GRAPEVINE NUTRITION

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Summary

Ensuring optimal vine nutrient status is an integral part of sound vineyard management. The process starts before vineyard establishment with a methodical sampling of soil and laboratory soil analyses. For established vines, plant tissue analysis, coupled with visual vine observations, is used to assess vine nutrient needs. Plant tissue analysis can also be used to diagnose suspected foliar nutrient deficiency symptoms. Of the 16 elements required for normal growth and development, only nitrogen, magnesium, boron and potassium (rarely) have been found at low or deficient levels in Virginia grapevines. Specific fertilizers are recommended for the corrections of these specific nutrient deficiencies.

Introduction

Grapevines require 16 essential nutrients for normal growth and development (Table 1). Carbon, hydrogen, and oxygen are obtained as water by roots or as gases by leaves. The remaining nutrients are obtained primarily from the soil. The **macro-nutrients** are used in relatively large quantities by vines and are often supplemented as applied fertilizers. The **micro-nutrients,** although no less essential, are needed in very small quantities. When one or more of these elements is deficient, vines may exhibit foliar deficiency symptoms, reductions in growth and crops, and may be predisposed to winter injury or death. Maintaining adequate nutrient availability is thus critical for optimum vine performance and profitable grape production.

Table 1. Nutrients essential for normal grapevine growth and development.

Obtained from air and water	Obtained from soil: Macro-nutrients	Obtained from soil: Micro-nutrients
Carbon (C)	Nitrogen (N)	Iron (Fe)
Hydrogen (H)	Phosphorus (P)	Manganese (Mn)
Oxygen (O)	Potassium (K)	Copper (Cu)
	Calcium (Ca)	Zinc (Zn)
	Magnesium (Mg)	Boron (B)
	Sulfur (S)	Molybdenum (Mo)
		Chlorine (Cl)

Ensuring adequate vine nutrition begins in the preplant phase of vineyard establishment. Soil samples should be collected at that time to determine if lime or other fertilizers are needed. Soil depth, texture and internal drainage must also be evaluated before the vineyard is established because deficiencies in those factors can lead to poor root growth and reduced nutrient absorption.

Grapevines typically grow very slowly during the first few months after being planted in the vineyard. That slow growth is due to a small root system and minimal carbohydrate reserves in the rooted cutting. The temptation is to try to stimulate growth with fertilizer application. Unfortunately, young vines are occasionally injured more than benefited by fertilizer applied during the first season. Besides possible root burning, excessive nutrient availability can lead to poor wood maturation in the fall and subsequent winter cold injury. Soil fertilizer application in the year of planting is therefore only recommended with inherently infertile soils. In that case, a 4-ounce per vine application of 10-10-10 (or equivalent nitrogen analysis fertilizer) is generally sufficient. The fertilizer should be applied in a ring 12 to 18 inches from the base of the vine after planting, or in early March for vines set the previous fall. As an alternative to soil application, foliar fertilizer can also be used on young vines. The foliar fertilizer provides a rapid but temporary response. Sprayable 20-20-20 or similar analysis materials are suitable; but read the fertilizer directions for rates of application and precautions.

Under most conditions, if the vineyard soil was well prepared and soil pH was adjusted prior to planting, vines will require very little if any fertilizer application in the first few years of growth. Poor growth of young vines is more often due to lack of water, weed competition, over-cropping, or poor disease control. Fertilizer will not compensate for those stresses.

As vines mature and crops are harvested, many vineyards will require periodic application of one or more nutrients and adjustment of pH with lime. Vineyards are sometimes fertilized on the basis of speculation, habit, or wishful thinking. At the other extreme, some growers avoid any fertilizer for fear of over-stimulating growth. In other cases, entire vineyard blocks might be fertilized when only specific areas of the block require fertilizer. Inappropriate vineyard fertilization can result in inadequate or excessive vine vigor, poor fruit set, impaired leaf photosynthetic ability, and reduced fruit quality. In some cases, such as with boron, excess availability can cause vine injury more severe than the deficiency symptoms. It is therefore important that growers have a sound basis for determining the fertilizer needs of their vines.

There is no single method for accurately assessing vine nutrient needs. Instead, a combination of soil analysis, plant tissue analysis, and visual symptoms is used.

SOIL ANALYSIS

Physical soil features should be evaluated in the site selection process (see VCE Publication 463-016). The soil must meet minimum standards of depth and internal water drainage. Soil survey maps should be consulted to determine the agricultural suitability of any proposed site. The history of crop production at the site, or in nearby vineyards, can provide some indication of grape production potential. Sites that have been in recent cultivation are usually in better condition than pasture or abandoned farm land.

Detailed soil analyses must be made prior to vineyard establishment, primarily to determine pH, but also soil fertility. Soil test kits are available from some Cooperative Extension offices or from commercial laboratories (see **'Soil and plant tissue testing services'** in the Appendix). Soil samples can be collected either with a shovel or a cylindrical soil probe. In either case, samples must be representative of the area to be planted. Sites greater than two or three acres should be sub-divided and sampled separately if differences in topography or soil classification exist. Collect samples when the soil is moist and not frozen; fall is an excellent time. Each sample should consist of 10 to 20 sub-samples that are thoroughly mixed. Exclude surface litter, sod, large pebbles and stones, and retain about a pound of the mixed soil for testing. The top few inches of soil are usually quite different from deeper soil with respect to pH and nutrient availability. For this reason, it is best to divide each soil probe into two samples: one of 0- to 8-inch depth, and a second of 8- to 16-inch depth. Grape roots can grow much deeper than 24 inches in loose, well aerated soil. But because of limited ability to significantly alter soil characteristics below 24 inches, there is little point in collecting deeper samples.

