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Interpretation of Soil and Water Analysis

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Grapevines are sensitive to high levels of soluble salts and toxic ions in both soil and irrigation water. Vine growth and production can be severely restricted when vineyards are established on soils high in toxic ions (sodium, chloride, and boron), soluble salts (saline soil), or adsorbed sodium (sodic or alkali soil), or high in soluble salts and adsorbed sodium (saline-sodic soil).

Soil and water analyses are useful for determining the suitability of a site for vineyard planting and, in an established vineyard, for diagnosing problems caused by salts and indicating appropriate corrective measures. Growers often use test results to appraise salinity, pH (acidity-alkalinity), and specific ion toxicities (boron, chloride, and sodium). Table 15.1 lists laboratory determinations commonly used for water and soil quality testing. Tables 15.2 and 15.3 list irrigation water quality and soil quality guidelines for grapevines. The following discussion is intended to help you interpret and understand laboratory soil and water analyses.

Saturation Percentage

Saturation percentage (SP) is expressed as grams of water required to saturate 100 grams of dry soil and is an indication of soil water retention. One-half of the SP is approximately the amount of water the soil holds at field capacity (moisture content of soil in the field 2 or 3 days after a thorough wetting of the soil by rain or irrigation water). One-fourth of the SP approximates the permanent wilting point (PWP) of the soil (soil moisture percentage at which plants wilt and fail to recover turgor). The available water is estimated by taking the difference between field capacity and PWP and represents the amount of water the soil can store that is available to the plant. Saturation percentage can be related back to soil texture and cation-exchange capacity (Table 15.4). When you sample and test the soil profile by increments (such as every foot), the SP can indicate changes in soil characteristics with depth. A large variation of SP with depth can indicate a stratified layer or layers within the soil profile.

Acidity-Alkalinity (pH)

The pH of the soil or irrigation water is a valuable diagnostic measurement. It indicates whether soil water or irrigation water is acidic (pH 1 to 7), neutral (pH 7), or basic (pH 7 to 14). The pH is defined thus:

$$\mathrm{pH} = -\log_{10}\,[\mathrm{H}^+]\ (\mathrm{mol/L})$$

Table 15.1 Laboratory determinations used to evaluate soil and water quality

Laboratory determination	Reporting symbol	Reporting unit	Soil	Water	Equivalent* weight (*mg/meq*)
Saturation percentage	SP	%	X	—†-	—
Acidity-alkalinity	pH	0–14	X	X	—
Electrical conductivity	EC_e, EC_w	dS/m or mmho/cm§	X	X	—
Calcium	Ca^{++}	meq/L	X	X	20
Magnesium	Mg^{++}	meq/L	X	X	12
Sodium	Na^+	meq/L	X	X	23
Carbonate	$CO_3^=$	meq/L	X	X	30
Bicarbonate	HCO_3^-	meq/L	X	X	61
Chloride	Cl^-	meq/L	X	X	35
Sulfate	$SO_4^=$	meq/L	X	X	48
Boron	B	mg/L or ppm¶	X	X	—
Sodium adsorption ratio	SAR	—	—	X	—
Exchangeable sodium	ESP	%	X	—	—
Lime requirement	LR‡	tons/acre	X	—	—
Gypsum requirement	GR	tons/acre	X	—	—
Lime	$CaCO_3$	%	X	—	—

*ppm = meq/L × equivalent weight (mg/meq)

†Not applicable

‡LR is also referred to as leaching requirement.

§Both reporting units (dS/m and mmho/cm) have the same value: 1 dS/m (decisiemen per meter) = 1 mmho/cm (millimho per centimeter). dSm has replaced mmho as the most acceptable reporting unit.

¶Both reporting units have the same value: 1 mg/L = 1 ppm.

Table 15.2 Guidelines* for interpreting laboratory data on the suitability of irrigation water for vineyards (acceptable range for pH: between 6.5 and 8.4)

Problem and related constituents	No problem	Increasing problem	Severe problem†-
Salinity:‡ stunts vine growth			
ECw (dS/m or mmhos/cm)	<1	1.0 to 2.7	>2.7
Permeability: affects rate of water movement into and through soil			
ECw (dS/m or mmhos/cm)	>0.5	0.5 to 0.2	<0.2
SAR§ (an estimation of the permeability hazard)	<6	6 to 9	>9
Toxicity: specific ions that can injure and affect vine growth			
Sodium (meq/L)¶	<20	—	—
Chloride (meq/L)¶	<4	4 to 15	>15
Boron (ppm)	<1	1 to 3	>3
Miscellaneous			
Bicarbonate (meq/L)#	<1.5	1.5 to 7.5	>7.5
Nitrate-nitrogen (ppm)	<5	5 to 30	>30

*NOTE: Guidelines are flexible and should be modified when warranted by local practices, experience, special conditions, or method of irrigation.

