IMPROVING WATER PENETRATION

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Supplying adequate water to a mature orchard without stressing the tree from either saturation or insufficient soil water storage is the number one goal for optimal irrigation management. For a large percentage of surface irrigated orchards in California, the number one problem is infiltrating the right amount of water to maximize crop performance. Insufficient water penetration is the inability of the soil to take in enough water, penetrating deep enough in the active root zone to sustain the crop until the next irrigation. The problem is typically associated with flood irrigated orchards and less frequent irrigation (every 10 to 20 days), but can also be a problem for drip systems as well.

Across California, mature pistachios use a depth of 40 to 48 inches of water use per year. For the southern San Joaquin Valley, this demand can easily exceed 25 inches for June, July and August together. When poor water penetration occurs, underirrigation is probable.

Ironically, poor water penetration not only leads to inadequate irrigation; it can also increase the time the soil remains saturated at the surface. As the lower rootzone dries out, the tree is more dependant on water from near surface roots, but poor water penetration (and especially high frequency drip irrigation) may render this zone saturated much of the time and significantly increase root diseases such as Phytophthora (see Plate 1). Common symptoms of poor water penetration are outlined below:

SYMPTOMS OF SLOW WATER PENETRATION

- Midseason depletion of deep soil-water and inadequate recharge of subsoil water, even after long irrigations.
- Water that ponds on the soil surface for long periods, disrupting orchard access.
- Reduced vegetative growth and yield.
- Reduced split percentage.
- Higher incidence of root diseases resulting from poor soil aeration.

THE WATER PENETRATION PROCESS

The first step in determining a solution or remedial practice for poor water infiltration is to take a close look at the process of water penetration. At the onset of irrigation, water infiltrates at a high rate. Initially the soil is dry and may have cracks through which water can infiltrate rapidly. As the soil wets from the surface into the root zone, the distance from the soil surface (and standing water) to the **"wetting front"** of infiltrating water increases. At this point clay particles swell, closing surface cracks and limiting access to small, drier soil pores beneath. After this point, these initial cracks and pores become less important in sustaining infiltration rates. Infiltration rates decrease significantly and water moves only by the force of gravity through the larger "macropores" in the soil. Depending on the soil, as much as 50 to 80% of your total infiltration may occur in the first 3 to 6 hours of a 24-hour set. It is precisely because of this reason that surface irrigation down a quarter mile run can be done somewhat uniformly even though the tail end may only get 4 to 6 hours of water compared to the head end.

The stability of soil "aggregates" and these larger pores depends on the interaction of soil minerals and the salinity of the water in these pores (Figure 1). As the irrigation continues, the salt composition of the soil-water begins to more closely reflect that of the irrigation water, which is generally less saline. This process of chemical change also reduces infiltration rates.

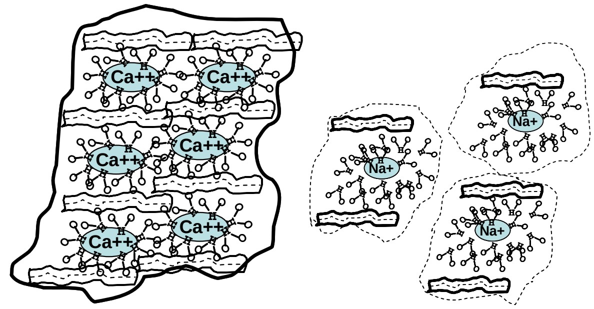

Fig. 1. Conceptual illustration of soil aggregate stability: forming stable aggregates with plentiful calcium on clay exchange sites (left), compared to weak soil aggregates due to low salinity and/or excessive sodium in the soil pore water.

Not only does the rate of infiltration slow down after the first few hours of irrigation, but successive irrigations over the season compact the surface and decrease the soil's ability to infiltrate water. Figure 2 shows how cumulative infiltration slows way down after the first 6 hours and decreases with each irrigation over the season. The addition of gypsum to this very low salinity irrigation water did improve infiltration on 8/4.

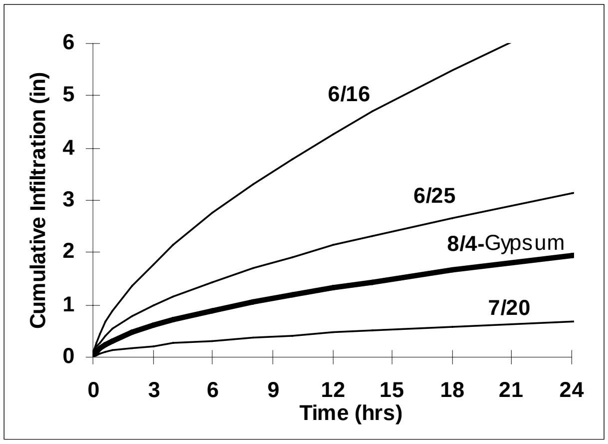

Fig. 2. Cumulative depth of infiltration for Wasco sandy loam over the season for the same furrows in furrow irrigated cotton at the Shafter Field Station (Shafter, CA 1995) with low salinity canal water (0.02 dS/m).