Soil test results will indicate whether adjustments to pH and macro-nutrients are necessary. Soil test data are not customarily used to assess the need for nitrogen or trace elements for vineyards, although they can be included if there are reasons to suspect a need for testing. Specific recommendations are provided with the test results to correct soil deficiencies. Perhaps the most important information provided by the soil test is the value of the soil pH. Soil pH is a measure of the acidity or alkalinity. The pH scale is numbered from 0 to 14. A value of 7 is neutral. pH values less than 7 reflect acidity, whereas numbers above 7 are indicative of alkaline conditions. The pH scale is logarithmic; a pH of 5.0 is 10 times more acidic than a pH of 6.0 and 100 times more acidic than pH 7.0. Soil pH is determined by many factors, including the parent material, the amount of organic matter, the degree of soil leaching by precipitation, and by additions of lime or acidifying fertilizers.

Grape species differ substantially with respect to the optimum pH for growth. Varieties of *Vitis vinifera* generally grow best at a pH between 6.0 and 7.0, whereas the native American grapes (*e.g.*, 'Concord', 'Niagara', *etc.*) and the hybrids of American species and *V. vinifera* (*e.g.*, 'Seyval', 'Vidal blanc') tolerate lower pH values (5.0 to 6.0). Muscadine grapes (*V. rotundifolia*), which are grown in small amounts in southeast Virginia, do best between pH 5.5 and 6.0.

Adjusting Soil pH

Soil pH adjustments in Eastern U.S. vineyards, with few exceptions, are made to increase, rather than decrease, pH. The pH of acid soils can be raised by applying lime. That simple statement unfortunately oversimplifies the complexity of soil acidity problems—particularly in established vineyards. It is extremely difficult to increase the pH in all but the top few inches of soil once vines are planted. This is particularly true once a permanent cover crop has been planted and cultivation is no longer desirable. For that reason it is ***extremely*** important to determine soil pH, and raise it if necessary, before the vineyard is established. The applied lime should be incorporated as thoroughly and as deeply as possible. Common agricultural-grade liming materials (*e.g.*, ground limestone) have very low solubilities and will move very little, if at all, beyond the first few inches when applied to the soil surface. Even if cultivation is used, lime incorporation beyond about 12 inches is unlikely with conventional tillage equipment. Sub-soil pH can be raised somewhat by applying lime and cultivating deeply (12 to 24 inches) with a chisel plow or subsoiler. Some research has been conducted with lime injectors, but that technology will not be readily available to most grape growers.

Most vineyard soils tend to become acidic even if they are limed to pH 6.5 at the time of establishment. Acidification occurs due to leaching of basic ions from the soil profile, microbial activity, and the addition of acidifying fertilizers such as ammonium sulfate. Fungicidal sulfur applications can also be expected to reduce soil pH. Soil tests should therefore be conducted every two to three years after vineyard establishment to monitor pH.

The materials commonly used for agricultural liming are the oxides, hydroxides, carbonates, and silicates of calcium, or mixtures of calcium and magnesium. Commercial bulk application of lime will typically involve spreading of ground limestone which contains calcium carbonate or mixtures of calcium and magnesium carbonate. Limestone that contains a high proportion of magnesium carbonate is termed dolomitic limestone. Calcitic limestone is more reactive than dolomitic limestone; however, dolomitic limestone can be useful in situations where available magnesium is low. The oxides and hydroxides (hydrated lime = calcium hydroxide) are more reactive and have a greater neutralizing value than the carbonates. These materials are, however, unpleasant to handle. They absorb moisture and can cake, and they can irritate skin and injure tissues of the eyes, nose, and mouth. Oxides and hydroxides are also more expensive than carbonates. In addition to dry materials, liquid lime formulations are available from some distributors. The choice of what liming material to use will likely be determined by what is locally available. Most of the cost of liming is due to transportation and spreading.

The amount of lime needed for a particular acidity problem is affected by a number of factors including: (a) pH, texture, and amount of soil organic matter; (b) grape species to be planted; and (c) type and particle size of lime used. Obviously, recommendations cannot be provided here for all situations. Table 2 does, however, provide some guidelines for liming based on initial pH and soil type. In practice, individual rates of lime application should not exceed 3 or 4 tons/acre. Where soils are strongly acidic, several applications of 2 to 3 tons/acre each, over a period of several years, will likely be more effective than a single, massive dose.

Table 2. Estimated quantity of lime (ground limestone) in tons per acre required to increase pH values in three different soil types.

pH of unlimed soil	Soil type Sandy	Loamy	Clayey
		pH desired: 6.8	
4.8	4.25	5.75	7.0
5.0	4.0	5.25	6.25
5.5	3.0	4.0	4.75
6.0	2.0	2.75	3.25
6.5	1.25	1.5	2.0
		pH desired: 6.5	
4.8	3.5	4.5	5.0
5.0	3.0	3.75	4.25
5.5	1.75	2.5	3.0
6.0	1.25	1.5	2.0

Plant Tissue Analysis

Plant tissue analysis provides an objective means of determining the nutrient status of grapevines. Tissue analysis reveals the concentration of essential nutrients or elements *absorbed* by or within vine tissues. In most respects, tissue analysis is superior to soil analysis results, which indicate only the relative *availability* of nutrients. A high availability of a particular nutrient in the soil does not necessarily mean that the plant can extract enough of that nutrient to meet its needs. To be meaningful, tissue analysis must entail: (i) a standardized tissue sampling procedure; (ii) accurate and precise analytical methods for determining the elemental concentrations of tissue samples; (iii) standard references with which to compare diagnostic sample values; and (iv) a means of interpreting diagnostic data and making sound fertilizer recommendations to the grower. In practice, a grower will collect the tissue sample and submit it to a lab for analysis. The lab follows standardized procedures for determining the mineral nutrient concentration of the tissue. Elemental concentrations of the diagnostic sample are compared with standard grapevine tissue references from healthy vines. Based on those standards, elements or nutrients in the diagnostic sample are classified as being either adequate, high, or low/deficient. Fertilizer recommendations to increase nutrients that are low or deficient can be made either by the lab or a grape specialist. Growers should contact university or commercial labs for further information on submission procedures (see **'Soil and plant tissue testing services'** in the Appendix).

