VITICULTURE & ENOLOGY
UNIVERSITY OF CALIFORNIA DAVIS

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Title: **"Foliar fertilization in vine mineral nutrient management programs"**

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In: Proceedings of the Soil Environment and Vine Mineral Nutrition Symposium. P. Christensen and D.R. Smart (Eds.), pp 83-90. American Society of Enology and Viticulture, Davis, CA. 2005.

This is a wonderful review of foliar nutrient applications by an authority in grapevine nutrition. Foliar spray application is widely used to supply specific nutrients to many crops, including grapevines. Nutrient foliar sprays are most commonly used to correct **micronutrient problems**. This is for two reasons: 1) it takes a very small amount to correct the deficiency, and 2) many micronutrients are readily fixed by most soils, so they soon become unavailable to the plant with soil fertilization. The advantages of foliar spray compared to soil fertilization include: 1) immediate response, 2) convenience of combination sprays, and 3) comparatively low cost. On the other hand, foliar sprays have some disadvantages: 1) the response is only temporary, 2) only very low doses can be applied, and 3) there are limitations due to foliar toxicity.

- **Mode of entry**. When nutrients are applied directly to the foliage, they must penetrate 3 barriers: 1) the waxy cuticle covering the epidermal cells, 2) the cell wall of the epidermal cells, and 3) the plasma membrane of the epidermal cells. Permeation of nutrients through the cuticle occurs by diffusion through "holes" in the cuticle that are water-friendly (hydrophilic pores). Permeation through the plasma membrane occurs by active transport, a process requiring energy. The relative importance of penetration through the stomates versus penetration through the cuticle has been a point for discussion among researchers. Both seem to occur. Stomatal penetration seems to offer some advantage because 1) the absorbance surface is enlarged, and 2) the internal cuticle within the substomatal cavity is generally thinner. Other important sites for entry are insect punctures and leaf cracks and tears.

- **Barriers to foliar absorption**. The **age of the leaf** seems to affect the cuticle thickness. Young leaves have been shown to absorb more. **Environment** also influences cuticle development, since shade and humidity tend to favor thin cuticles. Finally, **hairs** on either side of the leaf can get in the way. They create hydrophobic surfaces that prevent water from fully contacting the cuticle. The amount of hair (degree of pubescence) of each particular variety should be taken into consideration when deciding the use of a surfactant.

- **Role of surfactants**. Surfactants are chemicals that lower surface tension, which is the force that prevents surfaces from wetting. Surfactants act at two levels: 1) They increase the area of contact and retention time in the "nooks and crannies" of the foliage, and 2) they modify the external wax barrier, making it more permeable. There are two types of surfactants: ionic and non-ionic. In grapes, treatment with surfactants has been shown to make nutrients more available. **Non-ionic surfactants worked better than ionic ones** because they 1) are inert in the presence of salts, 2) they are compatible with most organic ions, and 3) they do not form insoluble salts in the presence of hard water.

- **Role of chelates.** Chelates (from the Greek *chele*=claw) are compounds that like to bind to metal ions, preventing them from becoming "fixed" or immobile, and so unavailable to the plant. The most well-known chelate is ethanediaminotetraacetic acid (EDTA). Results with chelates in foliar sprays have been mixed. EDTA forms of Fe, Mn, and Zn have shown less absorption when compared to the respective non-chelated forms. However, EDTA forms have shown greater translocation within the plant than the naked metals. We will next review the most frequent nutrient problems, first the **micronutrients**, then some **Macronutrients.**

- **Micronutrients. 1) Zinc deficiency (Zn)**. Zn is the most widely deficient nutrient in California. Symptoms of Zn deficiency are known as *"little leaf"* (reduced leaf size, intervenial chlorosis, opened-up basal sinus, asymmetric leaves, zig-zag shoots). In a study that compared several forms of Zn, chelated Zn did not prove to be more effective. Instead, neutral Zn and ZnO resulted in the highest and most prolonged increase in shot-tip Zn. The application concentration recommendation is 2 g/l for neutral Zn and 5 g/l for ZnO (1 g/l if $ZnSO_4$ is used). For the same amount of Zn applied, dilute applications (1200 liters/ha) were more effective than concentrated applications (230 liters/ha). Optimal time for application, in order to improve fruit set and berry development, is **from two weeks prior to bloom to full bloom.** In severe cases, repeated sprays at 2 to 3 week intervals are needed. Fall sprays were ineffective in reducing Zn deficiency symptoms in the following spring.