The following characteristics have the greatest influence on water penetration:

Soil

- Dryness at start of irrigation
- Distribution/size of soil particles and pores
- Surface access to soil pores
- Cracks
- Total salinity of soil pore water
- Composition of soil pore water salinity
- Nonuniformity of root zone soil, layering

Irrigation water

- Total salinity
- Composition of salinity
- Depth of water applied to the soil surface

Water penetration can only be improved by increasing soil pore volume, individual pore size and access to pores. Total water salinity and the composition of salts influence the way soil particles "aggregate" or stick together. Chemical or mechanical modification of aggregation and/or pore volume will improve water penetration.

Pore size, volume and water holding capacity

Pores are the spaces between soil particles through which water and air move. Porosity is the total volume of all the pores and cracks per volume of soil. Pore size and total porosity determine soil water holding capacity.

Sandy soils: Soils with high sand content (spherical particles) tend to have larger individual pores but lower total porosity. This can result in high infiltration rates (with some exceptions), but less stored water in the rootzone. However, these soils also have lower clay content and, especially if it is a fine sand with a significant amount of silt, may have very poor development of soil aggregates. Some of the soils in the southern San Joaquin Valley with the worst water penetration are fine sandy loams and sandy silt loams.

Clay soils: Clay-dominated soil tends to have more small pores and a higher water holding capacity than sandy soils. Water moves more slowly through the smaller pores, because smaller pores provide more surface area for water to adhere to and thus create more resistance to water flow. But clays are made up of microscopic electrically charged mineral plates (as illustrated in Figure 1) that can group together into much larger aggregates. These aggregates can become larger than sand particles and actually create large macro pores. The small pores within an aggregate remain, and larger pores are formed between the aggregates. They also shrink as the soil dries, developing cracks that may go as deep as 2 to 4 feet. The cracks are then a major channel for water penetration; usually swelling shut after wetting. A good number of these soil types have higher infiltration rates than some sandy soils. The net effect is more and larger pores, which significantly enhance water penetration and gas exchange.

Organic matter: Soil organic matter plays a significant role in stabilizing soil aggregates due to increasing the number of exchange sites in the soil matrix, encouraging microbial activity which produces waste products that help bind soil particles together and increasing pore size bulk pore size by decreasing soil bulk density.

Soil crust formation

Formation of soil crusts decreases infiltration by impeding the access to soil pores beneath the crusting layer. The crust is formed due to the dispersion of soil aggregates and loss of porosity at the soil surface. Weak cementation often follows when the soil dries. The formation of a soil crust or surface seal in reducing infiltration has been recognized as a problem in California agriculture since the early 1900's.

In arid and semiarid areas, soil crusts are often the result of sodic conditions (excess exchangeable sodium in the soil or irrigation water, and/or too little total salinity) in fine-textured silty soils. In the early and mid-1900's when water and land were relatively cheap, these soils were the focus of reclamation and amendment strategies to open up new cropland. These conditions are mainly problems for growers on the west side of the San Joaquin Valley.

More recently, attention has focused on crusting/penetration problems on many coarse to medium-textured, nonsaline and nonsodic soils. After decades of cultivation on many of these orchard soils there can be a significant decrease of larger pores within the surface profile. In some cases the problem has been made worse by the use of very low salinity irrigation water (via the Friant-Kern Canal) along the east side of the San Joaquin Valley to replace groundwater pumping. The increased use of herbicides for no-till orchard floor management can also decrease soil organic matter and soil microbial activity. This also results in decreased soil aggregation and reduced pore size. Soil surface crusts can be divided into either **structural crusts** or **depositional crusts** as defined below.

Structural crusts

A structural soil crust is formed by the destruction of existing soil aggregates and a subsequent reorganization of the resident soil particles into a **"sealing layer".** The destruction of soil aggregates can occur as a result of mechanical energy, such as droplet impact from rain and sprinklers, and/or lack of sufficient chemical energy to hold soil particles together. The mechanical breakdown of soil aggregates tends to sort soil particles; leaving a film of finer particles on top that clogs the entry of water into the larger pores beneath. In furrow and flood systems this process is called **"slaking"** and is usually a combination of mechanical and chemical dispersion of soil aggregates. The structural crusting at any given spot is compounded by additional depositional crusting laid down from clays and silt carried in from the upstream part of the furrow.

