# MANAGING SALINITY, SOIL AND WATER AMENDMENTS

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Pistachios are better adapted to moderately saline, calcareous soils more then any other commercial tree crop. But proper assessment of potential salinity problems cannot be made just looking for visible salt precipitate on the soil surface or around drip emitters (Plate 15A).

This chapter discusses the role of salinity management in establishing and maintaining a successful pistachio orchard. Recommendations are based on the use of soil and water analyses as practical and economical salinity management tools. We will discuss how to:

1. Collect representative soil and water samples.
2. Understand terms used in an analytical report.
3. Check the quality of an analytical report.
4. Diagnose different types of salinity problems.
5. Make remedial management decisions.

## SOIL AND WATER ANALYSIS

### Sampling Approaches

There are two basic philosophies for sampling soils and water to diagnose and manage salinity problems. **(1) Marginal soil/water quality is often found in area being developed:** sampling is essential prior to planting an orchard, and continued annually or biannually for routine monitoring; or **(2) Soils and water are mostly uniform and of good quality, previous crops show no toxicity symptoms:** 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.

### Soil sampling

Salinity can vary considerably throughout an orchard. You should take at least one composite soil sample for several depths in each **"zone"** in the orchard having a similar soil type. USDA soil surveys are good starting points for targeting sampling areas. Even for very uniform fields, a minimum of one composite sample for each 40 acres should be taken. Figure 15a illustrates the possible soil variability for a 160 acre field in Kern County. Fields that have been planted to row crops like cotton and have been furrow irrigated for many years may have **"head** and **tail zones"** that need separate sampling due to differences in leaching. Excavating a backhoe pit to a six or seven foot depth in each area allows a visual examination of the soil profile to assess potential drainage problems and the depth of ripping required. Soil samples for each 1 to 2 foot increment (or layer) can be taken from these pits but should be composited with other sub samples from the same area as described below.

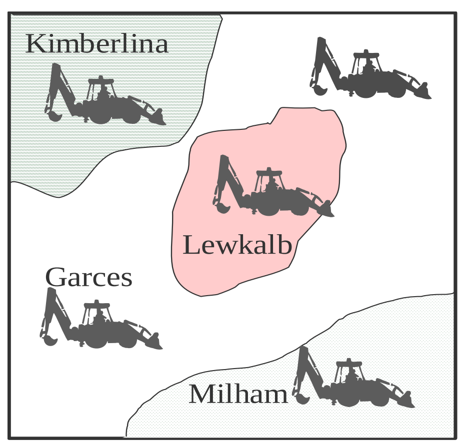


**Figure 15a.** Soil type variability and required sampling areas for a 160 acre orchard development.

Begin by sampling the soil to at least a 4-foot depth in six to twelve locations (each spot 20 to 200 feet apart) for a given area/soil type. A two to three inch diameter auger works best. Use an open loop-type "Dutch auger" for moist clay soils. A closed barrel auger with opposing cutters is required for sandy or dry soils (see Plate 15B). A rubber mallet is very useful for loosen-ing/removing the soil from the auger. Use four buckets and mix the samples from the different holes into one bucket for a given depth (i.e. 0-1', 1-2', etc.) together to form one large sample for that depth. This means you would end up with 4 composite samples for that soil type. Take about 1.5 pounds of this sample to your ag laboratory the same day. If you have to wait a few days to submit your samples then air dry the sample by placing it in a large paper bag set outside in a dry area exposed to the wind. Compositing minimizes the number of soil samples requiring analysis, while achieving the most representative average data for the field.

Repeated soil sampling in existing orchards every couple of years for evaluating salinity and amendment management strategies should be done the same time each season with respect to rainfall patterns, irrigation scheduling and water distribution (i.e. drip wetted area) around the tree. This ensures that salinity distribution and accumulation reflect the long-term trends occurring in the orchard and not just different levels of applied water and crop ET (evapotranspiration – water use) for that year. Sampling after harvest provides a salinity assessment in an orchard when root zone salinity is usually highest. Irrigation is commonly delayed, or deficit, during harvest allowing salts to accumulate in the root zone. Also, fall sampling gives the most advance notice that additional irrigation water may be needed for salinity control during the winter season when the ground is cold, trees are dormant and extra irrigation for leaching is less likely to cause water logging and disease problems.

The method of irrigation and the ability to apply water uniformly must be considered to collect representative samples. In flood-irrigated pistachios, sampling 5 to 10 feet to the side of a tree row is the best location. In sprinkler-irrigated pistachios, sample across the sprinkler pattern to ensure that two-thirds of the composite includes soils from the center of the wetting pattern (these receive the most applied water) and about one-third from the edges of the wetting pattern, where salts tend to accumulate. The same method applies to micro sprinklers and drip irrigation.

Variable soil textures contribute to non-uniform salinity levels in an orchard. Sandy loam tends to have lower salinity than silt loam and clay loam, because infiltration rates are often higher and leaching is greater in sandy loam. Sampling from similar soil types reduces variability in salinity levels. Uniform growth is a good indicator of uniform soil type and/or water availability.

**Why sample multiple depths?** If infiltration is a problem or irrigation set duration is too short, salinity in the top 1 to 2 feet will often be higher than the 3 to 4 foot depths. Surface soils containing salinity and sodium/chloride levels far in excess of the irrigation water usually indicates that soil crusting restricts water infiltration and that irrigation water quality is probably also part of the problem. For this case a soil sample from 0 to 3 inches along with a water sample may be important to diagnose crusting problems. With adequate irrigation to meet crop ET, good water penetration and a small amount of leaching, the rootzone salinity ($EC_e$) at the 4 foot depth of a non-saline soil will be about 2 to 3 times the salinity of the 0 to 2 foot depth. **Note of caution for micro-irrigation systems:** If the $EC_e$ at the 4 foot depth is four to six times greater than the top foot of rootzone there is a good chance that your irrigation scheduling has been too efficient – resulting in deficit irrigation and no leaching. In this event, recheck soil salinity levels in the spring after winter rainfall and preirrigation recharge. In general, the salinity over all depths can be averaged to determine the potential impact of salinity on pistachio ET and possible specific ion toxicities.

**Annual crop with aerial/satellite and GPS imagery for field evaluation** can provide greater detailed information than "zone" sampling. This is best done when the field is planted to wheat, alfalfa or cotton. The resulting map, coupled with GPS coordinates, will more accurately outline different "quality zones" in the field then does a USDA soil survey. Composite sampling as described above is then done in these zones and the resulting recommendations for soil amendments applied with GPS guided variable rate equipment. For fields with a high degree of variability in salinity, alkalinity and sodicity this approach might actually save money compared to conventional sampling and improve overall orchard development by concentrating the right amount of soil amendments in the right place. However, this overall system is more expensive than conventional sampling and requires the assistance of a professional consulting company.

## Water sampling

Sampling irrigation water for salinity assessment is much simpler than sampling soils. First, rinse a plastic container in the water that is to be sampled. Collect a small sample (4 to 8 oz.). Completely fill the container with water; this eliminates air, which would otherwise promote calcium carbonate precipitation.

Before taking a sample from a well, let the pump run for at least 30 minutes; 2 to 4 hours when the average EC > 1.5 dS/m. This should be sufficient time to flush the well of static water, stabilize salinity and establish the pumping water elevation that represents the primary water-bearing strata. If the orchard site is surrounded by other deep wells, sample in July-August when groundwater pumping is the greatest. Collect a representative water sample for laboratory analysis to establish a baseline. If the pumping groundwater depth varies considerably over the year and is declining, invest in an inexpensive portable electrical conductivity (EC) meter (costs about $50) and monitor the total salinity of the well water every 4 to 8 weeks Submit a new sample for analysis when the total salinity ($EC_w$) increases about 20 percent. Otherwise, a sample once every 3 years is sufficient.

