

## Mineral Nutrition and Fertilization

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Of the sixteen chemical elements essential for plant growth, only four—nitrogen, potassium, zinc, and boron—are important for fertilizing raisin vineyards. Three others—magnesium, iron, and manganese—are uncommonly or rarely deficient. Phosphorus deficiency has not been documented in raisin vineyards; thus far it has been restricted to certain foothill and coastal wine grape district soils.

Typically, an individual raisin grower only has to be concerned with supplementing one or two of the more important nutritional elements. In general, soils in raisin vineyards on the San Joaquin Valley floor are deep or moderately deep, allowing for good root exploration and mineral extraction. Thus, most of the nutritional requirements are provided from native soil minerals. The exception, nitrogen, most commonly requires fertilizer supplementation. In this chapter we will discuss five elements: nitrogen, potassium, magnesium, zinc, and boron.

### NITROGEN

Nitrogen (N) is an important constituent of the protein makeup of all plant parts and is part of the chlorophyll molecule's structure. Deficient vines are of low vigor and their foliage is a paler, light green color. In contrast, vines with a plentiful N supply will have large, dark green leaves, rapid shoot growth, and a larger, more dense leaf canopy.

Nitrogen is part of the organic fraction of the soil and is present in the soil solution, mostly in the form of nitrate compounds ( $\text{NO}_3$ ). Nitrates are subject to movement and leaching with rainfall and irrigation water. The organic N reserves are limited by the relatively low proportion of organic matter in San Joaquin Valley soils, which remains low because organic materials break down rapidly in the warm, irrigated environment. Raisin vineyard soils typically include about

0.5 to 1.0 percent stabilized organic matter, with the lower amounts in sandier soils. Most of this is in the top 1 foot of soil where prunings and vegetation are incorporated. As a rule of thumb, only about 5 to 10 pounds of N per acre (5.5 to 11 kg/ha) is mineralized each year from this stabilized organic fraction. Consequently, N fertilizer is commonly needed, particularly on sandy soils.

### Occurrence

A soil's N requirement is a function of the soil type, its fertilization history, N contributions from cover crops and irrigation water, irrigation practices, the grapevine variety and rootstock, and ultimately vine growth and leaf canopy development. Nitrogen is almost always needed in sandy or shallow soils, especially where nematodes or phylloxera affect root health. Newly planted vineyards often require N augmentation because of their more limited root systems. The need lessens with finer-textured soils of increasing depths. Previous crops of alfalfa or N-fertilized row crops will minimize the need for N in a young vineyard. Some raisin vineyards are irrigated with well waters that contribute significant amounts of N to the vineyard due to their nitrate content.

Vines grafted onto the vigorous nematode-resistant rootstocks 'Ramsey' ('Salt Creek'), 'Freedom,' and 'Harmony' have lower requirements for N due to their more vigorous and explorative root systems. 'Freedom' in particular is known to increase the N status of grafted fruiting varieties.

Vineyard problems stemming from too much N are more common than those stemming from too little. This is due in part to the ease with which N can be applied, its reputation as a general remedy for poor growth, and the relative inconvenience of applying spot-treatments of N. Much easier is a blanket treatment of the whole field, but if only spot treatment is necessary a blanket treatment can bring N levels too

high in some areas of the field. Once you have identified high N areas, withhold further fertilizer from those areas until growth has moderated to a desirable level. This may take two or more years, especially on fine-textured soils.

### Symptoms and Diagnosis

Nitrogen deficiency is hard to diagnose by foliar symptoms; they are not easily recognized until the deficiency becomes severe, a rare occurrence. The outward symptoms appear as a uniform, pale green to yellowish leaf color and reduced shoot growth, shown in Plate 14.1. Most commonly, the only evidence that a vineyard is low in N is its reduced vigor.

Always consider other possible causes of weak growth as you make your assessment. Soil problems such as hardpan, compaction, and poor water penetration may be primary limiting factors. Root pests (nematodes and phylloxera) can also seriously restrict root development. As long as these conditions exist, N applications will be of limited value in improving vine growth.

Symptoms of excess N are easier to identify than deficiency symptoms, and excess N can adversely affect raisin yield and quality. The foliage of an affected vine is lush, with large, dark green leaves. Shoots grow rapidly, have long internodes, tend to be flatter, and tend to have poor wood maturity at pruning. Strong lateral shoot growth develops, further contributing to a dense canopy with a shaded interior. The shaded interior leaves may become yellow from a lack of photosynthesis. Fruit set at bloom may be reduced (Plate 14.2). Vine fruitfulness is lower as a result of poor cane selection and reduced bud fruitfulness. A higher incidence of the waterberry disorder is associated with vines with too much N. The fungal disease problems powdery mildew, phomopsis cane and leaf spot, and summer bunch rot are exacerbated by vigorous canopies of high N.

Vines that have enough growth to fill the trellis system without shading the canopy interior excessively are receiving sufficient N. A healthy vine should have some open gaps in the foliage canopy, and at least 20 percent of the fruit and interior leaves should be exposed to some direct sunlight at any given time of day. This exposure can take the form of intermittent sun flecks on individual leaves. The presence of totally shaded leaves is undesirable; for the purposes of photosynthesis, more than three layers of healthy leaves is considered excessive. As a grower, you must judge the level of vigor and canopy conditions according to the rate of shoot growth, cane quality and maturity, bud fruitfulness, and light exposure of the interior leaves and clusters.

### Laboratory Analysis

Soil analysis is of no value in determining N need. This is due to the transient nature of its main available form (nitrate [NO<sub>3</sub>]) in the soil profile and the unavailability of the organic-N fraction until it is mineralized. Nitrate moves with other salts in the soil solution, so concentrations vary drastically depending on the distance and depth from the nearest drip emitter or furrow, and are altered with each irrigation or rain event. Also, the rate of mineralization and the eventual availability of organic N cannot be readily quantified or predicted.

Tissue analysis for nitrate N (NO<sub>3</sub>-N) can help you verify vine N status and guide you in devising a fertilizer program in a 'Thompson Seedless' vineyard. This technique involves the collection of leaf stems (petioles) at bloom from the opposite cluster position on the shoot. Vineyard blocks, soil types, and areas with differing vine growth rates should each be sampled separately. Sample these areas again for two or three years to establish seasonal variations and patterns of fertilizer need. Consult your UC Cooperative Extension Farm Advisor or a commercial diagnostic laboratory for guidance on sampling and interpretation of results.