A structural crust is made up of a layer at the surface, generally sorted so that the fine particles are on top, and a compacted layer below. In flood systems, where we have completely saturated conditions and physical transport of fines down the furrow or border, a third "washed-in zone" can be created that is not usually found under sprinklers. This zone is made up of individual dispersed clay particles that migrate through the larger particles of the upper crust and lodge just below the compacted zone; causing a deeper "clogged" clay layer that can be many times the thickness of the surface crust. The impact of structural crusts in limiting water penetration is most pronounced in medium to light-textured soils.

Depositional crusts

Formed by the sedimentation of fine soil materials over the native soil surface, a depositional crust limits access to the larger resident soil pores. This type of soil crust is most often the result of high-velocity water in the head end of the furrow or watershed eroding fine particles that settle out when the water slows. The size of the particles in suspension is small (the particles are usually clays); their plate-like structure forms a very effective barrier to soil pores. Reduced infiltration from this type of crusting can sometimes be made worse when irrigating with effluent waters from dairy lagoons or wastewater treatment plants. Suspended organic particles as well as sediments acts as clogging agents and can interfere with the ability of the soil to resist dispersion.

Both structural and depositional crusts are thin, characterized by higher density, greater strength and smaller pores than the underlying soil. These crusts are usually less than ¼ inch thick (Figure 3 and Plate 2), but often limit infiltration for the entire rootzone.

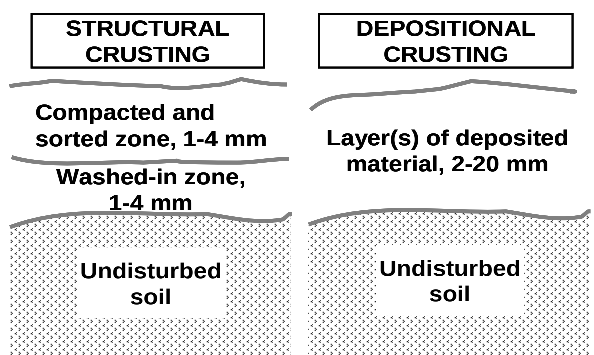

Fig. 3. Conceptual illustration of structural and depositional crusts.

Impact of soil and water salinity

In California orchards and vineyards structural crusting is by far the greatest limitation to adequate water penetration. As mentioned earlier, the most effective weapon against poor water penetration and crusting is **aggregate stability.**

The important soil and water factors that we can most easily test and manipulate are:

1. Total salinity, measured as EC
2. Sodium Adsorption Ratio, SAR
3. pH

(The chapter on ***Managing Salinity, Soil and Water Amendments*** provides the reader with a detailed explanation of these and other chemical criteria.)

The salinity of the surface soil is determined by measuring its electrical conductivity (EC). The EC is an important factor in determining crusting. However, the water around soil particles (that is, soil-water) is strongly influenced and rapidly modified by the constituents of irrigation water. Reduced EC in the soil-water causes clay swelling to increase, reducing the size of soil pores. Irrigation water with an EC of less than 0.3 decisieman per meter (dS/m) can cause problems on most soils. Each soil has a unique amount of soil-water salinity (flocculation threshold) at which dispersion of the particles occurs. Dispersion is also dramatically affected by the ratio of sodium to calcium and magnesium, called (obviously) the Sodium Adsorption Ratio (SAR).

Above an EC of 0.3 dS/m researchers have worked out general guidelines (Table 1 and Figure 4) that can be used to diagnose potential infiltration problems as EC and SAR change. In general, aggregate stability increases as EC increases and the SAR decreases.

Table 1. Potential for a water infiltration problem.

SAR*	Problem Likely EC_e[1] or EC_w[2]	Problem Unlikely EC_e or EC_w
0.0—3.0	< 0.3	> 0.7
3.1—6.0	< 0.4	> 1.0
6.1—12.0	< 0.5	> 2.0

Source: Ayers and Westcost (1985).
*Sodium Adsorption ratio.
[1] Electrical conductivity of extract indicates that soil is saturated past soil salinity.
[2] Electrical conductivity of water indicates irrigation water salinity.

