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The Use of Soil and Water Analysis

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Grapevines are sensitive to high levels of soluble salts in both soil and water. Sodium, chloride, and boron are toxic to vines at levels that do not affect other crops, such as cotton. Vine growth and production can be severely restricted when vineyards are established on soils high in soluble salts (saline soil), or adsorbed sodium (sodic or alkali soil), or both (saline-sodic soil).

Soil and water analyses are useful for determining the suitability of a vineyard site for planting and, in existing vineyards, diagnosing problems caused by salts and indicating appropriate corrective measures. Test results are often used to appraise salinity, pH (acidity-alkalinity), and certain toxicities (boron, chloride, and sodium).

Table 1 lists laboratory determinations commonly used for water quality and soil salinity testing. Tables 2 and 3 list guidelines for irrigation quality and soil salinity for grapevines. The following discussion is intended to help interpret and understand laboratory soil and water analyses.

Saturation Percentage

Saturation percentage (SP), expressed as grams of water required to saturate 100 grams of soil, is a measurement of soil texture, water-holding capacity, and cation exchange capacity.

One-half of the SP is approximately the amount of water soil holds at field capacity (moisture content of soil in the field 2 or 3 days after a thorough wetting of the soil profile 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 turgidity). The available water is the difference between field capacity and PWP and represents the amount of water the soil can store that is available to the plant. Table 4 shows the relationship between the saturation percentage, soil texture, cation exchange capacity, and available water.

When the soil profile is sampled and tested by increments (such as every foot) the SP can indicate changes in soil texture with depth. A large variation of SP with depth indicates a stratified layer or layers within the soil profile.

Acidity-Alkalinity (pH)

Soil reaction or pH is a valuable diagnostic measurement. It indicates whether soil is acidic (pH 1-7), neutral (pH 7), or basic (pH 7-14). The pH is defined as the logarithm of the reciprocal of the hydrogen ion concentration. The equation is:

$$pH = -\log_{10}[H+] \text{ (mol/l)}$$

As the concentration of hydrogen ions in a soil solution or water increases, it becomes moreacid; conversely, as the concentration of hydrogen ions decreases it becomes more alkaline. A normal pH for soil and water ranges from 6.5 to 8.0; a pH beyond this range can result in nutritional and growth problems for grapevines.

Three processes are largely responsible for soil acidification: leaching of bases (Na^+, CA^{++}, Mg^{++}, K^+), removal of bases by the crop, and repeated application of acid-forming fertilizers, such as those containing ammonium. Fine-textured soils or those containing free lime (calcium carbonate), as many California soils do, 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 use of acid-forming fertilizers, and should have their pH monitored regularly.

When acidification occurs, top soil is affected first. Soil should be sampled in 6- 12-inch increments down to 2 to 3 feet for pH determination to establish the depth to which acidification has occurred and to help in estimating the liming requirement. When soil pH values fall much below 6.0, liming generally improves crop production.

The lime requirement (LR) to raise the pH can be estimated by laboratory analysis. 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 layer of soil one pH unit from an initial pH of 4.5 or 5.5 is about one-half ton for sandy soil up to about 2 tons for a clay loam soil. Usually, only the surface foot of soil will have become acidic enough to require liming.

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 concentrate in the soil profile unless irrigations and rainfall, in excess of tree evapotranspiration, leach excess salts below the root zone. As the salt content in irrigation water increases so does the amount of water required to leach the soil.

To measure soil salinity in the laboratory, a saturation extract is made by mixing soil with distilled water; the resulting paste flows slowly when tipped on its side. Soil water is then vacuum extracted and the extract is analyzed 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 (Ece) of the extract is a measure of total dissolved salts in the solution.

By definition, a saline soil has an electrical conductivity of the soil-saturated extract (Ece) of more than 4 mmhos/cm (at 25°C). In water, 1 mmho/cm of electrical conductance is approximately 640 ppm (1700 lb salt per acre-foot). Vines do best when the soil ECe is less than 1.5 mmhos/cm in the root zone (to a depth of 3 to 4 feet). Yields and vine growth are substantially reduced as ECe increases above 2.5 mmhos/cm. The primary effect of total salinity is a reduction of water availability to roots through osmotic effects.

Vineyards are usually located on well-drained soils and are irrigated with good quality water; thus, winter rainfall is adequate to accomplish leaching. However, when soil analysis indicates excessive salt accumulation in the root zone, heavier irrigations or an additional irrigation in spring or fall are necessary for adequate leaching.

To achieve proper leaching, it may be necessary to improve irrigation distribution and uniformity by improving the level of the field or system design, or to modify 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 not necessary with saline conditions, unless excess sodium is present.