The specific recommendations for tissue sample collection will depend on the grower's objectives. There are basically two different reasons to conduct plant tissue analyses. One reason is for routine nutrient status evaluation. The other is to diagnose a particular visual disorder for which a nutrient deficiency is suspected.

Routine nutrient status evaluation: The general nutrient status of vines should be evaluated on an annual or two-year basis to gauge the vineyard's need for, or response to, applied fertilizer. Such tests will usually detect deficiencies before visual symptoms are manifest. This strategy is intended to avoid having to make *corrective* fertilizer applications in favor of *maintenance* applications.

Time to sample: The concentration of most essential nutrients varies in the plant throughout the growing season. For example, the concentration of nitrogen in grape leaves is higher at bloom time than at veraison (onset of rapid fruit maturation) or near fruit harvest. For other nutrients, such as potassium, research has shown that foliar concentrations at late-summer (70 to 100 days after bloom) are better correlated with vine performance than are concentrations diagnosed at bloom-time. One might ideally sample vines at different times of the season to evaluate different nutrients; however, that is both inconvenient and expensive. A compromise is to choose a well defined stage of vine development that provides useful information for the majority of nutrients that might be out of balance. For these and other reasons, it is recommended that samples be collected at full-bloom, which is considered to exist when about two-thirds of the flower caps have been shed. Because the tissue concentrations of many of the essential elements are rapidly changing in the early part of the growing season, it is important to sample as close to full-bloom as possible.

Tissue to collect: Sample each variety separately because nutrient concentrations may vary somewhat between varieties. Collect 100 petioles from leaves that are located opposite the first or second (from bottom) flower cluster of the shoot. Petioles are the slender stems that attach the leaf blade to the shoot (Figure 1). Collect petioles systematically throughout the vineyard block to ensure that the total block was represented. If different portions of the vineyard (hills vs. low areas, for example) produce differences in vine growth, separate samples should be collected from each of those areas. Collect no more than one or two petioles per vine. Choose leaves from shoots that are well exposed to sunlight and that are free of physical injury or disease. Immediately separate the petioles from leaf blades and place the petioles in a small, labeled *paper* bag or envelope. Allow the petioles to dry at 80 to 90°F for 24 hours then submit the samples for analysis.

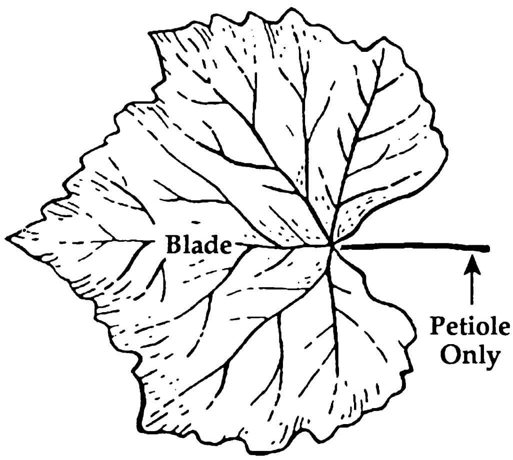

Figure 1. Remove and retain only the leaf petiole for tissue analysis. Collect petioles from leaves located opposite the bottom flower clusters at full bloom.

Commercial and some university labs will provide an interpretation of tissue analysis results if the grower requests that information. Sufficiency ranges for nutrients from bloom-sampled vines are presented in Table 3. Concentrations that exceed the sufficiency range do not necessarily indicate a problem. For example, some fungicides contain manganese, copper, or iron which, if the materials were recently applied to the vines, will elevate the test results for those elements. On the other hand, elements that are lower than sufficient may need to be applied as fertilizers.

Repeat sampling and diagnosing visual vine disorders: Certain elements, notably potassium, are best evaluated in late-summer when their concentrations become more stable. Where bloom-time samples indicate questionable nutrient levels, particularly with potassium, growers should make a second collection 70 to 100 days after bloom. These late-summer samples should consist of 100 petioles collected from the youngest fully expanded leaves of well exposed shoots. The youngest fully expanded leaves will usually be located from 5 to 7 leaves back from the shoot tip. Separate the petioles from leaf blades and submit only the petioles as described above.

For "trouble-shooting" suspected nutrient deficiencies, sample at any time during the season that symptoms become apparent. Collect 100 petioles from symptomatic leaves regardless of their shoot position. In addition, collect an equal number of petioles from non-symptomatic or healthy leaves of the same relative shoot position from which affected leaves were collected. Label and submit the two independent samples so that their elemental concentrations can be compared.

Table 3. Sufficiency ranges of essential elements based on bloom-time sampling of leaf petioles.

Nutrient[z]	Sufficiency range
Nitrogen	1.20 - 2.20 %
Phosphorus[z]	0.15 - ? %
Potassium	1.50 - 2.50 %
Magnesium	0.30 - 0.50 %
Iron[z]	40 - ? ppm
Manganese	25 - 1000 ppm
Copper	7 - 15 ppm
Zinc	35 - 50 ppm
Boron	30 - 100 ppm

[z]Nutrients of Table 1 that are not shown here are unimportant from a nutrient management perspective or do not have reliable standards for Virginia vineyards.