These sodium-based guidelines will not necessarily work for all soils. Some California soils outside of the San Joaquin Valley contain a large amount of serpentine clays (some areas of Napa Valley, for example). As a result, they are rich in Mg and relatively low in Ca. In such an environment, Mg may behave like Na, and the result is unstable soil that tends to disperse and become impermeable. Although the diagnostic criteria for such conditions have not been extensively tested, some professional consultants suggest that when the Mg to Ca ratio exceeds 1:1 then serpentine soils may develop infiltration problems. Soils rich in exchangeable K may also have infiltration problems. Some reports maintain that when K is the predominant cation, it has the same effect on soil stability and porosity as does Na: the soil becomes less stable, disperses at the surface and seals over. Soils with a predominance of montmorillonite and illite clays are most easily dispersed by excess Mg. Hydrous oxides of aluminum (Al) and iron (Fe) and organic matter components, however, exert a stabilizing force on clay; a force that acts against the dispersing effect of sodic water or waters with very low salinity.

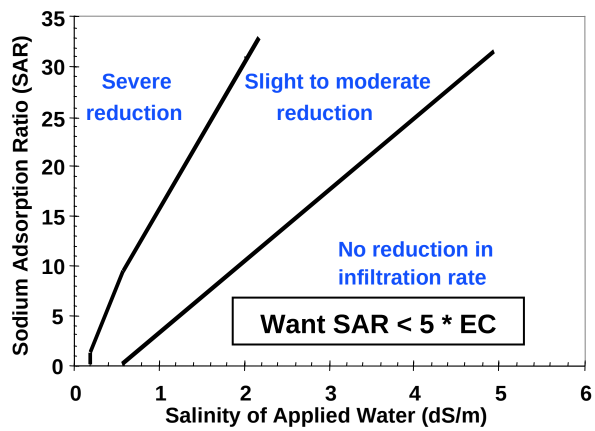

Figure 4. Interaction of total salinity as EC with the sodium adsorption ratio of applied water for causing potential infiltration problems. (Ayers and Westcott., 1985)

IRRIGATION MANAGEMENT OPTIONS

Reviewing management options for applying and scheduling irrigation water is always the first step in dealing with water penetration problems.

Alternate water supply: For many flood irrigated orchards in the Shafter-Wasco area of Kern County the simple solution is alternating irrigations between well and canal water.

Increase irrigation frequency: For other orchards the best answer may be a dormant season laser level of the middles and increase irrigation frequency to every 5 to 7 days instead of 10 to 14 days in July and August. It is imperative to have a very uniform grade to insure excellent drainage with no ponding in the middle of the orchard and a tailwater return system to exercise this option. Otherwise waterlogging and disease will cause damage to the trees.

Switch to microirrigation: Obviously this option provides the grower with the greatest flexibility and precision of irrigation depth and chemical amendments. Virtually all soils will infiltrate the 0.5 to 1.5 inch/day application rate that most micro systems are designed for *if* the water were uniformly applied over the whole orchard floor. The rub is that you are applying water to a much reduced wetted area directly under the emitter. What does this mean?

Drip irrigation system application example:

1. Orchard spacing = 19 x 20 = 380 sq feet
2. System: single-hose 4, 1 gph drippers/tree
3. Total application rate = 0.41 inches/day
4. Wetted diameter under drip = 4 feet
5. Wetted area of orchard floor = 50.3/380=13.2%
6. **Infiltration in wetted area = 0.41/0.132 = 3.1 inches/day**

To meet the peak ET of 0.3 to 0.32 inch/day in July this means irrigating 3 out of 4 days. The bottom line is you need to infiltrate 9 inches of water through the soil underneath the dripper every 4 days! This is the reason some drip irrigated orchards still have runoff and/or low-lying swampy areas in the field. On the other hand, a 12 gph micro sprinkler throwing an 18 foot diameter pattern applies 1.81 inches/day to the wetted area and only needs to run 1 day out of 4 to meet peak demand.

Solving a penetration problem by modifying irrigation practices and using an auger to check soil moisture is always the starting point and will be less costly than various amendments and/or cover crops. However, many soils still require additional amendments and improved cultural practices to stabilize soil porosity and prevent soil crusting and decreased water penetration. The next sections of this chapter discuss these options.

Whichever options are chosen the single most important thing you can do is to **make sure that rootzone soil moisture is completely recharged by the end of February.**

PREVENTION OF SOIL CRUSTS

Where soil permeability is low, prevention of soil crusting is often the best course of action and usually the most economical. Prevention includes the application of amendments, use of soil surface covers, soil organic matter management, and improved irrigation management. However, once a crust has formed, tillage may be required before other options can be effective.