The amount of extra water needed to leach through the soil profile to remove soluble salts depends primarily on the initial soil salinity level, the technique of applying water, and soil type. However, a general rule of thumb is that 1 foot of extra water will reduce the salinity of the upper foot of soil by 70 to 80 percent.

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.

By definition, a sodic soil has an exchangeable sodium percentage (ESP) of greater than 15; that is, 15 percent 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. Toxicity symptoms can appear in grapevines before significant soil structure deterioration occurs; to avoid toxicity the ESP in the root zone should be below 10. By contrast, some crops, such as cotton, can tolerate high levels of sodium (ESP 40 to 60); however, reduction in growth and production does occur at these high levels because of adverse soil structural conditions rather than sodium toxicity.

When a sodic condition is identified, a laboratory analysis can be performed to determine the gypsum requirement. This indicates the amount of calcium required to displace sodium. After an amendment is applied, the displaced sodium must be leached below the root zone. Deploying organic materials, such as manure, cover crops, crop residues, and so forth, may help provide a better soil structure for leaching. In established vineyards, heavy irrigations during the dormant period for the purpose of leaching 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 irrigation water and those in the soil. When used for irrigation, waters with high sodium relative to calcium and magnesium are likely to result in a sodic soil. Water's sodium hazard is evaluated by the sodium adsorption ratio (SAR):

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \; (meq/l)$$

Carbonate ($CO_3^{=}$) and bicarbonate (HCO_3^{-}) can aggravate an Na hazard by precipitating some of the exchangeable calcium and magnesium. The adjusted SAR (adj SAR) accounts for this; laboratories often report SAR and adj.SAR.

Waters with low adj.SAR dissolve lime from the soil and increase exchangeable calcium. Waters with high adj.SAR cause calcium to precipitate and decrease exchangeable calcium and can lead to sodic conditions. Irrigation waters with adj.SAR values below 6 are preferable; when values exceed 9, problems can occur.

Gypsum should be used to replace precipitated calcium when using water with a high adj.SAR. It is normally applied to the bottom of furrows or that portion of the soil surface wetted by irrigation water. Two tons of gypsum per acre every year or so is a common rate; incorporation is not necessary.

Slow Infiltration Associated with High-Purity Water

Irrigating with water that is very pure may slow infiltration into sandy loam or finer-textured soils. This can occur when water contains less than 250 ppm of soluble salts (Ecw < 0.4 mmho/cm). It is a common problem on the east side of California's San Joaquin Valley, where the primary irrigation source is canal water originating as snowmelt from the Sierra Nevada mountains and containing only 50 to 100 ppm total salts. With certain soils water infiltration can drop to less than 0.1 inch per hour, making it difficult to satisfy the vineyard's water requirements.

Application of gypsum can help rectify water penetration problems created by using pure irrigation water. The water infiltration rate can be increased as much as fivefold by applying 1 to 2 tons of gypsum per acre in late spring or early summer, just before peak evapotranspiration. Gypsum is generally beneficial for three to five irrigations. Infiltration can also be improved by applying gypsum directly to the irrigation water at a rate of 300 to 500 pounds per acre-foot. Although specially designed equipment is required to apply gypsum to water, less gypsum is needed than a soil application to achieve desired results.

Toxicity - Excess Sodium, Chloride, Boron

Grapevines are sensitive to sodium and chloride, whereas most herbaceous crops, such as cotton, grains, and vegetables, are not. Accumulation of sodium or chloride ions in leaves may impair leaf stomatal closure and reduce vine growth. Marginal leaf burn strongly indicates toxicity caused by sodium or chloride or both. Leaf analysis is the most useful tool in 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 analysis are essential when determining the suitability of a vineyard site, especially in areas where sodium, chloride, and boron levels are known or are suspected of being high.

Problems with chloride toxicity often occur in vineyards planted on saline soils not fully reclaimed and/or when high chloride irrigation water is used. It is much more difficult to correct asalinity problem after the vineyard is planted, underscoring the importance for complete reclamation before planting.

Occasionally, chloride toxicity of grapevines has occurred following application of fertilizers containing chloride, (i.e. potassium chloride [KCl] on poorly drained soils. The problem can be easily corrected by leaching excess chloride from the root zone; nevertheless, use fertilizers containing chloride cautiously. Avoid using on poorly drained soils. Preferably apply in fall, allowing winter rainfall to leach chloride before budbreak.

Boron interferes with chlorophyll synthesis and is toxic at levels only slightly greater than required for nutritional purposes. Toxicity is common where soils are derived from marine sedimentary material, with both soil and groundwater likely to contain high levels of boron.
Soil and water analyses can help indicate a potential boron hazard. Soil samples should be taken to 5 feet as boron levels are often higher in the subsoil. Vineyards should not be planted where boron levels in the root zone exceed 1 to 2 ppm 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 to properly leach.

