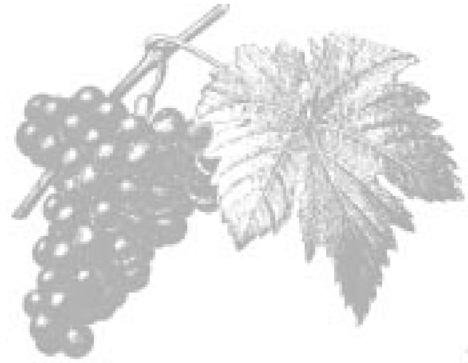
Chapter 8

Pest Management



Grapes are subject to attack by many different pests, including diseases, insects, and wildlife such as deer and birds. Weeds, which compete with the vines for soil moisture and nutrients, may also be included in this list. Recognizing and understanding the nature of these pests is essential to minimizing crop losses. This chapter briefly describes the major pests that routinely threaten bunch grapes in Virginia and North Carolina and discusses available control measures.

Many pest and disease problems can be managed by adjusting cultural practices to make conditions unfavorable for pests or pathogens. Despite use of cultural controls, however, chemical pesticides are usually required for effective control of many of the fungal diseases and some of the insects that attack many of the popular grape varieties. Pesticide recommendations change often because of changes in registrations, product manufacture, and product efficacy. Current information on chemical control measures for grapes can be obtained through your county Cooperative Extension office; however, understanding the biology of the pests helps greatly in using chemical control measures effectively. Some chemicals have very specific modes of action; they are therefore effective on some pests but useless against others. More detailed and comprehensive information on disease and insect identification may be found in the publications listed at the end of this chapter.

Diseases and Insects

Fungal and Bacterial Diseases

Most if not all varieties of grapes grown in Virginia and North Carolina are susceptible to one or more diseases. Serious crop loss or even vine death can occur if vines are not protected. Most of these diseases are caused by microscopic living organisms, including fungi, bacteria, and viruses. Other disorders can be caused by nonliving agents or growing conditions, such as chemical toxins, environmental stress, or nutrient imbalance. Some of those disorders produce symptoms very similar to diseases of biological origin. Diseases caused by fungi are among the most common and severe. In addition, two bacterial and several viral diseases are common in this region.

Black Rot

Black rot, caused by the fungus *Guignardia bidwellii,* is the most common and most destructive fungal disease of bunch grapes in the eastern United States. Varieties and species vary in their susceptibility to black rot, but most of the commonly grown vinifera and hybrid varieties should be considered highly susceptible. The fungus overwinters as specialized structures in fruit clusters on the soil or retained on the vine. The fungus releases spores from these structures in the spring with the arrival of warm, wet weather.

All young, green tissues are susceptible to infection with the onset of growth. Leaves are susceptible to infection for about one week after unfolding; berries are susceptible until they attain about 9 percent soluble solids concentration (9° Brix). Symptoms appear on leaves as tan, circular lesions one to two weeks after infection occurs (Figure 8.1). The lesions soon produce small, black pycnidia, which release additional spores during wetting periods. The process of infection, pycnidia formation, and spore release is repeated throughout the spring and summer if weather conditions are favorable. For this reason, it is crucial to avoid the primary infections. Berry infections cause direct crop loss through shriveling and drying of the fruit (Figure 8.2). The hard, blackened berries remain attached to the cluster stem (rachis).

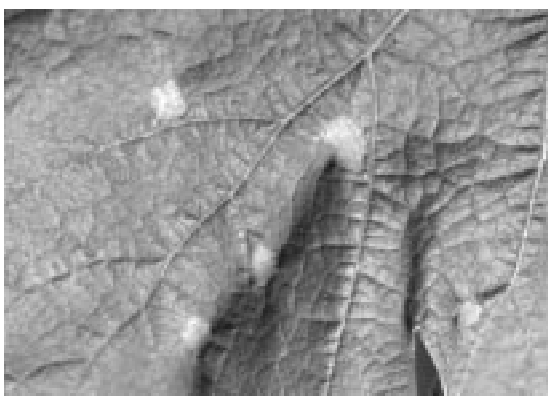


Figure 8.1 Foliar lesion caused by black rot.

Figure 8.2 Fruit decay caused by black rot.

CONTROL. Cultural practices can help to control black rot. Providing adequate canopy ventilation through shoot thinning, shoot positioning, and selective removal of leaves from fruit zones is helpful. The black rot fungus overwinters in mummified fruit from the previous season. Most of this residual fruit is usually found on the vineyard floor, but some clusters may remain on the trellis. It is important to remove these clusters from the trellis at winter pruning. In addition to cultural practices, application of fungicides is generally necessary to avoid black rot development on most varieties. Protective fungicides must be applied routinely (at 10- to 14-day intervals) starting early in the growing season, typically at the 3-inch shoot stage or earlier. The frequency of application depends on the product used as well as the amount of rainfall that occurs after the fungicide has been applied. Curative, or postinfection, fungicides are also available and can be integrated into a black rot control program.

Most of the black rot primary inoculum (fungal spores that produce primary infections) is released before bloom. Thus, effective prebloom control of black rot will greatly reduce the risk of postbloom infections. However, fungicidal protection should be maintained through véraison, especially if primary infections have occurred.

Downy Mildew

Downy mildew is favored by warm, wet growing seasons, and most grape varieties of commercial importance are moderately to highly susceptible to attack. The causal fungus *(Plasmopara viticola)* can affect all green tissues, but symptoms are usually noticed first on leaves.

Foliar symptoms are initially observed as yellowish lesions bounded by leaf veins on the leaf's upper surface. Soon after these lesions are observed, a white, cottony, feltlike or "downy" mass will be observed on the corresponding underside of the leaf (Figure 8.3). This downy growth is distinctive and should not be confused with the natural hairiness or pubescence found on the lower leaf surface of many grape varieties. The downy mass consists of the fungus's spore-bearing structures that emerge through natural pores in the leaf called *stomata.* The spores, termed *sporangia,* can be washed or blown to other susceptible tissues and cause secondary infections. In the presence of free water and favorable temperatures, sporangia release zoospores that can also invade other green tissues, leading to secondary infections.

With repeated disease cycles, foliar downy mildew lesions can be numerous enough to result in defoliation. This situation is not uncommon in mid- to late summer as spray programs are curtailed to meet pesticide label restrictions and in anticipation of harvest. In addition to appearing on leaves, downy mildew is often observed on young shoot tips and fruit clusters. Fruit infections lead to a direct loss of crop due to shelling of the berries. As with most other common fungal diseases, a heavy infestation in one year makes control more difficult during the following year because more inoculum remains in the vineyard. The downy mildew fungus overwinters principally as sexually produced spores in leaves, fruit, or infected shoot tips. Those spores germinate in early spring to begin the disease cycle again.

CONTROL. Measures to hasten drying of wetted foliage — such as maintaining a relatively thin or open canopy — will retard downy mildew development. Effective control with most grapes, however, depends upon fungicide applications. Protective fungicides must be applied before downy mildew infection periods. During periods of rapid shoot growth or frequent rains, adequate protection may require spraying at 10- to 14-day intervals.

Figure 8.3 Downy mildew lesions on the underside of the leaf.

Powdery Mildew

Powdery mildew, caused by the fungus *Uncinula necator*, can be one of the most destructive diseases affecting bunch grapes. All succulent green tissues of the vine are susceptible to infection at some point in their development. Foliar infections reduce photosynthetic function and can cause defoliation. Berries are susceptible to infection until they attain about 8° Brix (Figure 8.4). Infected berries often split, dry, or rot from secondary pathogens.

Figure 8.4 Powdery mildew symptoms.

Powdery mildew is thought to overwinter primarily as structures termed *cliestothecia* in dead leaves and lodged in the rough bark of the trunks and cordons. Cleistothecia release spores in the spring under favorable temperature and moisture conditions. Primary infections lead to the powdery lesions which, in turn, produce an abundance of conidial spores. Conidia are blown by winds to other tissues and cause repeating stages of the disease. Temperatures of 68° to

77°F are optimal for infection and development of the disease, and conidia production is favored by high relative humidity.

Initial disease development often occurs on shoots located within the shaded canopy interior. Powdery mildew lesions initially appear as dusty white or gray discolorations or lesions. The powdery or dusty fungal growth, as well as the subtending host tissue, darkens with time. Lesions on dormant canes are visible as dark red blotches.

CONTROL. Although good vine canopy management will help, effective control of powdery mildew for most commercial varieties requires application of protective fungicides. Some of the most effective synthetic products used against powdery mildew are in a chemical class known as sterol-inhibiting (SI) fungicides. These fungicides block the biosynthesis of certain metabolites that the fungus requires for normal growth and development. The specific mode of action minimizes effects on nontarget organisms but can lead to resistance development if the SI fungicides are misused.

The development of powdery mildew resistance to one or more of the SI fungicides registered for grapes is a real threat because the effectiveness of the fungicide will be reduced or entirely lost. Resistance is most likely to occur where (1) growers rely exclusively on the SI fungicides for season-long mildew control; (2) the rates at which the fungicide is applied are on the low end of recommended ranges; (3) the interval between consecutive sprays exceeds the label recommendation; or (4) combinations of the first three errors are made. Be sure to seek and follow local, current recommendations for alternating SI fungicides with fungicides having broader modes of action.

Phomopsis Cane and Leaf Spot

Phomopsis cane and leaf spot (phomopsis), also called *excoriose* in Europe, is caused by the fungus *Phomopsis viticola*. Many of the commercial grape varieties in this region are susceptible. Phomopsis symptoms are commonly seen first in the spring as elongated dark brown or black lesions near the base of shoots. Shoot lesions can coalesce and cover much of the basal two to six internodes. The lesions can also extend onto the cluster stems. Severely blighted shoots and clusters are subject to wind breakage and stunted growth. Phomopsis also causes leaf lesions, again primarily on the lower leaves of the shoot. Affected leaves have small yellow or light green spots with dark centers. Leaf lesions can drop out, giving a shot-hole appearance. Severely affected leaves drop prematurely. Early-season symptoms generally do not progress more than about six internodes up the shoot.

Phomopsis symptoms are easily observed on canes during winter pruning. The dark, sunken lesions are visible on the lower nodes of canes. Affected canes often have a bleached or whitish appearance. Upon close examination with a magnifying lens, small, dark fruiting structures called *pycnidia* can be observed on affected canes. Pycnidia produce and release spores under favorable conditions in the spring. The spores are washed by rain or frost control sprinklers to young green tissues where infection occurs. Necrotic lesions appear three to four weeks later.

Phomopsis is inactivated by the heat of summer, but the progress of the disease can resume in late summer in the form of berry rots. Infected berries turn brown, shrivel, and may drop. It is thought that most fruit infections result from lesions on the cluster stem or berry pedicels.

The conditions favoring severe phomopsis development include a past history of the disease (inoculum present); several days of rainy, cloudy weather; temperatures of 40° to 45°F; shoots that are only several inches long; and no protective fungicides present. Phomopsis tends to increase in severity each year in unprotected vineyards. Once phomopsis has become established, several years of careful management may be required to bring the disease under control.

CONTROL. A combination of cultural and chemical measures should be used to manage phomopsis. If diseased canes are present in the vineyard, prune out as much of this wood as possible. Do not leave pruning stubs greater than ½ inch long and, where possible, remove dead spurs that might be present from the previous season. Recent research has shown that diseased wood can serve as a source of inoculum for more than one year. Phomopsis spreads slowly from vine to vine, so the disease is often localized. Low-lying areas of the vineyard are often the most severely affected. Pruned wood should be immediately chopped in the vineyard or removed and burned. Chemical control measures may be necessary for adequate control where phomopsis inoculum is present. Fungicides should be applied early, when shoots are ½ to 1 inch long, and applications repeated until weather conditions are unfavorable for infection.

