IMPROVING WATER PENETRATION IN VINEYARDS

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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 vineyards and less frequent irrigation but can also be a problem for drip systems as well. Poor water penetration can also increase the time the soil remains saturated at the surface.

Poor water penetration (and especially high-frequency drip irrigation) may render the shallow zone saturated much of the time and significantly increase root diseases and nutritional deficiencies.

SYMPTOMS OF SLOW WATER PENETRATION

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

THE WATER PENETRATION PROCESS

The first step in determining a solution or remedial practice for a water infiltration problem is to take a close look at the process of water penetration. The following characteristics have the greatest influence on water penetration:

Soil

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

Irrigation Water

- Total salinity
- Composition of salinity
- Depth of water over soil surface

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. After the first few hours, these factors become less important in sustaining infiltration rates. As the soil wets from the surface into the root zone, the distance from the soil surface to the wetting front of infiltrating water increases, minimizing the effect of soil dryness and the depth of water over the surface. Additionally clay particles swell, closing cracks and limiting access to soil pores and decreasing infiltration rates.

Concurrent with the wetting process, the soil-water contained between soil particles is changed. The salinity and 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 helps reduce infiltration rates. Gravity remains a constant driving factor throughout the irrigation process.

Water penetration can only be improved by increasing soil total pore volume, individual pore size and providing easy access to surface pores. Practices of using physical disruption, chemical and organic additions all attempt to influence one or more of these factors.

Pore Size and Volume

Pores are the voids between soil mineral and organic particles in soils, the spaces through which water and air move. Soils with a predominance of sands (spherical particles) tend to have larger pores. Soils with larger pores generally have higher infiltration rates, with some exceptions. Clay-dominated soils (clays are plate-like particles) tend to have smaller pores. Water usually moves slowly through smaller pores, because smaller pores provide more surface area for water to adhere to. Also, clays tend to shrink and swell, a characteristic that leads to cracks that aid water infiltration.

Aggregates

Individual soil particles can clump together, forming larger structures called aggregates. The small pores within particles remain and larger pores are formed between the aggregates (Figure 1). The net effect is larger pores, which significantly enhance water penetration and gas exchange. The soil water salinity and individual mineral constituents as well as organic matter plays a significant role in stabilizing soil aggregates and increasing pore size.

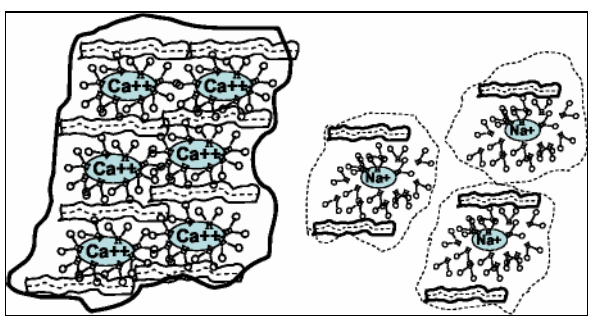

Figure 1. Conceptual illustration of soil aggregate stability: forming stable aggregates with plentiful calcium on clay exchange sites (left), compared to weak soil aggregates due to low salinity and/or excessive sodium in the soil pore water.

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. 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. These soils were "reclaimed" by adding soluble calcium and leaching out the sodium salts.

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 vineyard 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 many of the surface water districts) along the east side of the San Joaquin Valley to replace groundwater pumping. Additionally, wells contain high bicarbonates and relatively low calcium levels. The increased use of herbicides for no-till 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.

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 (Figure 2).

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.

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 one tenth of an inch thick (Figure 2), but often limit infiltration for the entire root zone.