Unfortunately, critical levels for petiole NO<sub>3</sub>-N at bloom have been established only for 'Thompson Seedless.' 'Zante Currant' and 'Muscat of Alexandria' typically show higher petiole NO<sub>3</sub>-N values than 'Thompson Seedless,' while typical 'Fiesta' values are lower. These variations are in large part indications of inherent varietal differences in the N assimilation process rather than vine N uptake and vigor. Thus, tissue analysis interpretation based on 'Thompson Seedless' critical NO<sub>3</sub>-N values could be misleading with other varieties. Even with 'Thompson Seedless,' you should never use tissue analysis as the principal guide for N fertilization. Only use it to supplement or verify your observations of vine growth and vine canopy assessment in relation to fertilizer practices.

The critical bloom petiole NO<sub>3</sub>-N values for 'Thompson Seedless' are

deficient, <350 ppm

questionable, 350 to 500 ppm

adequate, 500 to 1,200 ppm

more than necessary, 1,200 to 2,000 ppm

excessive (increasing negative effects), >2,000 ppm

possibly toxic, >8,000 ppm

### Fertilizer Practice

A 10-ton per acre (22 t/ha) 'Thompson Seedless' grape crop removes approximately 30 pounds (33 kg/ha) of N from the vineyard acre. In theory, this would be the per-acre amount of N that would need to be replenished each year in a raisin vineyard with average to above-average yields. This N comes from various sources: the residual N in the soil, including the N that is returned in the fallen leaves and pruned canes; N that is stored in and remobilized from the permanent vine parts, particularly the roots; and the nitrate that is added to the soil in well water, cover crops, and applied N fertilizer. Consider all of these sources of N as you assess your fertilizer needs. This dynamic system of N cycling within the vineyard prevents any sudden changes in vine N needs and provides a "cushion" of supply.

Determining how much N to apply is a sort of a compromise between production and quality. A deficient vine will have a smaller crop but the highest fruit maturity. A vine with a moderate N status will achieve optimum production and intermediate fruit maturation. The addition of N beyond the moderate status will further delay fruit ripening and lower raisin quality with no increase in yield. For example, in a 4-year N fertilization study of 'Thompson Seedless' vines (1988–1991, UC Kearney Agricultural Center), researchers observed the level of fruit soluble solids was 0.6 °Brix lower with no increase in yield for every increase of 25 pounds of N fertilizer per acre (28 kg/ha). The airstream sorter percentage for B and better raisin grades dropped about 5 percent for each 25-pound increase in N. See chapter 30, Raisin Quality, for a description of the raisin grading process.

The rate of fertilizer N you will apply to meet vine requirements is based on numerous vineyard trials and years of grower experience. Changes in irrigation methods and new knowledge of N dynamics in grapevines have enabled us to greatly improve N fertilizer efficiency and reduce application rates. This is the result of improved irrigation scheduling based on daily observations or historical data on evapotranspiration requirements, the use of soil moisture monitoring equipment, the adoption of drip irrigation techniques, and a greater knowledge of vine N utilization and raisin quality effects. In many cases, growers have been able to reduce their previous N application rates by 50 percent or more.

The two most important practices toward improving N fertilizer efficiency have been the introduction of drip irrigation and improving the timing of fertilizer applications. Fertilization via drip irrigation equipment lets you apply N in small increments over time when vine uptake and needs are greatest. The fertilizer is applied directly to areas of greatest root concen-

tration. Drip irrigation minimizes leaching as long as irrigation does not exceed plant water use (read more about drip irrigation scheduling in chapter 17, Water Management and Irrigation Scheduling). In contrast, the tendency to overwater with furrow and flood irrigation contributes to lower N plant use efficiency.

We have also learned more about fertilizer timing to improve the efficiency of N fertilization under furrow irrigation. Most importantly, avoid applying N in winter and early spring. The fertilizer is very susceptible to leaching during this period, especially if you irrigate for frost protection. Also, a grapevine depends heavily on N that it stores in its roots and other permanent vine parts for early growth. This minimizes the need for soil N at bud break. Consequently, N is best applied in late spring after the frost danger period and when vine uptake and demand are increasing. A good application time is at the fruit set stage after bloom. Postharvest is another good time. A postharvest application provides the most N to the vines for storage to support growth the following year and is fairly efficient in terms of overall vine use. Postharvest applications should be incorporated with irrigation as soon as possible after harvest, to take advantage of warm fall weather for plant uptake and storage. The vines should also have an intact and functioning leaf area for this purpose. Avoid fertilization during fruit ripening, since it has the potential to delay sugar accumulation. Also, this is when the fruit itself accumulates N, which is of no value to the raisin crop.

Split applications can minimize leaching and extend N availability under furrow irrigation. This is especially true in sandy soils or where weak areas would benefit from additional spot treatment. For example, a portion of the fertilizer could be applied at fruit set and the remainder postharvest in a sandy vineyard soil. Another approach would be to fertilize the entire vineyard at fruit set and then treat only the weaker soil areas again postharvest. This would amply supply the area of normal vine growth while giving a boost only to the weaker vine areas.

The major forms of N fertilizer and their important characteristics are listed in Table 14.1. Anhydrous ammonia use in vineyards has declined due to the cost and availability of application equipment. Liquid materials have increased in popularity due to their ease of handling and the convenience with which they can be applied via drip irrigation equipment. Generally, however, the choice of fertilizer formulation can be based mostly on cost. The nitrate form moves readily in the soil solution and may be preferred if the N has to be available to plants immediately. Otherwise, the ammonium and urea forms are satisfactory. In warm, moist soil, they will convert to nitrate within a few days of application. Urea and ammonium forms should always

**Table 14.1** Nitrogen (N) fertilizer characteristics

Form	Nitrogen product	Percentage nitrogen	Equivalent lb fertilizer for 1 lb nitrogen*	Advantages and disadvantages	Acidification potential (lb pure lime [CaCO <sub>3</sub> ] to neutralize fertilizer per lb nitrogen)
Gas	Anhydrous ammonia	82	1.22	(a) In irrigation water: fertilizer 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 <sup>†</sup>
	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.  $50 \times 4.76 = 238$  lb fertilizer/acre ( $56 \times 4.76 = 267$  kg fertilizer/ha).

<sup>†</sup>B=Provides a basic residue as lime rather than an acid residue.

be drilled below the soil surface or immediately incorporated, since they are subject to volatilization losses if left on the surface. The acidification potential of an N fertilizer should be considered when applied to acid soils. This is shown in Table 14.1 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 such as urea and ammonium—especially ammonium sulfate—should be avoided on soils with pH of less than 6.