To establish a baseline for surface water, take samples from canals or ditches with flowing water. Submit the first sample for analysis and use this as a reference point. As described for groundwater monitoring, use a portable electrical conductivity meter to determine how often the surface water supply should be analyzed. If possible, submit a water sample for analysis on the same day that it is collected. If the sample must be stored, refrigerate it to minimize changes in salinity. Storage at room temperature will allow calcium (Ca), and bicarbonate ($HCO_3$) to precipitate and lower the total salinity level of the water. Usually, irrigation districts test for irrigation water quality and can supply you with that information.

## Reading Laboratory Analytical Reports

An analysis of an irrigation water sample or a saturated soil extract (the most common method of analyzing soil salinity in the alkaline soils of the western U.S.) measures dissolved salts. Additional salts in the form of ions are attached to electrically charged "exchange sites" on clay particles in the soil. These ions affect soil structure and infiltration, but do not add to possible salt toxicities. We will discuss the importance of these ions later. Table 1 lists the determinations usually provided in an analytical report relating to irrigation water or a soil extract. Analytical results can be lengthy and full of unfamiliar terms. This section will explain what these terms (**listed in bold)** mean.

## Terminology and Units

After the composite soil sample is dried and ground, distilled water is added to make a saturated paste. The water is then extracted from the sample by vacuum and used for all the analyses listed in Table 1.

The ***saturation percentage*** **(SP)** equals the weight of water required to saturate the pore space divided by the weight of the dry soil. Saturation percentage is useful for characterizing soil texture. Very sandy soils have SP values of less than 20 percent; sandy loam to loam soils have SP values between 20 and 35 percent; and silt loam, clay loam and clay soils have SP values from 35 to over 50 percent. Also, salinity measured in a saturated soil can be correlated to soil salinity at different soil-water contents measured in the field. As a rule, the SP soil-water content is about two times higher than the soil-water content at field capacity. Therefore, the soil salinity in a saturation extract is about half of the actual concentration in the same soil at field capacity.

**Table 1.** Laboratory determinations and units for evaluating irrigation water quality and soil salinity.

| Test | Symbol | Units | Soil | Water |
|---|---|---|---|---|
| Saturation % | SP | % | Yes | No |
| Acidity-alkalinity | pH | None | Yes | Yes |
| Electrical conductivity | $Ec_e$, $Ec_w$ | dS/m | Yes | Yes |
| Calcium | $Ca^{2+}$ | meq/l | Yes | Yes |
| Magnesium | $Mg^{2+}$ | meq/l | Yes | Yes |
| Sodium | $Na^{+}$ | meq/l | Yes | Yes |
| Bicarbonate | $HC0_3^-$ | meq/l | Yes | Yes |
| Carbonate | $C0_3^{2-}$ | meq/l | Yes | Yes |
| Chloride | $Cl^-$ | meq/l | Yes | Yes |
| Sulfate | $S0_4^{2-}$ | meq/l | Yes | Yes |
| Boron | B | mg/l (ppm) | Yes | Yes |
| Nitrate-nitrogen | $NO_3^-N$ | mg/l (ppm) | Yes | Yes |
| Sodium Adsorption Ratio | SAR | none | Yes | Yes |
| Adjusted Sodium Adsorption Ratio | $SAR_{adj}$ | none | No | Yes |
| Exchangeable Sodium Percentage | ESP | % | Yes | No |
| Lime Requirement | LR | tons/ac | Yes | No |
| Gypsum Requirement | GR | tons/ac-6 in | Yes | No |
| Lime Percentage | $CaC0_3$ | % | Yes | No |

The ***pH*** of a soil or water measures hydrogen ion concentration (activity). Although pH is closely related to bicarbonate concentration and the availability of some macro and micronutrients, it does not correlate with total salinity. It is, however, important when selecting the most appropriate soil amendments.

The **electrical conductivity** (denoted as $\mathbf{EC_e}$ for extracts from soil and $\mathbf{EC_w}$ for irrigation water) is a measure of total salinity based on how easily an electric current passes through the extract, but it does not give any indication of the salt composition. However, EC is one of the most important numbers on your analysis because nearly all crop salt tolerance levels are based on EC. The internationally accepted reporting unit for EC is in *deciseimens per meter* (dS/m). This unit is equal to *millimhos per centimeter* (mmhos/cm), which is still used by some labs. Many labs that do environmental and ag testing will often report $EC_w$ in *micromhos per centimeter* (µmhos/cm). Divide these values by 1,000 to obtain dS/m or mmhos/cm.

Another term often found on analytical reports is *total dissolved solids* (TDS). This is the weight of all soluble salts in milligrams per liter of water (mg/l) on analytical reports. About 640 mg/l equals 1 dS/m. TDS is not useful in evaluating salinity problems because crop tolerance thresholds are correlated with $EC_e$ and $EC_w$, rather than with TDS.

Salts such as sodium chloride (NaCl) and calcium sulfate ($CaSO_4$) consist of positively charged cations and negatively charged anions bonded together by opposing charges. In irrigation water or soil-water, many of the bonds are broken, and the water consists of individual cations and anions. To understand the impact of salinity on soil structure and crop tolerance, soil and irrigation water samples must both be analyzed for these soluble cations and anions. **Calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), and sodium ($Na^+$)** are the major cations in soil extracts and irrigation water. Although potassium is important as a nutrient, it has a low solubility relative to Ca, Na and Mg salts and soluble $K^+$ is usually a very minor component of salinity. **Bicarbonate ($HCO_3$), sulfate ($SO_4^{2-}$) and chloride ($Cl^-$)** are the main anions in most soil extracts and irrigation water. Along with these anions, **boron (B) and nitrate-nitrogen ($NO_3^-N$)** are commonly reported in analytical results. Boron does not contribute significantly to total salinity and the osmotic effects (salt stress) on plants, but it is important in diagnosing specific ion toxicity. Knowing the $NO_3^-$N content of the soil and irrigation water is valuable in making fertilizer decisions, but nitrate does not contribute significantly to the total salinity.

The preferred unit for reporting individual cations and anions is ***milliequivalents per liter* (meq/l)**. This unit is used specifically in salinity evaluation and reporting. Most agriculturists who work with pesticides, fertilizers, and tissue analyses are familiar with parts per million (ppm) and milligrams per liter (mg/l) but unfamiliar with meq/l. When all ions are reported in meq/l this provides the best comparison of the relative ionic strength of the different cations and anions. Clay particles in soil are negatively charged and *adsorb* the positively charged cations. It is the concentration of the charges, not the weight of the ions that affects soil structure and eventually the decisions you will make on soil amendments. Reporting cation and anions in meq/l is one of the hallmarks of a quality agricultural lab. These numbers are easily converted back to the weight of the various salts, which is needed when calculating the tonnage of required amendments. Table 2 shows how to convert from meq/l to mg/l.