Eutypa Dieback

Eutypa is a wood-rotting disease caused by the fungus *Eutypa lata*. Eutypa is rarely observed in young vineyards but becomes increasingly common in vineyards as they exceed eight years in age. All commercially important varieties are susceptible. Eutypa symptoms are most obvious in early spring when shoots are 1 to 2 feet long. At this stage shoots on affected wood will appear stunted. Leaves will be unusually small, yellowed, and cupped downwards. They will often bear necrotic spots or regions. Leaf margins may be tattered. Often, the shoots on only one trunk of a multiple-trunk vine or on one cordon of a bilaterally trained vine will be affected.

Early-season shoot symptoms become more difficult to spot as the season progresses and as adjacent healthy shoots obscure the affected growth. Therefore, a thorough vineyard examination in the spring, coupled with the flagging of affected vines, trunks, or cordons, is an important step in keeping eutypa under control. Trunks and cordons that bear affected shoots should be examined for evidence of a canker or dead region of wood around large pruning wounds. Such wounds will be below the region of affected shoots (in the direction of the roots). Affected trunks and cordons may exhibit a wedge of darkened, dead tissue when a cross-sectional cut is made through an affected portion of the wood.

The disease cycle commences when eutypa spores infect the vine. Principal sites of infection are pruning cuts made in two-year-old or older wood. Those cuts are frequently made in older vineyards where trunks and cordons are being renewed, especially after winter injury. The source of inoculum is affected trunks and cordons in the vineyard, and possibly alternative hosts near the vineyard. Based on research in New York, it is likely that eutypa spores are released from these sources throughout the year, with peak discharge in mid- to late winter (January through March). Rain or snowmelt is required for spore release, and this moisture is also needed for spores to enter the fresh pruning wounds. Wounds are susceptible to infection for up to about four weeks; however, the period of infection is greatly reduced when cuts are made in the spring.

Spore germination occurs rapidly, but the fungus attacks the wood very slowly. Consequently, symptoms are not apparent for the first few years after infection occurs. A canker, as well as the shoot symptoms described above, are usually apparent by the third or fourth year after infection. The entire vine, or at least the affected trunk, will eventually be destroyed by the fungus if the affected vine parts are not removed.

CONTROL. Eutypa dieback control can be approached in three ways: inoculum reduction, infection reduction, and eradication.

1. Inoculum Reduction. The most abundant source of inoculum is infected trunks and arms or cordons that are several years old and sporulating. Again, these spores can be discharged continuously throughout the year but are most abundant during late winter and early spring —the traditional pruning period. The amount of inoculum present should be reduced by removing affected wood from the vine and from the vineyard. Burn or bury the wood that is two years old or older. It is not necessary to remove pruned canes, as these are not sources of inoculum. When removing affected cordons and trunks, make the pruning cut 12 or more inches below the suspected point of infection. This should ensure that all eutypa-affected tissue is removed from the vine. See, however, the following discussion about double pruning.

2. Infection Reduction. Removal and burning of affected wood alone will not control eutypa. Assume that some inoculum will remain in the vineyard. The first step in avoiding infection is to delay large pruning cuts (cuts into wood two or more years old) until spring, when wounds heal more rapidly. For Virginia and North Carolina, this would mean pruning no earlier than about one month before bud break. Unfortunately, for large vineyards it is not practical to start pruning this late and complete the task before bud break. An alternative, therefore is to use a form of double pruning. Double pruning entails making two cuts to remove the intended vine part. Consider, for example, the intended removal of a damaged cordon. The first pruning cut is made about 6 inches beyond the intended point of removal. This cut is made during the routine winter pruning. The vine is then flagged for later identification. At or around bud break a second cut is made to remove the extra 6 inches of damaged cordon. With double pruning we assume that the initial cut will become infected; however, because the fungus grows slowly, the infected tissue is removed when the second cut is made in the spring. Infection can be further reduced by painting all large pruning wounds with a fungicidal suspension. Check with your Cooperative Extension Service agent for specifics on this practice.

3. Eradication. Elimination of infected wood from the vineyard is extremely important to eutypa management. Affected trunks and cordons must be cut below the cankered or discolored wood. In some cases this will require removal of entire trunks or entire vines. Again, the removed parts must be burned or buried, otherwise they will continue to supply inoculum for years. Multiple trunk training systems (see chapter 6) give the grower more opportunities to compensate for eutypa and to avoid yield reductions.

Anthracnose or Bird's-Eye Rot

Anthracnose, caused by the fungus *Elsinoë ampelina*, occurs in Virginia and North Carolina but is usually confined to a few varieties, notably Vidal blanc, in particularly wet years. Anthracnose weakens the vine and reduces the quality and quantity of affected fruit. Foliar symptoms appear as abundant circular lesions with brown or black margins. The centers of such lesions are light colored and dry. They eventually drop out, producing a shot-hole appearance.

Young leaves and shoot tips are particularly susceptible to infection. Fruit clusters are susceptible to infection from their first appearance until véraison. Berry lesions are circular, sunken, and ashy gray. In the late stages of the disease the spots have a dark border. The name *bird's-eye rot* is derived from the appearance of the berry lesions. Following early-season anthracnose infections, repeating stages of the disease may occur on unprotected vines, leading to severe crop loss.

CONTROL. Extra precautions should be taken with susceptible varieties during high rainfall years, especially where anthracnose has been previously observed. Copper fungicides, applied as dormant sprays or during the growing season, offer control. Because copper can burn sensitive varieties, consult your Cooperative Extension Service agent for specific recommendations on its use. Certain synthetic fungicides are also effective against anthracnose.

Botrytis Bunch Rot

Botrytis bunch rot is caused by the fungus *Botrytis cinerea*, a pathogen that causes disease in many horticultural crops besides grapes. Botrytis reduces both the quantity and quality of grapes, and it predisposes fruit to attack by other opportunistic pathogens. The disease is favored by cool, moist weather and by the conditions found within shaded canopy interiors. Symptoms and sporulating fungal growth can occur on leaves as well as fruit, but berry infections are the more destructive.

Early-season infections may occur during flowering. These infections are thought to be followed by a period of fungal inactivity, after which fungus growth resumes as the berries ripen. After véraison, berry infections can occur directly through the epidermis or through wounds caused by grape berry moth larvae, birds, hail, or other sources of injury. Infected fruit dehydrates in arid regions or during prolonged dry weather. In this region, infected fruit often cracks and becomes infected with secondary organisms. The fungus typically produces a mass of brownish gray spores on the berry surface (Figure 8.5). Conidial spores are capable of causing repeating cycles of disease.

CONTROL. Varieties differ in susceptibility to botrytis. White-fruited varieties with compact clusters such as Riesling and Seyval are particularly susceptible. Some degree of control can be achieved by canopy manipulation to improve ventilation. In Virginia, selective thinning of leaves in the fruit zone has been helpful. Effective grape berry moth control is also important. Several fungicides provide some measure of botrytis control. Unfortunately, these materials are seldom totally effective and must be used conservatively to avoid development of fungicide-resistant strains of botrytis.

Figure 8.5 Symptoms of botrytis bunch rot.

Nonspecific Fruit Rots

Wounded grapes are subject to attack by a number of secondary pathogens, including other fungi, bacteria, and yeasts. Some of these organisms produce objectionable by-products such as acetic acid. Acetic acid imparts a vinegar odor to rotting fruit (sour bunch rot). These opportunistic pathogens are often of consequence only after mechanical wounding of the fruit, as by hail, or after a primary pathogen such as botrytis has invaded the fruit. Most, however, are of greatest severity under conditions of high humidity, abundant rainfall, and poor canopy ventilation.

CONTROL. Owing to the diverse nature of secondary rot-causing organisms, chemical control is usually ineffective. However, fungicides routinely applied to control primary grape pathogens may be effective in retarding development of nonspecific fruit rots. Cultural control is aimed at avoiding infections of controllable diseases and preventing fruit injury by insects, birds, and other wildlife. Canopy management practices that promote fruit zone ventilation are helpful in reducing infections by opportunistic pathogens.

Bitter Rot and Ripe Rot

Bitter rot and ripe rot are fungal diseases of fruit that appear after véraison. Both diseases are more prevalent and severe during wet seasons and both impart a bitter taste to affected berries as well as wines produced from affected fruit. The bitter rot fungus generally enters the berry through the pedicel. In white-fruited varieties, infected berries initially exhibit concentric rings of browning tissue. As the rot progresses, numerous raised pustules develop and rupture the cuticle of the berry. Spores are dark and may give a sooty appearance to the infected berries. Affected berries soften and may drop within a few days of disease development. Berries that remain attached shrivel and dry, and thus these diseases may be mistaken for black rot or the fruit-rotting stage of phomopsis cane and leaf spot.

Ripe rot is less common than bitter rot, although under humid conditions it, too, can be destructive. Fruit infections occur at all stages of berry maturation, although symptoms are not apparent until after véraison when the fungus can complete development. Infected berries initially develop circular, reddish brown lesions that expand to involve the entire berry. Pink masses of conidial spores may be produced. Infected berries shrivel and drop from the cluster.

CONTROL. Fungicides targeted at black rot and downy mildew generally control both bitter rot and ripe rot. Removal of residual fruit clusters at dormant pruning reduces the availability of inoculum.

Grown Gall

The causal organism of crown gall is a bacterium *(Agrobacterium tumefaciens*, more recently named *A. vitis*). This bacteria has numerous strains that enable it to cause disease in many plant species, including grapes. *A. vitis* can survive in soil independent of living grape tissue for many years and may infect vines through wounds caused by mechanical damage or cold injury. More important, perhaps, is the fact that the bacteria are known to exist systemically in plant material and can be distributed by propagating infected stock. Infected vines may not show disease symptoms unless wounding, such as by cold injury, occurs.

The bacteria transfer a portion of their genetic material into the host vine's cells in and around the wounded tissue. This material contains a sequence of genes that can override the host cell's genetic code and cause the grapevine cells to produce abnormal quantities of growth-regulating compounds. These compounds result in undifferentiated host cell division and cell growth, which is apparent as callus-like galls or tumors. These galls may remain superficial or they may girdle the trunk, leading to trunk death in one to two years.

CONTROL. It may be possible to control crown gall by planting vines that are free of the *A. vitis* bacteria. Several programs are currently aimed at large-scale propagation of vines free of systemic bacteria. Until this plant material is widely available, managing vines to avoid cold injury, or to compensate for injury, is the most effective strategy.

Pierce's Disease

Pierce's disease (PD) is caused by a bacterium *(Xylella fastidiosa)* that is spread by one or more species of sharpshooter leafhoppers. Pierce's disease is widespread throughout the southeastern United States and is the chief constraint to production of certain bunch grapes, especially varieties of *Vitis vinifera,* in that region. The disease has also been identified in several southeastern Virginia vineyards and in at least one vineyard on Maryland's eastern shore since 1990.

Symptoms of Pierce's disease vary with season and variety but may include (1) delayed bud break, (2) stunted shoot growth, (3) marginal "burning" or dying of leaf tissue, (4) wilting or premature coloring of fruit, (5) uneven maturity of canes, and (6) gradual dying of the root system and degeneration of the vine. Symptoms tend to be most severe in vines that are stressed, as by drought, and intensify in late summer as the fruit begins to mature.

Infection occurs when leafhoppers bearing Pierce's disease bacteria feed on susceptible vines. The bacteria are transmitted to the vine, reproduce, and form large aggregates. The bacterial masses, as well as gums produced by the vine, block the xylem, or water-conducting tissues, of the vine. The resulting symptoms are largely due to this blockage and resemble many of the effects of drought stress. Infected vines may die within a year of infection, or they may persist for five or more years. Peirce's disease is decidedly more severe in regions with mild winters. Varieties differ in their susceptibility; Chardonnay and Pinot noir are particularly susceptible, whereas Riesling is generally more tolerant. However, no variety of *V. vinifera* or *V. labrusca* is totally immune.