Table 14.2 gives rate recommendations for N fertilizer. The rates for drip irrigation are lower than those

for furrow irrigation because of potential differences in fertilizer efficiency. With drip irrigation, apply N in increments over time. This will not improve fertilizer efficiency under good irrigation management, but will reduce leaching losses if the vines' water requirements are sometimes exceeded. Incremental fertilization may also help to minimize the availability of N at times when excess N may accumulate in the foliage. Temporary disorders attributable to excess N are associated with alternating periods of warm and cool weather in the spring.

These rates should be adjusted for the nitrate content of well water. All well waters contain some nitrates,

**Table 14.2** Suggested nitrogen (N) application rates in furrow-irrigated and drip-irrigated raisin vineyards

Vineyard conditions	Rate (lb N per acre)*		Application timing	
	Furrow	Drip	Furrow	Drip
Vigorous vines with some excess growth.	0	0		
Medium vigor vines with an adequate canopy; medium- to fine-textured soils.	20–40	10–25	Apply in late spring and/or postharvest. A portion can also be applied postharvest.	Apply 2–5 lb N/ac weekly in spring.
Below average vigor vines; inadequate canopy for trellis; sandy soils	50–60	30–40	Split applications preferred: apply 2× in late spring to early summer or 1× in spring plus 1× postharvest.	Same as above.

\*To convert from pounds nitrogen per acre to kilograms nitrogen per hectare, multiply by 1.12.

ranging from a trace to levels that exceed the vineyard requirement. A water analysis by a commercial laboratory will tell you the nitrate content in parts per million. This value, multiplied by 2.73 (for NO<sub>3</sub>-N), will give you the number of pounds of N contained in 1 acre-foot of water (a multiplier of 1.53 converts ppm NO<sub>3</sub>-N to kg N/1,000 m<sup>3</sup>). For example, 1 acre-foot of water containing 5 ppm NO<sub>3</sub>-N will contribute 13.7 pounds of N (5 × 2.73 = 13.7). This would supply over 40 pounds of N per acre to a vineyard receiving 3 acre-feet of water—sufficient for most vineyards’ N requirements. Excess N problems are often associated with well water nitrates in excess of 5 ppm NO<sub>3</sub>-N.

Use extreme caution in applying N to vines grafted onto the nematode-resistant rootstocks ‘Ramsey’ (‘Salt Creek’), ‘Freedom,’ or ‘Harmony.’ They are prone to excess vigor and usually do not require N fertilization. ‘DOVine,’ a very vigorous early ripening variety, should also receive only sparing amounts of N.

**Organic Sources of Nitrogen**

Farm manure, grape pomace, and commercial compost can be good sources of N. Their value can be compared to that of other commercial fertilizers by calculating their per-pound N cost based on N analysis. They have additional value, however, because of the gradual and extended availability of their N. This characteristic makes the N sources of greatest value in the more readily leached sandy soils. Apply larger amounts during

the first year of use, since the N will be slow to mineralize, and thus slow to become available to the vines. These rates can be diminished over years of continued use as a result of the gradual mineralization of residual organic N from previous years’ application. Refer to UC ANR Publication 21505, *Organic Soil Amendments and Fertilizers*, for more detailed information on organic N sources.

Cover crops can be good N sources and will extend N availability. A winter legume such as vetch or bur clover can contain from 20 to 125 pounds of N per vineyard acre (22 to 140 kg N/ha), depending on the planted area and its level of growth and maturity. Research has shown that the N released from a disked-in, good stand of vetch cover crop can supply the equivalent N value of a 50-pound N -per-acre (56 kg N/ha) commercial N application. This would be sufficient for most vineyards except those of low vigor or those on very sandy soils.

The extended availability of N provided by cover cropping is especially advantageous in sandy soils. For this purpose, growers may consider using a cereal such as Merced rye or barley in conjunction with N fertilization. The cereal is seeded in the fall with 50 to 80 pounds of N per planted acre (56 to 90 kg N/ha) or 25 to 40 pounds of N per vineyard acre (28 to 45 kg N/ha) with every middle planted. The developing cover crop uses the N, and then releases it back to the vines as it decomposes the following year. This serves to trap N that could otherwise be leached by winter rains, and to extend N availability through the irrigation season.

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**POTASSIUM**

Compared to nitrogen fertilization, potassium (K) fertilization needs are less frequent and more spotty in raisin vineyards. Reasons for this include the more steady supply of K provided by soil minerals, the depth of most raisin vineyard soils, and the resistance of K to losses from leaching. Potassium deficiency is most commonly confined to small areas of a vineyard—typically no larger than 1 to 3 acres. When vines are deficient, however, the vine symptoms and crop effects can be dramatic. On the other hand, an overabundance of K is of no benefit to the vine or the crop. Growers sometimes apply K fertilizer in an attempt to improve raisin quality. This idea probably originated from knowledge of K’s role in the plant’s formation of sugars and starches. However, trials in raisin vineyards with low (but not deficient) levels of K in leaf tissue have not shown yield or fruit quality responses.

## Occurrence

Potassium deficiency is mostly observed in sandy soil areas or where land leveling has removed topsoil. These areas are typically low in soil K. Root problems such as soil compaction, poor water drainage, nematodes, and phylloxera can also impede K uptake. A large crop can contribute to K deficiency as a result of the heavy demand for K by ripening fruit. One ton of raisins will remove approximately 17 pounds (0.4 kg) of K from the vineyard area. Thus, certain vine areas may only show K deficiency symptoms in high crop years. Water stress can also increase this deficiency by reducing vine uptake of K.

Grape varieties differ in their susceptibility to K deficiency when grown on their own roots. No raisin variety is known to be highly susceptible. ‘Thompson Seedless’ is intermediate in susceptibility, while ‘Zante Currant’ and ‘Muscat of Alexandria’ are low. The rootstocks ‘Harmony,’ ‘Freedom,’ and ‘Ramsey’ (‘Salt Creek’) reduce the potential for K deficiency. Vines on these rootstocks can remove higher amounts of K from the soil than own-rooted vines.

## Symptoms and Diagnosis

You can easily detect a K deficiency by watching for leaf symptoms. These symptoms usually appear in midsummer as a fading of green color at the leaf edges and between the main veins. The leaf margins tend to curl upward and become necrotic (Plate 14.3). Mild deficiencies will not show until late summer, approaching harvest. Severe deficiencies may appear around bloom and may ultimately affect most of the leaf area with chlorosis in addition to leaf margin necrosis (Plate 14.4).