†-Special management practices and favorable soil conditions are required for successful production.

‡Assumes that rainfall and extra water applied to compensate for inefficiencies of normal irrigation will supply the crop needs plus about 15% extra for salinity control.

§Sodium Adsorption Ratio: permeability problems are more likely to occur if water is low in salts than if it is high.

¶With overhead sprinkler irrigation, sodium or chloride in excess of 3 meq/L under extreme drying conditions may result in excessive leaf absorption, leaf burn, and crop damage. If overhead sprinklers are used for cooling by frequent on-off cycling, damage may occur even at lower concentrations.

#Bicarbonate (HCO_3^-) in water applied by overhead sprinklers may leave white deposits on fruit and leaves (not toxic, but reduces market acceptability).

Table 15.3 Guidelines* for interpreting laboratory data on the suitability of soil for vineyards

Problem and unit of measurement	No problem (<10% yield loss expected)	Increasing problem (10 to 25% yield loss expected)	Severe problem (25 to 50% yield loss expected)
Salinity:			
EC_e (dS/m or mmhos/cm)	1.5 to 2.5	2.5 to 4	4 to 7
Permeability:			
ESP (estimated)	<10	10 to 15	>15
Toxicity:			
Sodium			
(meq/L)	—	>30	—
(ppm)		>690	
Chloride (meq/L)	<10	10 to 30	>30
(mg/L or ppm)	<350	350 to 1,060	>1,060
Boron (mg/L or ppm)	<1	1 to 3	>3
Miscellaneous:			
pH	5.5 to 8.5	—	—

*NOTE: Guidelines are flexible and should be modified when warranted by local practices, experience, special conditions, or method of irrigation. Interpretations are based on chemical analyses of the soil saturation extracts from soil samples representing a major portion of the root zone—usually the top 2 to 3 feet of soil.

The pH is an indication of the concentration of hydrogen ions (H^+) in the water or soil solution. Soil solution pH is usually measured on soil-saturated paste or extract. As the concentration of hydrogen ions in water or in a soil solution increases, hydrogen becomes more active and the soil or water becomes more acidic; conversely, as the concentration of hydrogen ions decreases the soil or water becomes more alkaline. A normal pH for soil or water ranges from 6.0 to 8.0; a pH beyond this range can cause nutritional and growth problems for grapevines. The pH can be used as an indicator of the predominant cations and anions. For example, irrigation water with a high pH indicates the potential for the precipitation of calcium carbonate salt, which can plug emitters in a drip system.

Three processes are largely responsible for soil acidification: the leaching away of bases (Na^+, Ca^{++}, Mg^{++}, K^+), the removal of bases by the crop, and the repeated application of acid-forming fertilizers, such as those that contain ammonium (ammonium sulfate, urea, UN32, etc.). Fine-textured soils or those that contain free lime (calcium carbonate), a characteristic of many California soils, have considerable buffering capacity that reduces the acidification effect. However, sandy soils low in cation-exchange capacity and without free lime may acidify rapidly, especially with the use of acid-forming fertilizers. These coarse-textured soils should be monitored regularly for pH level.

When acidification occurs, topsoil is affected first. Soil should be sampled in increments of 6 or 12 inches (15 or 30 cm) from the surface down to 2 to 3 feet (0.6 to 0.9 m) for pH determination in order to establish the depth to which acidification has occurred. When soil pH values fall much below 6.0, liming is recommended. A pH below 5.5 is often associated with soil chemical and physical problems and with mineral nutrient deficiencies (Plate 15.1).

The amount of lime necessary to raise the soil pH one unit varies with soil texture. The approximate amount of finely ground limestone needed to raise the pH of a 7-inch (18 cm) layer of soil 1 pH unit from an initial pH of 4.5 or 5.5 is about ½ ton for sandy soil and 2 tons for clay loam soil. Usually, only the foot of soil nearest the surface will have become acidic enough to require liming. A laboratory lime requirement test can be performed to estimate the amount of lime needed to raise the pH to a desirable level.