**Table 2.** Conversion factors to go from meq/l to mg/l. (mg/l = meq/l x conversion factor).

| Cation/Anion | Symbol | Conversion Factor |
|---|---|---|
| Calcium | $Ca^{2+}$ | 20 |
| Magnesium | $Mg^{2+}$ | 12 |
| Sodium | $Na^+$ | 23 |
| Bicarbonate | $HCO_3^-$ | 61 |
| Carbonate | $CO_3^{2-}$ | 30 |
| Chloride | $Cl^-$ | 35 |
| Sulfate | $SO_4^{2-}$ | 48 |

The **unadjusted sodium adsorption ratio (SAR), adjusted sodium adsorption ratio ($SAR_{adj}$), and exchangeable sodium percentage (ESP)** are calculated from the individual cation and anion determinations. These indices must be used along with the EC values to evaluate salinity and sodicity accurately. (The calculation of these indices is covered in more detail in Chapter 14, but their importance is described below.)

The **unadjusted SAR** indicates the ratio of Na to Ca and Mg in a soil-water extract or irrigation water sample. An increasing SAR value indicates higher levels of Na in comparison to Ca and Mg. Rising levels of Na reduce soil stability, decrease water infiltration and increase the chance of Na accumulating to toxic levels in leaf tissue. Use the SAR to evaluate sodicity problems rather than Na cation levels alone. More Na can be tolerated in a soil extract or water sample when Ca increases proportionally to Na.

The **$SAR_{adj}$** is calculated and reported only for water samples. This index predicts the reaction of $HCO_3$ with Ca when water is applied to the soil. Irrigation water with low levels of $HCO_3$ or $CO_3$ anions usually has an $SAR_{adj}$ that is very similar to its unadjusted SAR. Such water will very slowly dissolve lime from the soil and contribute Ca to offset Na in the soil-water. Irrigation water high in $HCO_3$ or $CO_3$ usually has an $SAR_{adj}$ higher than its unadjusted SAR. Such water precipitates Ca with $HCO_3$ and forms lime, which reduces free Ca levels in the soil-water and increases the proportion of Na. Prior to 1988, $SAR_{adj}$ was calculated according to an empirical equation using pH constants, ($pH_c$). This has since been proven to overestimate $SAR_{adj}$. The new procedure is based on the proportion of Ca and $HCO_3$ in a water sample. If there is any doubt about how the laboratory calculated $SAR_{adj}$ and the laboratory cannot clarify which procedure was used, simply use the unadjusted SAR.

**ESP** is closely related to SAR. These ratios differ in that SAR is an index used for water alone; comparing soluble Na to soluble Ca and Mg. The ESP is for soil only; indicating the amount of Na+ ions bound to exchange sites in the soil. Today, most laboratories do not measure ESP directly because this requires extra analyses to measure the total cation exchange capacity and the exchangeable Na content. Instead, most laboratories report an estimated ESP based on a correlation between SAR and ESP (see Chapter 14).

Most laboratory reports of a soil analysis provide either a **gypsum requirement (GR) or**

**a lime requirement (LR).** A **GR** is usually provided for alkaline soils with pH above 7 and SAR above 10 to 15. A **LR** is only for acid soils with a pH less than 7. The most common method of determining the GR is the Schoonover test. It measures how much soluble Ca must be added in the form of gypsum to replace nearly all the Na on the soil exchange sites.

### Verification of quality lab results

A good report will give the cation and anion concentrations in meq/l. The accuracy of the analysis can be evaluated by two methods described below. These checks are illustrated by referring to Table 3 as a sample analytical report.

**Table 3.** Example irrigation water quality analysis to demonstrate how to check the quality of a laboratory report.

| Analysis: | Example |
|---|---|
| pH | 8.4 |
| $EC_w$ | 1.0 dS/m |
| Ca | 0.5 meq/l |
| Mg | 0.1 meq/l |
| Na | 9.6 meq/l |
| $HCO_3$ | 4.2 meq/l |
| $CO_3$ | 1.0 meq/l |
| Cl | 4.6 meq/l |
| $SO_4$ | 0.1 meq/l |
| B | 0.7 mg/l |
| $NO_3$ | 5.2 mg/l |
| SAR | 17.5 |
| $SAR_{adj}$ | 16.6 |

**Check 1: Cation-anion balance method**

Salts such as NaCl, $NaHCO_3$, and $CaSO_4$ consist of cations and anions bonded together by electrical charges. For each cation there is an equivalent charge (meq) of anion bonded to form the salt. This is referred to as the cation-anion balance. Using Table 3:

$$\mathbf{Na + Ca + Mg \approx HCO_3 + CO_3 + SO_4 + Cl}$$
$$\mathbf{10.2\ meq/l \approx 9.9\ meq/l}$$

When dissolved in a water sample or soil extract, the bonds are broken and the salts exist as individual cations, anions, or neutral ion pairs. The individual cations and ions must be reported in meq/l to perform this check. Omit B and $NO_3$ in conducting this check procedure, because they are reported in mg/l and are usually an insignificant amount of the total salinity.

**Check 2: Comparing total salinity to sum of cations or anions**

The salinity level, $EC_{w,}$ multiplied by a factor of 10 will about equal the sum of the cations or anions if the analysis is valid. Using Table 3:

$$\mathbf{EC_w * 10 \approx (Na + Ca + Mg) \text{ or } \approx (HCO_3 + CO_3 + SO_4 + Cl)}$$
$$\mathbf{1.0 * 10 \approx 9.9 \text{ or } 10.2}$$

In this example, the sum of the individually measured cations or anions is in close agreement to the value calculated from $EC_w$*10.

Beware of a report in which the EC multiplied by 10 exactly equals the sum of either the cations or anions, or where the cations exactly equal the anions. Such a result may indicate that some of the individual cations and anions were estimated by subtraction rather than determined by direct measurement. $SO_4$ and Na are the most likely elements to be estimated, because measuring them requires additional analytical steps and expense.

## DIAGNOSING POTENTIAL SALT PROBLEMS

Salinity analyses are used to diagnose three types of salinity conditions in the field: (1) root zone salinity and crop salt tolerance, (2) poor water infiltration rates, and (3) potential accumulation of specific elements to toxic levels.

### Pistachio salt tolerance

A high soil $EC_e$ or $EC_w$ value indicates high salinity. Excessive salts reduce the amount of water that plant roots can absorb from the soil and thus rob energy from the plant by reducing photosynthesis. Trees grown in saline soil may show symptoms of water stress even though the soil may appear or feel as though it contains sufficient soil-water. Crop evapotranspiration, ET, is directly related to vegetative growth. As water vapor leaves the open stomata on the leaves carbon dioxide ($CO_2$) enters for the production of carbohydrates. When rootzone salts are too high the trees may display inadequate shoot growth, reduced nut size, and increased incidence of sunburn and kernel shrivel. Necrotic (brown, dead) tissue along leaf tips and margins may indicate excess salt absorption and accumulation. Decades of research work in many crops has established accepted soil salinity thresholds and relative yield decline for many crops (Figure 15b).

Pistachios, however, are much more salt tolerant than other nut crops such as almond and walnut. Laboratory studies in Iran and the US (Ferguson, et al., 2002) and a nine-year field study in Western Kern County indicate that pistachios can be irrigated with water as salty as 8 dS/m without significant yield reductions (Sanden, et. al, 2004). For this long-term field study, however, it took nearly five years to raise the rootzone salinity to the 8 to 12 dS/m level with leaching fractions (discussed later) around 30 to 40% and 2 to 6 inches of effective winter rainfall. The trees were planted into a soil with an $EC_e$ of about 4 dS/m and established using freshwater from the California Aqueduct (EC of 0.3 to 0.8 dS/m) for 5 years before commencing irrigation with saline water. All trees were budded to Kerman. The UCB rootstock showed a slight early yield advantage until the irrigation water salinity reached 12 dS/m (average soil salinity of 13.4 dS/m), at which point the yield of UCB1 and Atlantica declined significantly compared to the Integarima (Pioneer Gold I and II) rootstock. These studies also show some difference between rootstocks in their ability to exclude Na and decrease the toxicity symptoms of this ion. Using UCB1 as the more sensitive rootstock, the average soil ECe and individual tree yield, a salinity threshold of 9.4 dS/m with a relative yield decline of 8.4% per unit increase in EC above this level was identified (Figure 15b). This places the salt tolerance of pistachio close to that of cotton. This experiment ended in 2002.