Potassium deficiency should not be confused with the springtime disorder *spring fever*. Spring fever produces leaf symptoms similar to those of K deficiency, but “spring fever” symptoms appear early in spring before bloom and only affect basal leaves as shown in Plate 14.5. The symptoms are temporary and are outgrown after bloom. In contrast, K deficiency usually begins in the middle section of the shoot and continues to develop later in the season. “Spring fever” has been shown to be a N metabolism disorder caused by fluctuating spring temperatures and cloud conditions. Because, despite appearances, it is not directly related to K supply, it is sometimes called *false potash*.

## Laboratory Analysis

Soil analysis is of little value in determining vine K needs. While a soil sample can determine whether the K concentrations are relatively low, medium, or high, those levels have no direct correlation to vine uptake.

This is because there are so many other factors that affect vine K uptake and utilization, including soil depth, degree of soil compaction, root pest damage, variety, rootstock, irrigation practice, and crop size.

Tissue analysis, on the other hand, is very useful in diagnosing K nutritional problems. It measures the K status of the plants themselves rather than just a limited portion of the soil matrix from which the roots are feeding. Bloom samples consisting of opposite-cluster petioles provide information on the general status of K nutrient levels. You can delineate adequate, marginal, and deficient K areas by sampling defined vineyard areas. The critical values for bloom samples are 1.0 percent K or less (deficient) and 1.5 percent K or more (adequate). For areas with marginal values between 1.0 and 1.5 percent K, resample in midsummer at veraison by taking recently mature leaf petioles. The critical range for deficiency at that time is 0.5 percent K or less. The values given above apply to all raisin varieties.

## Fertilizer Practice

Response to K fertilizer can only be detected in vineyard areas with visible symptoms of deficiency. The affected area should be identified and mapped for later (usually winter) treatment. High rates and concentrated placement of K fertilizers are needed to overcome the strong K-fixing power of soil. For the quickest response, apply the fertilizer in a single heavy application rather than in small annual amounts. In general, the speed and degree of vine recovery, as well as the duration of effectiveness, improve as rates are increased. Due to high K fixation within clay lattices, deficiencies can be especially difficult to correct in soils high in clay content. However, few raisin vineyards are planted on such soils, so that the rates described below generally apply to the usual range of raisin vineyard soil textures: loamy sand to fine sandy loam.

The data in Table 14.3 show the differences in K content and other characteristics of commonly available potassium fertilizer or “potash” forms. One fertilizer form offers no advantage over any other in terms of K response, but their relative costs vary widely. Unfortunately, the most economical form (KCl) contains chloride, which can cause salt injury to vines. It should only be used in well-drained soils of low salt content; it requires leaching with irrigation water after application. Use potassium sulfate if there are concerns about possible chloride injury from KCl. Potassium nitrate is too expensive to be considered as a source of K alone. Potassium-magnesium sulfate is usually marketed as a means to avoid an induced magnesium (Mg) deficiency when applying high rates of K. In theory, this is because the presence of one inhibits the plant’s absorption of the other. However, induced Mg deficiency is extremely rare in raisin vineyards and does not warrant the cost

**Table 14.3** Potassium (K) fertilizer characteristics

Form	Potassium product	Percentage K <sub>2</sub> O*	Percentage potassium	Advantages and disadvantages
Dry	Potassium sulfate K <sub>2</sub> SO <sub>4</sub>	53	43	Most popular due to safety to plants and high K content; contains 18% sulfur. Low solubility limits liquid formulation; readily applied with gypsum solution applicators for drip.
	Potassium chloride KCl	62	51	Highest K analysis and lowest cost; high solubility for liquid formulations. Chloride can cause salt injury.
	Potassium nitrate KNO <sub>3</sub>	46	38	Contains 14% N. Most expensive dry form.
	Potassium-magnesium sulfate K <sub>2</sub> SO <sub>4</sub> · 2MgSO <sub>4</sub>	22	18	Contains 10% magnesium (Mg) to offset potential Mg deficiency. High cost for K content; Mg may interfere with K uptake.
Liquid	Potassium thiosulfate K <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	25	21	Contains 17% sulfur; acid-forming for alkaline soils.
	Potassium carbonate K <sub>2</sub> CO <sub>3</sub>	0–0–30		High pH is suitable for acid soils; high solubility for liquid formulation and drip irrigation.
	Potassium sulfate K <sub>2</sub> SO <sub>4</sub>	1–0–8		N (as ammonia) is commonly included in the formulation to assist K <sub>2</sub> SO <sub>4</sub> solubility.
	Potassium chloride KCl	0–0–8 or 10		Most economical liquid formulation. Often sold with 2% N content.

\*Multiply K<sub>2</sub>O (called *potash* by the fertilizer industry) by 0.83 to determine actual potassium content.

of combining Mg with a K fertilizer (as in potassium-magnesium sulfate). In fact, the applied Mg will in turn compete for uptake with K, the target nutrient.

Dry, mixed (*complete*, containing N, P, and K) fertilizers are expensive and inefficient sources of K. Because most supply less than 100 pounds of K per acre (112 kg K/ha) per year, they can take years of treatment to correct a deficiency. Foliar sprays of K, such as potassium nitrate, have shown no promise in correcting K deficiency.

More expensive forms or formulations are sometimes used with drip irrigation. This is especially true of liquid products that are easily injected into drip systems. Some contain other nutrients; others, such as potassium thiosulfate and potassium carbonate, have unique chemical properties. They can be effective under drip irrigation because of the way vines respond to lower rates, but they are not cost-effective with furrow irrigation. You have to weight their convenience or special features against cost-effectiveness. Remember too, that the less-expensive dry forms, potassium sulfate and potassium chloride, can be used quite effectively with drip irrigation. Fertilizing with drip irrigation is discussed further below.

Tailor your fertilizer rates to match the severity of any deficiency as well as your irrigation method. High-

er rates are required to correct areas of increased deficiency, and furrow irrigation requires higher rates than drip (Table 14.4). Drip irrigation allows fertilizer to be placed in areas of high root concentration and frequent water application. This improves K distribution in the soil and improves root uptake.