CONTROL. There are essentially no practical chemical controls of Pierce's disease. Insecticidal control of vectors has not been effective and, because leafhoppers have such a wide range of alternative hosts, eliminating those hosts is not practical. Site selection and choice of grape varieties has been the most practical measure for avoiding losses. Mildly affected vines may recover if subsequently exposed to freezing temperatures during the winter. However, the specific conditions necessary for this recovery are poorly understood.

Viral Diseases

Although there are numerous virus-induced grape diseases, only a handful have economic importance in this region. Unlike a waterborne or airborne pathogen such as that which causes powdery mildew, most viruses spread slowly from vine to vine; their normal transmission may be entirely dependent upon a specific insect, nematode, or human vector. All viruses are transmissible by grafting an affected bud to a healthy vine or rootstock during propagation. Thus, a single diseased vine in the source block may yield 20 or more infected vines by propagation. Worldwide recognition of the importance of virus diseases has led to the formation of clean stock certification programs that have been instrumental in reducing the spread of virus diseases.

Viruses do not have specialized reproductive structures but rely instead on the grapevine cells to replicate and multiply themselves. Viruses disrupt normal host cell function, and that impairment of function leads to altered plant appearance, reduced performance, injury, or death. Viral diseases are usually identified and confirmed in three ways: by visual symptoms, by budding or grafting tissue from a suspect vine to an indicator vine (a process called indexing), and by specific biochemical tests. Three virus diseases — tomato ringspot, tobacco ringspot, and leafroll — are prevalent in this region. This section provides a brief overview of the major characteristics of these diseases.

Leafroll

Leafroll symptoms are most pronounced on red-fruited vinifera varieties such as Merlot, Cabernet Sauvignon, and Cabernet franc, which prematurely express deep red pigments in leaves of affected plants. Foliar symptoms become obvious in late summer and appear first on the older leaves of the shoot. Reddening is generally confined to the interveinal region of the blade, with major veins remaining green. Leaf yellowing may occur with some varieties. The margins of affected leaves roll or curl downward, giving rise to the name *leafroll.* Affected vines are often less vigorous than healthy vines, and fruit ripening is delayed. Crop reductions on the order of 20 percent are common each year. Limited data also indicate that leafroll virus may slightly reduce the cold hardiness of vines.

Vines suspected of being infected with leafroll can be tested by commercial laboratories equipped to conduct the specific biochemical tests. (See the listing of laboratories at the end of this chapter.) This process entails sampling tissues of the suspect vine and sending the samples to the laboratory. For leafroll, the recommended diagnostic tissues are leaf petioles collected from symptomatic vines in late summer. Insect transmission of leafroll virus is rare; the widespread occurrence is due chiefly to propagating diseased vines.

CONTROL. Control of leafroll is straightforward: vines should be purchased only from certified clean stock programs. This will reduce but not completely eliminate the likelihood of obtaining leafroll-infected plant material. Random collection of budwood from affected vineyards only ensures that leafroll continues to be spread. Leafroll rarely kills vines, and the affected vines can persist in the vineyard for many years. Considering the cost of replacement, the rarity of vine-to-vine transmission in the vineyard, and the relatively subtle effects of leafroll on crop quality and quantity, rogueing of affected vines is not recommended.

Tomato Ringspot (Tomato Ringspot Virus Decline)

Tomato ringspot virus symptoms are most commonly observed with interspecific hybrids. Vidal blanc and Chelois have been particularly good indicators in Virginia. Vinifera varieties are susceptible to infection, but the more common varieties appear to tolerate the virus without impaired vine performance. Symptoms vary with variety.

Initial symptoms on Vidal are sparsely filled fruit clusters or the presence of clusters bearing numerous small berries — about one-third the normal berry size. In some cases both symptoms are observed. Other clusters on the same vine may be healthy and there may be no obvious reduction in vine vigor. With other varieties, the disease may cause severe shoot stunting and very poor fruit set. Leaf yellowing, leaf distortion, and slight leaf margin rolling may also be observed with some varieties. The name ringspot is derived from the observation that the virus causes light circular spots on the foliage of some hosts. The ringspots are not easily or consistently observed on grape leaves. With mild winters, affected vines may persist for many years. In cooler regions, vines are often killed to the ground within three to four years, the only remaining growth arising from base buds on the trunk.

Vines suspected of being infected with tomato ringspot virus can be tested by commercial laboratories, as mentioned in the discussion of leafroll. The tissues generally recommended for assay are young shoots (5 to 6 inches long) collected shortly after bud break. Suckers arising near the ground level are good for these samples.

The virus infects a wide host range, including many fruits, as well as numerous weeds common to vineyards in the eastern United States. The virus is often introduced to the vineyard via infected nursery stock. It may also be present in a newly established vineyard in the roots of certain weeds, in fruit crops grown previously, and in surviving nematodes. Tomato ringspot virus can be transmitted in infected plant material and is also vectored by dagger nematodes *(Xiphinema americanum),* common in eastern U.S. vineyards. Nematodes are very small, round worms that feed in or on the roots of vines and vineyard weeds. Nematode-transmitted viruses are acquired from infected vines or weeds and are disseminated during this feeding activity. Tomato ringspot virus may also be borne in the seed of some weeds.

Tobacco Ringspot

Like tomato ringspot, tobacco ringspot virus is endemic to the northeastern United States. Tobacco ringspot symptoms are indistinguishable from those of tomato ringspot, and control measures are similar. Alternative weed hosts differ somewhat between tomato and tobacco ringspot virus. In addition, tobacco ringspot virus is believed to infect vinifera vines more readily than it does interspecific hybrids. However, tobacco ringspot virus has been detected in Villard noir and Chambourcin vines (both hybrids) in Virginia. Control measures are similar to those for tomato ringspot virus.

CONTROL. As with leafroll, control of both tomato and tobacco ringspot virus starts with purchasing clean plant material from certified sources. However, even certified material may become infected in the vineyard by nematode feeding. Nematode transmission can be reduced by keeping broad-leaved weeds such as dandelion, plantain, and lambsquarters under control.

These weeds can serve as reservoirs for the virus. Good field tolerance to the virus is shown by 5C and C-3309 rootstocks. Vines grafted to these common rootstocks have shown good survival rates at known tomato ringspot virus sites.

Occasionally, when a vineyard is heavily infested with tomato or tobacco ringspot virus, poor yields or actual vine loss make it necessary to reestablish the vineyard. Once the decision has been made to renovate a vineyard, two courses of action may be taken.

1. The ideal approach is to remove all grapevines and the trellis. Kill remaining vines in late summer after harvest with glyphosate herbicide used at a label rate specified for woody weeds. Two applications may be necessary. Pull the vines that winter, removing as much of the larger root system as possible. Make any desired soil amendments (such as liming) and thoroughly cultivate the site. Plant the site to a grass cover crop, such as fescue, and control weeds through mowing for at least two years. Reestablish the vineyard using virus-tested stock grafted to 5C or C-3309 rootstock. If Vidal is reestablished, it too should be grafted.

2. An alternative approach, but one which has some inherent limitations, is to kill and pull vines as described above but leave the trellis intact. Control weeds under the trellis and in the alleys. Apply lime if needed. Cultivate the row middles if a grass cover crop is not present and then establish a cover crop. Keep the site free of broad-leaved weeds and replant in one to two years with grafted vines. Plant the vines between former vine locations, rather than using the same spacing in the row. This will alter the relationship between vine spacing and post spacing but should result in better establishment of the new vines.

Insect Pests and Mites

Numerous insects and several mite species can attack bunch grapes. Some, such as the grape berry moth, are chronic pests in almost all vineyards. Many others, such as aerial phylloxera, affect a small proportion of vineyards in numbers large enough to require the use of control measures. The insects described in this section are often found in damaging numbers in commercial Virginia and North Carolina vineyards.

Japanese Beetles

Among the most visible feeders of grape foliage are Japanese beetles, which account for the greatest number of insecticide applications in many vineyards. Despite the insect's intensive feeding and the resultant grower concern, vigorous grapevines can tolerate a certain amount of beetle defoliation.

Japanese beetles overwinter as larvae in the soil, where they feed on grass roots in the autumn and spring. Following pupation, adult beetles emerge in late spring and may be present in vineyards until September. The adult beetles are approximately ½ inch long and are green with copper-colored wings. The beetles feed on leaves, often in large numbers, but rarely feed on fruit. Feeding is concentrated on the upper, younger leaves of the canopy. Mating occurs and eggs are deposited in the soil, where the young larvae feed on grass roots and where they overwinter.

A certain amount of defoliation is tolerable with established, vigorous grapevines. As a rule, if vines retain at least 15 healthy leaves per shoot, no delay of fruit maturation should occur. Occasional insecticide sprays may be necessary to keep feeding within tolerable limits. Young or weak vines should be protected more diligently. Broad-spectrum insecticides, such as carbaryl, are effective against Japanese beetles but have the undesirable effect of reducing beneficial insect populations. Indeed, intensive insecticide applications can increase the incidence of certain secondary pests, such as European red mites. Thus, insecticides should be used judiciously.

A bacterial insecticide is commercially available for lawn and turf application to control Japanese beetle larvae feeding. This product (milky spore disease) may reduce injury to turf by larval feeding but it is unlikely to have a measurable impact on the number of adult beetles that fly into a vineyard. Similarly, attractant traps are unlikely to trap enough adults to reduce beetle levels effectively. Traps may actually attract more beetles from afar and result in greater feeding injury than if traps were not used.

Grape Berry Moth

The grape berry moth is widely distributed east of the Rocky Mountains. It overwinters in pupal form. Adults emerge in early to mid-May in Virginia but somewhat earlier in North Carolina. Mating occurs and the first generation eggs are deposited on flower clusters at or before bloom. Newly hatched larvae feed on the blossoms and small berries, webbing clusters together and often destroying the entire cluster. In three to four weeks the larvae become full grown and pupate. Second-generation moths emerge in 10 to 24 days and repeat the mating and egg deposition processes. At least three and possibly four generations of grape berry moths have been observed in Virginia. Second and subsequent generation larvae feed on developing berries. After véraison the infested berries may be prone to fruit-rotting organisms.

Adult moths, which do no direct damage to grapes, have a wing spread of about ½ inch and are drab brown with a gray or blue band across the back. The larvae are greenish or gray-green and may exceed ½ inch in length. Some reduction in damage may be obtained through cultivation of leaf litter under the trellis in early spring before first-generation adults emerge. Pheromone mating disruption has been found effective under certain conditions in Virginia.

Grape Phylloxera

The grape phylloxera is native to the eastern United States but is of little importance on the grapes native to eastern North Carolina. The biology of this plant louse is very complicated. One form of this aphid-like insect feeds on foliage, where it causes gall-like growths. Other forms feed on the roots of the grape. American species of grape, such as *Vitis riparia, V. labrusca,* and *V. rupestris,* are generally tolerant of the root feeding that occurs, although their foliage may be heavily infested with aerial forms. *V. vinifera* varieties are severely injured by phylloxera root feeding and for this reason must be grafted to pest-resistant rootstocks in this region. Several commercially important hybrid grape varieties, including Seyval and Villard blanc, are highly susceptible to aerial phylloxera feeding. Six or more generations occur per year, and galling may be severe enough to warrant an insecticide application. Feeding and galling are most severe on young, recently emerged leaves.