Saline Conditions

Irrigation water adds dissolved salts to soil. Vine roots then extract the water or it evaporates from the soil surface, leaving behind most of the salts. These salts

Table 15.4 Relationship of saturation percentage (SP) to soil texture, cation-exchange capacity (CEC), and available water (field capacity minus permanent wilting point)

SP	Soil texture	CEC (*meq/100 gm*)	Available water (*in/ft*)
Below 20	sandy or loam sand	2–7	<0.6
20–35	sandy loam	7–15	0.6–1.0
35–50	loam or silt loam	15–30	1.0–1.5
50–65	clay loam	30–40	1.5–2.0
65+	clay or peat	>40	>2.0

concentrate in the soil profile unless irrigation applications and rainfall in excess of vine evapotranspiration leach excess salts below the root zone.

To measure soil salinity in the laboratory, technicians make a saturation extract by mixing soil to a specific consistency using distilled water. The resulting paste flows slowly when tipped on its side. The technician then vacuum-extracts the soil water and analyzes the water extract for water-soluble salts: sodium (Na^+), calcium plus magnesium (Ca^{++} + Mg^{++}), chloride (Cl^-), carbonate plus bicarbonate ($CO_3^=$ + HCO_3^-), sulfate ($SO_4^=$), boron (B), and nitrate nitrogen (NO_3-N). The electrical conductivity of the soil-saturated extract (ECe) is a measure of total dissolved salts in the solution.

By definition, a saline soil has an ECe of more than 4 decisiemens per meter (dS/m, equivalent to millimhos/cm [mmhos/cm]) at 25°C (77°F). One dS/m of electrical conductance indicates approximately 640 ppm of salts in the soil (1,700 pounds of salts per acre-foot) (6.25 metric tons per hectare meter depth [this conversion factor must be adjusted upward when the water is high in sulfate]). Vines, because of their sensitivity to salt, do best when the soil ECe is less than 1.5 dS/m in the root zone (to a depth of 3 to 4 feet [0.9 to 1.2 m]). Yields and vine growth are reduced substantially as ECe increases above 2.5 dS/m. The primary effect of total soil salinity is to reduce the availability of water to roots via osmosis.

Raisin vineyards in California are typically planted on well-drained soils and are irrigated with good quality water; thus, winter rainfall is adequate to accomplish leaching. When soil analysis indicates excessive salt accumulation in the root zone, however, heavier irrigations or an additional irrigation in spring or fall is necessary for adequate leaching.

To achieve proper leaching in all parts of the vineyard, you may have to improve irrigation distribution and uniformity by improving the slope of the field or system design or irrigation management. It may also help to modify the soil structure by ripping an impervious hardpan or mixing a stratified soil profile. Drainage lines may be required when a high water table is present. Soil amendments such as gypsum are generally unnecessary with saline conditions unless the soil has excess sodium.

The amount of extra water needed to leach through the soil profile and remove soluble salts depends primarily on the initial soil salinity level, the irrigation water quality, the irrigation method, and the soil texture. However, a general rule of thumb in sandy soils is that 1 foot (30 cm) of extra water will reduce the salinity of the upper foot of soil by 70 percent. As the salt content in irrigation water increases so does the amount of water required to leach the soil.

Cation-Exchange Capacity

Cation-exchange capacity (CEC) is a measurement of the soil's ability to hold positively charged ions and nutrients. Knowledge of the principles of soil cation exchange is of paramount importance to understanding the reclamation of sodium-affected soil and the mobility or immobility of fertilizer or other ionized chemicals in the soil.

Soils are composed of sand, silt, and clay particles, along with a small organic fraction. Clays, which are platelike crystalline structures less than 2 microns (µm) in diameter, are the smallest soil mineral particles. Because of their unique crystalline structure and large surface area, clays have a highly reactive surface with a net negative electrical charge. The organic fraction also has a net negative electrical charge, but its content in the soil and thus its contribution to cation exchange is generally low for most California soils.