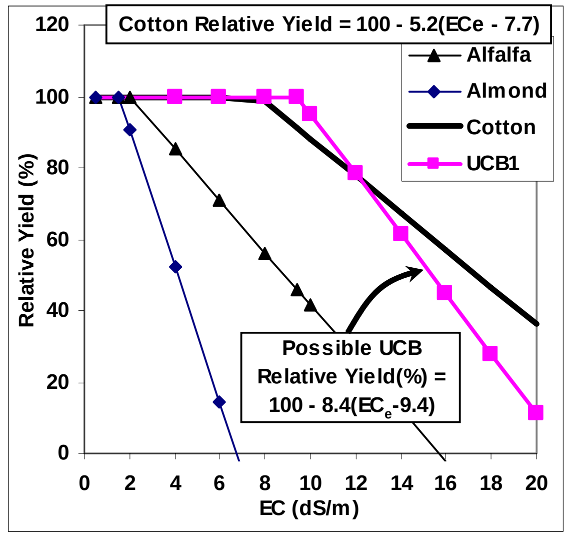


**Figure 15b.** Relative yield (RY) of various crops as a function of soil $EC_e$. (Sanden, et al. 2004).

A large-scale study was initiated in 2005 to evaluate the development of newly planted pistachios into mature trees using irrigation water salinity of 4.5 to 5 dS/m with 8 to 10 ppm B.

Even though these tests indicate that pistachio can tolerate saline irrigation water up to 8 dS/m, experience from more than 600 acres of 25 year old Atlantica production blocks 2 miles north of this field trial suggests that ultimate tree size may be reduced at long-term soil salinity levels of 5 to 10 dS/m compared to soils with an average ECe of 2 to 5. However, yields on a per tree basis are similar to the trees in the non-saline soils.

## Salinity impacts on ET

Figure 15c shows evapotranspiration (ET) data for 2001 from the long-term field trial. Estimates include some drainage for salinity treatments. Full pistachio ET for the season was estimated at 45.6 inches. After starting with a full profile, applied irrigation ranged from 33.5 for the 12 dS/m treatment to 41.5 inches for the 0.7 dS/m control. \ Field measurements (using the neutron probe) were taken 24 hours after irrigation ceased and the day before the following irrigation. Decreased ET usually means decreased vegetative production, but does not necessarily mean decreased nut yields.

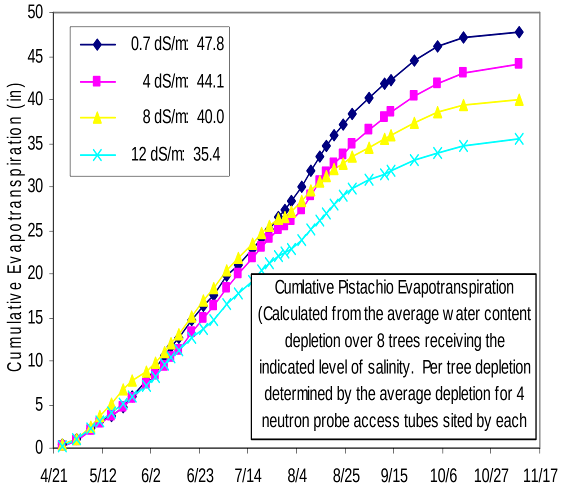


**Figure 15c**. Comparative seasonal transpiration for all irrigation salinity levels as determined by soil water content depletion between irrigations.

As a percentage of the 0.7 dS/m ET, the ET for the 4, 8 and 12 dS/m irrigation waters was 92%, 84% and 74%, respectively. For the 8 and 12 dS/m treatments this includes several inches of slow leaching throughout the season. Deficit irrigation studies by Dave Goldhamer showed that in-shell yields could still be maintained with 75% of full ET. However, percent of split nuts can be reduced during sensitive periods.

Based on this study and a margin of safety, use Table 4 as a guide when reviewing the soil and water EC for your proposed orchard site. These limits assume that irrigation is managed to provide an annual leaching fraction to prevent salt accumulation. ('Leaching fraction' is defined later in this chapter.)

The field trial used to estimate the above guidelines used saline water where Na was three to five times the concentration of the Ca. Some Westside tile drainwater or shallow groundwater can run as high as 5 to 10 times the Na over Ca. These guidelines may overestimate salt tolerance when Na, Cl and/or B get to these higher ratios when compared to Ca.

**Table 4.** Guidelines to evaluate orchard soils and water supplies for excess salinity for mature pistachio trees

| | Degree of restriction for pistachio | | | |
|---|---|---|---|---|
| Salinity off | Unit | None | Increasing | Severe |
| Avg. root Zone[1] | dS/m | <6 | 6–8 | >8-12 |
| Irrigation water[1] | dS/m | <4 | 4–8 | >8-12 |

[1] Guidelines based on field data where annual leaching fractions were 5 to 10% for "No restriction", 10 to 20% for "Increasing" and 20 to 40% for the "Severe" level

## Toxic accumulations

**"Specific ion toxicity"**, the accumulation of Na, Cl and/or B to the point of toxicity, can take several years. An excess of these elements in the soil or irrigation water can cause ions to accumulate in the woody tissue and eventually in the leaves. **Leaf burn** on leaf margins often means excess Cl or Na in leaf tissue. The margins of foliage containing excess B will develop a similar leaf burn that can also have a black edge and expand into **interveinal necrosis** with **twisting and curling of the leaves. "Gumosis"**, oozing of sap in excessive amounts from the trunk of the tree, can also occur. Accumulation of Na, Cl, or B ions is likely to reduce production of necessary plant hormones and contribute to nutritional disorders. Plate 15C shows the typical leaf symptoms associated with these toxicities.

It is important to diagnose ion accumulation before levels become elevated in the woody and leaf tissues. Once ions accumulate there, the trees have no mechanism to rapidly expel them. Correcting the toxicity in the root zone may require several seasons of proper irrigation management. Analysis of soil, irrigation water and leaf tissue can diagnose conditions in which toxic ion effects may be a concern. Pistachios have a root physiology that can exclude the uptake of excessive Cl or Na. Unfortunately, we do not have sufficient data to separate the impacts of salinity in general from the thresholds for specific ion toxicity for Na, Cl and B.

In the previous field experiment in NW Kern County, Cl and Na concentrations were about 40 and 60 meq/l, respectively, for the 8 dS/m irrigation water. This equaled an SAR of about 20. Boron concentration was 1 ppm. These levels in the irrigation water resulted in only slight amounts of marginal leaf burn. In sand tank trials at the USDA salinity lab in Riverside, California, rootstock seedlings showed significant leaf burn after one season of irrigation with water having an EC of 8 dS/m and 10 ppm B. However, the weight/growth of woody tissue was equal to seedlings grown with non-saline water (Ferguson, et. al, 2002). In the large Kern County trial begun in 2005, there has been no leaf burn at all after one season of irrigation with well water having an EC of 4.5 dS/m and 11 ppm B.

