 1989, Sanden, et al., 2004)

Crop	EC_{thresh} (dS/m)	Slope (%)	Sodium (meq/l)	Chloride (meq/l)	Boron (ppm)
Almond	1.5	19	S	S	0.5-1.0
Apricot	1.6	24	S	S	0.5-0.75
Avocado			S	5.0	0.5-0.75
Date palm	4.0	3.6	MT	MT	
Grape	1.5	9.6		10-30	0.5-1.0
Orange	1.7	16	S	10-15	0.5-0.75
Peach	1.7	21	S	10-25	0.5-0.75
Pistachio	**9.4**	**8.4**	**20-50**	**20-40**	**3-6**
Plum	1.5	18	S	10-25	0.5-0.75
Walnut			S		0.5-1.0

Table 3 summarizes EC thresholds and the slope of the yield decline (Relative yield (%) = 100 – Slope(Soil ECe – Threshold EC)), along with specific ion toxicities for various tree and vine crops in California. Many crops, and especially different varieties and rootstocks do not have documented thresholds. Remember, these numbers are guidelines only. The soil texture/mineralogy, drainage/aeration, irrigation system/scheduling and the ratio of certain salts to others will shift these numbers up or down. Rootstock and variety (especially with grapes) can also have a significant impact. Compare your soil and water numbers to your neighbor. A good number of highly productive Westside Fresno County almond orchards on Panoche soils are irrigated with high calcium well water that is over the EC (total salt) threshold for almonds. In Westside Kern County some growers have pushed the limits, irrigating with wells that have the same EC as some of these Fresno orchards, but the sodium concentration is 10 times the calcium and the orchard performs poorly.

Correcting water quality with gypsum

The following example calculations show how to estimate the quantity of gypsum required to improve infiltration. (Tables 4 and 5 give detailed information on the chemistry, equivalent rates and comparative costs for calcium and acid-type amendments. The following example refers to these tables.)

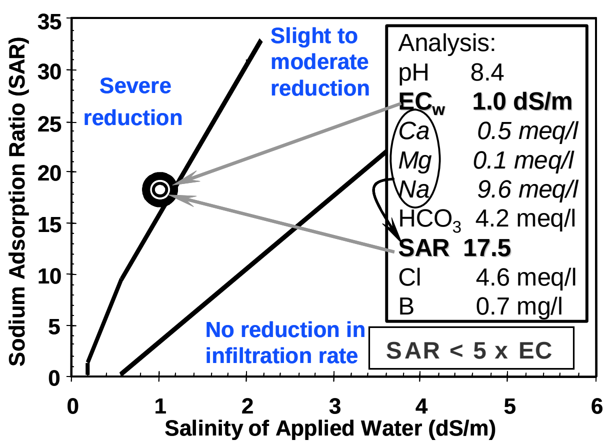


Fig. 2. Estimating potential infiltration problems and determining amendment options from an irrigation water analysis.

Example: calculating gypsum rates

A partial water analysis is shown in Figure 2. This water presents absolutely no salt or ion tolerance problems for the most crops, but the high SAR, especially given the high pH and bicarbonate levels, indicate significant infiltration problems, as indicated by the large black circle in the figure. This means salts can accumulate with little or no leaching and cause problems to sensitive crops like almonds. To achieve good infiltration some of the Na needs to be offset with Ca. You want to treat the water by injecting gypsum. Four steps are required to calculate the right rate:

Example (continued)

1. Determine the purity of the gypsum and the actual lbs/ac-ft needed for 1 meq/l Ca:
   From Table 4, 234 lbs/ac-ft @ 100% = 1 meq/l
   If the solution gypsum purity ~ 92%:
   234 / 0.92 = 254 lb/ac-ft/meq/l Ca
2. Use desired application rate to calculate additional Ca and new water EC:
   (500 lb/ac-ft) / 254 ≈ 2 meq/l

New EC = 1.0 + 0.2 = 1.2 dS/m

3. Calculate the new SAR = $Na/((Ca+Mg)/2)^{0.5}$
   SAR = $9.6/((2.5+0.1)/2)^{0.5}$ = 8.4
4. Locate the intersection of the new SAR and EC on the infiltration chart (as shown in Figure 2).

