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Amending Soil and Water Chemistry in Drip Irrigated Table Grape Vineyards

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The first California drip systems were installed in 1969 in citrus groves located in San Diego County. Growers were searching for a way to save water and reduce exorbitant water costs. Their pioneering effort paid off and news of this new irrigation technology soon spread. In 1972, the first drip system was installed in a table grape vineyard in Tulare County. Today, drip irrigation is widely used by table grape growers in the San Joaquin Valley, and the technology has evolved in all areas from irrigation scheduling and engineering to managing soil and water chemistry.

Hydraulic gradients and soil-water movement with drip are distinctly different than furrow/flood irrigation. Both drip and furrow irrigated vineyards begin the growing season with 100% of the soil profile wetted by rainfall (except during drought years). But differences in soil water and salt distribution within the profile occur soon after irrigation begins. With furrow/flood irrigation, the entire root system is periodically rewetted by irrigations, and salts are uniformly moved downward in the profile. In contrast, with drip only a fraction (20 to 50%) of the root system is effectively wetted during summer months. The shape of the wetted zone beneath emitters depends on the unsaturated flow characteristics of the soil and the rate of water application. Salts in the soil move towards the periphery of the wetted zone and towards the surface in row middles.

Under drip irrigation, the vine's water and nutrient requirements are mined by roots from a limited soil volume compared to furrow/flood irrigations. In addition, amendments and fertilizers are applied to this limited soil volume. This magnifies the impacts on the soil chemical and physical properties. Problems with soil acidification and water infiltration are more common with drip irrigation, and the unique soil water and salt distribution in the soil under drip affect vine nutrition.

Acidification: The effect of adding acid or acid forming compounds on soil pH is determined by the soil's buffering capacity. Soils of the southern San Joaquin Valley are generally well buffered. Soils are predominately alkaline in reaction (pH greater than 7) with a high base exchange (more than 50% calcium). This is typical for soils forming in an arid environment. Groundwater is also predominately alkaline as groundwater chemistry reflects the chemistry of surrounding soil and parent rock. Severe soil acidification (to pH 5 or lower) is not a widespread problem in San Joaquin Valley vineyards, but it is becoming more and more common, particularly with drip irrigation. Acidic soils (below pH 5 to 5.5) can impact vine growth, yield, and fruit quality.

Vineyards at risk of acidulation are those vineyards on soils with low buffering capacity, irrigated primarily with canal water, and fertilized with acid forming fertilizers. In Tulare County, soil types at greatest risk are sandy soils associated with alluvial fans and with no free lime in the profile (Cajon and Tujunga series); also, highly weathered, noncalcareous hardpan soils developed on old alluvial fans and terraces (San Joaquin and Exeter series). Canal water is low in salt (25 to 50 ppm of total soluble salts) and calcium, has no neutralizing power, and can dissolve and remove calcium carbonate from the soil, potentially lowering pH. In contrast, typical groundwater on the east side of Tulare County contains moderate levels of salinity (250 to 500 ppm). Much of the pump water actually adds calcium carbonate (200 to 600 pounds of lime per acre-foot) which can neutralize an equivalent input of acid.

Acid input to the soil comes from a variety of sources. Most significant is the use of ammoniacal fertilizers which produce H+ (acid) when ammonium (NH_4^+) is oxidized to nitrate ($N0_3^-$). The acidification potential of an N fertilizer should be considered when applied to acid soils. This is shown in the table as the amount of pure lime (pounds calcium carbonate) needed to neutralize the equivalent of 1 pound of N for each fertilizer material. Materials with a high acidification potential should be avoided on soils with pH of less than 6. Instead, use compounds with an alkaline soil reaction that raise pH such as calcium nitrate. Potassium carbonate is very soluble and can be easily applied through the drip system. It will neutralize an equivalent amount of acid and would be a good choice when potassium fertilization is necessary and the soil is too acidic.

Water Infiltration: Low salinity water (less than 0.5 dS/m and especially below 0.2 dS/m) tends to leach surface soils free of soluble minerals and salts, especially calcium, reducing their strong stabilizing influence on soil aggregates and soil structure. Without salts and without calcium, the soil disperses, and the dispersed finer soil particles fill many of the smaller pore spaces, sealing the surface and greatly reducing the rate at which water infiltrates the soil surface. Very low salinity water (less than Ecw = 0.2 dS/m) almost invariably results in water infiltration problems.

Slow water infiltration is a serious problem in some east side vineyards, especially with drip irrigation. With drip irrigation, irrigation water must infiltrate a small surface area to satisfy the vines' evapotranspiration needs. If infiltration is inadequate, puddling occurs and the vines will show water stress even though more than adequate amounts of water have been applied. Water logging near the surface kills vine roots, and the inadequate distribution of water in the profile limits the volume of the root zone effectively wetted making matters worse.

Gypsum and other soluble calcium compounds can double or triple the infiltration rate over that of untreated low-salt water. Gypsum is the amendment most often used, but other calcium sources are also effective. Calcium nitrate and CAN-17 are effective but can only be used in limited amounts: the nitrogen applied must not exceed the vines' requirement for nitrogen fertilizer.