**Fertilizing under furrow irrigation.** This requires deep placement of K fertilizer in a concentrated band close to the vine to maximize fertilizer concentration and movement in the root zone. Preferably, the fertilizer is

**Table 14.4** Suggested potassium (K) application rates to correct deficiency in furrow and drip irrigated raisin vineyards with two K sources

Vine deficiency	Rate (lb fertilizer per vine)*			
	Furrow		Drip	
	K <sub>2</sub> SO <sub>4</sub>	KCl	K <sub>2</sub> SO <sub>4</sub>	KCl
Mild	3	2.5	0.5	0.5
Moderate	4	3.5	1	1
Severe	5–6	4.5	2.5	2

\*To convert pounds to kilograms, multiply by 0.454.

drilled or applied by hand in the bottom of the furrow. This places the fertilizer near the root zone and provides for water application directly over the fertilizer. Direct water application is absolutely necessary with KCl because of the need to leach chlorides below the root zone. Fall to early winter application is preferred so that winter rains can help move the fertilizer into the root zone. This is especially true for potassium chloride, which should also receive an early winter irrigation to begin the chloride leaching process.

**Fertilizing with drip irrigation.** You can apply fertilizer directly through a drip system. You will have to make repeated applications, however, in order to achieve the desired rate to correct a deficiency. Also, it may be difficult to limit the application to the deficient areas of the vineyard. For these reasons, you may want to apply the fertilizer by hand only to the K-deficient area. Place the recommended per-vine amount of potassium sulfate or potassium chloride directly under emitters and irrigate it in. You may want to shovel a small basin under each emitter as a place to put the fertilizer. Once the deficiency is corrected, K can be periodically applied through the irrigation system for vineyard maintenance.

Potassium chloride applications under drip also require leaching irrigations. Observation indicates that adequate leaching of chlorides can be obtained by running 1 gallon-per-hour (4 L/hr) emitters for 24 hours for a rate of 1 pound (0.45 kg) KCl per vine or for 48 hours for a rate of 2 pounds (0.9 kg) KCl per vine.

Some of the liquid formulations of K that are particularly well suited for drip irrigation are given in Table 14.3.

If you anticipate regular applications of K fertilizer, you may want to consider using a gypsum applicator. This high-capacity machine will meter dry, less-expensive forms such as potassium sulfate or potassium chloride into drip irrigation systems. Otherwise, you may have to repeat hand applications or use more expensive K liquid fertilizer solutions.

Deficient areas will probably require periodic re-treatment. Typically, the rates recommended in Table 14.4 will correct a deficiency for about 3 years, possibly longer. You can tell whether it is time to re-treat by looking for the first reappearance of symptoms and using petiole laboratory analysis. Re-treat the area once mild symptoms reappear or petiole K levels suggest preventive treatment.

Some growers prefer to apply lighter rates of K annually to prevent the reoccurrence of deficiency. This is a satisfactory practice with drip irrigation, but under furrow irrigation K fertilizer is most efficient when applied less frequently and at higher rates. We do not recommend mixed fertilizers as a source of K. These expensive formulations often contain nutrients such as

phosphorus that are not needed, and their K content in relation to other nutrients is often inadequate for K maintenance, let alone for correction of a deficiency.

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## MAGNESIUM

Magnesium (Mg) deficiency is a very minor nutritional problem in raisin vineyards. Symptoms develop infrequently and are usually mild. The most common problem is the confusion of Mg deficiency with other nutrient deficiencies, notably K. The plant needs Mg to activate many enzymes required for plant growth and as a structural component of compounds needed in protein synthesis. It is a primary constituent of the chlorophyll molecule, so deficiency causes leaf chlorosis.

### Occurrence

Magnesium is moderately leachable in soil and, as with calcium (Ca), greater amounts are often found in the subsoil than in upper parts of the soil profile, especially on older, highly weathered soils. Magnesium deficiency is more prevalent on old, leached hardpan soils, wind-modified sandy soils, and recently reclaimed alkali soils. Fill areas from land leveling are more susceptible due to the further burying of the higher-Mg subsoil. Likewise, young vines are more deficiency-prone until their root systems penetrate subsoils. 'Thompson Seedless' is more susceptible than other raisin varieties.

### Symptoms and Diagnosis

Magnesium is mobile within the plant and, under deficient conditions, is readily translocated from older to younger tissue. Thus, older, basal leaves show the first signs of chlorosis, usually in mid- to late summer. The chlorosis begins at or near the leaf edge and progresses inward between the primary and secondary veins (Plate 14.6). Some border of green color remains along the main veins; the chlorotic area may become almost creamy-white. The remaining green tissue surrounding the main veins is best described as a "Christmas tree pattern." The chlorotic margins can become necrotic and turn brown as the deficiency becomes more advanced.

The symptoms of Mg deficiency are distinguishable from those of K deficiency in several important ways. Magnesium shortage produces a striking, creamy-white chlorosis at the outer edges that borders abruptly with green, normal tissue toward the leaf center. The chlorosis of K deficiency is more of a fading of green having an indistinct border with normal, green tissue.



Magnesium deficiency mostly appears in late summer and only on basal leaves. Potassium deficiency usually begins in midsummer in the middle of shoots and progresses toward the shoot tips. Thus, basal leaves are almost never affected by K deficiency except in severe cases that appear in the spring.

**Laboratory Analysis**

As is the case for K, soil analysis does not adequately represent Mg availability throughout the soil and root profile. Tissue analysis can detect potential problems or verify Mg deficiency. Bloom petiole samples indicate deficiency at and below 0.2 percent Mg; 0.2 to 0.3 percent Mg is considered questionable, while over 0.3 percent Mg is adequate. Critical petiole levels become less reliable after midseason. Magnesium levels tend to increase in the tissues even while deficiency symptoms develop. This may be due to the accumulation of unavailable Mg within the tissues.

**Fertilizer Practice**

You can ignore very mild deficiencies, as they do not contribute to economic loss. A very mild deficiency is characterized as symptoms appearing on a few basal leaves in localized vineyard areas. The effects are not considered economically important because only a small proportion of old leaves are affected late in the growing season, at which point they serve little plant function. Also, spot-treatment with relatively high rates of fertilizer and concentrated placement are needed.

Magnesium sulfate (Epsom salts) is the fertilizer of choice due to its availability and cost. Application rates and methods are similar to those for K. Adjust them according to the severity of the deficiency. High rates and deep placement are recommended with furrow irrigation. These rates can be reduced to one-third to one-half with drip irrigation. Hand placement in a small excavation under each emitter allows very localized application as compared to application through the drip system. The recommendations in Table 14.5 are for loamy sand to fine sandy loam soils. Incorporate the fertilizer with irrigation soon after application. Re-treat according to reappearance of symptoms.