Only about ¼ of this B remains soluble when checking a saturated paste soil analysis. This means that some soils have the ability to 'lock-up' B and reduce its potential toxicity.

If soil or water analysis indicates levels of Na, Cl or B higher than these, then carefully monitor leaf tissues. It may be only a matter of time before one or more ions accumulate to toxic levels in the trees. Soil and water analyses over time should show declining or steady levels of these ions. If they increase in concentration then you should rethink your amendment strategy, irrigation scheduling and leaching. Table 5 gives specific ion toxicity limits for Cl and B in leaf tissue.

**Table 5.** Critical levels of specific ions in leaf tissue. (For August tissue samples prior to harvest.)

| | Degree of toxicity | | |
|---|---|---|---|
| | None | Increasing | Severe |
| Specific ion | | Levels in Leaf Tissue | |
| Chloride (%) | <0.2 | 0.2-0.3 | >0.3 |
| Boron (mg/l) | <300 | 300-700 | >800 |

### Nitrate-nitrogen

Nitrate toxicity ($NO_3^-$) becomes a concern when too much N fertilizer is applied. If over application is severe, the first effect may be defoliation; but the trees will most likely regrow with tremendous vigor. Foliage may grow so large, in fact, that the leaves curl. Use soil and water analyses to avoid over-use of fertilizer and instead achieve highly efficient N management practices.

The number most ag labs report is the amount of N in the form of nitrate. Hence, the term is written $NO_3^-$N. This makes it easy to convert the number on the report into equivalent pounds of N available for crop nutrition. For irrigation water an $NO_3^-$N level from 0 to 3 mg/l is considered low; from 3 to 10 mg/l is considered moderately low to moderately high; and above 10 mg/l is considered high. In a soil sample taken from a depth of 1 foot, an $NO_3^-$N level from 0 to 10 mg/l is considered low; 10 to 20 mg/l moderately low to moderately high; and a level exceeding 20 mg/l high.

To convert the level of $NO_3^-$N in a water analysis to pounds of N per acre-foot of water, multiply the concentration reported in mg/l by 2.7. (There's 2.7 million pounds of water in an ac-ft.) For example, if the analysis reports that a sample of water contains 2.3 mg/l of $NO_3^-$N, the sample contains 6.2 pounds of N per acre-foot of water.

Similarly, you can convert the level of $NO_3^-$N reported in a soil analysis to pounds of N per acre-foot of soil. In the lab report, find the level of $NO_3^-$N (ppm) in a composite sample that represents all samples taken to a depth of 1 foot. Multiply the number by 4. (There's about 4 million pounds of soil in an acre-ft. For example, if the analysis reports that the sample contains 9.7 mg/l of an $NO_3^-$N the amount of N is 38.8 pounds per acre-foot. Make sure that the lab is reporting $NO_3^-$N as ppm in dry soil and not the $NO_3^-$N concentration of the saturation extract. The latter requires a different calculation to estimate the pounds of N/ac-ft of soil.

## RECLAIMING SALINE SOILS and MANAGING SALINITY OVER TIME

The first part of this discussion deals with reclamation or correcting an existing salinity problem. This discussion assumes that an orchard or potential orchard site has excess salinity, toxic levels of specific ions, poor infiltration rates, or some combination of these problems.

The second part of this discussion focuses on maintenance of acceptable levels of soil salinity. This discussion assumes that the orchard has been established on a soil already suitable for pistachio production. In this case, the goal is to manage the soil and irrigation water to: 1) avoid salinity buildup, 2) accumulation of toxic ions and 3) maintain acceptable infiltration rates.

Whether the objective is reclamation prior to planting or maintenance, proper management of irrigation water is the key to handling salinity. The application of soil and water amendments is also an important component of salinity management but is not required in all situations. A few general concepts are critical to achieve effective reclamation or salinity maintenance:

## Drainage

Good drainage is the single most effective tool for salinity management. This usually means the absence of hardpans or impermeable clay layers within 12 feet of the surface that tend to "perch" water and prevent the free movement of water and salts below the rootzone.

Successful leaching for salinity control is much more difficult to achieve on poorly drained soils due to the much slower movement of water and salts below the rootzone. Often impermeable clay layers create shallow, or 'perched' water tables that are often very salty. The depth of this perched water often fluctuates throughout the season. It is closest to the soil surface in the spring and farthest in the fall. As a result, salinity that may be leached to deeper soil depths in the fall is often transported back into the root zone in the spring, when the water table rises.

Pistachios can be grown on soils that are impacted by shallow water, and, if the water is not too saline, even use some of this water for crop ET. But personal experience managing irrigation on thousands of acres of pistachios on the Westside of the San Joaquin Valley has shown that maintaining profitable yields on these soils requires more attention to detail than soils with no drainage problems. Many of these soils produced only marginal cotton yields under flood irrigation, but can be converted to profitable pistachio production with the low-volume precision application of water using micro irrigation systems (Plate 15D). Pistachios can survive under very high levels of salinity and soil saturation, but the combination of these conditions will certainly reduce crop ET and growth. When developing fields with areas prone to these conditions it is often advisable to increase the amount of dormant irrigation and leaching in the "tight" area, and reduce applied irrigation during the season to avoid over saturation. Plate 15E illustrates this situation by the reduced tree growth in the row adjacent to a drainage ditch compared to the next row over. The perched water depth was about 7 feet, but the rootzone under the small trees was saturated up to 2 feet below the surface due to "subbing up" of perched water. If possible, select new fields for development where shallow groundwater stays at least 10 feet below the ground surface.

Some fields are underlain by layers or 'buried stream channels/stringers' of course sand that may intersect adjacent unlined canals. These layers can act as a conduit for fresh water during the season and provide some "subirrigation" for deep rooted pistachios. If the field is already well reclaimed and this subirrigation effect does not "sub up" excess water into the top 3 to 4 feet of the rootzone, the trees can be managed to achieve optimal growth and yield and save the grower as much as a foot of irrigation water. This is the case for several pistachio orchards in the Buttonwillow area, but growers must monitor soil moisture to avoid over saturation.

## Impact of irrigation frequency and method

Small quantities of water (1 to 2 inch depth per application) applied frequently over several days is more effective for moving salinity below the root zone than an equal depth of water applied in one large flood application. One-time applications of large quantities of water tend to percolate rapidly through the larger cracks and pores in the soil. Much less water percolates through the small pores and the result is a higher salt concentration remaining in the small pores. Sprinkler and micro irrigation or rainfall allow much more time for salts to diffuse out of the small pores and into the water moving through the big pores and ultimately leach out of the rootzone. Leaching by this method is most effective during the winter when surface evaporation from the soil and crop transpiration is the lowest. Drip irrigation that leaves a minimum of wetted soil on the orchard floor is more effective for leaching during the summer than flood irrigation, but again it is important to avoid long periods of saturation.

## RECLAMATION

The ***depth of leaching required for reclamation*** is an estimate of the depth of water needed to reduce soil salinity to a level that will not cause yield loss for pistachio. It is commonly expressed as inches of water required per foot depth of soil in the root zone. Reclamation is needed when excessive salts will restrict production in an existing orchard or are found to be higher than acceptable tolerance levels in a soil being considered for development of a new orchard. Table 6 shows the leaching required to reclaim soils with various degrees of higher initial salinity.