Calcium must be added continuously to the irrigation water in order to maximize infiltration. When application of gypsum to irrigation water is discontinued, infiltration rates drop to near control levels within a few weeks. The occasional addition of calcium to the irrigation water is not effective in maintaining infiltration rates. To optimize infiltration rate using canal water, finely ground gypsum should be added to water at a rate of 500 to 900 pounds of gypsum per acre-foot, on a continuous basis. This increases the calcium concentration in the water by 2 to 4 meq./L. The spreading of gypsum on the soil surface and down the vine row (where the drip line is located) also improves infiltration, but the benefit may not last the entire season. Gypsum must be reapplied the beginning of each irrigation season. Don't apply in the fall because winter rains will leach the calcium and the benefit will be lost by spring. Ammonium-based fertilizers and potassium applied through the drip system may reduce infiltration rates.

Vine Nutrition and Fertilization: The unique distribution of water and salt in the soil beneath a drip system helps reduce the leaching of nitrogen and other nutrients. Also, the proliferation of annual roots in a limited volume of soil enhances uptake of applied nutrients. With drip irrigation, salts in the soil move to the periphery of the wetted zone and towards the surface in row middles. Very little water, salts, or nutrients are lost below the root system providing irrigations are scheduled properly.

This was demonstrated by research applying nitrogen fertilizer through a drip system which showed that multiple applications of nitrogen fertilizer were no more efficient than a single application (slug). Research in a drip irrigated vineyard using isotopically labeled ammonium sulfate and comparing multiple applications versus slug treatment are shown in Table 2. No clear advantage in multiple applications was apparent. The percent N derived from fertilizer in leaves, roots, trunk, and canes did not vary with application technique. Note: To reduce the potential for salt injury, no more than 20 pounds of nitrogen should be applied in a single application.

Calcium, potassium, magnesium interact or compete on the soil's cation exchange, and they compete for entry into plants. It has been noted in vineyards in the San Joaquin Valley, particularly with drip irrigated vineyards, that applying calcium over the years, to improve water infiltration, has reduced potassium and magnesium levels in the vine. Also, the application of potassium through the drip system has been implicated in the subsequent appearance of magnesium deficiency. The interaction of calcium, potassium, and magnesium on grapevine nutrition, particularly with drip irrigation, needs to be investigated more thoroughly.

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Table 1. Nitrogen (N) fertilizer characteristics

Form	Nitrogen product ammonia	Percentage nitrogen	Equivalent lb fertilizer for 1 lb nitrogen*	Advantages and disadvantages	Acidification potential (*lb pure lime [$CaCO_3$] to neutralize fertilizer per 1b nitrogen*)
Gas	Anhydrous ammonia	82	1.22	(a) In irrigation water: fertilizer ammonia distribution is only as uniform as water penetration down furrow runs; some surface losses into air. (b) Soil injection: some loss if soil is trashy, cloddy, dry, or sandy. Special equipment required for application.	1.80
Dry	Ammonium sulfate	21	4.76	Acid residue suitable for alkaline soils but is undesirable in acid soils.	5.24
	Ammonium nitrate	33.5	2.98	High N analysis; half immediately available as nitrate and half delayed as ammonia.	1.82
	Calcium nitrate	15.5	6.45	Immediately available and no soil surface volatilization loss. Contains 19% calcium; non-acidifying. Higher cost per lb N than other dry forms.	1.29 B[1]
	Urea	46	2.17	Highest N analysis; cost competitive.	1.56
Liquid	Aqua ammonia	20	5.0 (0.66 gal)	Has lower free ammonia than anhydrous and requires less expensive application equipment. Direct soil injection need not be as deep as with anhydrous.	1.80
	CAN-17 (calcium ammonium nitrate)	17	5.92 (0.47 gal)	Contains two N forms + -8% calcium; low acidification potential.	0.53
	UAN-32 (urea ammonium nitrate)	32	3.12 (0.28 gal)	High N analysis. Contains three N forms to extend availability.	1.78
	Urea solution	23	4.37 (0.46 gal)	Can be cost competitive.	1.56
	Ammonium nitrate solution	20	4.98 (0.47 gal)	Contains two N forms; half immediately available and half delayed.	1.82

*Multiply pounds elemental N desired per acre (or kg n/ha) by this factor to also determine pounds of fertilizer per acre (or kg fertilizer/ha). Example: 50 lb N/acre (56 kg N/ha) of ammonium sulfate. 50 x 4.76 = 238 lb fertilizer/acre (56 x 4.76 = 267 kg fertilizer/ha).

[1]B = Provides a basic residue as lime rather than an acid residue.

Table 2. The % N derived from fertilizer in leaves sampled 7/18/84, 9/20/84, and 5/7/85; and root, trunk and canes sampled in dormancy

Fertilizer partitioning treatments	Total N[1] applied (lbs/acre)	% Fertilizer Nitrogen: Leaves 07/18/84		09/20/84		05/07/85		Storage tissue[2] dormant	
Check	0	0	a[3]	0	a	0	a	0	a
1 application (4/27)	40	8.48	b	9.26	b	4.17	b	5.19	b
2 applications (4/27, 5/11)	40	8.53	b	9.55	b	5.01	b	4.51	b
8 applications (weekly, 4/27 to 6/19)	40	8.68	b	9.10	b	5.80	b	4.78	b

[1] ^{15}N-depleted ammonium sulfate applied 1984.
[2] Values represent average for root, trunk, and cane samples.
[3] Means within columns with like letters are not significantly different at the 5% level.