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**ZINC**

Zinc (Zn) deficiency is the most widespread micronutrient deficiency of raisin vineyards. It is estimated that as many as 20 percent of raisin vineyards contain areas of deficiency. However, the actual total area affected may be nearer to 5 or 10 percent of raisin acreage,

**Table 14.5** Suggested magnesium sulfate (MgSO<sub>4</sub>) fertilizer rates to correct deficiency in furrow-irrigated and drip-irrigated raisin vineyards

Severity of deficiency	% leaves with symptoms	Pounds of magnesium sulfate per vine*	
		Furrow irrigation	Drip irrigation
Mild	<10%	2	1/2-1
Moderate	10-20%	3-4	1 1/2
Severe	>20%	5	2

\*To convert pounds to kilograms, multiply by 0.454.

since Zn deficiency is localized to specific areas within each affected field.

**Occurrence**

Zinc deficiency mostly occurs in sandy soils of low Zn content. Reclaimed alkali and calcareous (high-lime) soils are also susceptible because their relatively high pH reduces the availability of Zn. Areas that have been cut heavily in land leveling, old poultry yards and coral spots, and sandy soils that have been subjected to heavy manure applications are sometimes associated with chronic Zn deficiency.

Vine parentage or genetics influences susceptibility to Zn deficiency. 'Muscat of Alexandria' is the most susceptible raisin variety, while 'Thompson Seedless,' 'Zante Currant,' 'Fiesta,' and 'Monukka' are moderately susceptible. Vines grafted onto the nematode resistant rootstocks with *Vitis champinii* parentage—'Dogridge,' 'Ramsey' ('Salt Creek'), 'Freedom,' and 'Harmony'—are more prone to Zn deficiency.

**Symptoms and Diagnosis**

Depending on severity, Zn deficiency can affect foliage as well as fruit. Mild deficiencies only affect fruit. The results are reduced fruit set and the presence of *shot berries*. The shot berries range in size from small berries, which always remain hard and green, to intermediate berries, which are delayed in ripening. Some berries of normal size and maturity are usually present in the clusters, as shown in Plate 14.7.

More severe deficiencies will show foliar symptoms as well as a higher incidence of fruit symptoms. Shoot growth is stunted, with shorter internodes and a greater prominence of short lateral shoots. Leaves tend to be smaller with a widened petiolar sinus (where the petiole is attached to the blade). Leaves on lateral shoots can be unusually small. Interveinal chlorosis has a faded green color. Leaf veins will also be light in

color and somewhat transparent, but bordered with a narrow band of darker green (Plate 14.8).

### Laboratory Analysis

Soil analysis is of no value in determining Zn need as it is not possible to establish critical values. This is because the range of soil Zn concentrations is very narrow, and many soil and plant factors affect root uptake and vine requirements.

Tissue analysis can accurately determine a vineyard's Zn status and confirm deficiency symptoms. This helps to separate Zn deficiency from other conditions that affect fruit set: weather extremes at bloom, excess N, virus disease, and boron deficiency. Critical Zn levels have been established for bloom samples of opposite cluster petioles. Deficiencies occur at or below 15 ppm Zn, while 25 ppm and more are adequate. The questionable range is from 16 to 24 ppm Zn.

Be careful not to sample tissue that has been treated with a foliar nutrient spray containing Zn. It will contaminate the sample, nullifying what would otherwise be meaningful results. Always take the samples prior to any nutrient spray application, even if it means sampling ahead of bloom.

### Fertilizer Practice

**Foliar sprays.** Most Zn deficiencies can be corrected with foliar sprays. Timing and per-acre rate of Zn are of greatest importance. Studies of spray timing have shown the period from two weeks before bloom up to bloom (60 to 70 percent of caps off) to be the optimal application period for correction of fruit symptoms. Applications after fruit set stage will not benefit berry development, but later sprays are sometimes needed to correct foliar symptoms.

Many Zn compounds and products have been evaluated in trials, including chelates and combinations with other nutrients. Research has consistently shown the neutral- or basic-Zn products (50 to 52 percent Zn) and Zn oxide (75 to 80 percent Zn) to be most effective on a label rate per-acre basis. Rates of 4 to 5 pounds per acre (4.5 to 5.6g/ha) for neutral-Zn and 2 to 3 pounds per acre (2.25 to 3.35 kg/ha) for Zn oxide or top label rates are suggested where Zn deficiency is apparent. You can use lower rates if the deficiency is mild. Products that include chelating agents or nutrient combinations add to the cost and may reduce response due to their typically lower rates of Zn per acre.

A dilute spray of 100 to 150 gallons per acre (935 to 1,400 L/ha) is more effective than a low-volume (20 to 30 gallons per acre [187 to 280 L/ha]), concentrated application of Zn. Growers should consider dilute applications for correction of moderate to severe defi-

ciencies. Mild deficiencies can be corrected using either spray method. Take care when applying neutral-Zn or Zn oxide with a concentrate sprayer. These products are of low solubility and tend to settle in spray equipment. They require good agitation and the occasional flushing of sprayer lines.

**Soil application.** Soil application of Zn has not been very successful under furrow irrigation. A tendency toward soil fixation necessitates the use of very high fertilizer rates. Broadcast applications are ineffective. Deep, concentrated fertilizer placement is required, and one treatment lasts 2 or 3 years at the most. This kind of treatment is only recommended in localized, severely deficient areas where foliar sprays are not satisfactory. Moderately successful rates for soil-applied Zn in furrow-irrigated vineyards are given in Table 14.6. Generally, growers have had the best success with young vines on sandy soils. By concentrating the material by hand at each vine, you can improve on the success rate of a continuous band application. Late winter to early spring application is preferred.

Plant response to a soil application of Zn is greatly improved with the use of drip irrigation. Drip provides the fertilizer with more continuous wetting to enable Zn movement into the root zone. It can be applied through the drip system or hand-placed directly under each emitter. Optimum rates in trials to date are given in Table 14.6. Early spring, pre-bloom application is preferred. In general, Zn sulfate has been more successful than ZnEDTA chelate on a cost-per-acre basis. However, economics and assurance of response still favor foliar sprays. Comparatively high Zn rates are still required with drip and the treatment may not last longer than a year. Except in severe cases, repeated foliar spray treatment is probably the most economical way to correct most Zn deficiencies.

**Table 14.6** Zinc (Zn) soil application rates for moderate to severe deficiencies\*-

Zinc product	Drip irrigation <sup>†</sup>	Furrow irrigation <sup>‡</sup>
Zinc sulfate	12% solution, 15 to 20 gal/acre (1.38 lb Zn/gal)	36% granular, 1 to 3 lb/vine
EDTA chelate	9% solution, 3 to 4 gal/acre (1 lb Zn/gal)	9% solution, 3 to 6 oz/vine

\*Mild deficiencies can be corrected at lower rates than given above.