Tillage

Shallow tillage can disrupt both structural and depositional crusts. In cases of moderate crusting problems, one tillage per season can restore infiltration rates. However, in soils with severely reduced infiltration, tilling before each irrigation is common. Shallow tillage to disturb the surface crust is accomplished using shallow disc, harrow or even rolling cultivator. A spade-type cultivator can be used that actually fractures any disc or plow-pans that might be at 8 to 10 inches and then lifts the soil with out mixing it.

The middles of pistachio orchards are cultivated regularly to prevent weeds and avoid attracting sucking insect pests. This tillage operation is often successful in preventing water penetration problems that may be severe in adjacent, non-cultivated almond orchards.

Organic matter management

All soils contain a small component of organic matter, from 0.5 to 2% in the San Joaquin Valley. Uncultivated soils contain more organic matter than those cultivated under typical orchard conditions. With this reduction in organic matter often comes reduction of the stability of soil surface aggregates.

The application of soil organic mixtures can increase porosity, percentage of macropores, aggregate stability, and thus increase the infiltration rate. However, the organic matter content of soils in arid or semiarid areas does not increase because of the rapid rate at which the organic matter decomposes. In a 10-year study conducted at the University of California, Davis, researchers incorporated cover crops into the soil. The percentage of organic matter in the soil did not increase over that time. The infiltration rate, however, did increase.

The implication of this and other research is that organic additions are beneficial by virtue of the products of their decomposition. These products consist of polysaccharides and polyuronides, which act as binders to stabilize aggregates. To be effective, organic matter additions or cover cropping should be continual, because decomposition products are short-lived, especially in California’s climate.

Crop residues: Trees provide leaves and prunings that can be left in the orchard for decomposition or incorporation. Interest in chipping or shredding brush is growing as a result of restrictions on burning. Correctly prepared brush can add a significant quantity of organic matter. Be sure to prepare brush properly. Chip prunings into small pieces, and shred brush more than once, or disc to incorporate material.

Manure, green waste and mulches: Animal manures have long been applied to orchards to supply nutrients and improve water infiltration. If you use manure, be aware of the potential effects of salinity and sodicity and have a plan for preventing them. Manure often contains weed seeds, so be prepared to handle unwanted vegetation as well. Meek, et al. (1982) more than doubled infiltration rates in a Holtville clay in the Imperial Valley with as little as 10 ton/ac dairy manure. However, the benefit declined by half at the end of the first season and was completely gone at the end of the second year. This was true for even a 40 ton/ac application.

Green waste is a term used for a mixture of lawn clippings, prunings and garden materials. The mixture is increasingly available for agricultural use. Currently it is available in raw form and in various states of decomposition. The composted materials offer a high ratio of organic materials per unit volume. Green waste is easily spread, and its viable weed seed content is low. Recent work in citrus has shown significant reduction in water use by reducing evaporation with an 8 to 12 inch thick application of woody greenwaste mulch (Ben Faber, UCCE Ventura County, personal communication). Increased density of rooting and soil porosity at the soil surface underneath the mulch was also found. A banded application of greenwaste compost on the hoses of double-line drip in pistachios improved rootzone water content and decreased runoff in the year of application (Blake Sanden, unpublished data.)

Cover crops

While pistachio middles in mature orchards are generally kept clean it is useful to briefly mention the use of cover crops as they can be a valuable tool in reclaiming marginal ground during the development of a young orchard. Cover crops protect the soil surface from droplet impact under sprinkler irrigation as well as provide significant organic matter biomass for decomposition and microbial stabilization of soil aggregates. In addition, cover crops can slow the velocity of surface water, reducing erosion and subsequent depositional crusting.

Water use: However, cover crops can compete with trees for nutrients and water. If an orchard contains clover as a perennial cover crop or actively growing winter and summer resident vegetation, water use can increase by 10 to 20 percent (Table 2, Prichard et al. 1989). The orchard manager must supply additional water or crop stress will occur. The use of winter annual cover crops and vegetation control strategies during summer months, such as chemical mowing, can reduce the water requirement.

Table 2. Water use by a mature almond orchard with cover crops and bare soil.

Treatment	Increase in water use (%)
Resident vegetation	120
Clover	110
Bromegrass	98
Bare soil	100
Chemical mowing	100

*Water use is relative to that of bare soil.

Dry matter production: Cover crops can be planted as annuals or perennials, or be resident vegetation. Mature trees with full canopies may shade out cover crops by mid season. Annual cover crops or resident vegetation consisting of winter and summer annuals can produce 2 to 4 tons of aboveground dry matter. The ratio of top portion to underground dry matter (roots) has been estimated at 1.5:1. Thus, a cover crop that yields 6,000 pounds (2,715 kg) biomass per acre above ground yields about 4,000 pounds (1,810 kg) per acre below ground, in the form of roots. Total biomass from the cover crop is 10,000 pounds per acre (5 tons/acre or 11,000 kg/ha).