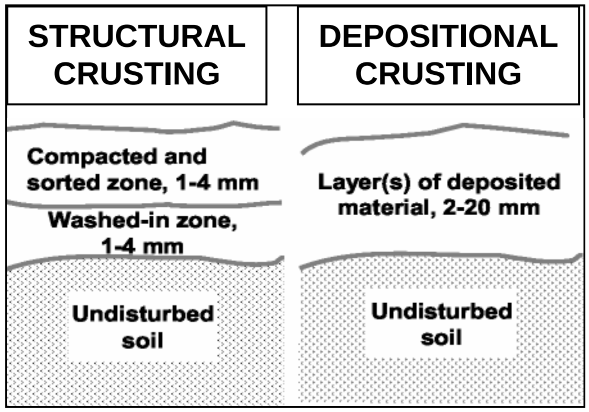

Figure 2. Conceptual illustration of structural and depositional crusts.

Impact of Soil and Water Salinity

In California 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. Adjusted Sodium Adsorption Ratio, adj.SAR (Sodium, Calcium, Magnesium, Carbonate, and Bicarbonate)

The salinity of the surface soil is determined by measuring its electrical conductivity (EC). The EC is an important factor in determining the potential for 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 decisiemans per meter (dS/m) can cause problems on most soils. (Note that dS/m is equal to mmho/cm which has been used in the past.) 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 the Sodium Adsorption Ratio (SAR).

Table 1. Potential for a water infiltration problem.

SAR*	Problem Likely ECe[1] or ECw[2]	Problem Unlikely ECe or CW
0.0 – 3.0	< 0.3	> 0.7
3.1 – 6.0	< 0.4	> 1.0
6.1 – 2.0	< 0.5	> 2.0

Source: Ayers and Westcot (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.

Above an EC of 0.5 dS/m general guidelines (Table 1 and Figure 3) 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. As a general guideline the SAR should be less than 5 times the EC.

These sodium-based guidelines will not necessarily work for all soils. Some California soils contain a large amount of serpentine clays. 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 suggest that when the Mg to Ca ratio exceeds 1:1 then serpentine soils may develop infiltration problems. Soils rich in exchangeable K (or after K injection) 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 (shrink swell) 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.

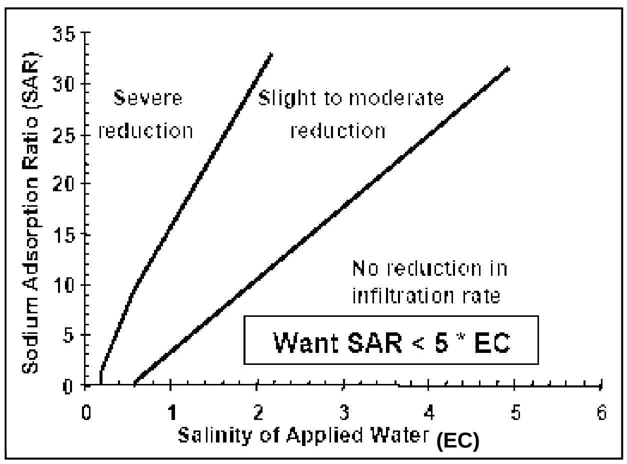

Figure 3. Interaction of total salinity as EC with the sodium adsorption ratio of applied water for causing potential infiltration problems. (Ayers and Westcott., 1985)

High carbonate (CO_3^-) and bicarbonate (HCO_3^-) in water essentially increases the sodium hazard of the water to a level greater than that indicated by the SAR. High CO_3^- and HCO_3^- tend to precipitate calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) when the soil solution concentrates during soil drying in alkaline soils. The concentrations of calcium and magnesium in soil solution are reduced relative to sodium and the SAR of the soil solution tends to increase.

An adjusted SAR value may be calculated for water high in carbonate and bicarbonate if the soil being irrigated contains free lime (calcareous soil). The adjusted SAR and knowledge of soil properties help determine management practices when using high bicarbonate water.

Low salt waters with EC values of less than 0.5 are corrosive and deplete surface soils of readily soluble minerals and all soluble salts. They often have a strong tendency to dissolve rapidly all sources of calcium from surface soils which then break-down, disperse and seal, resulting in poor water penetration

MITIGATING WATER INFILTRATION DIFFICULTIES

Irrigation Management

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 vineyards a solution is alternating irrigations between well and canal water if available.