These guidelines assume the leaching requirement is applied in several small irrigations or rains, with periods of 2 or more day's drainage in between. Any water lost to evaporation must be estimated and added to the amounts shown in Table 6. The guidelines also apply to leaching of Cl and Na. Because of low solubility, leaching excess B requires as much as five times the water needed to leach other salts, depending on soil type and the residual of precipitated B in the profile.

**Table 6.** Depth of leaching water required per foot of rootzone to be reclaimed given the initial average salinity and final desired salinity.

| Desired Rootzone Salinity (dS/m) | *Inches of water/foot of rootzone Required to leach initial salinity of: | | | |
|---|---|---|---|---|
| | **6** dS/m | **8** dS/m | **10** dS/m | **12** dS/m |
| **3** | 1.2 | 2.0 | 2.8 | 3.6 |
| **5** | 0.2 | 0.7 | 1.2 | 1.7 |
| **7** | 0 | 0.2 | 0.5 | 0.9 |

*Applicable for all irrigation waters less than 1.0 dS/m. Adapted from research reported by Hoffman, G.J. 1986. Guidelines for reclamation of salt-affected soils. Applied Agricultural Research, Vol. 1(2):65-72.

**Reclamation Example (Using Table 6)**

Suppose a grower has a parcel of land that is being considered for orchard establishment. Laboratory analyses of the irrigation water indicate excellent quality with an EC of 0.4 dS/m. The average root zone salinity prior to any land preparation is 12 dS/m. The grower would like to have low soil salinity levels for pistachios to a depth of at least 5 feet.

Table 6 shows that 3.6 inches of water per foot depth of rootzone (above the water needed to bring the soil to field capacity) will be required to drop the salinity to 3 dS/m. This equals 18 inches total to reclaim all 5 foot of rootzone soil. Due to the high salt tolerance of pistachio, the Kern County salt tolerance study suggests that a rootzone salinity of 5 dS/m is probably acceptable. Reclamation to this level only requires 1.7 inches/ft or 8.5 inches for the 5-foot rootzone. In practice, some of this leaching can be done after planting (assuming good drainage) in the form of excess water with each irrigation. This can be especially effective with drip irrigation where only a fraction of the whole rootzone volume (usually 20 to 40%) is being reclaimed.

If leaching is attempted in one irrigation, with a large application of water, the leaching efficiency will decline; it may require more than three times the quantity of water to achieve the same level of reclamation.

If the field overlies shallow water, care must be taken to avoid complete saturation of the rootzone. When saturation occurs it is easier for salts from the lower depths to rise back up into the rootzone through capillary action as evaporation pulls water back toward the soil surface after the irrigation. For this reason winter reclamation is preferred.

**(Note on "Field Capacity":** All depths of water listed for reclamation or leaching fractions assume that the soil profile is already at field capacity. Following a crop of alfalfa, cotton or wheat the rootzone may be depleted by 5 to 12 inches of water to 6 feet. This water must be replenished before any salts can be leached below the rootzone with additional water.)

## Maintaining acceptable rootzone salinity

Root zone salinity increases when salts are transported into the orchard with irrigation water. The only way of decreasing salinity is transporting salts out of the root zone with deep percolation. This is referred to as leaching, and it is an important function of irrigation.

The ***leaching requirement for maintaining acceptable salinity levels*** is the fraction of infiltrating water that is not used to refill the rootzone or for crop ET but instead percolates below the rootzone. It is expressed as a percentage rather than as a specific quantity, so discussion of leaching fraction can be applied to orchards with various water requirements and water qualities. As the quantity of applied water increases, or as the concentration of the salts in the water increases, more salinity is transported into the orchard. Therefore, more leaching is required to leach salts below the root zone.

Variations in irrigation water quality and soil salinity create the need for different **leaching fractions (LF)** from one orchard to the next. Table 7 provides leaching fractions required for irrigation water qualities from 0.5 to 6 dS/m to maintain two different rootzone salinity levels.

**(NOTE:** These leaching fractions are most appropriate for soils that have already been reclaimed and under continuous cultivation for several years. When this situation exists it is possible to calculate a desired *leaching fraction* (as in Table 7) to achieve a given rootzone salinity. The ***leaching requirement*** is similar to the leaching fraction, but can only be established as a *requirement* when an absolute salinity tolerance threshold has been established for the crop. The *leaching requirement* is then the *leaching fraction* that maintains the rootzone at or below the threshold level.)

**Table 7.** Leaching fraction required to maintain a specific level of root zone salinity with increasing salinity in the irrigation water.

| Irrigation Water EC of: (dS/m) | Leaching Fraction (%) Required To Maintain Rootzone Salinity 3 dS/m | 6 dS/m |
|---|---|---|
| **0.5** | 5 | 5 |
| **1** | 10 | 5 |
| **2** | 20 | 10 |
| **3** | 35 | 15 |
| **4** | 55 | 25 |

Adapted from Hoffman, G.J. 1996. “Leaching fraction and root zone salinity control.” *Agricultural Salinity Assessment and Management*. American Society of Civil Engineers. New York, N.Y. Manual No. 7:237-247

**Leaching Fraction Example (See Table 7)**

Mature pistachios in the San Joaquin Valley grown in a clean-cultivated orchard planted to a non-saline soil consume about 42.0 inches of water annually. The irrigation water supply has an **$EC_w$ of 1 dS/m, and the goal is to maintain an average root zone $EC_e$ of 3 dS/m.** Table 7 shows that an **LF of 10% is required**.

**Reqd Irr = ET * (1 + LF) = 42 * 1.1 = 46.2 in**

If the irrigation water $EC_w$ was instead 3 dS/m then, LF = 42.0 x 1.35 = 56.7 inches.
***(Note: adequate drainage to handle any excess water above ET is imperative. Monitor soil moisture during the season to avoid saturating the rootzone. If significant leaf burn was observed during the season then sample soil salinity as of the end of October and use the Reclamation Table 6 to estimate needed winter leaching.)***

Unless your trees begin to decline in the middle of the season and your soil and irrigation water salinity are extremely high (> 6 dS/m) it is usually sufficient to apply water to meet normal crop ET plus some extra for irrigation system non-uniformity. For a new border system with tail-water return this may be 15 to 25%, drip 10 to 15%, or microsprinkler 6 to 15% more water over ET. (***Note: an actual “distribution uniformity”, DU, for the orchard should be established by***

***a field evaluation.)*** When using this approach, rootzone salinity may increase some during the season, but should return to acceptable levels with a post-harvest irrigation, winter rainfall and a light spring irrigation to set your fertilizer. Experience has shown this to be the best program ***when combined with a continuing sampling program as outlined below.***

### The need for resampling

Every orchard has many factors unique to that location that can impact tree response to water and salinity management. These include nonuniform-ity of applied irrigation, imperfect scheduling and often variable ET of the trees, extended harvest cutoff, and variable interaction of soils to different irrigation water quality and fertilizer application. Thus, the effectiveness of the above guidelines can only be verified by resampling the soils on an annual or biannual basis. Repeated sampling will confirm that your salinity management strategy is on track or if adjustments need to be made. Monitoring field moisture levels during the season is always your first checkpoint.