Maintaining or improving infiltration: Cover crops can prevent decline of infiltration rates over the season (Prichard et al., 1989). Table 3 shows that the cover crops prevented a nearly 50% decline in infiltration by the end of the season in this almond orchard study. Increases are attributed to physical factors, such as channels created by roots; surface protection; and increased soil aggregation. Compared to bare ground, soil with a

Table 3. Accumulated infiltration at 120 minutes through various cover crops and bare soils in a mature almond orchard.

	Early season (mm)	Late season (mm)
Clover	66.8 a	63.2 a
Resident vegetation	52.3 a	54.9 a
Bromegrass	52.8 a	65.3 a
Chemical mowing	63.0 a	39.1 b
Bare soil	53.3 a	32.5 b

Numbers followed by different letters are significantly different @ 0.05 level.

cover crop has greater aggregate stability and more macropores.

USING CHEMICAL AMENDMENTS TO IMPROVE INFILTRATION

Chemical amendments to improve water penetration are really doing only one thing – decrease the resistance to water moving through the profile. This is done in two ways: 1)Maintaining or improving soil structure by releasing free calcium (salts and acids) and/or stabilizing aggregates with binders and conditioners (PAM) or 2) Decreasing the surface tension of water with surfactants (PENMAX®, etc.) In all, four types of chemical amendments are used to improve water penetration problems: salts, calcium-supplying materials, acids or acid forming materials, and soil conditioners, including polymers and surfactants.

Salts: Any fertilizer salt or amendment that contains salts when applied to the soil surface or when the amendment is dissolved in irrigation water increases the salinity of the irrigation water and ultimately influences the soil-water. Whether the increased salinity is advantageous depends on the SAR of the irrigation water. In terms of the effects of salt alone, increasing the salinity above an EC of 4 dS/m has little effect on infiltration.

Calcium materials: The first thing that comes to most people's minds when speaking of improving water penetration on tough alkali soils is the use of **gypsum**. There is no other soil amendment in the southwestern United States, with the possible exception of dairy manure, that has been applied to more acres with more tons. Adding calcium salts to soil and water increases both the total salinity as well as soluble calcium. Calcium salts commonly used on alkali (high pH) soils include gypsum, calcium chloride (CaC1), and calcium nitrate ($CaNO_3$). These are fairly soluble and can easily be applied though the irrigation water. Lime and dolomite are used only for broadcast applications on acid soil as they are virtually insoluble in alkali conditions.

Gypsum injection rates for water

Injection of gypsum in the irrigation water is the most common amendment practice in the San Joaquin Valley. 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. The following example calculations show the reader how to estimate the quantity of gypsum required to improve infiltration. (Tables 8 and 9 in the following chapter, ***Managing Salinity, Soil and Water Amendments,*** give detailed information on the chemistry, equivalent rates and comparative costs for calcium and acid-type amendments. The following example refers to these tables.)

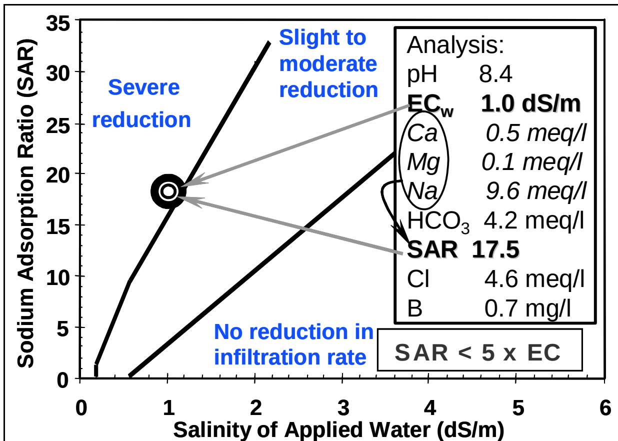

Fig. 5. Estimating potential infiltration problems and determining amendment options from an irrigation water analysis.

Example: calculating gypsum rates (Figure 5)

A partial water analysis is shown in Figure 5. This water presents absolutely no salt or ion tolerance problems for the pistachio tree 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. 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 9, 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 6).

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.