- **2) Boron deficiency (B)**. Boron is unique among the micronutrients because of its narrow margin between deficiency and toxicity. It is also a very immobile micronutrient. Boron symptoms include failure to set a normal crop (*shot berries, misshapen berries*) and interveinal chlorosis. Foliar sprays are very effective in increasing boron levels. The only exception the author notes is the attempt to correct drought-induced boron deficiency in early spring. Those symptomatic tissues would have differentiated in the buds during the previous fall, and no boron treatment is able to reverse that! The optimal time for treatment is **in the fall after harvest**. Application of boron to mature vines through drip irrigation is also effective and safe. The recommended dose for boron is 1.1 kg/ha <u>per year</u> (reference for table grapes). But individual sprays should not exceed 0.7-0.9 kg/ha or else phytotoxicity can occur. The author sends out this warning: "Boron treatment should always be monitored with tissue analysis because of its narrow range of plant tolerance and its wide differences depending on growing conditions and rainfall patterns".

- **3) Manganese deficiency (Mn)**. Mn deficiency symptoms are *interveinal chlorosis* which appears in mid- to late summer. Thus, recommended time of application is **late spring to early summer** (as a preventative treatment). Mn sulfate is the form most widely used. The recommended rates are 1-2.5 g/l. Because its mobility is higher, Mn corrections last longer than, say, boron or Zn.

- **4) Iron deficiency (Fe)**. The interveinal chlorosis (yellow foliage) typical of Fe deficiency is mostly found in high-lime content soils, where it is called *lime-induced chlorosis*. Cold, wet soils are another cause of deficiency, particularly in the spring. Luckily, the problem fixes itself as the weather warms up. If your soil is alkaline, a non lime-tolerant rootstock (with *Vitis berlandieri* parentage) should had been used. If this didn't happen, repeated foliar sprays may help, but correction is usually incomplete and temporary, as Fe is immobile. Three biweekly sprays **around bloom** have been able to correct moderate problems, but as the author points out, this may have been due to normal plant recovery as weather improved, not to Fe itself. In a study comparing different sources of Fe (lignosulfonate-Fe, DTPA-Fe, EDDHA-Fe, $FeSO_4$), minor differences were seen, and no preferable form was reported. Ferrous sulfate was found to be the least effective form.

- **Macronutrients**. The use of foliar spray with macronutrients has shown limited benefits when compared to micronutrients. Some of the reson were: 1) a complete lack of response (as with phosporus), 2) no response unless many applications were made (as with nitrogen and potassium), 3) concerns with leaf phytotoxicity (as with magnesium), and 4) difficulty to elevate tissue levels due to nutrient immobility, as with calcium. Soil fertilization seems best for these high-demand nutrients.
- "**Combo" sprays.** There are many commercially available "complete" foliar fertilizers, or nutrient "cocktails", offered under several brand names. While these can be used for maintenance, the author believes they are a poor choice for treating nutrient deficiencies. This is because unnecessary nutrients can interfere with the absorption of a needed nutrient. According to the author, it is preferable to first determine what nutrient is deficient through tissue analysis and visual diagnosis, and then correct with a single-nutrient spray.

In summary, deficiencies of the micronutrients zinc, manganese, and boron can be readily corrected through nutrient foliar application. Timing is critical due to the limited duration of effectiveness:
_ *Zinc* should be applied two weeks before bloom to full bloom.
_ *Boron* is most effective when applied in the fall.
_ *Manganese* application is not justified until early to mid summer.
_ *Iron* has only reduced effectiveness and, if used, repeated applications in the spring are recommended.
Additives, nutrient combinations, and chelates all showed little or no benefit, but surfactants did increase nutrient uptake. Foliar applications of the macronutrients nitrogen and potassium have little or no benefit, and foliar application of the macronutrient calcium is still questionable.

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