Grape Root Borer

The grape root borer is the larval stage of a clear-wing moth. The adults resemble a wasp. They are dark bronzed brown and yellowish orange and measure about 1 inch in length. The larvae measure 1 inch or more in length and are generally white with brown heads. Eggs are laid on foliage in late summer. One moth may lay as many as 400 eggs during August and September. Eggs hatch promptly; the larvae drop to the soil and bore into the crown and larger roots, where they feed for two or three years. The extensive injury to roots results in loss of vine vigor, reduced yields, and eventual death of the vine. Pupation and emergence usually occur in the summer of the second year. Pupation takes place in cocoons near the soil surface. In Virginia, adults emerge from mid-July to late July, and their shed pupal cases may be observed near the base of affected vines. Adult moths do not feed on grapes, but mating occurs and additional eggs are laid.

Control of this destructive insect is difficult. Registered insecticides for the larval stage are available, but their efficacy is uncertain. One cultural control measure involves mounding soil beneath the vines after the larval stage has pupated in late June. In theory, the adults are then unable to dig to the surface when they exit their cocoons. Timing of mounding is critical and varies with vineyard location: if done too early, the larvae simply tunnel into the mounded soil before pupating; if done too late, the adults may have already emerged.

Climbing Cutworms

Climbing cutworms are a group of related moth species whose larvae can feed on grapevine buds. Cutworm feeding results in lack of shoot development from swollen buds or destruction of recently emerged shoots. Cutworm larvae feed at night and seek shelter in soil and debris during the day. The larvae are smooth, brown or gray, and have stripes running the length of their bodies. A quick search around the base of an affected vine can usually reveal the pest.

Feeding begins in the spring when buds begin to enlarge. The extent of damage depends not only on the cutworm population but also on the duration of the bud-break stage. During cool springs, when the period from bud swell to bud break is delayed, damage can be extensive. Vineyards should be monitored carefully for cutworm feeding in the period leading up to bud break and for a week or two thereafter. Treatment with an insecticide is warranted if feeding affects more than 2 percent of the buds. Cutworm control can be improved by spraying in the late afternoon or early evening to ensure that fresh residues are present when feeding commences.

Bees and Wasps

Bees and wasps usually feed on ripe grapes through injuries caused by other insects, birds, and splits in the skins of overripe berries. Some large wasps are capable of causing direct injury to berries, but honey bees and most wasps are only opportunistic feeders attracted to split or otherwise damaged berries. Insecticides with either zero or very short preharvest interval restrictions may be sprayed to provide some control of bees and wasps. Pickers with severe allergies to bee stings should be advised of sting risks if bees are present at harvest. Latex rubber gloves can provide some protection against stings. Although not extensively tested, some growers have reported limited success at reducing bee populations by locating and destroying nests and by using commercially available bee traps.

European Red Mite

The European red mite is the principal mite pest of grapes in this region. This mite overwinters as tiny brick-red eggs concentrated around the nodes of canes. The eggs hatch in early spring, and nymphal stages begin feeding on young leaves. Adult mites are red and no larger than the period at the end of this sentence. Six or more generations may occur per year, with the peak population often occurring in late August or September. Deposition of winter eggs begins in August and continues into the fall. Mite feeding causes grape leaves to develop a uniform chlorotic or brownish cast, sometimes referred to as mite bronzing. Older leaves show symptoms before younger leaves. With severe infestations, the impaired photosynthesis caused by mites can delay sugar accumulation. Infestation and foliar symptoms usually develop in “hot spots” but will soon spread to entire vineyard blocks if the mite population continues to build unchecked by miticides or natural predators.

If European red mites were numerous in the previous year and overwintering eggs are common, a superior oil spray should be applied at the rate of 2.0 gallons of oil per hundred gallons of water per acre. Apply the oil about the time of bud break. Sprays applied much earlier will have less effect on mite eggs. Superior oil may be applied after green tissue is exposed; however, the oil should not be mixed with other pesticides and should not be applied if a frost is expected within 48 hours. Oil acts by suffocating the eggs and is most effective if applied just before mite eggs hatch. Oil sprays will delay or prevent mites from reaching economically damaging levels. If population development is sufficiently delayed, natural enemies may be able to suppress the buildup.

When miticides are needed, apply well-timed sprays. Apply sprays only to economically important populations. An action threshold for use on grapes has been provisionally set at 5 mites per leaf (10 mites per leaf on labrusca types). Such recommended treatment levels are approximations because of variability among varieties, crop loads, plant stress, weather, and other environmental interactions. When mites exceed these levels, monitor populations closely to determine foliar injury. Heavy bronzing of foliage must be prevented, but minor bronzing is tolerable. In fact, if minor visible injury is tolerated, the likelihood of eventual biological control increases. Most miticides currently available work best on motile (nonegg) stages. Applying such a spray kills the active mites present, but many eggs will survive and hatch. This surviving generation may require a second miticide application 7 to 10 days after the first spray.

Miticides should be used cautiously. Most are relatively expensive, and mites have a tremendous potential to develop resistance to miticides, making control measures ineffective. Mites are secondary pests, rising to economic status after elimination of their natural enemies by sprays for key pests such as Japanese beetle and grape berry moth.

A variety of predators attack the European red mite. Examples are *Stethorus punctum,* a small lady beetle adapted to feeding on mites, and *Amblyseius fallacis,* a predatory mite. Avoid pesticides that are detrimental to predatory populations. Unfortunately, one insecticide very damaging to mite predators is carbaryl, widely used in vineyards. Even some noninsecticidal pesticides are damaging to *Amblyseius,* such as benomyl, captan, and even paraquat when applied while the predatory mites are in their overwintering quarters in the ground cover.

Wildlife

Birds

Many species of birds are fond of ripe grapes and will quickly cause appreciable crop loss if not controlled. Birds are daytime feeders and can be identified if you happen to be in the vineyard when they are present. Otherwise, the clues to bird feeding are peck marks in individual berries, remnants of berry skins retained on the rachis (cluster stem), and selective feeding on individual berries of the cluster, leaving the rachis intact. Birds tend to consume the darkest pigmented berries first, leaving the greener, unripe berries for a later day. Feathers in the vine are an obvious clue. Vines under or close to roosting areas such as a treeline or overhead power lines are the most vulnerable. Dark-fruited, small-berried winegrape varieties are particularly susceptible, as are all seedless varieties.

Options to control bird feeding are diverse; few are entirely effective. They include recorded distress calls played on audio equipment in the vineyard; electrical wires mounted in the vineyard to shock birds attempting to land; various reflective materials intended to frighten; gas cannons with loud, frightening reports; various balloons and kites suspended above the vineyard intended to simulate bird predators; shooting; and enclosing the vines in netting to exclude birds. All of these devices have limitations. Most birds will eventually overcome their aversion to the various scare tactics. Bird netting, although laborious to apply and remove as well as expensive, is the choice where total, environmentally benign control is desired.

Deer

The white-tailed deer is remarkably adaptable and can be found in rural as well as suburban settings. Deer depredation may be identified by sighting the deer in the vineyard or by their pattern of feeding. Deer lack upper incisors and feed by tearing off leaves, shoots, and ripening grapes. Their feeding produces jagged edges that distinguish deer browsing from damage caused by other animals. Look for rachises that are torn or shredded and shoot tips and leaves that have been stripped. Deer may be deterred from vineyard feeding by various scare tactics, repellents, fencing, or regulated shooting. Each method has limitations. Whatever method or methods are used, they should be implemented well before the damage becomes intolerable. Once deer have learned about the source of food, it will be exceedingly difficult to discourage them.

SCARE DEVICES. Scaring deer with noisemakers or visual objects offers, at best, a temporary solution. Scare tactics include propane cannons, electronic acoustic recordings, pyrotechnics, and physically patrolling the vineyard with people or dogs. Noise emitters should be moved every few days so that deer do not become accustomed to the sounds. Their disadvantage is that they often become a nuisance to vineyard owners or neighbors. Permitting domestic dogs to roam the vineyard deters deer to a limited degree.

REPELLENTS. A wide range of taste- or odor-active repellents are available (Table 8.1). Taste repellents are usually sprayed directly onto the plant and are formulated to be distasteful to

Table 8.1. Examples of Commercially Available Deer Repellents for Crop and Noncrop Use

Product	Manufacturer	Mode of Action	Active Ingredients
Hinder Deer and Rabbit Repellent	Thompson Hayward Chemical Company 5200 Speaker Rd Kansas City, KS 66106	Taste/odor	Ammonia; mixed rosin and fatty acids
Magic Circle Deer Repellent	J.C. Ehrlich Chemical Co. 840 William Lane Reading, PA 19612	Odor	Bone tar oil
Hot Sauce Animal Repellent	Miller Chemical and Fertilizer Co. P.O. Box 333 Hanover, PA 17331	Taste	Capsaicin
Deer-A-Way	Deer Away 7744 W. 78th St. Minneapolis, MN 55435	Odor and taste	Putrescent egg solids
Big Game Repellent	McLaughlin Gormly King Co. 8810 Tenth Ave. N. Minneapolis, MN 55427	Odor and taste	Putrescent egg solids

Note: Products in this table may be obtained through pesticide or fertilizer supply companies. Be certain to read the entire label before purchasing and using these or other crop protection chemicals. Some animal repellents are registered by the U.S. Environmental Protection Agency as pesticides, and use of those products in a manner inconsistent with their labels is prohibited by law. The Virginia and North Carolina Cooperative Extension Services do not endorse these products and do not intend discrimination against other products that may also be suitable.

deer. Because of the potential to leave distasteful residues, some of these products may be restricted to use on nonbearing vines or used only during the period before fruit set. As with nonsystemic fungicides and insecticides, sprayable repellents must be reapplied after heavy rains and as new, unprotected growth develops. Odor repellents deter deer by scent alone. Some products include ingredients that deer associate with humans, such as aromatic constituents of soaps. Depending upon formulation, the odor repellents may be sprayed on or around vines or mounted on the trellis. Here are some keys to using repellents effectively:

❑ Apply the repellent before damage occurs. Periods when damage is likely may be predicted by past experience. Do not allow a feeding pattern to become established.

❑ Feeding pressure will be greatest when alternative food sources are scarce. Repellents may work well when other food is available but may fail miserably if little else is available for deer. This may partially explain year-to-year variation in repellent effectiveness or mixed results among different vineyards.

❑ Monitor the effectiveness of the repellents. Reapply them or alternate with other tactics if necessary.

❑ Rotate repellents or implement alternative strategies so that deer do not become accustomed to a specific odor or taste.

Besides sprayable repellents, at least three other odor-active repellents have shown some measure of effectiveness in vineyards and orchards.

1. Human Hair. The odor of humans deters deer. Hair can be obtained from barbershops. Place a handful in a mesh bag and hang it from trellis wires around the perimeter of the vineyard. Replace it yearly before the fruit ripens.

2. Animal Tankage. A mixture of blood and other animal products from slaughterhouses or poultry-processing facilities may be used as a deer repellent. Place ½ to 1 cup of this mixture in mesh bags and hang them from trellis wires around the vineyard perimeter before the fruit attracts deer. Note, however, that this material may attract dogs and other animals.

3. Soap Bars. Purchase small hotel-use soap bars by the case. Leave the wrappers on to slow weathering. Drill a hole in each bar and thread a string through it; then hang the bars from trellis wires around the perimeter of the vineyard. Fragrant soaps are particularly alarming to deer.

FENCING. Fencing is probably the most effective means of excluding deer from vineyards. Although the initial costs may be high, the near-perfect protection afforded makes fencing economical, especially taking into account the fact that a well-constructed fence will last 20 years or more. Fencing may be either electrified or nonelectric. Nonelectric fences are usually made of a woven mesh and may be 8 to 12 feet in height. The advent of high-tensile-strength (HT) fence wire, coupled with high-voltage, low-impedance electric fence chargers, has made electric fencing the preferred option for deer fences. Many designs exist, but the least complicated may be the most effective and easiest to install and maintain. The six-wire vertical design depicted in Figure 8.6 shows an effective, modified version of the Penn State five-wire design. An optional hot (+) wire located about 4 or 5 inches above the ground will provide good deterrence of raccoons and other small animals; however, it is essential that the soil under the fence be kept free of weeds that can reduce the effectiveness of the fence charger if they contact the positive wires. The six-wire fence is only about 5 feet tall, a height that deer have no difficulty in jumping. However, approaching deer will first attempt to crawl through or under the fence before jumping. The high-energy output of the charger modifies deer behavior, training deer to avoid the fence.