Visual Observations

Foliar symptoms of nutrient deficiencies and observations of vine vigor and crop size are important clues as to whether vines are suffering nutrient stress. It is, however, possible to be misled by foliar disorders because some are of non-nutritional origin. For example, some herbicide toxicity symptoms bear similarities to certain nutrient deficiencies. And, to the inexperienced, European red mite feeding injury may be misinterpreted as a nutrient deficiency. The correct interpretation of foliar disorders requires a certain amount of experience and understanding of pattern expression. In general, there are three different patterns of symptoms to examine: patterns within the vineyard; patterns on a given vine; and patterns on a particular leaf.

Variation in symptoms within the vineyard can provide useful clues as to whether a nutrient deficiency is the cause of observed symptoms. With undulating or hilly topography, nutrient deficiency symptoms are usually first observed on the higher sites, especially where soil erosion has occurred. In particular, nitrogen, potassium, magnesium, and boron deficiencies may be anticipated to occur first at higher sites due to thinner top-soil and reduced moisture. Soil moisture aids movement of nutrients to the root/soil interface and under droughty conditions nutrient deficiencies can develop.

Vine-to-vine variation in symptoms can also provide meaningful clues. Generally, a nutrient deficiency will affect sizable portions of a vineyard and rarely only one or two vines at random.

Peculiar symptoms that appear on only a few vines throughout the vineyard, or where healthy vines alternate with symptom vines, suggest a biological pest. Leafroll virus, for example, will produce distinct foliar symptoms on red-fruited varieties, and affected vines may be directly adjacent to healthy vines.

The position or age of symptomatic leaves on a given vine also provides information about which nutrient might be causing the deficiency symptoms. Generally, deficiencies of the mobile elements such as nitrogen, potassium, and magnesium will appear on older or mid-shoot leaves. Deficiency symptoms of some of the less mobile trace elements, notably iron and zinc, first appear on the youngest leaves of the shoot.

Finally, the peculiar pattern of symptoms on individual leaves will also yield information. Specific patterns are described under individual elements, below, and are summarized in Table 4 for three commonly deficient macro-nutrients.

Table 4. Characteristics of foliar deficiency symptoms of nitrogen, potassium and magnesium.

	Leaf injury pattern		Location of the most
Nutrient	**Mild symptoms**	**Severe symptoms**	**severely affected leaves**
Nitrogen	General fading of green leaf color	Pronounced leaf yellowing/chlorosis	Basal to mid-shoot leaves
Potassium	Interveinal and marginal chlorosis	Necrosis or scorching of leaves from margins inward	Mid-shoot leaves
Magnesium	Interveinal chlorosis which does not extend to leaf margin on at least some leaves	Necrotic spots and severe leaf chlorosis, including chlorosis of leaf margins	Basal to mid-shoot leaves

Aside from foliar symptoms, observations on vine vigor and fruit set/yield can be used to further diagnose a suspected nutrient deficiency. Uniformly weak vine growth, for example, may point to a need for added nitrogen; however, one must first consider that water stress, overcropping, or disease will also constrain growth. Poor fruit set, straggly clusters, and uneven berry size and shape could suggest a boron deficiency; again, however, similar symptoms might point to tomato ringspot virus infection.

It should be obvious, then, that the diagnosis of a nutrient deficiency will rely on experience, but should be confirmed with a combination of visual and quantitative analyses.

Fortunately, of the 16 essential elements required by grapevines, only nitrogen, potassium, magnesium and boron are commonly deficient in this region. The following text provides an overview of the role, symptoms, and correction of deficiencies of each.

NITROGEN

Role of nitrogen: Vines use nitrogen to build many compounds essential for growth and development; among these are proteins, including all enzymes, amino acids, nucleic acids, and pigments — including the green chlorophyll of leaves and the darkly colored anthocyanins of fruit.

Symptoms and effects of nitrogen deficiency: Nitrogen deficiency is not as easily recognized as are deficiencies of certain other elements such as magnesium or potassium. The classical symptom is a uniform light green color of leaves, as opposed to the dark green of vines that receive adequate nitrogen. However, nitrogen deficiency is considered severe if leaves show this uniform light green color. Other clues that point to nitrogen deficiency are a slow rate of shoot growth, short internodal length, and small leaves. Insufficient nitrogen can also reduce crop through a reduction in clusters, berries, or berry set. Thus, nitrogen deficiency might be noted as a reduction in yields over several years. **Note:** other factors such as drought, insect and mite pests, and overcropping can also cause symptoms similar to those described here.

Excess nitrogen: Nitrogen stimulates vegetative growth. If excess nitrogen is available to vines, an excessive stimulation of vine growth may occur. Shoots of such vines can grow late into the fall and may attain 8 to 10 feet in length. Conventional trellis and training systems do not accommodate such extensive growth and some form of summer pruning might be needed to create an acceptable canopy microclimate for fruit and wood maturation. The percentage of shoot nodes that mature (become woody) can also be decreased when excessive nitrogen results in late-season continuation of growth.

Yields can also suffer from excessive nitrogen uptake. Yield reductions can occur due to reduced bud fruitfulness caused by shading of buds in the previous year. Yields can also be reduced due to inadequate fruit set in the current year. In the latter situation, vigorous shoot tips can provide a stronger "sink" than the flower clusters for carbohydrates, nitrogenous compounds, and hormones that are necessary for good fruit set.

Some growers believe that **any** added nitrogen will reduce the cold hardiness of vines. This is an unfortunate misconception. If vines exhibit poor vigor and are not producing good crops as a result of nitrogen deficiency, the addition of moderate amounts of nitrogen (30 to 60 pounds of actual nitrogen per acre) will not reduce their cold hardiness and will undoubtably improve their overall performance.