Nitrogen in Well Water

Nitrate nitrogen (NO_3^--N) in groundwater can contribute significant amounts of nitrogen towards a grapevine's nutritional requirement and should be considered when planning a fertilizer program. The average seasonal water application for a mature, fully canopied vineyard is 2.5 to 4 acre-feet per acre. Nitrogen levels in irrigation water often range from 5 to 50 pounds of nitrogen per acre-foot. This would supply 15 to 150 pounds of nitrogen per acre, assuming an application of 3 acre-feet of water each season.

Laboratories report NO_3^--N concentrations in ppm (mg/1. This is converted to pounds of nitrogen per acre-foot by multiplying by 2.7.

Table 1. Laboratory determination used to evaluate water quality and soil salinity status.

Laboratory determinations	Reporting symbol	Reporting units	Soil	Water	Equivalent* Weight (mg/meq)
Saturation percentage	SP	%	X	-**	-
Acidity-alkalinity	pH	-	X	X	-
Electrical conductivity	Ec_e, Ec_w	mmhos/cm,dS/m	X	X	-
Calcium	Ca^{++}	meq/1	X	X	20
Magnesium	Mg^{++}	meq/1	X	X	12.2
Sodium	Na^+	meq/1	X	X	23
Carbonate	CO_3^-	meq/1	X	X	30
Bicarbonate	HCO_3^-	meq/1	X	X	61
Chloride	Cl-	meq/1	X	X	35.4
Sulfate	SO_4-	meq/1	X	X	48
Boron	B	mg/l or ppm	X	X	-
Adjusted sodium Adsorption ratio	adj.SAR	-	-	X	-
Exchangeable sodium (%)	ESP	%	X	-	-
Lime requirement	LR	tons/acre	X	-	-
Gypsum requirement	GR	tons/acre	X	-	-
Lime (%)	$CaCO_3$	%	X	-	-

*ppm = meq/1 x equivalent weight (mg/meq)
**not applicable

Table 2. Guidelines for Interpreting Laboratory Data on Water Suitability for Grapes

Problem and related constituents	No problem	Increasing problem	Severe problem[a]
Salinity[b] - affects water availability to crop EC_w (in mmhos/cm)	<1**	1.0 to 2.7	>2.7
Permeability - affects rate of water movement into and through soil Ecw (in mmhos/cm) adj.SARc - (an estimation of the permeability hazard)	>0.5 <6	0.5 to 0.2 6 to 9	<0.2 >9
Toxicity - of specific ions which affect growth of crop Sodium (meq/1)* Chloride (meq/1)* Boron (ppm)	<20 <4 <1	- 4 to 15 1 to 3	- >15 >3
Miscellaneous Bicarbonated Nitrate-nitrogen (ppm)	<1.5 <5	1.5 to 7.5 to 30	>7.5 >30

The acceptable range for pH is between 6.5 and 8.4
*With overhead sprinkler irrigation, sodium or chloride in excess of 3 meq/1 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.
**<means "less than"; >means "more than".
[a]Special management practices and favorable soil conditions required for successful production.
[b]Assumes that rainfall and extra water applied due to inefficiencies of normal irrigation will supply crop needs plus about 15% extra for salinity control.
[c]Adjusted Sodium Absorption Ratio. Permeability problems are more likely to occur with low-salt water than with high.
[d]Bicarbonate (HCO_2) in water applied by overhead sprinklers may cause white deposits on fruit and leaves (not toxic but reduces market acceptability).
Note: Guidelines are flexible and should be modified when warranted by local practices, experience, special conditions, or method of irrigation.

Table 3. Guidelines for Interpreting Laboratory Data on Soil Suitability for Grapes[a]

Possible problem and unit of measurement	No problem (less than 10% yield loss expected)	Increasing problems (10 to 25% yield loss expected)	Severe problems (25 to 50% yield loss expected)
Salinity Ec_wmmhos/cm	 1.5 to 2.5	 2.5 to 4	 4 to 7
Permeability ESP (est.)	 Below 10	 10 to 15	 Above 15
Toxicity Chloride meq/1 (mg/1 or ppm) Boron mg/1 or ppm Sodium (meq/1)	 Below 10 (350) Below 1 ---	10 to 30 (350 - 1060) 1 to 3 Above 30 (690 ppm)	 Above 30 (1060) Above 3 ---
Miscellaneous pH	5.5 to 8.5	---	---

[a]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.

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

Table 4. Relationship of saturation percentage (SP) to soil texture, cation exchange capacity (CEC), and available water (field capacity-permanent wilting point).

SP	Soil Texture	CEC (meq/100 gm)	Available H_20 (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