Products for HT electric fencing are available from numerous sources, including those

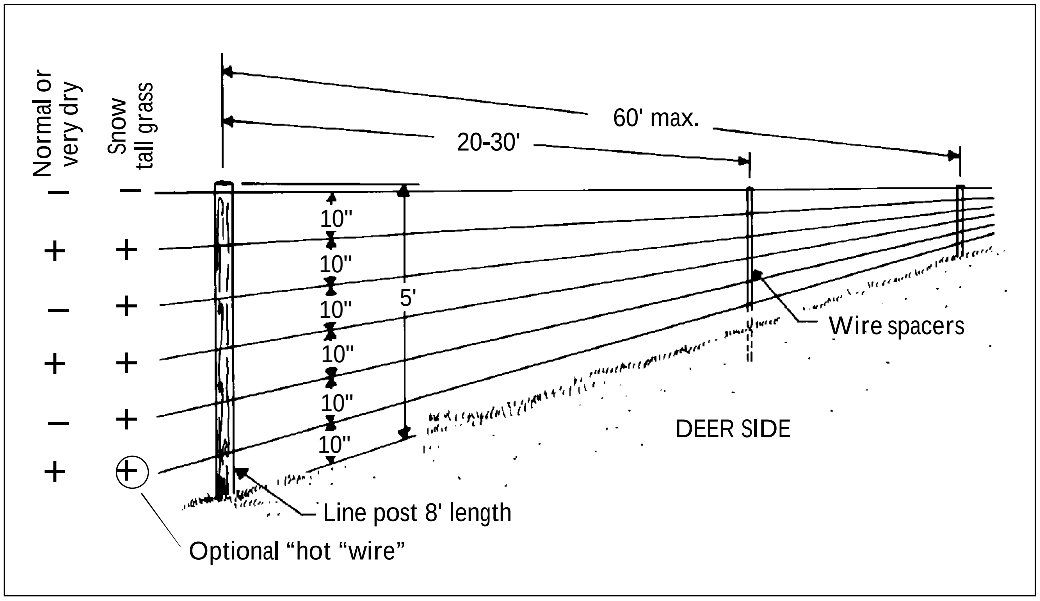


Figure 8.6 An effective design for a six-wire electric fence to exclude deer from the vineyard.

listed at the end of this chapter.* Properly charged fences produce an extremely unpleasant but noninjurious shock. Therefore, electric fences should always be posted to alert people to avoid accidental shock.

Electric fences must be kept charged continuously. Upon being questioned, most growers who complain about ineffective electric fence operation confess that the fence was not constantly charged. It is best to erect the fence before the vineyard ever bears a crop; the deer are much less tempted to investigate what is on the other side. Clear at least 10 feet of brush and trees from the outside (deer side) of the fence. This gives uninitiated deer plenty of room to approach the fence, touch it with their moist noses, and receive a shock. Keep vegetation, including weeds, clear of the charged wires. When vegetation touches the wires, it drains off some of the energy, resulting in rapid battery discharge and insufficient shocking energy. A preemergence herbicide can be applied under the fence to keep weeds down.

Depending upon terrain and how much brush clearing is involved, a battery-operated, solar-recharged, six-wire electric fence can be installed around a 5-acre vineyard for $1,500 to $2,000 in material costs.

* Fence chargers energize the fence in short bursts (0.0003 second long) one or two times per second. The energy is measured in joules (watts X seconds) and varies from less than 1 to more than 9 for typical fence chargers. The resistance of the fence is measured in ohms and increases with the length and the number of "shorts," such as those caused by vegetation contacting the energized wire or wires. Battery-operated chargers are suitable for energizing up to 15 miles of fencing and may be recharged during daylight hours with solar panels. Chargers operated by alternating current (AC) from the electrical mains are preferred in other cases because of their reliability and freedom from the need to recharge batteries.

REGULATED SHOOTING. Under certain conditions, farmers, including grape growers, can obtain permits to selectively destroy deer that are causing crop damage. Virginia has several programs involving regulated harvests of deer. Least desirable, but sometimes necessary, is the issuance by the Department of Game and Inland Fisheries of "closed season kill permits." These special permits can be obtained from your local game warden when circumstances do not warrant deferring control until hunting season. Before permits are issued, you must demonstrate to a game warden that deer damage is occurring. In Virginia, you can find your local game warden by calling the department's Richmond office at 804-367-1000.

The Damage Control Assistance Program, a deer control program administered by the Department of Game and Inland Fisheries, offers an alternative to destruction of deer outside the normal hunting season. Under the program, the grower is issued damage seals based on investigations by the local game warden, who must verify damage and explain the options available to the grower. The number of seals issued depends upon the intensity of damage at the site. Harvesting of deer then occurs during the regular deer firearms season, not at the time the damage occurs.

References

Pearson, R. C., and A. C. Goheen. 1988. Compendium of Grape Diseases. St. Paul, MN: APS Press. 93 p.

West Virginia University (WVU) Cooperative Extension offers a series of excellent publications on deer and deer control strategies, including electric fence design and construction. Information on these publications can be obtained by contacting WVU Cooperative Extension in Morgantown, West Virginia.

Consult your county Cooperative Extension Service agent for current pesticide recommendations.

Supplies and Services

Suppliers of fencing and electric fence charging materials include:

Gallagher Power Fence, Inc.
18940 Redland Road
PO Box 708900
San Antonio, TX 78270
(512) 494-5211

West Virginia Fence Corp.
U.S. Rt. 219
Lindside, WV 24591
(304) 753-4387

Kiwi Fence Systems, Inc.
RD 2 Box 51A
Waynesburg, PA 15370
(412) 627-8158

Kencove Farm Fence
111 Kendall Lane
Blairsville, PA 15717
(800) 536-2683

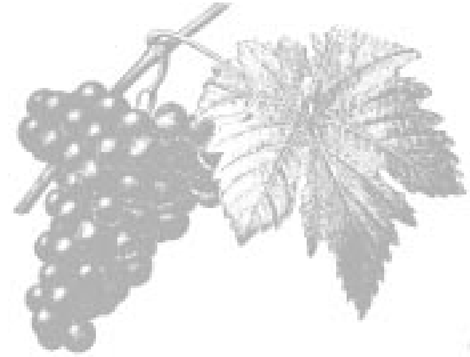
Laboratories offering disease testing services for viruses and Pierce's Disease:

AgDia
30380 County Rd. 6
Elkhart, IN 46514
(219) 264-2014

Agri-Analysis Associates
45133 County Rd. 32-B
Davis, CA 95616
(916) 757-4656

Chapter 9

Vine Nutrition



Grapevines require 16 essential nutrients for normal growth and development (Table 9.1). Carbon, hydrogen, and oxygen are obtained as the roots take in water and as the leaves absorb gases. The remaining nutrients are obtained primarily from the soil. Macronutrients are those used in relatively large quantities by vines; natural macronutrients are often supplemented with applied fertilizers. The micronutrients, 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, reduced growth or crop yield, and greater susceptiblity to winter injury or death. The availability of essential nutrients is therefore critical for optimum vine performance and profitable grape production.

Table 9.1. Nutrients Essential for Normal Grapevine Growth and Development

Obtained from Air and Water	Obtained from Soil: Macronutrients	Obtained from Soil: Micronutrients
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 whether 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 planting. That slow growth is due to a small root system and minimal carbohydrate reserves in the rooted cutting or grafted vine. Trying to stimulate growth with fertilizer application is tempting. Unfortunately, young vines are occasionally injured more than benefited by fertilizer applied during the first season. Under most conditions, if the vineyard soil was well prepared and the soil pH was adjusted before planting, vines will require very little if any fertilizer in the first few years of growth.

Poor growth of young vines is more often due to lack of water, competition by weeds, overcropping, or poor disease control than to inadequate soil fertility. Fertilizer will not compensate for those stresses. Besides possible root burning, excessive nutrient availability can lead to poor wood maturation in the fall and subsequent cold injury during the winter. Applying soil fertilizer in the year of planting is therefore recommended only if the soil is inherently infertile. In that case, a 4-ounce-per-vine application of a 10-10-10 fertilizer (or one having an equivalent nitrogen analysis) is generally sufficient. The fertilizer should be applied in a ring 12 to 18 inches from the base of the vine after planting or just before bud break for vines set the previous fall.

As an alternative to soil application, a foliar fertilizer can be used on young vines. The foliar fertilizer provides a rapid but temporary response. Sprayable 20-20-20 fertilizer or materials of a similar analysis are suitable, but read the fertilizer directions for rates of application and precautions.

Assessing Nutrient Needs of Mature Vines

As vines mature and crops are harvested, many vineyards 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 overstimulating 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. Therefore, it is important that growers have a sound basis for determining the fertilizer needs of their vines.

No single method exists for accurately assessing vine nutrient needs. Instead, a combination of soil analysis, plant tissue analysis, and visual symptoms should be used. These methods are discussed in detail in the following sections of this chapter.

Soil Analysis

Physical soil features should be evaluated in the site selection process. (See chapter 4.) 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 farmland.

Detailed soil analyses must be made before the vineyard is established, primarily to determine pH but also soil fertility. Soil test kits are available from some county Cooperative Extension Centers or from commercial laboratories. (See the listing of soil and plant tissue testing services at the end of this chapter.) 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 larger than 2 or 3 acres should be subdivided and each section sampled separately if there are differences in topography or soil classification. Collect samples when the soil is moist and not frozen; fall is an excellent time. Each sample should consist of 10 to 20 subsamples 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 from the 0- to 8-inch depth and a second from the 8- to 16-inch depth. Grape roots can grow much deeper than 16 inches in loose, well-aerated soil. Because the ability to alter soil characteristics significantly below that depth is very limited, there is little point in collecting deeper samples.

Soil test results will indicate whether adjustments to pH and macronutrients are necessary. Soil test data are not customarily used to assess the need for nitrogen or trace elements for vineyards, although tests for those nutrients can be included if there are reasons to suspect a deficiency. The test results are accompanied by specific recommendations for correcting soil deficiencies.

Perhaps the most important information provided by the soil test is the pH value. Soil pH is a measure of acidity or alkalinity on a scale from 0 to 14. A value of 7 is neutral. Values less than 7 reflect acidity, whereas numbers above 7 indicate 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 a pH of 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 previous additions of lime or acidifying fertilizers.

Grape species differ substantially in 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 (such as Concord and Niagara) and the hybrids of American species and *V. vinifera* (for example, Seyval and Vidal blanc) tolerate lower pH values (5.0 to 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 very difficult to increase the pH below the top few inches of soil once vines have been 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 (for example, ground limestone) have very low solubilities and will move very little, if at all, below the first few inches when applied to the soil surface. Even with cultivation, lime incorporation beyond about 12 inches is unlikely with conventional tillage equipment. Subsoil pH can be raised somewhat by applying lime and cultivating deeply (12 to 18 inches) with a chisel plow or subsoiler. Research has been conducted with lime injectors, but that technology is not available to most grape growers.

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

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 typically involves spreading ground limestone, which contains calcium carbonate or mixtures of calcium and magnesium carbonate. Limestone containing 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 is 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 liming material is often 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 soil pH, texture, and organic matter content; the grape species to be planted; and the type and particle size of lime used. Obviously, recommendations cannot be provided here for all situations. Table 9.2, however, provides some guidelines for liming based on initial pH and soil type. In practice, individual rates of lime application should not exceed 4 tons per acre. Where soils are strongly acidic, several applications of 2 to 3 tons per acre each over a period of several years will likely be more effective than a single, massive dose.