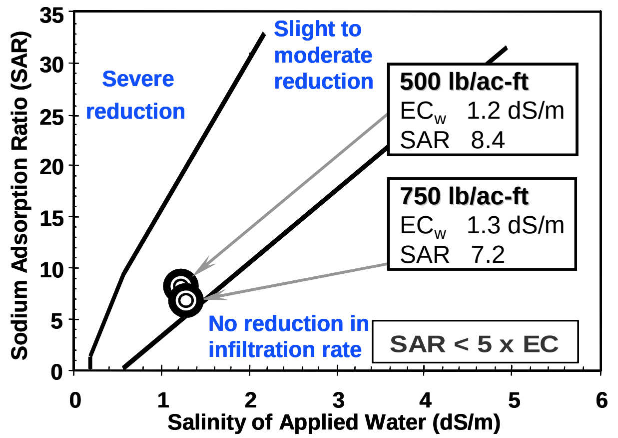

Fig. 6. Revised infiltration potential after gypsum amendment to irrigation water for 500 and 750 lb/ac-ft injection rates.

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 gypsum:	**622 lb/ac**
(Using Table 9, next chapter)	
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 orchard, 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. Plates 3, 4 and 5 show different types of gypsum solutionizer machine set ups.

Water-run gypsum in flood irrigation: Of course gypsum can also be injected into water that is applied to surface irrigated borders and furrows, but the expense of a silo and solutionizer machine plus the high grade gypsum is quite high. A few growers have set up silos to auger solution grade gypsum directly into the standpipe attached to the mainline and field valves. Turbulence at this point is usually sufficient to dissolve the gypsum.

A four year trial in almonds in Kern County used the simplest approach for mid-season water run gypsum application. About 250 lbs of coarse 75% purity "Lima" gypsum was applied next to the alfalfa valves at the head end of the field using a terragator equipped with a side-throw belt (Plate 7) in the beginning of May and again in July. Total calcium applied to the head end was of course much higher than at the tail end using this technique but the benefit to infiltration as determined for the whole check was significant by mid-season (Figure 7, Sanden, 2005).

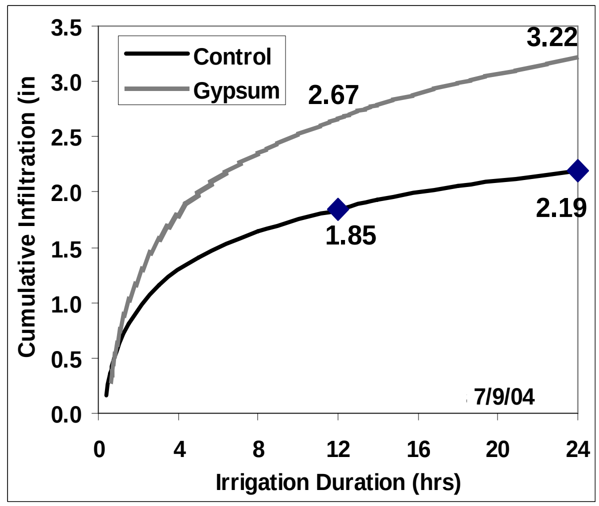

Fig. 7. Infiltration benefit of water-run, coarse grade 75% purity gypsum in almonds.

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). Since these materials form an acid in the soil reaction, they all can reduce soil pH if applied at sufficiently high rates. Given the rapid increase in trucking costs and the fact that reclaimed elemental sulfur is readily available from oil refineries at a very reasonable price; this amendment will supply the greatest amount of Ca for your amendment dollars.

Water-run acid: The water used for the above gypsum example would be a good candidate for acidifying amendments. Starting in the late 1950's the Harmon SO_2 Generator (manufactured in Bakersfield) was the first production ag "sulfur burner" made available to farmers. These machines 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 9 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 will rapidly drop the pH 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. Brass valves, transite pipe and some membranes and plastics in older systems irrigation systems (pre-1992) are sensitive to pH ≤ 4.5. Newer, all plastic systems with fiberglass or epoxy-lined filters are supposed to be good to a pH of 2.5.

A plastic venturi injector can be used for injecting acid, but non-corroding solid displacement pumps are preferred for accuracy and safety. **As a general rule of thumb, however, you don't want the water pH to drop below 5.** In the final analysis, a cheaper and less involved alternative is to band ground sulfur on drip lines or under microsprinklers.

Soil conditioners: There are two types of amendments in this category; organic polymers and surfactants.