### Predicting long-term salinity using WATSUIT

A computer program called WATSUIT (Oster and Rhodes, 1990) can very accurately predict long-term EC and concentrations of various salts for a given irrigation water quality and desired leaching fraction. This model has been developed into a user friendly Windows-based program by Laosheng Wu (Soil/water specialist, UC Riverside) and can be downloaded from the following link:

**http://envisci.ucr.edu/index.php?file=faculty/wu/wu.html**

*(Go to "Download: WATSUIT for Windows" on the bottom part of the page then follow the Setup instructions.)*

This model assumes that crop water use follows a 40, 30, 20 and 10% pattern from the top to the bottom quarter of the rootzone. This is not always true depending on the soil and the irrigation system/scheduling, but the final average EC and specific ion accumulations are also calculated for the whole rootzone

### Additional digital aids

An Excel file, **Cnvrsn-Infilt-LeachCalc,** is available for download from the Fruits and Nuts website http://fruitandnuts.ucdavis.edu. This spreadsheet will convert lab data from mg/l (ppm) to meq/l, generate an SAR and ESP value to assist in identifying the degree of potential infiltration problems and calculate the depth of reclamation leaching required a soil based on your data.

Finally, one of the best references for *Water Quality for Agriculture* (Ayers and Westcot, 1985) is published by the United Nations Food and Agricultural Organization under that name as Drainage Paper 29 and is available for free download@:

http://www.fao.org/DOCREP/003/T0234E/T0234E00.htm

## SOIL AND WATER AMENDMENTS

Soils with poor infiltration rates can usually be improved when treated with amendments. Their purpose is to improve soil structure for better percolation of water/leaching of salts, improving aeration and in some situations alter pH. Although organic matter and crop rotation play a significant role in improving soil structure and fertility, the following discussion will focus on inorganic amendments, like gypsum, that make calcium (Ca) available to improve soil structure. More specific examples and comments on cover crops and organic amendments can be found in the chapter on ***Assessment and Improvement of Water Penetration.***

The point is to increase the concentration of Ca ions attached to exchange sites in the soil in order to displace Na and, in some instances, Mg and K. Na and, to a lesser degree, Mg and K cause swelling and dispersion of clay particles when a soil is irrigated. Ca, on the other hand, when attached to the electrical exchange sites on clay particles stabilizes soil aggregates, increases soil porosity and thereby improves infiltration. Soils that seal up are usually dominated by Na. Most soil or water amendments contain, or help release, higher amounts of Ca that helps displace these dispersive ions.

Soils and waters with high SAR values and relatively low EC will be the most responsive to amendments. As EC increases higher SAR values can be tolerated before causing excessive soil dispersion and sealing as shown in Figure 15d (Ayers and Westcott, 1985). In the field trial mentioned in the previous section on "Salinity Impacts on ET"; when the irrigation water EC was 8 dS/m the SAR exceeded 20, but infiltration was never a problem.

Irrigation water that is too low in salts (EC<0.2 dS/m) can often cause dispersion/soil-sealing problems even if the SAR is low. Above this level, a good rule of thumb is to keep SAR < 5 x EC. When this condition is met, but the rootzone salinity is still excessive, leaching may be the most appropriate first step toward correcting the salinity problem before addition of amendments.

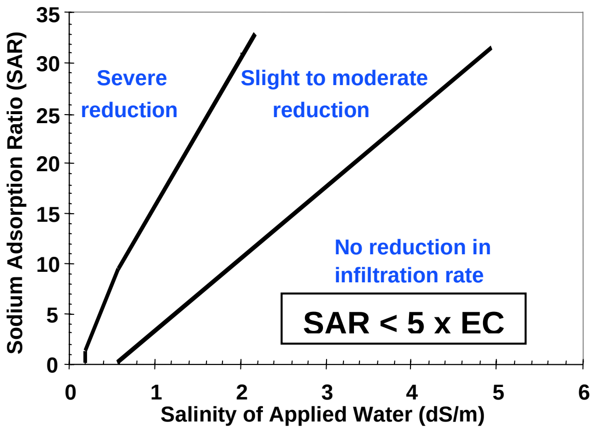


**Figure 15d.** Interaction of total salinity as EC with the sodium adsorption ratio of applied water for causing potential infiltration problems.

## Types of amendments

The two general types of amendments are calcium salts and acid-forming amendments. Calcium salts are direct suppliers of calcium, and acid-forming amendments are indirect calcium suppliers through the breakdown of native soil lime that usually exists in high pH soils.

Common calcium salts include gypsum ($CaSO_4 \bullet 2H_2O$), lime (also called calcite, $CaCO_3$), dolomite ($CaMg(CO_3)_2$), calcium chloride ($CaCl_2$), and calcium nitrate (Ca(2). Calcium nitrate and calcium chloride are highly soluble while gypsum is only moderately soluble over a wide range of pH. Where soil and water pH>7.2; dolomite and lime are only slightly soluble over an extended period of time.

Applying the highly soluble salts through the irrigation water is convenient, but typically more expensive. High-grade product and special injection equipment is usually needed for this method. (*See Water Penetration Chapter for example calculations and equipment.)* Gypsum is reasonably simple to add to irrigation water and is less expensive than $CaCl_2$ and $CaNO_3$ per unit of Ca. Lime and dolomite are unsuitable as a water-run amendment as they are nearly insoluble. Gypsum, $CaCl_2$, or $CaNO_3$ have negligible effects on soil pH. Lime or dolomite are soil applied only and used to increase the pH of acid soils.

Sulfur (S), sulfuric acid ($H_2SO_4$), urea sulfuric acid (commonly available as NpHuric®, $H_2NCONH_2 \bullet H_2SO_4$), Nitro-Sul ($(NH_4)_2S_2$), and lime sulfur ($CaS_x$+ $CaSO_x \bullet XH_2O$) are some of the more common acid-forming amendments used in salinity management. Since all contain S or $H_2SO_4$ but no Ca, they supply exchangeable Ca indirectly, by dissolving lime that is native to the soil. The S compounds undergo microbiological reactions that oxidize S to $H_2SO_4$. The acid dissolves soil-lime to form a calcium salt (gypsum), which then dissolves in the irrigation water to provide exchangeable Ca. The acid materials do not have to undergo the biological reactions, but react immediately with soil-lime on application. Acid-forming amendments can also increase the availability of Ca in irrigation water by neutralizing $HCO_3$ and $CO_3$ that otherwise tie up some of the Ca to form lime precipitates. Since these amendments form an acid in the soil reaction, they all can reduce soil pH if applied in sufficient quantity.

## Amendment selection

Selection of a soil amendment for reclamation of a new orchard site or to maintain acceptable infiltration rates in an existing orchard, is largely dependent on the presence or absence of lime in the soil and the relative cost of the materials. As long as lime is abundant in the soil (particularly the surface soil), consider either a calcium salt or an acid-forming amendment.

**The choice of amendment then depends on the following parameters:**

1) **Cost.**
2) **How quick a response is desired.**
3) **The depth to which reclamation is desired.**
4) **The degree of soil pH correction desired.**

Table 8 lists the various amounts of amend-ments needed to supply equal amounts of ex-changeable Ca to the soil or irrigation water.

Another factor influencing the choice of an amendment is the compound that will be added to the root zone. Some amendments add sulfates ($SO^{2-}_4$), others chloride ($Cl^-$), or nitrate ($NO_3^-$). $NO_3$ and Cl content will limit how much of these materials can be added. The amount of N should not exceed annual crop needs. Concentration of the Cl and impact on the pistachios should be insignificant when irrigation is sufficient. There have been no reports of $SO^{2-}_4$ accumulating to toxic levels in pistachios.