Causes of nitrogen deficiency: Nitrogen is the essential element used in greatest amounts by vines. In older vineyards, nitrogen is the nutrient most commonly requiring addition on a routine basis. Once absorbed by the vine, nitrogen can be lost through fruit harvest and the annual pruning of vegetation. Considering that grape berries contain approximately 0.18 percent nitrogen, a 5-ton crop will remove approximately 18 pounds of nitrogen per acre from the vineyard. The depletion of nitrogen will be even greater if cane prunings (about 0.25 percent nitrogen) are removed from the vineyard. Given an annual export (crop) of nitrogen with no input (fertilizer), most soils will eventually be depleted of readily available nitrogen. Nitrogen depletion will occur most rapidly with soils that have a low organic matter content. Much of the nitrogen in soils is associated with organic matter. Through a series of reactions involving soil organisms, the pool of organic nitrogen is converted to forms (ammonical and nitrate-nitrogen) capable of being absorbed by vines and other plants. When soil nitrogen reserves are exhausted, nitrogen must be applied to satisfy the vines' needs.

Vines grafted to pest-resistant rootstocks (*e.g., Vitis vinifera* varieties) are often more vigorous than non-grafted vines, and their requirements for nitrogen fertilizer may be substantially less than that for own-rooted vines. However, grafted grapevines are not immune to nitrogen deficiency. The robust root system of grafted vines is capable of exploring a large volume of soil. Even so, continued cropping or soil mismanagement will eventually exhaust available soil nitrogen.

Assessing the need for nitrogen fertilizer: There is no single index that serves well as a guide in assessing the vine's need for nitrogen fertilizer. Instead, we use a number of observations, made over several consecutive years to determine the vine's nitrogen status. Vines fall into three general categories with respect to their nitrogen status: deficient, adequate, and excessive. Symptoms of vines in each category might include:

Nitrogen deficient:

- Vines consistently fail to fill available trellis with foliage by the first of August
- Crop yield is chronically low
- Cane pruning weights are consistently less than 1/4 pound per foot of row or per foot of canopy for divided canopy training systems (for example: less than 1.75 pounds for vines spaced 7 feet apart in the row)
- Mature leaves are uniformly small and light green or yellow
- Shoots grow slowly and have short internodes
- Shoot elongation ceases in mid-summer
- Fruit quality may be poor, including poor pigmentation with red-fruited varieties
- Bloom-time petiole nitrogen concentration is less than 1 percent

Nitrogen status adequate

- Vines fill trellis with foliage by first of August
- Yields are acceptable
- Cane pruning weights average 0.3 to 0.4 pounds per foot of row
- Mature leaves are of a characteristic size and uniform green color
- Shoots grow rapidly and have internodes 4 to 6 inches long
- Shoot growth ceases in early fall
- Fruit quality and maturation period are normal for variety
- Bloom-time petiole nitrogen concentration is between 1.2 and 2.2 percent

Excessive nitrogen

- Shoots fill trellis with an excess of foliage: shoots 8 to 10 feet long by mid-July
- Fruit yields low due to few clusters and/or poor fruit set
- Cane pruning weights consistently exceed 0.4 pounds per foot of row (*e.g.*, 3 or more pounds of cane prunings for vines spaced 7 feet apart in the row)
- Mature leaves are exceptionally large and very deep green
- Shoot growth is rapid and internodes are long (6 or more inches) and possibly flattened
- Shoot growth does not cease until very late in the fall
- Fruit maturation is delayed
- Bloom-time petiole nitrogen is greater than 2.5 percent

Again, the occurrence of symptoms listed under 'deficient' does not prove that nitrogen is limiting growth. Drought, in particular, will cause similar symptoms. Nitrogen fertilizer will not overcome problems arising from the lack of water or other growth-limiting factors.

Correcting nitrogen deficiency: It is preferable to avoid nitrogen deficiency rather than wait until correction of a deficiency is necessary. Maintaining an appropriate nitrogen status is based on past experience, observations on vine performance, and supplemental use of bloom-time petiole analysis for nitrogen concentration. Once nitrogen deficiency symptoms are visually detected, yield or quality losses have already been sustained and the deficiency will require time to correct.

If nitrogen fertilizer is warranted, application at a rate of 30 to 50 pounds of ***actual*** nitrogen is a prudent starting point. Don't be surprised if an initial application of nitrogen has no pronounced effect in the year of application. It occasionally takes two years for added nitrogen to have an impact on vine performance. This is because much of a vine's early-season nitrogen needs depend upon nitrogen stored in the vine from the previous growing season. Thus, nitrogen applied to vines in the current year may have its greatest benefit in the following season.

There are several forms of nitrogen fertilizer commercially available. All will satisfy the vines' needs (Table 5). Urea or ammonium nitrate will probably be the most economical forms in most areas of Virginia. Ammonium based fertilizers such as urea and ammonium nitrate should be incorporated into the soil to minimize volatilization (and hence loss) of ammonia. Rain within one or two days of application is a convenient, if not predictable, means of incorporation. Alternatively, soil cultivation, as by de-hilling of grafted vines, is acceptable. Recommendations for application of actual nitrogen must be translated into rates based on commercial formulations. A recommendation for 40 pounds of ***actual*** nitrogen per acre, for example, would require 87 pounds of urea/acre; or 114 pounds of ammonium nitrate/acre; or 190 pounds of ammonium sulfate/acre.

Table 5. Common nitrogen-containing fertilizers. To this list could be added liquid nitrogen, anhydrous ammonia, and "complete" fertilizers such as 10-10-10. However, specialized equipment for application, or greater cost per unit of nitrogen may need to be considered with those forms.

Nitrogen source	Percent actual N	Price per 50-lb bag*	Cost per lb actual N
Urea	46	$8.75	$0.38
Ammonium nitrate	35	$6.95	$0.40
Ammonium sulfate	21	$4.95	$0.47
di-ammonium phosphate	18	$6.70	$0.74
Calcium nitrate	16	$6.95	$0.87

* Prices quoted in Northern Virginia effective 1993. Prices are significantly cheaper if product is purchased in bulk. However, the quantities of nitrogen that will be applied in most Virginia vineyards do not warrant the inconvenience of bulk handling.