Table 9.2. Estimated Quantity of Lime (Ground Limestone) in Tons Per Acre Required to Increase pH Values in Three Different Soil Types

	Soil Type		
pH of Unlimed Soil	**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	
4.0	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

Analyzing plant tissue 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, which indicates 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 (1) a standardized tissue sampling procedure; (2) accurate and precise analytical methods for determining the elemental concentrations of tissue samples; (3) standard references with which to compare diagnostic sample values; and (4) a means of interpreting diagnostic data and making sound fertilizer recommendations to the grower.

In practice, a grower collects the tissue sample and submits it to a laboratory for analysis. The laboratory technician 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 adequate, high, or low (deficient). Fertilizer recommendations to increase the concentration of nutrients that are low or deficient can be made either by laboratory personnel or a grape specialist. University and commercial laboratories can provide further information on submission procedures. (See the listing of soil and plant tissue testing services at the end of this chapter.)

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

ROUTINE NUTRIENT STATUS EVALUATION. The general nutrient status of vines should be evaluated annually or every other year to gauge the vineyard's need for or response to applied fertilizer. These tests will usually detect deficiencies before symptoms become visible. Corrective fertilizer applications are then usually unnecessary because minor deficiencies can be corrected by adjusting the fertilizer used in routine maintenance applications.

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 than at véraison (onset of rapid fruit maturation) or near harvest. For other nutrients, such as potassium, research has shown that foliar concentrations in late summer (70 to 100 days after bloom) are better correlated with vine performance than are concentrations diagnosed at bloom. One might ideally sample vines at different times of the season to evaluate different nutrients, but 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 change rapidly in the early part of the growing season, it is important to sample as close to full bloom as possible.

Sample each variety separately because nutrient concentrations may vary somewhat among varieties. Collect a total of 100 petioles from leaves located opposite the first or second flower cluster from the bottom of the shoot. Petioles are the slender stems that attach the leaf blade to the shoot (Figure 9.1). Collect petioles systematically throughout the vineyard block to ensure that the entire block is represented. If different portions of the vineyard (for example, hills versus low-lying areas) exhibit differences in vine growth, collect separate samples 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.

Commercial and some university laboratories 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 9.3.

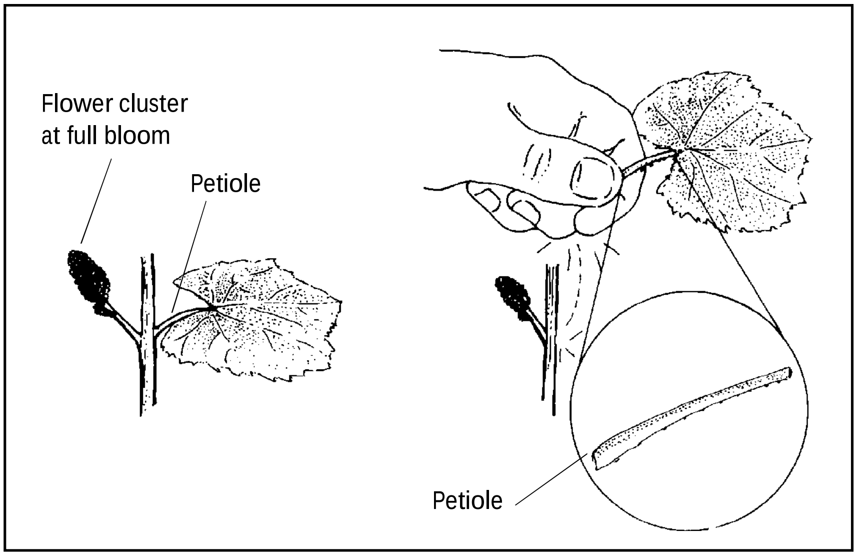


Figure 9.1. Remove and retain only the leaf petiole for tissue analysis. Collect petioles from leaves located opposite the bottom flower cluster at full bloom.

Table 9.3. Sufficiency Ranges of Essential Elements Based on Bloom-Time Sampling of Leaf Petioles

Nutrient[a]	Sufficiency Range	
Nitrogen	1.20 – 2.20	%
Phosphorus[a]	0.15 – ?	%
Potassium	1.50 – 2.50	%
Magnesium	0.30 – 0.50	%
Iron[a]	40 – ?	ppm
Manganese	25 – 1,000	ppm
Copper	7 – 15	ppm
Zinc	35 – 50	ppm
Boron	30 – 100	ppm

[a] Nutrients of Table 9.1 that are not shown here are those that are unimportant from a nutrient management perspective or those for which reliable standards have not been established for Virginia and North Carolina vineyards.

Concentrations that exceed the sufficiency range do not necessarily indicate a problem. For example, recent applications of fungicides that contain manganese, copper, or iron can elevate the test results for those elements.

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 of potassium, a second set of samples should be collected 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 five to seven leaves back from the shoot tip. Separate the petioles from leaf blades and submit only the petioles as described above.

DIAGNOSING VISIBLE VINE DISORDERS. For trouble-shooting suspected nutrient deficiencies, sample anytime 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 nonsymptomatic or healthy leaves in 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.

Visual Observations

Inspections of foliage for symptoms of nutrient deficiencies and observations of vine vigor and crop size provide important clues as to whether vines are suffering nutrient stress. However, it is possible to be misled by foliar disorders because some are not nutritional in origin. For example, some herbicide toxicity symptoms are similar to those of certain nutrient deficiencies. And, to the inexperienced person, 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 expected to occur first at higher sites because of thinner topsoil and reduced moisture. Soil moisture aids movement of nutrients to the root-soil interface, and under drought conditions, nutrient deficiencies can develop.

Vine-to-vine variation in symptoms also provides 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 symptomatic vines, suggest a biological pest. Leafroll virus, for example, will produce distinct foliar symptoms on some red-fruited varieties (for example, Cabernet franc), 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 appear on older or midshoot 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 particular pattern of symptoms on individual leaves can also yield information. Specific patterns for individual elements are described in the following section and are summarized in Table 9.4 for three commonly deficient macronutrients.

In addition to foliar symptoms, observations of vine vigor and fruit set and 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, first consider that water stress, overcropping, and disease can also constrain growth. Poor fruit set, straggly clusters, and uneven berry size and shape could suggest a

Table 9.4. Characteristics of Foliar Symptoms of Nitrogen, Potassium, and Magnesium Deficiencies

	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 or chlorosis	Basal to midshoot leaves
Potassium	Interveinal and marginal chlorosis	Necrosis or scorching of leaves from margins inward	Midshoot leaves
Magnesium	Interveinal chlorosis that does not extend to leaf margin on at least some leaves	Necrotic spots and leaf chlorosis, including chlorosis of leaf margins	Basal to midshoot leaves

boron deficiency. Remember that similar symptoms might point to a tomato ringspot virus infection.

It should be obvious, then, that the diagnosis of nutrient deficiencies depends on experience and should be confirmed with a combination of visual examination and laboratory tests.

Specific Nutrient Deficiencies and Their Correction

Fortunately, of the 16 essential elements required by grapevines, only nitrogen, potassium, magnesium, and boron are commonly deficient in this region. This section provides an overview of the role of these nurtients, the symptoms of deficiencies, and options for correcting the deficiencies.

Nitrogen

ROLE OF NITROGEN. Vines use nitrogen to build many compounds essential for growth and development. Among these are amino acids, nucleic acids, proteins (including all enzymes), 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 classic symptom is a uniform light green color of leaves (Figure 9.2), as compared to the dark green of vines that receive adequate nitrogen. Nitrogen deficiency is considered severe if leaves show this uniform light green color. Other clues pointing to nitrogen deficiency are slow shoot growth, short internodal length, and small leaves. Insufficient nitrogen can also reduce crop yield through a reduction in clusters, berries, or berry set. Thus, nitrogen deficiency might be observed as a reduction in yield over several years. It is important to remember, however, that other factors such as drought, insect and mite pests, and overcropping can also cause similar symptoms.

Figure 9.2. Nitrogen deficiency symptoms.

EXCESSIVE NITROGEN. Nitrogen stimulates vegetative growth. If excess nitrogen is available to vines, excessive vine growth may occur. Shoots of such vines can grow late into the fall and may attain a length of 8 to 10 feet. 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 causes growth to continue late in the season.

Yields can also suffer from excessive nitrogen uptake. Yield reductions can result from reduced bud fruitfulness caused by shading of buds in the previous year. Yields can also be reduced by 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 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 undoubtedly 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 that most commonly must be added routinely. 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 removes approximately 18 pounds of nitrogen per acre from the vineyard. The reduction in nitrogen is even greater if cane prunings (about 0.25 percent nitrogen) are removed from the vineyard.

Given a removal of nitrogen in the crop and prunings with no input (fertilizer), most soils will eventually be depleted of readily available nitrogen. Nitrogen depletion occurs most rapidly in soils having 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 other forms (ammonia 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 (for example, *Vitis vinifera* varieties) are often more vigorous than nongrafted 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. No single index serves well as a guide in assessing the vine's need for nitrogen fertilizer. Instead, a number of observations should be made over several consecutive years to determine the vine's nitrogen status. Vines can be grouped into three general categories with respect to their nitrogen status: deficient, adequate, and excessive.

Nitrogen deficient vines commonly exhibit these symptoms:

- ❑ Vines consistently fail to fill the available trellis with foliage by the first of August.
- ❑ Crop yield is chronically low.
- ❑ Cane pruning weights are consistently less than ¼ 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 midsummer.

❑ Fruit quality may be poor, including poor pigmentation of red-fruited varieties.

❑ Bloom-time petiole nitrogen concentration is less than 1 percent.

If the nitrogen status is adequate, vines typically exhibit these characteristics:

❑ Vines fill the trellis with foliage by the first of August.

❑ Yields are acceptable.

❑ Cane pruning weights average 0.3 to 0.4 pound per foot of row.

❑ Mature leaves are of a size characteristic for the variety and are uniformly green.

❑ Shoots grow rapidly and have internodes 4 to 6 inches long.

❑ Shoot growth ceases in early fall.

❑ Fruit quality and the maturation period are normal for the variety.

❑ Bloom-time petiole nitrogen concentration is between 1.2 and 2.2 percent.

With excessive nitrogen, vines may present these symptoms:

❑ Shoots fill trellis with an excess of foliage: shoots are 8 to 10 feet long by mid-July.

❑ Fruit yields are low because there are few clusters, poor fruit set, or both.

❑ Cane pruning weights consistently exceed 0.4 pound per foot of row (for example, 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; internodes are long (6 inches or more) 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 as typical of nitrogen-deficient vines does not prove that nitrogen is limiting growth. Drought, in particular, can 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 far better to prevent nitrogen deficiency than to wait until correction of a deficiency is necessary. Maintaining an appropriate nitrogen status is based on experience, observations of vine performance, and supplemental use of bloom-time petiole analysis of 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 application of nitrogen fertilizer is warranted, a prudent starting point is to apply it at a rate of 30 to 50 pounds of actual nitrogen per acre. Do not be surprised if an initial application of nitrogen has no pronounced effect in the year of application. It sometimes takes two years for added nitrogen to have an impact on vine performance because much of a vine's early-season nitrogen needs are met by 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.