<sup>†</sup>To convert gal/ac to L/ha, multiply by 9.35; to convert lb/gal to kg/L, multiply by 0.12.

<sup>‡</sup>Range of rates covers young (1 to 3 years old) to mature (4 years or older) vines. Granular material (36%) should be side-dressed or trenched in at a 6- to 10-inch (15 to 25 cm) depth. Chelate solutions are side-dressed or banded in furrows on each side of the vine row and irrigated in.

## BORON

Boron (B) is unique among the micronutrients because of the narrow “acceptable” range of soil B levels that fall between deficiency and excess (toxicity). Only a small fraction of B in the soil (about 0.4 ppm B in a saturated soil extract) is needed by the plants, and 1.0 ppm or more can be toxic. Both deficiencies and toxicities occur in the San Joaquin Valley in association with soils of certain origins. Deficiencies are associated with the granitic and basaltic alluvial soils originating from the Sierra Nevada on the east side of the San Joaquin Valley; toxicities that appear on the valley’s west side soils originate from the marine sedimentary deposits of the Coast Range.

### Occurrence

Boron deficiency is much less common and more isolated than Zn deficiency. This is because of the geographical limits of very low-B soil and irrigation water. Such soils are mostly located east of the California State Highway 99 in association with old flood plains and alluvial fans of the Merced, San Joaquin, Kings, and Kaweah Rivers. Of these, the soil associated with the Kings River are affected the most, particularly if they are irrigated with canal water. Thus, most B deficiencies in raisin vineyards have been found in the Clovis, Lone Star, Sanger, Reedley, Del Rey, Fowler, Selma, and Kingsburg districts. Even in those areas, B deficiency is not extensive—occurring mostly on sandy soils, in low spots, or near irrigation valves where excessive leaching with irrigation water occurs. Occasional instances have also been found in cut areas of leveled hardpan soils. These are the highly weathered, older alluvial terrace soils such as the San Joaquin and Exeter series.

### Symptoms and Diagnosis

Boron deficiency symptoms are fairly complex and depend on their severity and the time of the year. Generally, they can be separated into two categories: (1) early, drought-induced, spring growth deficiency and (2) later, true soil deficiency.

Early, drought-induced deficiency appears at bud break with erratic, slow, distorted shoot growth. The shoots will be dwarfed, with short internodes that may grow in a zigzag manner. The lower leaves on affected shoots are misshapen into a fan shape, with prominent veins and a crinkled appearance as shown in Plate 14.9. Some shoot tips may die and numerous lateral shoots may grow on the stunted shoots.

This deficiency is only associated with dry soil conditions in the fall and winter. Boron supply is known to be reduced by low soil moisture. It is believed that such

an induced, lowered supply contributes to a temporary B deficiency in the developing tissues of the dormant buds. The condition interrupts normal development of the shoot growth tissue that first emerges at bud break the following spring. Therefore, symptoms appear on the first leaves and shoot nodes that emerge. The condition is most often outgrown once the symptomatic shoot growth is completed and the vines resume adequate B uptake.

Later, true soil deficiency mostly occurs during April to June on the growth that is differentiated in the current season. This is when a low-B soil cannot supply enough B to support rapid spring shoot growth. The deficiency is not usually related to soil moisture. It occurs with true soil deficiency, especially with the use of low-B canal water and in years of high rainfall. The most serious and common effects are on berry set and growth. In severely affected vines, a poor fruit set at bloom can result in almost no crop. More moderately affected vines will have many clusters that set numerous *shot berries* that persist and ripen along with normal berries on the same cluster. The shot berries are distinctive in size and shape: their size is quite uniform and their profile is very round to somewhat flattened on the ends as shown in Plate 14.10. In contrast, Zn-deficient shot berries vary from one another in size, shape, and ripening rate.

Mildly deficient vines may only show fruit symptoms, demonstrating that fruit set is the vine function that is most sensitive to low B. Foliar symptoms will appear with increased severity. Affected leaves show irregular, yellowish mottling between the veins (Plate 14.11). Some shoot tips stop growing and die. After a few weeks vines resume normal growth, which hides the symptomatic leaves.

### Laboratory Analysis

Soil and water analysis can be used to determine B toxicity levels. The critical level for excess B is 1 ppm, both for soil and for irrigation water. Boron at lower values usually does not cause toxicity, while at higher values it contributes to excessive plant accumulation and toxicity. Levels above 3 ppm B will cause severe toxicity. Neither soil nor water analysis, however, is very useful in determining a B deficiency. This is due to the greater difficulty of detecting the very low values that indicate deficiency—below 0.4 ppm.

Tissue analysis is useful for determining both deficiency and toxicity. Bloom petiole analysis will determine the plant’s overall B status and the potential for deficiency or toxicity. Deficient vineyards will have B levels of 25 ppm or less; adequate levels are above 30 ppm; and totals of 100 ppm B and above indicate possible toxicity. In general, B toxicity attributable to

high soil and water levels is only found on the west side of the San Joaquin Valley. Boron toxicity on the east side of the valley where most raisin vineyards are grown would only come from overfertilization with B. Therefore, tissue analysis can also be used to monitor a B fertilizer program to avoid excess B.

**Fertilizer Practice**

Follow instructions closely when using B fertilizer since higher than recommended rates can cause toxicity. Boron is the least costly and easiest nutrient deficiency to correct, so we recommend that you apply B as a precaution where mild deficiency symptoms have been detected or tissue levels are near the deficient range. Such treatment may prevent unpredictable increases in deficiency in some years.

**Soil broadcast application.** You can treat small vineyards by hand-broadcasting a B fertilizer (20 percent B analysis) onto the soil at 20 pounds per acre (22.4 kg/ha) or 2/3 ounce (19 g) per vine for vine spacings of 7 x 12 feet to 8 x 12 feet (2.13 x 3.66 to 2.44 x 3.66 m). Apply the fertilizer in the winter so rainfall can dissolve the material and move it into the root zone. One treatment will be effective for about 5 years. Other granular or crystalline products containing 14.3 to 14.9 percent B can also be used with broadcast application. One ounce (28 g) of these lower-analysis materials per vine can be used for the above vine spacings. Because of their low solubility, these products are not suitable for the spray or drip irrigation applications described below.