Organic polymers, mainly water-soluble polyacrylamides (PAM) and polysaccha-rides, are used to stabilize the soil surface. These extremely long-chain molecules literally wrap around and through soil particles to bind aggregates together. This action helps resist the disruptive forces of droplet impact and decrease soil erosion and sediment load in furrow irrigation systems. They can improve infiltration on soils with illite and kaolinitic clays common in the northwest US, but USDA researchers in Fresno have found that infiltration is not improved in soils with mostly montmorillinite clays typical of soils in the San Joaquin Valley. Water-soluble PAM is not to be confused with the crystal-like, cross-linked PAMs that expand when exposed to water. These materials do not influence water penetration; rather they enhance the water-holding capacity of soils for small-scale applications as with container nurseries.

Organic polymers can have different effects on infiltration. The effect depends on polymer properties—such as molecular weight, structure, and electrical charge—and salinity of the irrigation water. Interactions between a polymer and a water molecule also affect the flocculation threshold of shrink-swell clays.

There are also charged (ionic) and non-charged (nonionic) polymers which can behave differently depending on whether they are added to a very pure water (like the Friant-Kern where EC is 0.03 to 0.1 dS/m) or higher salinity water like the California Aqueduct (0.5 to 0.8 dS/m).

Researchers have noted a correlation between polymer effectiveness and sprinkler irrigation or rain. Polymers have been shown to work best when sprayed on the soil surface at a rate of about 4 pounds per acre, and then followed with an application of gypsum in soil or water delivered in the form of high-energy droplets.

Other "conditioners" include synthetic and natural enzymes, microbial soups and a vast array of products that are nothing more than 'snake oil'. Only a small number of these materials have real data to back up claims of effectiveness.

Surfactants, or 'wetting agents', are amendments that reduce the surface tension of water. They are usually most effective in soils that contain a high percentage of organic matter or are covered with mulch. Such soils include turf soils, forest soils and burned range land. They are usually pretty costly to use for large-scale agricultural applications. Farmers both swear by and swear at some of these products, which are generally used at rates of 0.25 to 1 gallon/acre.

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 investing heavily in amending these soils as you may not see an economical improvement.

Broadcast, banded and surface applied amendments

While adding amendments directly to the water is ideal for managing soils with infiltration problems caused by surface crusting, there are a variety of other needs that may require application of amendments to the soil. Less costly, usually coarser materials can be applied in this manner and serve other purposes then just to improve water penetration. One major use of broadcast amendments is to aid dormant season leaching for reclamation reduction of rootzone salinity. The other purpose is to alter pH to free up micronutrients or to supply them directly in the amendment. The next chapter, ***Managing Salinity, Soil and Water Amendments,*** briefly discusses these application techniques at the end of the chapter. Fertility benefit is not addressed.

Deep tillage in mature orchards

In some extreme situations growers become desperate to try anything. In most cases, judicious use of amendments and practices already mentioned should have been put in place years earlier. However, some orchards have been planted to non-uniform layered soils without any deep tillage prior to planting and examination of backhoe pits reveals significant hardpan and other layers that limit root development. Tillage of orchard middles in orchards with rows of 18 feet or less is limited to a single pass with a deep ripper. For wider rows, two passes may be possible, but this will be limited by the size of the tractor and the spread of the tree scaffolds.

CAUTION: Ripping will damage existing roots especially in orchards where water penetration has been limiting for a long time. However, the improved soil characteristics and root pruning will help to encourage new root growth. Roots take time to begin growing and regrowth varies with the season and the carbohydrate status of the tree. In any event, do not till all the middles at once. Modifying alternate middles each year produces the best results. Ripping should be most effective in the fall, after harvest when tree water use is low, soils are dry and easy to shatter and mix. There is virtually no data on proving the benefits of this practice.

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Plate 1. Phytophthora damage and growth of Poria in almonds due to poor water penetration and waterlogging of top 1 foot of rootzone under double-line drip and high-frequency, 16 hour/day "off-peak" irrigation scheduling.

Plate 2. Surface sealing of Wasco sandy loam due to very low salinity in soil and irrigation water.

Plate 3. Surface sealing of Milham sandy clay loam in flood almonds due to low salinity, sodic well water. Penetration only to 7 inch depth after 32 hours (bottom). Surface remains saturated 8 hours after end of set.

Plate 4. Mobile gypsum solutionizer machine with horizontal mixing bar for injecting gypsum slurry into drip system.

Plate 5. Gypsum injection machine attached to large silo for automatically adding bulk solution grade gypsum.

Plate 6. Batch mixer with vertical mixing bar. Suitable for dissolving some fertilizers for injection as well as solution-grade gypsum.

Plate 7. "Lima" gypsum (75% purity) side banded next to orchard alfalfa valves @ 250 lb/check for dissolving into water stream during irrigation. Material and application cost $6/acre.