Several forms of nitrogen fertilizer are commercially available. All will satisfy the vines' needs (Table 9.5). Urea or ammonium nitrate are commonly the most economical forms in this region. 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 but unpredictable means of incorporation. As an alternative, soil cultivation, as by dehilling of grafted vines, is acceptable. Recommendations

Table 9.5. Common Nitrogen-Containing Fertilizers

Nitrogen Source	Percentage of Actual Nitrogen	Price Per 50-pound Bag[a]	Cost Per Pound of Actual Nitrogen
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

Note: 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.
[a] Prices quoted are those for northern Virginia in 1993. Prices are significantly lower if the product is purchased in bulk. However, the quantities of nitrogen needed in most Virginia and North Carolina vineyards do not warrant the inconvenience of bulk handling.

for application of actual nitrogen must be translated into rates based on commercial formulations. A recommended application rate of 40 pounds of actual nitrogen per acre, for example, would require 87 pounds of urea, 114 pounds of ammonium nitrate, or 190 pounds of ammonium sulfate per acre.

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

Apply nitrogen in a band under the trellis rather than broadcasting it over the entire vineyard floor. Under-trellis application can be done either by placing the fertilizer in a ring around individual vines or by banding it 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 the trunks — is a practical alternative for small vineyards. Regardless of the method used, apply nitrogen only 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, protein synthesis, solute transport, and 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 toward the center of the leaf. Leaf tissue adjacent to the main veins remains darker green, at least when the potassium deficiency is mild (Figure 9.3). Midshoot 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 upward or downward. Severe potassium deficiency also reduces shoot growth, vine vigor, berry set, and crop yield. Fruit quality suffers from reduced accumulation of soluble solids and poor coloration.

The symptoms described 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 when the soil pH is very basic (greater than 7.0) or acidic (less than 4.0). Experience and tissue analysis results from Virginia vineyards have rarely shown a need for added potassium. Indeed, excessive 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 the fruit may have an undesirably high 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 indicated that late-summer tissue sampling (70 to 100 days after bloom) was superior to bloom-time sampling for accurately gauging the vines' potassium status. Thus if visual observations (Table 9.4) or the bloom-time tissue analysis used for other nutrients indicate a marginal potassium level (Table 9.3), additional tissue samples should be tested in late summer to confirm the need for added potassium. Petioles of recently matured leaves (about the fifth to seventh back from the shoot tip of non-hedged shoots) are collected for late-summer samples. As in sampling for other nutrients, separate samples should be collected from regions of different topography or soil type.

Figure 9.3. Potassium deficiency symptoms. (Photo courtesy of T.J. Zabadal.)

CORRECTING POTASSIUM DEFICIENCY. Potassium deficiency is corrected by applying potash fertilizer. Short-term correction can be made with foliar-applied potassium fertilizer; however, the less-costly and longer-lasting remedy is soil application. Two commonly used potash fertilizers are potassium sulfate and potassium chloride (also called muriate of potash). Potassium chloride is generally much less expensive. Potassium may also be applied as potassium nitrate, but this fertilizer is usually very expensive. Application rates vary with the severity of potassium deficiency (see Table 9.6).

Table 9.6. Guidelines for Application of Potassium Chloride (KCl) or Potassium Sulfate (K_2SO_4) to Correct Potassium Deficiency

	Per Vine (lb)		Per-Acre Equivalent (lb)[a]	
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

[a] Based on approximately 600 vines per acre.

Potassium fertilizers should be banded under the trellis rather than broadcast 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 véraison and again immediately after fruit harvest.

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 interveinal (between the veins) chlorosis or yellowing. The nature of the chlorosis depends upon the grape variety, but generally the central portion of the leaf blade loses green color to a greater extent than the leaf margins (Figure 9.4). 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 varieties 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 are therefore usually confined to the older leaves except in cases of severe deficiency.

Figure 9.4. Magnesium deficiency symptoms.

Insufficient magnesium impairs protein synthesis and chlorophyll production, both of which reduce photosynthesis and sugar production. Evidence also exists 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 produced inconsistent results, suggesting that the problem is 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 nondeficient, bloom-sampled grape petioles. Research shows 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 to 1. Ratios of 10 to 1 and up to 20 to 1 are not unusual in petiole samples from Virginia vineyards. Soils formed from sandstones or granite, as are many of the soils in this region, and coastal sands are relatively low in magnesium. 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 9.3) coupled with visual observations should indicate whether to apply magnesium.

CORRECTING MAGNESIUM DEFICIENCY. Magnesium deficiencies can be corrected with either foliar or soil applications of magnesium fertilizers. Foliar application is appropriate to correct a mild deficiency or for short-term correction, but soil application offers a more long-term remedy.

If foliar application is chosen, spray the foliage with 5 to 10 pounds of magnesium sulfate ($MgSO_4$) in 100 gallons of water per acre. This measurement will assure uniform coverage of leaves. Apply the $MgSO_4$ three times at two-week intervals in the post-bloom period. This approach is significantly more effective than waiting until deficiency symptoms are evident in mid- to late summer. Magnesium sulfate can be purchased in a sprayable formulation from fertilizer dealers in 50-pound bags or it can be purchased at drug stores as Epsom salts in smaller quantities. The magnesium sulfate can be mixed with most fungicide or insecticide sprays unless the pesticide label cautions against this combination.

Long-term correction of magnesium deficiencies is achieved by periodic soil application of magnesium-containing nutrients. If the soil pH is also low (less than 5.5), high-magnesium-content limestone (dolomitic lime containing 20 percent magnesium) 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 where magnesium deficiency occurs. However, fertilizer-grade magnesium sulfate or other fertilizers containing some percentage of magnesium oxide (MgO) are generally available and sold either in bulk or in bags. Magnesium sulfate is applied at 300 to 600 pounds per acre (50 to 100 pounds of magnesium oxide per acre). To be most effective, magnesium sulfate or magnesium oxide should be banded under the trellis rather than broadcast over the vineyard floor. In small plantings, the fertilizer can be placed in rings 12 to 18 inches from the trunks of individual vines.

Boron

ROLE OF BORON. Boron is an essential micronutrient; very small quantities are required for normal growth and development. Boron has regulatory roles in carbohydrate synthesis and cell division. A deficiency 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 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 as retarded shoot growth and, in some cases, death of shoot tips. Shoots can also exhibit a zig-zag growth pattern, have shortened internodes, and produce numerous, dwarfed lateral shoots (Figure 9.5). 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.

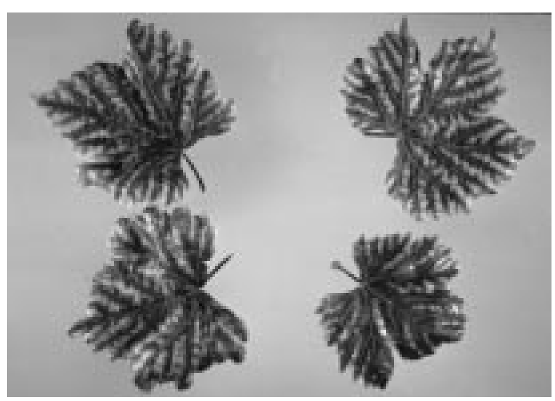


Figure 9.5. Boron deficiency symptoms. (Photo courtesy of T.J. Zabadal.)

A second category of boron deficiency develops later in the spring and is marked primarily 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 in which 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 phytotoxicity if the boron concentration is already sufficient (Figure 9.6).

Figure 9.6. A boron toxicity problem.

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 containing less than 30 parts per million (ppm) are considered marginally deficient, although clear boron deficiency symptoms may not appear until the boron level drops to 20 ppm or lower. Soil pH, leachability of the soil, frequency of rainfall, and the amount of organic matter in soil affect the availability of boron.

A soil pH of 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 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.

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 may 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 foremost consideration in correcting boron deficiency is to determine whether the vines are actually deficient. Excess boron uptake leads to pronounced leaf burning and leaf cupping (Figure 9.6). 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 appear appropriate for this region 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 ½ 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 containing about 20 percent actual boron. Thus, 2.5 pounds of this material should be applied per acre to provide the ½ pound of actual boron needed.

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 that manner nor with any pesticide that cautions against boron incompatibility. Foliar application of boron is a temporary solution but has the advantage of avoiding a possibly excessive soil application. With proper calibration, boron can be applied in soluble form to the soil with irrigation equipment, with an herbicide sprayer, or with an airblast sprayer before bud break or after defoliation in the fall. In this case, the material should be applied at a rate of 3 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 apply uniformly to the soil because very small quantities are used.

Other Nutrients

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

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 maximum returns on the vineyard investment will not be realized. Good vine nutrition starts in the preplanting 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 observed. The producer must also be willing to apply lime and other fertilizers efficiently 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. University of California Division of Agricultural Sciences, Publication No. 4087. 40 pp.

Winkler, A. J., J. A. Cook, W. M. Kliewer, and L. A. Lider. 1974. General Viticulture. University of California Press. Berkeley, California. 710 pp.

Soil and Plant Tissue Testing Services

Call the laboratory to determine current pricing and submission information. Some laboratories, such as those at Cornell and Pennsylvania State Universities, 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 Service Lab
The Pennsylvania State University
University Park, PA 16802
(814) 863-6124

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

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

Brookside Farm Laboratory
308 South Main St.
New Knoxville, OH 45871
(419) 753-2448

Agrico Chem Laboratory
P.O. Box 639
Washington Court House, OH 43160
(614) 335-1562

Plant Analysis Laboratory
Agronomic Division — NCDA
4300 Reedy Creek Dr.
Raleigh, NC 27607-6465
(919) 733-2655

Chapter 10

Grapevine Water Relations and Vineyard Irrigation

Like other perennial plants, mature grapevines have extensive root systems and therefore, unlike shallow-rooted annual plants, they are fairly tolerant of mild droughts. Nevertheless, a certain amount of moisture is necessary to support growth and development. Lacking sufficient moisture, vines will suffer water stress, which can reduce productivity as well as fruit quality. Supplemental moisture can be provided by permanent (solid-set) or temporary irrigation systems. Irrigation represents a substantial investment, but the benefits can far outweigh the costs in many vineyards.

The Vineyard Hydrologic Cycle

Water enters the vineyard as rainfall (Figure 10.1) or through irrigation. Some of this moisture drains out of the root zone into deeper soil layers and some runs off the soil surface. Water that remains in the root zone is available for absorption by the vine roots. A vineyard soil at field capacity (the amount of water that the soil can hold after gravitational drainage occurs) will lose moisture in two principal ways: through direct evaporation into the atmosphere and by transpiration from the leaves of the vines and any ground cover (Figure 10.1). Water moves out of the leaves through stomata, the small pores that admit carbon dioxide and release water vapor and oxygen. Collectively, transpiration and evaporation are referred to as *evapotranspiration.*

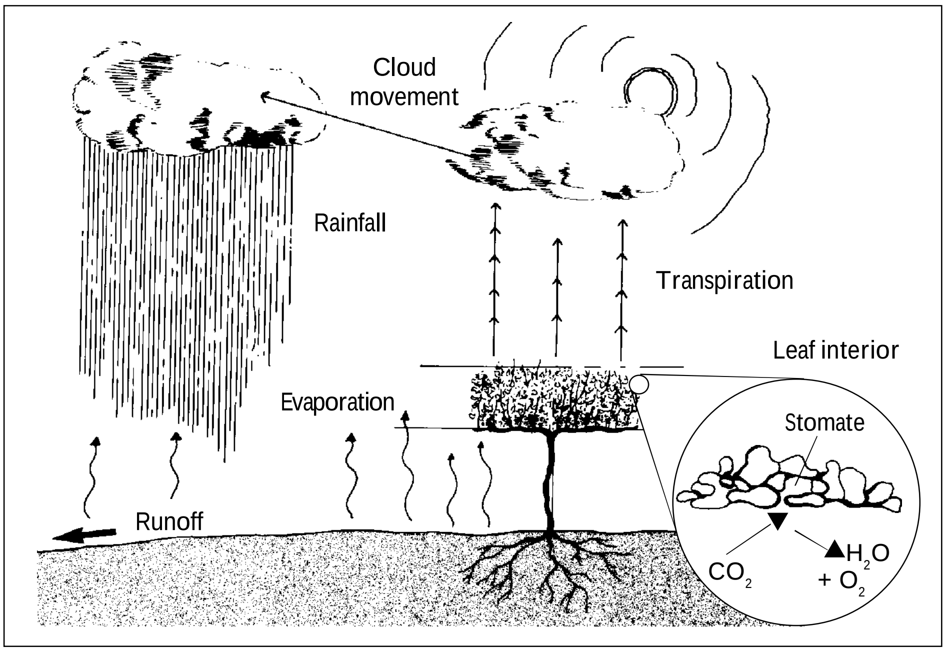


Figure 10.1 The vineyard hydrologic cycle. Water enters the vineyard as rainfall or irrigation and is removed through gravity, runoff, evaporation, and transpiration through plant leaves.