You can see that adding another 250 lbs/ac-ft (a 50% increase) gives a very small additional infiltration benefit and is not cost effective.

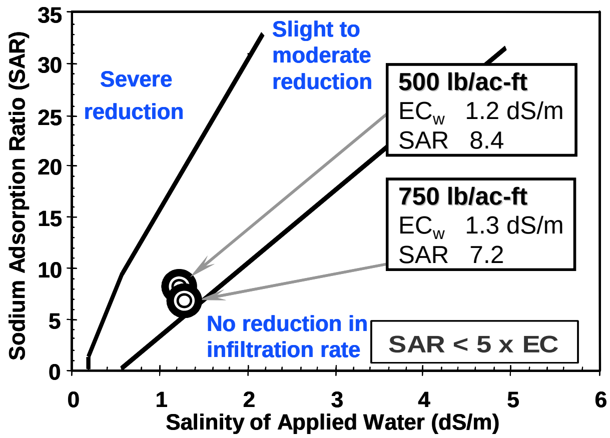


Fig. 3. Revised infiltration potential after gypsum amendment to irrigation water for 500 and 750 lb/ac-ft injection rates.

Practical field application example
(using above water)

Field size / system:	80 acre, single-line drip
Application rate:	0.45in/day
Flowrate:	700 gpm, 3.12 ac-ft/day
Required gypsum over 80 acres:	1,556 lb/day
Net gypsum application:	19.4 lb/ac
Total injection days for 25 ton silo:	**32 days**
Total season 100% gypsum:	**622 lb/ac**
(Using Table 4)	
Cost of solution gypsum:	**$29.50**
Cost of 2 t/ac pit gyp, applied:	**$59.90**

For most field settings, it is rarely necessary to inject gypsum all the time. Most growers will inject every other or every third irrigation (as would be the case in the above example) – often ending the season with a total application of 600 to 1000 lb/ac of 92% gypsum. This may or may not be sufficient for your ground, but even if you doubled the application frequency in the previous example, the cost of the 1,200 lb/ac high quality bulk gypsum would be the same as 2 ton/ac pit gyp applied during the dormant season. And the benefits of gypsum injection during the season are virtually always superior to dormant season applications.

Table 4. Amounts of amendments required for calcareous soils to replace 1 meq/l of exchange-able sodium in the soil or to increase the calcium content in the irrigation water by 1 meq/l.

Chemical Name	Trade Name & Composition	[a]Pounds/ Acre-6" to Replace 1 [b]meq exch Sodium	[a]Pounds/ Ac-ft of Water to Get 1 meq/L Free Ca
Sulfur	100% S	321	43.6
Gypsum	$CaSO_4 \cdot 2H_2O$ 100%	1720	234
Calcium polysulfide	Lime-sulfur 23.3% S	1410	191
Calcium chloride	Electro-Cal 13 % calcium	3076	418
Potassium thiosulfate	KTS -- 25 % K_2O, 26 % S	[c] 1890 3770	[c] 256 513
Ammonium thiosulfate	Thio-sul 12 % N, 26 % S	[d] 807 [e] 2470	[d] 110 [e] 336
Ammonium polysulfide	Nitro-sul 20 % N, 40 % S	[d] 510 [e] 1000	[d] 69 [e] 136
Monocarbamide dihydrogen sulfate/ sulfuric acid	N-phuric, US-10 10 % N, 18 % S	[d] 1090 [e] 1780	[d] 148 [e] 242
Sulfuric Acid	100 % H_2SO_4	981	133

[a] Salts bound to the soil are replaced on an equal ionic charge basis and not equal weight basis. Laboratory data show an extra 14 to 31%, depending on initial and final ESP or SAR, of the amendment is needed to complete the reaction

[b] The meq of exchangeable sodium to replace = Initial ESP – Desired ESP x Total meq/100 grams soil Cation Exchange Capacity.

[c] Assumes 1 meq K beneficially replaces 1 meq Na in addition to the acid generated by the S.

[d] Combined acidification potential from S and oxidation of N source to NO_3 to release free Ca from soil lime. Requires moist, biologically active soil.

[e] Acidification potential from oxidation of N source to NO_3 only.