Nitrogen fertilizer should be applied only during periods of active uptake to minimize loss through soil leaching. This includes the period from bud-break to veraison, and again immediately after fruit harvest. Generally, routine maintenance applications should be applied at or immediately after bud-break. This coincides with normal precipitation patterns that increase the likelihood of soil incorporation. Where applications in excess of 75 pounds of actual nitrogen per acre are required, a split-application should be used wherein 50 to 75 percent of the total is applied at bud-break, with the balance applied immediately after bloom. This ensures that some nitrogen is absorbed with spring rains, but also extends the absorption into the most efficient phase of nutrient uptake. The disadvantage with this approach is the extra labor involved.

Apply nitrogen in a band under the trellis rather than broadcasting over the entire vineyard floor. Under-trellis application can be done either by ringing individual vines or by banding with a modified, tractor-mounted fertilizer spreader. The quantities of nitrogen used are so small that ringing individual vines — at 12 to 18 inches from trunks — is a practical alternative for small vineyards. Regardless of the methods used, one should only apply nitrogen where it is needed. Poor vigor is more apt to be observed in vineyard regions of soil "export," or erosion, than in regions of soil "import": fertilize accordingly.

Potassium

Role of potassium: Potassium functions in a number of regulatory roles in plant biochemical processes including carbohydrate production, synthesis of proteins, solute transport, and in the maintenance of plant water status. Although potassium can account for up to 5 percent of tissue dry weight, it is not normally a component of structural compounds.

Symptoms and effects of potassium deficiency: Foliar symptoms of potassium deficiency become apparent in mid- to late-summer as a chlorosis or fading of the leaf's green color. This yellowing commences at the leaf margin and advances towards the center of the leaf. Leaf tissue adjacent to the main veins remains darker green, at least under mild potassium deficiency. Mid-shoot leaves are the first to express these symptoms.

With advanced or more severe potassium deficiency, affected leaves will have a scorched appearance where the chlorotic zones progress to brown, necrotic tissue. Leaf margins will curl either upwards or downwards. Severe potassium deficiency also reduces shoot growth, vine vigor, berry set and crop yield. Fruit quality suffers from reduced soluble solids accumulation and poor coloration.

The symptoms described above can also appear under conditions of extreme drought or extreme moisture. Furthermore, leaf scorching can also occur under some conditions from pesticide phytotoxicity. Phytotoxicity is generally most acute on the younger leaves, and shoots soon develop newer, unaffected leaves.

Causes of potassium deficiency: Vines grown in soils that are very high in exchangeable calcium and magnesium, and low in exchangeable potassium may require periodic potassium application. Potassium absorption may also be limited under very basic (> 7.0) or acidic (< 4.0) soil pH. Experience and tissue analysis results from Virginia vineyards have rarely shown a need for added potassium. Indeed, excess absorption, as evidenced by very high tissue potassium levels (3 to 5 percent of dry weight), is more often the case. There is some evidence that high foliar concentrations of potassium are associated with elevated potassium levels in maturing fruit; and, under some conditions, such fruit may have undesirably high fruit pH, which can negatively affect wine quality. Thus, aside from the cost, there is good reason not to apply potassium unless it is needed.

Assessing the need for potassium fertilizer: Visual observation of vine performance and foliar symptoms should be coupled with routine leaf petiole sampling to determine the potassium status of vines. Research in New York State indicated that late-summer (70 to 100 days after bloom) tissue sampling was superior to bloom-time for accurately gauging the vines' potassium status. Thus, if visual observations (Table 4) or the bloom-time tissue analysis used for other nutrients indicate a marginal potassium level (Table 3), additional tissue sampling in late-summer should be done to confirm the need for added potassium. Petioles of recently-matured leaves (about the 5th to 7th back from the shoot tip) are collected for late-summer samples. As with other nutrients, samples should be collected separately from regions of topographic or soil variation.

Correcting potassium deficiency: Potassium deficiency is corrected by application of potash fertilizer. Short-term correction can be made with foliar-applied potassium fertilizer; however, the cheaper and longer-lasting remedy is to make a soil application. Two commonly used potash fertilizers are potassium sulfate and potassium chloride (also called muriate of potash). Potassium chloride is generally much cheaper than potassium sulfate. Potassium may also be applied as potassium nitrate, but this fertilizer is usually very expensive. Application rates vary with the severity of potassium deficiency (Table 6).

Potassium fertilizers should be banded under the trellis rather than broadcasting over the vineyard floor. Banding assures that a major portion of the fertilizer will be available for root uptake and will minimize the amount fixed by soil colloids. Potassium can be applied anytime, but maximal uptake will probably occur between bud-break and veraison, and again immediately after fruit harvest.

Table 6. Suggested guidelines for application of potassium chloride (KCl) or potassium sulfate (K_2SO_4) to correct potassium deficiency.

	Per vine (lbs)		Per acre equivalent* (lbs)	
Vine deficiency	KCl	K_2SO_4	KCl	K_2SO_4
Severe	1.5	2.0	900	1,200
Moderate	1.0	1.3	600	800
Mild	0.5	0.7	300	400

*Based on approximately 600 vines per acre.

MAGNESIUM

Role of magnesium in the plant: Magnesium has several functions in the plant. It is the central component of the chlorophyll molecule—the green pigment responsible for photosynthesis in green plants. Magnesium also serves as an enzyme activator of a number of carbohydrate metabolism reactions. In addition, the element has both structural and regulatory roles in protein synthesis.