When salts are dissolved in water, they dissociate (divide) into charged particles that are either positive (cations) or negative (anions). Since unlike electrical charges attract and like charges repel, the negative charge on clay particles attracts cations and repels anions. For example, when table salt (sodium chloride [NaCl]) is dissolved, it dissociates to Na^+, the (positive) cation that is attracted to clay particles, and Cl^-, the (negative) anion that is repelled by clay particles.

The soil's CEC can be measured in the laboratory and indicates the soil's ability to hold cations against leaching. Usually expressed in milliequivalents (meq) per 100 grams of soil, the CEC of a soil increases with increasing clay or organic matter content. The reactivity and buffering capacity of a soil, in turn, increases with the soil's CEC. Mineral soils with a higher CEC typically are more fertile than those with a lower CEC, since the former tend to retain plant nutrients that the latter would lose through the leaching process.

Cations are adsorbed with different intensities based on the type and concentration of the cation in question and other ions in the soil solution. Generally, calcium and magnesium can displace sodium on the exchange site. To reclaim a sodic soil, you must first replace the adsorbed sodium with calcium (so long as the sodium is adsorbed, it cannot be leached). You accomplish this by applying an amendment that contains soluble calcium (gypsum or lime) or one that dissolves calcium precipitates upon reaction in the soil (sulfur or sulfuric acid). Potassium and ammonium ions are of similar size and fit nicely within clay layers, making them less vulnerable to leaching.

Sodic (Alkali) Soils

Soils that contain excessive amounts of exchangeable sodium (Na^+) in proportion to calcium (Ca^{++}) and magnesium (Mg^{++}) are termed *sodic* or *alkali* soils. Sodic soils are characterized by a dispersion of soil particles that reduces a soil's permeability to water and air (Plate 15.2). Sodic soils indirectly affect vine growth and productivity by degrading soil quality.

By definition, a sodic soil has an exchangeable sodium percentage (ESP) in excess of 15; that is, 15 percent or more of the soil's cation-exchange capacity (CEC) is associated with sodium and the remainder with calcium, magnesium, and other cations. Grapevines are very sensitive to sodium and its accompanying effect on soil permeability and aeration. To avoid any loss of vine growth and production, maintain the ESP in the root zone at less than 10.

When you identify a sodic condition, a laboratory analysis can determine the gypsum requirement. This indicates the amount of free calcium that must be supplied from gypsum to displace the excess sodium. After you apply an amendment, you have to leach the displaced sodium out the bottom of the root zone. Organic materials such as manure, cover crops, and crop residues may help provide a better soil structure for leaching. In established vineyards, you can schedule heavy irrigations for the dormant period to leach the soil and still minimize damage to vine roots from lack of aeration.

Sodium Hazard in Water

There is a close association between the composition and concentration of salts in the soil and the quality of the water used for irrigation. Waters higher in sodium than in calcium and magnesium are likely to cause soil sodicity. Water's sodium hazard is evaluated by the sodium adsorption ratio (SAR):

$$SAR = \frac{Na^{+}}{\sqrt{(CA^{++} + Mg^{++}) \div 2}} \quad (meq/L)$$

Carbonate ($CO_3^{=}$) and bicarbonate (HCO_3^{-}) can aggravate a sodium hazard by combining with and removing from the soil solution some of the exchangeable calcium (Ca^{++}) and magnesium (Mg^{++}). The adjusted SAR (adj. SAR) attempts to account for this effect, and laboratories often report both SAR and adj. SAR.

A water with a low SAR dissolves lime from the soil and increases exchangeable calcium. A water with high SAR causes calcium to precipitate and decreases exchangeable calcium, and this can lead to sodic conditions. Irrigation water with an SAR value below 6 is preferable; when the value exceeds 9 soil structure can deteriorate, resulting in slower water infiltration and reduced soil aeration.

Growers commonly use gypsum to replace precipitated calcium when using water with a high SAR. The gypsum is normally applied to the bottom of furrows or to that portion of the soil surface wetted by irrigation water. Two tons of gypsum per acre (4.5 t/ha) each year is a common rate; incorporation into the soil is not recommended. The application of gypsum to irrigation water is also a common practice when controlling sodium hazard in water.