Increase Irrigation Frequency

An increase in the frequency of irrigation while still applying the desired amount of water has often overcome infiltration limitations. This option essentially takes advantage of the higher early irrigation higher infiltration rate.

Switch to Micro-Irrigation

This option provides the grower with the greatest flexibility and precision of irrigation depth and chemical amendments. However the switch from a larger coverage system to a drip system requires the limited wetted area to intake a greater amount of water. This is the reason some drip irrigated vineyards still have runoff and/or low-lying swampy areas in the field.

Solving a penetration problem by modifying irrigation practices 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

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 in before other options can be effective

Tillage

In surface irrigation systems shallow tillage can disrupt both structural and depositional crusts. In cases of moderate crusting problems, a single 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.

Organic Matter Management

Uncultivated soils contain more organic matter than those cultivated under typical conditions.

The reduction in organic matter, a result of cultivation and the use of soil active herbicides, causes a reduction of the stability of soil surface aggregates.

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. The stabilization of soil aggregates can preserve porosity, percentage of macro pores, and thus increase the infiltration rate.

However, it is difficult to obtain significant increases organic matter content of soils in arid or semiarid areas due 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
Vines provide leaves and prunings that can be left in the vineyard for decomposition or incorporation.

Manure and Other Organic Materials
Animal manures have long been applied to vineyards to supply nutrients and improve water infiltration. It is a less common occurrence in vineyards do to the limited nitrogen requirement of the vines and limited availability. Grape pomace and composted pomace can provide many of the infiltration benefits with out providing excess nitrogen additions if application amounts are limited by the nitrogen requirement.

Cover Crops

Cover crops protect the soil surface from droplet impact under winter rainfall or sprinkler irrigation as well as provide significant organic matter biomass for decomposition and microbial stabilization of soil aggregates. In addition, cover crop residue can slow the velocity of surface water, reducing erosion and subsequent depositional crusting in surface irrigation.

Winter annual cover crops are most often planted in vineyards because they grow during the wet season reducing the competition for water and nutrients over perennial covers. They are sown or allowed to reseed in the fall and mowed or disked in the spring.

Annual cover crops can produce 1 to 3 tons of above ground dry matter per planted acre each season. The ratio top portion to underground dry matter (roots) has been estimated at 1.5:1.0 ratios. Thus, a cover crop that yields 4,000 pounds biomass per acre above ground yields about 2,667 pounds per acre below ground, in the form of roots. Total biomass from the cover crop is 6,667 pounds per acre (3.3 tons/acre).

Chemical Amendments

The addition of chemical amendments to water or soil can improve water infiltration by improving the chemical makeup of the water or soil. Chemical amendments usually increase the total salt concentration of the soil-water and decrease the sodium adsorption ratio (SAR) of the soil-water. Both of these actions enhance aggregate stability and decrease soil crusting and pore blockage.

Four types of materials are used to ameliorate water penetration problems: salts; calcium 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. The largest effect of a salt addition is with very low (less than 0.5 EC) salinity irrigation water.

Calcium Materials

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 (CaNO3). These are fairly soluble and can easily be applied though the irrigation water. Care should be taken if waters contain more than 2 meq/L bicarbonate. Adding gypsum to such waters through a drip system you will significantly increase your chances of plugging the system with lime precipitate. In these cases an acid application may provide a better solution. 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

Amendment rates from 1.0 to 3.0 meq/L Ca in the irrigation water 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. Table 2 lists the amount gypsum and other products to get 1 meq/L of calcium per acre foot of water. Applying 234 pounds of 100% pure gypsum per acre-foot of water equals 1 meq/L of Calcium.

It is rarely necessary to inject gypsum all the time. Injection every other or every third irrigation may be all that is necessary to end the season with the required amount. The benefits of gypsum injection during the season in drip irrigation systems are usually superior to dormant season applications.