Acids and acid-forming materials: Commonly applied acid or acid-forming amendments include sulfuric acid (H_2SO_4) products, soil sulfur, ammonium polysulfide, and calcium polysulfide. The acid from these materials dissolves soil-lime to form a Ca salt (gypsum), which then dissolves in the irrigation water to provide exchangeable Ca. The acid materials react with soil-lime the instant they come in contact with the soil. The materials with elemental sulfur or sulfides must undergo microbial degradation in order to produce acid. This process may take hours or years depending on the material and particle size (in the case of elemental sulfur).

Water-run acid: The water used for the Fig. 2 gypsum example would be a good candidate for acidifying amendments. Starting in the late 1950's sulfur burners were used to meter ground elemental sulfur into a small furnace. The burning produces sulfur dioxide which combines with water trickled through the machine to make sulfuric acid which is then injected into the irrigation water. In recent years, better pumps and safeguards have been developed to inject concentrated sulfuric acid directly.

Returning to our example water: you can see that the pH is quite high (8.4) and the bicarbonate, HCO_3, is 4.2 meq/l. If you add gypsum to this water and run it through a drip system you will significantly increase your chances of plugging the system with lime precipitate. Chances are that the soil to be irrigated with this water is also alkaline. If the soil pH>8, acidification of this water and/or the soil may be beneficial to crop growth. Neutralizing the HCO_3 will definitely increase free Ca in the soil/water matrix and improve infiltration. Using Table 1 we see that it takes 133 lbs/ac-ft of 100% pure sulfuric acid to release 1 meq/l Ca. (This assumes the acid contacts lime, $CaCO_3$, in the soil neutralizing the carbonate molecule and releasing the Ca^{2+}.)

This is the same amount of acid required to neutralize 1 meq/l of HCO_3 in the water. For our example water; you then need 4 x 133 = 532 lbs/ac-ft of 100% sulfuric acid. Additional acid drops the pH rapidly and you should have a "pH stick meter" or use a swimming pool test kit to make sure you know how much acid can safely be added to the water to avoid pH < 4.5. Damage to brass valves and other irrigation components can occur when pH<4.5.

Table 5. Approximate bulk purity and moisture content, field tons required and applied cost/acre for various calcium supplying amendments to provide for a 1 to 4 ton/ac 100% pure gypsum requirement. (Costs determined for Kern County, Fall 2005.)

Amendment	Average Purity (%)	Average Moisture (%)	Approx Cost/Ton	Field Tons & Total $/ac to Meet the Below 100% Gypsum Requirements: 1 ton/ac Tons	1 ton/ac *$	2 ton/ac Tons	2 ton/ac $	4 ton/ac Tons	4 ton/ac $
Westside Pit Gypsum	50	8	$14	2.17	**65**	4.35	**123**	8.70	**246**
'Lima' Gypsum (Ventacopa)	75	4	$23	1.39	**59**	2.78	**105**	5.56	**207**
Bulk Solution Gypsum[1] (dlvd)	92	3	$95	1.12	**106**	2.24	**213**	4.48	**426**
Ground Wallboard	92	5	$27	1.14	**55**	2.29	**98**	4.58	**189**
Soil Sulfur ("popcorn")[2]	99	6	$85	0.20	**32**	0.40	**51**	0.80	**89**
Soil Sulfur (granular)[2]	99	2	$90	0.19	**32**	0.38	**51**	0.77	**90**
Sulfuric Acid (applied)[2]	98	NA	$120	0.58	**76**	1.16	**151**	2.33	**302**
Thio-Sul[1,2] (delivered)	N-12, S-26	NA	$160	0.47	**80**	0.94	**160**	1.88	**319**
Lime Sulfur[2,3]	Ca-6, S-23	NA	$260	0.67	**194**	1.34	**374**	2.68	**736**
N-pHuric 10/55[1,2] (delivered)	N-10, S-18	NA	$210	0.63	**133**	1.27	**266**	2.54	**533**
Beet Lime[4]	60	10	$12	1.08	**37**	2.15	**60**	4.31	**113**

*Price assumes freight @ $10/ton, spreading (where applicable) @ $13/ac to 3t/ac. [1]Chemigation, no application cost. [2]Free lime must be present in soil. [3]Some free Ca but soil lime needed for complete reaction. [4]Acid soil only.