Symptoms and effects of magnesium deficiency: Deficiency is usually expressed in mid- to late-summer when basal (older) leaves develop an interveinal (between the veins) chlorosis or yellowing. The nature of the chlorosis is variety-dependent, but generally the central portion of the leaf blade loses green color to a greater extent than the leaf margins. Tissue near the primary leaf veins remains a darker green. As symptoms progress, the yellow chlorosis can become necrotic and brown. Magnesium deficiency of red-fruited cultivars can cause leaves to turn reddish rather than chlorotic. Because magnesium is mobile within the vine, younger leaves are supplied with magnesium at the expense of older leaves. Magnesium symptoms, therefore, are usually confined to the older leaves except in cases of severe deficiency.

Insufficient magnesium will cause an impairment of protein synthesis and chlorophyll production, both of which reduce photosynthesis and sugar production. There is also evidence that under some conditions, deficiencies of magnesium may be associated with an increased tendency of some varieties to exhibit bunch stem necrosis (BSN), a physiological disorder that affects fruit set and fruit ripening. However, magnesium applications to BSN-sensitive vineyards have provided inconsistent results, suggesting that the problem is much more complex than that of a single nutrient deficiency.

Causes of magnesium deficiency: Grapevines express magnesium deficiency symptoms because they are not obtaining sufficient magnesium from the soil. Magnesium accounts for approximately 0.25 to 0.75 percent of the dry weight of non-deficient, bloom-sampled grape petioles. Research has shown that vines having petiole magnesium concentrations of less than 0.25 percent at bloom will typically develop magnesium deficiency symptoms by mid- to late-summer. Magnesium deficiency is often observed where vines are grown in soils of low pH (less than 5.5) and where potassium is abundantly available. The likelihood of magnesium deficiency appears to increase when petiole potassium to magnesium ratios exceed 5:1. Ratios of 10:1 and up to 20:1 are not unusual in petiole samples from Virginia vineyards. Soils formed from sandstones or granite — as are many Virginia soils — and coastal sands are relatively low in magnesium content. Soils developed from limestone generally have higher magnesium levels. Plants grown on soil high in available potassium often express magnesium deficiency even though soil magnesium levels test relatively high.

Assessing the need for magnesium fertilizer: As with most other nutrients, leaf petiole sampling at bloom-time can be used to determine the vines' magnesium status. Tissue analysis results (Table 3), coupled with visual observations, should indicate whether magnesium application is needed.

Correcting magnesium deficiency: Magnesium deficiencies can be corrected with either foliar or soil applications of magnesium fertilizers. Foliar applications are appropriate for mild and/or short-term correction, but soil application offers a more long-term remedy.

Short-term: Spray foliage with 5 to 10 pounds of $MgSO_4$ per acre using 100 gallons of water per acre. This gallonage will assure uniform coverage of leaves. Apply the $MgSO_4$ three times, at two-week intervals, in the post-bloom period. This timing will be significantly more effective than waiting until deficiency symptoms are evident in mid- to late-summer. Magnesium sulfate can be purchased as ***sprayable*** $MgSO_4$ from fertilizer dealers in 50-lb bags or it can be purchased at drug stores as Epsom salt in smaller quantities. The $MgSO_4$ can be mixed with most fungicide or insecticide sprays, unless the pesticide label cautions against this combination.

Long-term: Long-term correction is achieved by periodic soil applications of magnesium-containing nutrients. If the soil pH is also low (less than 5.5), high magnesium-content (20 percent) limestone (dolomitic lime) is the preferred magnesium source and should be applied at 1 or 2 tons per acre. Unfortunately, dolomitic lime is not readily available in many areas of the state where magnesium deficiency occurs. Fertilizer grade magnesium sulfate or other fertilizers containing some percentage of magnesium oxide are, however, generally available and are sold either in bulk or in bags. Magnesium sulfate is applied at 300 to 600 pounds per acre (50 to 100 lbs magnesium oxide per acre). To be most effective, $MgSO_4$ or MgO should be banded under the trellis rather than broadcast over the vineyard floor. With small plantings, the fertilizer can be ringed 12 to 18 inches from the trunks of individual vines.

Boron

Role of boron: Boron is an essential micro-nutrient. That designation is due to the very small quantities required for normal growth and development. Boron has regulatory roles in carbohydrate synthesis and cell division. Deficiency of boron can disrupt or kill cells in meristematic regions of plants (regions of active cell division such as shoot tips). Boron deficiency also reduces pollen development and pollen fertility. Reduced fruit set is thus a common occurrence with boron deficient vines.

Symptoms and effects of boron deficiency: Boron deficiency symptoms can be easily confused with other vine disorders and, for that reason, must be confirmed by tissue analysis before attempting corrective measures. California literature distinguishes early season boron deficiency symptoms from symptoms that develop later in the spring or summer. The early season symptoms appear soon after bud-break and appear as retarded shoot growth and may include death of shoot tips. Shoots can also exhibit a zig-zagged growth pattern, have shortened internodes, and produce numerous, dwarfed lateral shoots. Those early season symptoms are thought to be more severe following a dry fall or when vines are grown on shallow, droughty soils; either situation reduces boron uptake.

A second category of boron deficiency develops later in the spring and is marked by reduced fruit set. The nature of the reduced set can range from the presence of a few normal-sized berries per cluster, to a condition where numerous BB-sized berries are also present. The "shot" berries lack seeds and often have a somewhat flattened shape as opposed to the normal spherical to oval shape. **A note of caution:** Poor fruit set is not necessarily due to boron deficiency. Other factors, such as tomato ringspot virus and poor weather during bloom, can reduce fruit set. Furthermore, the application of boron can lead to phytotoxic effects if boron is at or above sufficiency levels.