Do not use acid-forming materials when the soil zone lacks significant amounts of lime. Such a soil is neutral or acidic in pH, so only the use of calcium salts is appropriate. Lime or dolomite become preferable to gypsum and $CaCl_2$ than calcium salts. The acid-forming amendments will reduce soil pH when applied in sufficient quantity.

## Amendment rates for water

Amendments are most often added to water to improve water infiltration into the surface soil. Amendment rates from 1.0 to 3.0 meq/L Ca are considered low to moderate; rates that supply 3.0 to 6.0 meq/L Ca are considered moderate to high. For example, Table 8 indicates that an application rate of 468 pounds of pure gypsum, or 266 pounds of pure sulfuric acid, per acre-foot of water supplies the equivalent of 2.0 meq/L Ca. (This assumes that lime is abundant in the surface soil to react with the sulfuric acid).

**Table 8.** 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<br>3770 | [c] 256<br>513 |
| Ammonium thiosulfate | Thio-sul 12 % N, 26 % S | [d] 807<br>[e] 2470 | [d] 110<br>[e] 336 |
| Ammonium polysulfide | Nitro-sul 20 % N, 40 % S | [d] 510<br>[e] 1000 | [d] 69<br>[e] 136 |
| Monocarbamide dihydrogen sulfate/ sulfuric acid | N-phuric, US-10 10 % N, 18 % S | [d] 1090<br>[e] 1780 | [d] 148<br>[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.

As you add Ca the $EC_w$ increases and the SAR decreases. Remember the general rule of thumb for minimizing infiltration problems is:

**Desired SAR < 5 * EC**

(See the chapter on *Assessment and Improvement of Water Penetration* for a specific example on calculating optimal application rates.)

## Amendment rates for soils

Compared to amendment rates for water, those for soils are considerably higher as the aim is often to achieve a one-time reclamation. The purpose of applying a soil amendment is to reduce the exchangeable Na throughout the root zone, not just at the soil surface. For soils that have potential for pistachio production, the 100% Gypsum Requirement (GR) may range from 4 to 12 tons per acre (1 to 3 ton/ac-ft over a four-foot rootzone). Depending on the choice of amendment, Table 9 shows the cost can range from \$100 to \$1000/acre. If higher amendment rates are needed, the soils may be too costly to reclaim even for a salt tolerant, higher value tree like pistachio.

The GR determined by the Schoonover test is commonly provided on an analytical report as one method of determining an appropriate soil amendment rate. However, this estimate usually overstates the GR, because the method measures how much gypsum is needed to replace all the exchangeable Na adsorbed by a soil. **Complete replacement is unnecessary and uneconomical.** Usually supplying 40 to 75 percent of the GR should be sufficient to result in marked improvement.

**Note of caution:** Soils with extremely high silt content (>50 %), mica and/or zeolite clays often do not respond predictably when applying amendments. Consult local experts before invest-ing heavily in amending these soils as you may not see an economical improvement.

## Application methods

**1) Applying the amendment through the water**

Adding amendments directly to the water is ideal for managing soils with infiltration problems caused by surface crusting. On many soils, research has shown that as little as ½ inch of irrigation or rainfall can cause a crust that restricts infiltration. Such a crust is only at the soil surface and is often much thinner than 1 inch. Improving the quality of irrigation water with water-run amendments puts them at precisely the point where they are most needed. Such a soil needs relatively small amounts of amendment, but frequently applied. Water treatment makes this convenient and accurate. Before applying an acid-forming amendment in this situation, be certain that lime is present in the surface soil or that the water contains high levels of Ca and $HCO_3$. Care must also be taken to avoid damage to sensitive irrigation system parts when injecting acid directly. Brass valves, transite and cement pipe, for example, will start to pit when $pH < 4.5$. Some older style drip emitters (pre 1992) may also have membranes that are sensitive to acid.

Amendments in a liquid formulation are the easiest to apply in this manner and usually most effective in drip or microsprinkler irrigation systems. Solution-grade gypsum, injected as a slurry, is probably the most common amendment applied by this technique.

**2) Broadcasting the amendment over the soil surface then irrigating it in**

Broadcasting amendments, such as gypsum, onto the soil surface and irrigating the amendment into the soil is an alternative to water run application. The primary advantage to broadcasting is that the gypsum used is less expensive than that used for water-run treatments. However, for surface applications to be as effective the application has to be properly timed.

If infiltration is a problem in the summer months, then the amendment should be applied at the onset of summer and not during the preceding fall or winter. Applying the amendment too early (say winter or spring) will often mean it is no longer effective when you need it most (July and August) and the soil has again sealed up. Surface applications are most effective if applied monthly during June, July and August at rates equivalent to 250 to 1000 pounds of 100% gypsum per acre.

Use of finer, evenly graded gypsum will work more predictably when used in this manner. If only one application is to be made in the dormant season then it is preferable to use coarse material as the large chunks will require several irrigations to dissolve. Waste wallboard gypsum is ideal for this application. For orchards using alfalfa type valves, it is possible to place coarse gypsum in a 100 to 250 lb. pile right next to the valve and let the water carry it down the field. Growers often find mid-season broadcasting of gypsum to be a nuisance (or cause of crop damage) and prefer to add amendments to the water.

**Table 9.** 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.

**A word on sulfur:** generation of acid from elemental sulfur is a microbial process that only happens under extended wetting of the soil/sulfur interface and only on the surface of the sulfur particle. Gravel-sized sulfur particles can take up to 10 years or more to turn into sulfuric acid; especially if spread only on the surface. The finer the sulfur grind the quicker will be the acidifying affect. Incorporation as explained below is usually the best technique when using sulfur.

**3) Broadcasting the amendment and tilling it into the soil**

Land application of amendments (i.e. equiv-alent of 3-6 tons pure gypsum/ac) is most appro-priate when the objective is reclamation of a saline/sodic rootzone and not just the surface of the soil. When dealing with orchard site preparation, broadcast application of coarser, less refined amendments is usually the most economic. Incorporating the amendment by plowing, shanking, or slip-plowing will speed up reclamation by quickly getting the amendment to the deeper soil so the exchange reaction can occur. This practice is often accompanied by the banding technique described below to incorporate acid or sulfur down the tree row prior to planting.

**4) Surface applying or injecting the amend-ment in a concentrated band to only part of the soil surface.**

Banding acid forming amendments is most often done to correct a micronutrient deficiency in alkaline soils by lowering the soil pH to increase availability. The major concern, here, is crop fertility, but the practice usually benefits soil tilth and infiltration as well due to the release of free Ca from the soil lime. When preparing ground prior to planting, effective rates of acid applied only to the treated band range from 1 to 4 tons of acid per applied acre, depending on the lime content of the soil. In established orchards, however, applications should not exceed 1,500 pounds per applied acre (3 to 4 foot spray band) or crop damage may result. Even smaller amounts of acid or fine sulfur shanked into the soil under drip lines can be effective. This technique is very cost effective for banding gypsum along drip hoses and under microsprinklers.

This concentrates these amendments into areas of active rooting. It is not essential to modify the entire orchard floor with the limited wetting patterns of micro-irrigation. It takes 1 lb. of 92% bulk $H_2SO_4$ to neutralize 1 lb. of lime. This means 20 tons of acid (or about 7 tons of sulfur) is needed to neutralize a 1% lime content in an acre of soil 1 foot deep. But it is only necessary to dissolve all the lime in a small area of rooting to increase the availabilty of micronutrients. Application of acid-forming amendments in irrigation water can also be effective, as long as water is applied with drip or microjet irrigation.

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