Slow Infiltration Associated with Low-Salt Water

Irrigation with water that is very pure (low in salts) may slow infiltration into sandy loam or finer-textured soils. This can occur when the water contains less than 250 ppm of soluble salts or the electrical conductivity of the water (ECw) is less than 0.4 dS/m. This is a common problem on the east side of California's San Joaquin Valley, where the primary irrigation source is canal water that originates as mountain snowmelt from the Sierra Nevada and contains only 50 to 100 ppm total salts. With certain soils, water infiltration can drop to less than 0.1 inch (2.5 mm) per hour, making it difficult to satisfy the vineyard's water requirements during peak evaporative demand in June, July, and August.

By applying gypsum to the soil surface or irrigation water, you can help rectify water penetration problems associated with pure irrigation water by increasing salt levels. In this way you can increase the water infiltration rate as much as fourfold by applying 1 to 2 tons of gypsum per acre (2.25 to 4.5 t/ha) in late spring or early summer, just before peak evapotranspiration. A single gypsum application is generally effective for one to five irrigations. You can also improve infiltration by applying gypsum directly to the irrigation water at rates of 450 to 900 pounds per acre-foot (2 to 4 meq/L). Although specially designed equipment is required to apply gypsum to water, this approach uses less gypsum than a soil application to achieve the same results.

Toxicity: Excess Sodium, Chloride, Boron

Grapevines are more sensitive to sodium and chloride levels than are most field crops, such as cotton, grains, and vegetables. The accumulation of sodium or chloride ions in leaves may impair leaf stomatal closure and reduce vine growth. Marginal leaf burn indicates toxicity caused by sodium or chloride or both (Plate 15.3). Leaf analysis is the most useful tool for diagnosing salt injury to vines; however, soil and water analysis may be needed to complete the diagnosis in an established vineyard. Both soil and water analyses are essential when determining the suitability of a vineyard site, especially in areas where sodium, chloride, and boron levels are suspected of being high.

Problems with chloride toxicity often occur when vineyards are planted on saline soils that have not been fully reclaimed or when high-chloride irrigation water is used. It is much more difficult to correct a salinity problem after the vineyard is planted, and this underscores the importance of complete reclamation before planting.

Occasionally, grapevines have suffered chloride toxicity after the application of fertilizers that contain chloride (i.e., muriate of potash [KCl] on poorly drained soils). The problem can easily be corrected by leaching excess chloride from the root zone. Nevertheless, you should be cautious when using fertilizers that contain chloride. Avoid using them on poorly drained soils. When possible, time application for fall to allow winter rainfall to leach the chloride before budbreak.

Boron interferes with chlorophyll synthesis and is toxic at levels only slightly greater than are required for vine nutrition. Toxicity is common where soils are derived from marine sedimentary material, where both the soil and the groundwater are likely to contain high levels of boron. For raisin vineyards, the problem is mostly confined to the west side of the San Joaquin Valley.

Soil and water analyses can help indicate a potential boron hazard. Take soil samples down to 5 feet (1.5 meters), as boron levels are often higher in the subsoil. Vineyards should not be planted where boron levels in the root zone exceed 1 or 2 ppm (1 or 2 mg/L) in the saturated extract. Irrigation water should not contain more than 1 ppm. Boron-affected soils are slow and difficult to reclaim, requiring considerable amounts of water for proper leaching.

Nitrogen in Well Water

The annual nitrogen fertilizer requirement for grapevines depends on the harvest yield and ranges from 25 to 50 pounds of nitrogen per acre (28 to 56 kg N/ha) per year, which is low compared to most other crops. Nitrate nitrogen (NO_3-N) in groundwater can contribute significantly toward a grapevine's nutritional requirement. Be sure to monitor the nitrogen concentration of irrigation water, and include the nitrogen applied with irrigation water when you plan your fertilizer program.

The average seasonal water application for a mature, fully canopied raisin vineyard is 2 to 3 feet per acre (610 to 915 mm/ha). Nitrogen levels in irrigation water pumped from aquifers within the California raisin industry's growing area range from 2.5 to 10 pounds of nitrogen per acre-foot (9.2 to 36.8 kg N/ha-m), but can be as high as 30 pounds of nitrogen per acre-foot (110.3 kg N/ha-m). There have been instances of nitrogen toxicity occurring when the only source of irrigation water for the vineyard was well water high in nitrogen. Laboratories report NO_3^--N concentrations in ppm (mg/L). To convert this to pounds of nitrogen per acre-foot, multiply by 2.7 (multiply by 9.9 for kg N/ha-m).

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