Foliar boron deficiency symptoms may accompany the reduced fruit set if boron deficiency is severe. Foliar symptoms begin as a yellowing between leaf veins and can progress to browning and death of these areas of the leaf. Boron is not readily translocated throughout the vine. Thus, the foliar symptoms develop first on the younger, more terminal leaves of the shoot. As with early season deficiency symptoms, primary shoot tips may stop growing resulting in a proliferation of small lateral shoots.

Causes of boron deficiency: Grapevines are considered to have higher boron requirements (on a dry weight basis) than many other crops. For bloom-sampled vines, petioles testing less than 30 ppm are considered marginally deficient, although clear boron deficiency symptoms may not appear above 20 ppm. Soil pH, leachability of the soil, frequency of rainfall, and the amount of organic matter in soil affect the availability of boron. Soil pH less than 5.0 or greater than 7.0 reduces the availability of boron. Boron is actually very soluble at low soil pH but in sandy soils the increased solubility, if coupled with frequent rainfall, can lead to a leaching of boron from the root zone. Vines grown on sandy, low pH soils subjected to frequent rainfall are therefore prime candidates to express boron deficiency symptoms. Boron complexes with soil organic matter. Thus, topsoils, which generally contain more organic matter than do subsoils, provide vines with the bulk of their boron needs. If the topsoil of the vineyard is eroded, the availability of boron is apt to be reduced. Furthermore, droughts intensify boron deficiency; probably because the topsoil dries sooner than the subsoil. This drying pattern reduces the vines' ability to extract nutrients from the topsoil even though moisture and some nutrients can be obtained from the relatively moist subsoil.

Assessing the need for boron fertilizer: The first and foremost consideration in correcting boron deficiency is to determine if your vines are actually deficient. Excess boron uptake leads to pronounced leaf burning and leaf cupping. Therefore, it is imperative not to apply boron unless it is needed. Routine, bloom-time petiole sampling should be used to determine the vines' boron status.

Correcting boron deficiency: If plant boron levels are low, corrective measures can be made in the following season. Confirmed deficiencies are corrected by spraying soluble boron fertilizer on the foliage. Recommendations developed in New York State appear appropriate for Virginia and consist of two consecutive foliar sprays. The first application is made about two weeks before bloom. The second is made at the start of bloom but no earlier than 10 days after the first application was made. Apply 0.5 pound (one-half pound) of actual boron per acre in each spray using enough water to thoroughly cover the flower clusters. **It is important not to exceed this rate of application nor to reduce the 10-day interval between consecutive applications.** Solubor 20 is a borate fertilizer that contains about 20 percent actual boron. Thus, 2.5 lbs of this material should be applied per acre to provide the 0.5 pound of actual boron. The water-soluble packaging of certain fungicide and insecticide formulations reacts with boron to produce an insoluble product. Therefore, boron should not be tank-mixed with pesticides packaged in this manner, nor with any pesticide that cautions against boron incompatibility. Foliar application of boron is a temporary solution but has the advantage of not potentially making an excess soil application. With proper calibration, boron can be applied in soluble form to the soil with irrigation equipment or with an herbicide sprayer. In this case, the material should be applied at a rate of 3 to 5 pounds of actual boron per vineyard acre. Soil applications can be made at any time of the season but their effect will be delayed until the boron reaches the root zone. Dry formulations of boron, such as borax, are difficult to uniformly apply to the soil because of the small quantities used.

Other Nutrients

Other essential elements are generally found at or above sufficiency levels in Virginia vineyards and are currently of minor concern. Occasionally, tissue analysis results will show excessive levels of certain micro-nutrients such as iron, zinc, or copper. Those elevated levels are usually due to residues of fungicides that contain those elements, not to excessive root absorption. Some tissue analysis labs also include other elements, such as sodium (Na) and aluminum (Al) on test results. Those values have little meaning, however, for Virginia vineyards.

Conclusions

Achieving and maintaining adequate vine nutrition is but one component of sound vineyard management. If a nutrient is deficient, vines will not achieve optimal yields and fruit quality and the grower will not maximize returns from his investment. Good vine nutrition starts in the pre-plant phase and extends through the productive years of the vineyard. It requires recognition of visual deficiency symptoms and the use of specialized soil and plant tissue analysis techniques. Ideally, fertilizers should be applied when needed on a maintenance schedule, rather than waiting until a nutrient deficiency is expressed. The producer must also be willing to efficiently apply lime and other fertilizers where they are needed. Considering the low cost to benefit ratio of most fertilizers, that should not be a difficult management decision.

ADDITIONAL READING:

Christensen, L. P., A. N. Kasimatis, and F. L. Jensen. 1978. *Grapevine nutrition and fertilization in the San Joaquin Valley.* Univ. Calif. Div. Agric. Sci. Publ. #4087. 40 pp.

Winkler, A.J., J.A. Cook, W.M. Kliewer, and L.A. Lider. 1974. *General Viticulture.* Univ. Calif. Press. Berkeley, CA. 710 pp.

SOIL AND PLANT TISSUE TESTING SERVICES:

Call the lab to determine current pricing and submission information. Some labs, such as Cornell and Penn State, require samples to be submitted in their "kits."

A & L Eastern Agricultural Labs, Inc.
7621 Whitepine Rd.
Richmond, VA 23237
(804) 743-9401

Agricultural Analytical Services Lab
The Pennsylvania State University
University Park, PA 16802
(814) 863-6124

Plant Analysis Lab./ICP
Fruit and Vegetable Science Dept.
Cornell University
Ithaca, NY 14853
(607) 255-1785

Soil Testing Lab
145 Smyth Hall
Virginia Tech
Blacksburg, VA 24061
(703) 231-6893

Brookside Farm Lab.
308 So. Main St.
New Knoxville, OH 45871
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Agrico Chem Lab.
POB 639
Washington CH, OH 43160
(614) 335-1562

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2109 Blue Ridge Rd.
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