Table 2. Amounts of amendments required for calcareous soils to increase the calcium content in the irrigation water by 1 meq/L.

Chemical Name	Trade Name & Composition	Pounds/Ac-ft of Water to Get 1 meq/L Free Ca*
Sulfur	100% S	43.6
Gypsum	$CaSO_4 \cdot 2H_2O$ 100%	234
Calcium polysulfide	Lime-sulfur 23.3% S	191
Calcium chloride	Electro-Cal 13 % calcium	418
Potassium thiosulfate	KTS -- 25 % K_2O, 26 % S	256
Ammonium thiosulfate	Thio-sul 12 % N, 26 % S	110** 336***
Ammonium polysulfide	Nitro-sul 20 % N, 40 % S	69** 136***
Monocarbamide dihydrogen sulfate/ sulfuric acid	N-phuric, US-10 10 % N, 18 % S	148** 242***
Sulfuric Acid	100 % H_2SO_4	133

* Salts bound to the soil are replaced on an equal ionic charge basis and not equal weight basis.

** Combined acidification potential from S and oxidation of N source to NO3 to release free Ca from soil lime. Requires moist, biologically active soil.

*** Acidification potential from oxidation of N source to NO3 only.

Gypsum Rates Broadcast to Soils

An alternative to water treatment is broadcasting amendments such as gypsum on the soil surface and irrigating the amendment into the soil. The primary advantage to this approach is that it is often less expensive than water treatments. However, for surface application to be nearly as effective as water treatment, it must be properly timed. If infiltration is a problem in the summer months, then apply the amendment at the onset of those months—not in the preceding fall or winter. Too early an application and the amendment, carried by post harvest and winter irrigations and rainfall, will percolate to depths beyond where the crust forms. Surface applications are most effective when applied at rates equivalent to 500 to 1,000 pounds of gypsum per acre prior to the onset of irrigation. Use finely and consistently ground gypsum products in surface applications. Applications that are limited to the berm have been successful at decreased rates when using drip irrigation. For maximum effect on surface crusting do not till the soil after the gypsum is applied.

Acids and Acid-Forming Materials

Commonly applied acid or acid-forming amendments include sulfuric acid (H2SO4) 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 months 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.

Water-Run Acid
Acids are applied to water for two different purposes in relation to water infiltration problems. The first is to dissolve lime (the soil must contain lime) in the soil increasing the free Ca in the soil/water matrix and improving infiltration. The second is to prevent lime clogging in drip systems when adding gypsum to waters containing more than 2 meq/L bicarbonate.

Using Table 2, 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 Calcium.

This is the same amount of acid required to neutralize 1 meq/L of HCO_3 in the water. If the water contains bicarbonate the acid will neutralize the bicarbonate converting it to carbon dioxide which is released to the atmosphere. If acid applications exceed the bicarbonate level the pH of the water decreases dissolving lime in the soil.

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

Organic polymers, mainly water-soluble polyacrylamides (PAM) and polysaccharides, are used to stabilize the aggregates at the soil surface. These extremely long-chain molecules 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 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.

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 (surface waters where EC is 0.03 to 0.1 dS/m) or higher salinity water well waters (above 0.8 dS/m).

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.

Other amendments include synthetic and natural soil enzymes, and microbial soups. Although there is a long history of soil conditioner development and testing, not enough data exists on the materials to conclude they are uniformly effective.

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.

Deep Tillage in Mature Vineyards

Some vineyards 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 vineyard middles is limited to a single pass with the depth related to the draft force required and traction of the tractor.

CAUTION: Ripping will damage existing roots especially in vineyards where water penetration has been limiting root zone depth. However, the improved soil characteristics and root pruning will help to encourage new root growth. Roots take time to begin growing and re-growth 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 vine water use is low, soils are dry and easy to shatter and mix.

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