**Soil spray application.** Boron can be conveniently applied with banded herbicide sprays by merely adding the correct amount of soluble B product (20 percent B) to a calibrated herbicide sprayer. This method uses the equivalent of 1 pound actual B per acre (1.12 kg B/ha) per year. You can apply this amount annually or use higher amounts every 2 to 4 years. If applying once every two years, you would use 2 pounds of actual B per acre (2.24 kg B/ha) or 10 pounds of the 20 percent B product per acre (11.2 kg/ha); if applying B once every four years, you would use 4 pounds of actual B per acre (4.5 kg B/ha) or 20 pounds of the 20 percent B product per acre (22.5 kg/ha). Treatment should be timed to ensure that winter rainfall will move material into root zone.

Some B products can increase the pH of the spray solution to 8.7. This is a concern if you are including pH-sensitive herbicides such as glyphosate in the spray tank. Always measure the spray water pH and adjust it as needed with an acidifying buffer for pH-sensitive products.

**Foliar application.** Foliar sprays of 2 to 3 pounds per acre (2.2 to 3.4 kg/ha) of a 20 percent B soluble product are also effective. You can apply up to two sprays in the first year of treatment. Thereafter, one spray per year will maintain the vines at an adequate level.

You will need to check and adjust the pH of the spray solution when combining pH-sensitive pesticides or growth regulators with the highly soluble B products, as noted above under "Soil spray application."

**Drip irrigation application.** Growers who practice drip irrigation may wish to inject B through the drip system. However, there is limited experience with this practice. Plant sensitivity to B makes system calibration and application uniformity very important. You must keep in mind that grapevines that are irrigated regularly with water containing 1 ppm B can develop toxicity.

In mature vineyards, as much as 2.5 pounds of soluble B product (20 percent B) per acre (2.80 kg/ha) can be applied through the drip system in a single application. The full B fertilization for the year can be spread over several applications in the spring, early summer, and late fall. Apply no more than 5 pounds of the soluble B product per acre (5.6 kg/ha) per season for safety. Other soluble B fertilizer products such as a 10 percent B solution can also be used according to label recommendations.

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**OTHER NUTRITIONAL ELEMENTS**

Phosphorus (P), calcium (Ca), manganese (Mn), and iron (Fe) are other nutritional elements that have been documented as deficient in some California vineyards, but they are not discussed here because of their limited importance to raisin vineyards. Phosphorus and calcium deficiencies have not been confirmed in any California raisin vineyards; they are confined to very specific soil types and conditions not encountered in the San Joaquin Valley. Manganese and iron deficiencies are rare in raisin vineyards. Refer to *Grapevine Nutrition and Fertilization in the San Joaquin Valley* (listed in References) for further information on these nutrients.

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**R E F E R E N C E S**

Adams, D. O, K. E. Franke, and L. P. Christensen. 1990. Elevated putrescine levels in grapevine leaves that display symptoms of potassium deficiency. *Am. J. Enol. Vitic.* 41:121-25.

- Araujo, E. L. E. Williams, and M. A. Matthews. 1995. A comparative study of young 'Thompson Seedless' grapevines (*Vitis vinifera* L.) under drip and furrow irrigation. II. Growth, water use efficiency, and nitrogen partitioning. *Sci. Hort.* 60:251-65.
- Christensen, L. P. 1975. Long-term responses of 'Thompson Seedless' grapevines to potassium fertilizer treatment. *Am. J. Enol. Vitic.* 26:179-83.
- Christensen, L. P. 1984. Nutrient level comparisons of leaf petioles and blades in twenty-six grape cultivars on three years, 1979-1981. *Am. J. Enol. Vitic.* 35:124-33.
- Christensen, L. P. 1986. Additives don't improve zinc uptake in grapevines. *Calif. Agric.* 40(1):22-23.
- Christensen, L. P. 1986. Boron application in vineyards. *Calif. Agric.* 40(2):17-18.
- Christensen, L. P., and J. Boggero. 1985. A study of mineral nutrition relationships of waterberry in 'Thompson Seedless.' *Am. J. Enol. Vitic.* 36:57-64.
- Christensen, L. P., J. Boggero, and M. L. Bianchi. 1990. Comparative leaf tissue analysis of potassium deficiency and a disorder resembling potassium deficiency in 'Thompson Seedless' grapevines. *Am. J. Enol. Vitic.* 41:77-83.
- Christensen, L. P., and F. L. Jensen. 1978. Grapevine response to concentrate and dilute application of two zinc compounds. *Am. J. Enol. Vitic.* 29:213-16.
- Christensen, L. P., and A. N. Kasimatis. 1967. Correction of vineyard zinc deficiency by soil injection of zinc sulfate solutions. *Am. J. Enol. Vitic.* 18:217-24.
- Christensen, L. P., A. N. Kasimatis, and F. L. Jensen. 1978. Grapevine nutrition and fertilization in the San Joaquin Valley. Berkeley: University of California Division of Agricultural Science publication 4087.
- Christensen, L. P., W. L. Peacock, and M. L. Bianchi. 1991. Potassium fertilization of 'Thompson Seedless' using two fertilizer sources under drip irrigation. *Am. J. Enol. Vitic.* 42:227-32.
- Cook, J. A., P. P. Baranek, L. P. Christensen, and H. L. Malmstrom. 1968. Vineyard response to phosphate-zinc foliar sprays. *Am. J. Enol. Vitic.* 19:17-26.
- Kasimatis, A. N., and L. P. Christensen. 1976. Response of 'Thompson Seedless' grapevines to potassium application from three fertilizer sources. *Am. J. Enol. Vitic.* 27:145-49.
- Kliewer, W. M. 1971. Effect of nitrogen on growth and composition of fruits from 'Thompson Seedless' grapevines. *J. Am. Soc. Hort. Sci.* 96:816-19.
- Peacock, W. L., F. E. Broadbent, and L. P. Christensen. 1982. Late fall nitrogen application in vineyards is inefficient. *Calif. Agric.* 36(1):22-23.
- Peacock, W. L., L. P. Christensen, and F. E. Broadbent. 1989. Uptake, storage, and utilization of soil-applied nitrogen by 'Thompson Seedless' as affected by time of application. *Am. J. Enol. Vitic.* 40:16-20.
- Peacock, W. L., L. P. Christensen, and D. H. Hirschfeld. 1991. Influence of timing on nitrogen fertilizer application on grapevines in the San Joaquin Valley. *Am. J. Enol. Vitic.* 42:322-26.
- Williams, L. E. 1987. Growth of 'Thompson Seedless' grapevines: II. Nitrogen distribution. *J. Am. Soc. Hort. Sci.* 112(2):330-33.
- Williams, L. E., P. J. Biscay, and R. J. Smith. 1987. Effects of interior canopy defoliation on berry composition and potassium distribution of 'Thompson Seedless' grapevines. *Am. J. Enol. Vitic.* 42:118-22.