Summer Climate and the Potential for Drought

Agricultural meteorologists and climatologists use the expression *potential evapotranspiration,* or *PET,* to compare the water loss potential of different regions. PET, expressed in inches of water per unit of time, is a measure of how much evapotranspiration should occur from a moist surface. Evapotranspiration rates for vineyards vary according to the development of the vine canopy, presence or absence of ground cover, cultivation, and atmospheric conditions. Monthly precipitation is less than PET losses during summer months for many Virginia and North Carolina locations. Figure 10.2 illustrates the

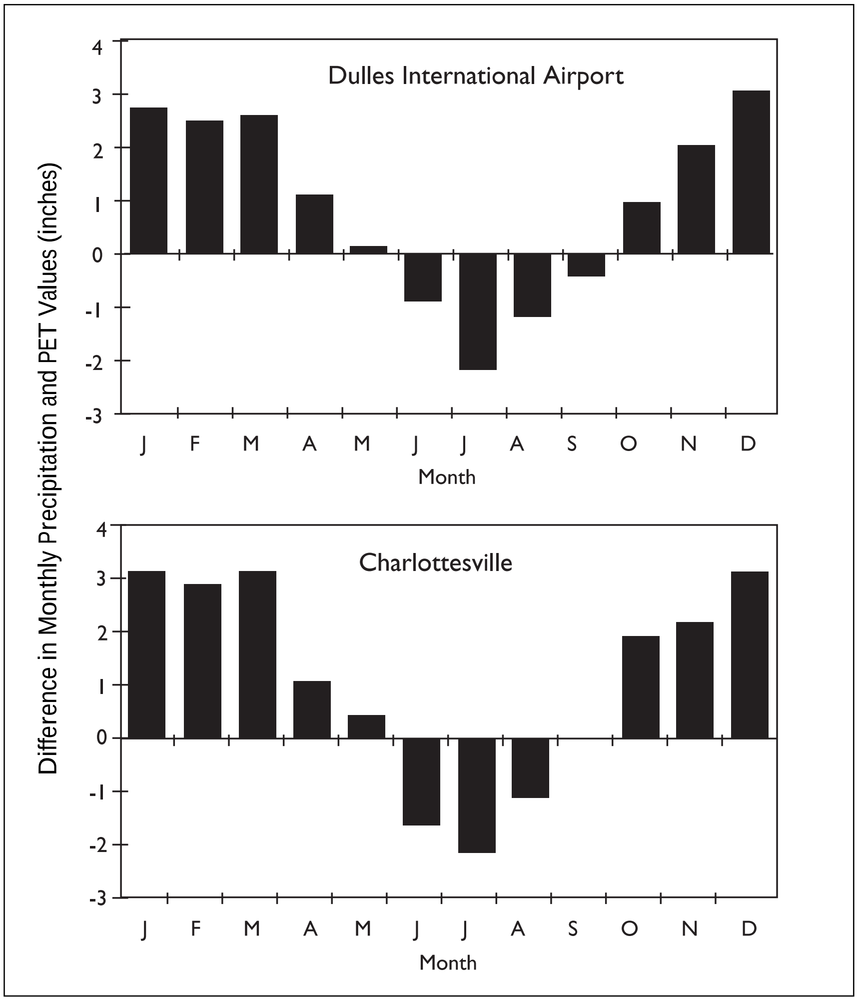


Figure 10.2 The imbalance between precipitation and potential evapo-transpiration (PET) for two Virginia locations.

imbalance between precipitation and PET values for two Virginia locations. Note the water deficits that occur at those stations during the summer months. Averaged across all of Virginia's National Weather Bureau stations, PET values exceed rainfall by an average of 1.5 inches per month during July.

Precipitation records indicate that most Virginia and North Carolina weather stations record between 40 and 60 inches of precipitation per year. However, those annual averages do not reflect the frequency of rainfall. Even monthly precipitation averages can give a misleading impression of moisture availability. Summer precipitation in this region often results from thunderstorms. Those storms are usually restricted to small areas, and significant precipitation might cover only a 10- to 50-square-mile area. Furthermore, because rainfall during thunderstorms is intense, less water is absorbed by the soil than if an equal amount of precipitation fell over a longer period. Thus, infrequent summer downpours may not satisfy the vines' critical need for moisture that would develop during extended hot, dry periods. Given high PET rates and the spotty nature of summer precipitation, summer droughts are not uncommon in this region. Consequently, irrigation may be of benefit at certain times during every growing season.

The Role of Water in the Vine

To an extent, all physiological processes in the plant are dependent upon water. In the larger scheme of plant processes, water plays a pivotal role in driving growth. The cells of adequately watered vines exert an outward pressure, which is termed *turgor pressure.* This pressure causes cell enlargement, which in turn leads to an increase in tissue and organ size, such as the lengthening of shoots. The lack of cell turgor pressure results in a flaccid or wilted appearance. Wilting occurs when the transpiration rates of leaves exceeds the ability of the vine to absorb water from the soil and conduct it to the leaves.

Symptoms of Water Stress

One of the first signs of drought is a change in the appearance of the vines. Rapidly growing shoot tips of well-watered vines appear soft and yellowish or reddish green. If large portions of the soil become dry, the rate of shoot growth slows and the shoot tips gradually become more grayish green, like the mature leaves. Tendril drying and abscission is also a useful early indicator of vine water stress. As water stress continues, leaves appear wilted, particularly during midday heat. Under prolonged and severe stress, leaves curl, brown, and eventually drop. Vines that suffer severe water stress begin to defoliate, exposing more of the fruit that had been shaded by foliage. Depending on the time and severity of water shortage, berries of stressed vines may not attain their full size. Water-stressed fruit exposed to the sun can sunburn and shrivel, much like a raisin. Water shortages also reduce the vine's ability to absorb nutrients from the soil. Symptoms of nutrient deficiencies are therefore more apparent during prolonged dry periods.

In addition to visual indicators, vine water stress can be measured with special instruments. Some instruments measure the water status of vines, whereas others measure the moisture status of the soil. Hand-held infrared thermometers can measure the temperature of vine canopies. The leaves of water-stressed vines are often warmer than the surrounding air because of reduced transpirational cooling. Leaves of well-watered vines are generally cooler than the air, even during the hottest period of the day. The moisture status of the soil can be determined with instruments that range from simple tensiometers to sophisticated neutron probes.

The water status of vines can also be measured by determining how much pressure is required to force water from a detached leaf. A wilted leaf will hold its remaining moisture with more tension (negative pressure) than will a fully hydrated leaf. The tension with which a leaf holds water is expressed in units of negative pressure called *milliPascals* (mPa). Figure 10.3 shows the changes in leaf water potential throughout the course of a day. The more negative the value, the more stressed the leaf is.

Leaf water potentials become more negative throughout the course of a day as the leaves lose moisture. The leaf water potential is generally most negative during the hottest part of the day and then decreases (becomes less negative) as vines regain their hydrated status in the cool of the night (Figure 10.3). When leaf water potentials reach about -1.2 mPa, stomata close. This closure conserves the remaining water in the leaf, but the "cost" of this water conservation is decreased sugar production. With stomata closed, carbon dioxide cannot enter the leaf and the photosynthetic conversion of carbon dioxide into sugars will not occur.

Extended periods of drought prevent the vine from regaining its hydrated status. Dehydrated leaves remain at or below -1.2 mPa for much of the day, and consequently photosynthesis is greatly reduced. The impairment of the photosynthetic processes will generally occur before leaves are visibly wilted. Reduced photosynthesis can explain why fruit fails to increase in soluble solids during periods of water shortage; little or no sugar is being manufactured. A point will be reached at which the daily stress of insufficient water will have an irreversible impact on the vine's performance. By the time leaf wilting occurs, vines are severely stressed.

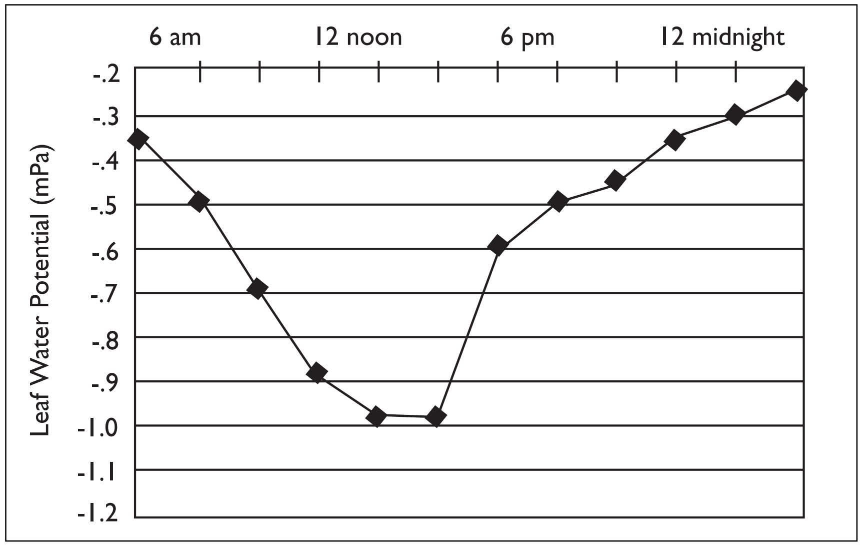


Figure 10.3. The leaf water potential is the most negative during the hottest part of the day.

Many processes are disturbed or impaired by water stress. The impairment of those processes depends on the severity of stress and can be characterized as either reversible or irreversible. Reversible effects include

- ❑ decreased cell turgor pressure
- ❑ reduced stomatal conductance (that is, less carbon dioxide enters the leaf)
- ❑ reduced photosynthesis (sugar production)
- ❑ decreased shoot growth rate
- ❑ reduced berry size.

These events are "normal" occurrences in the day-to-day cycle of growth and development even of adequately watered vines. As water stress intensifies, however, irreversible effects become apparent. These effects, in order of increasing water stress and severity, include

- ❑ irreversible reduction in berry size
- ❑ decreased fruit set
- ❑ *delayed sugar accumulation in fruit*
- ❑ *reduced bud fruitfulness in the subsequent year*
- ❑ reduced fruit coloration
- ❑ leaf chlorosis (yellowing) and eventual burning
- ❑ Berry shriveling
- ❑ Reduced wood maturation and possibly reduced vine cold hardiness
- ❑ Defoliation
- ❑ Vine death.

Two of these observations, indicated by italics, are of special interest because their occurrence is variable. Slight water stress can actually hasten sugar accumulation and increase bud fruitfulness by causing a somewhat more open or light-porous canopy. Exposed fruit tends to accumulate sugar at a faster rate than does shaded fruit. Furthermore, slowed vegetative growth reduces the “sink” strength of shoots and roots. Thus, more of the vine’s carbohydrates are directed to fruit “sinks.” Slight water stress, therefore, might result in hastened fruit maturation. However, with greater water stress, sugar accumulation is impaired and fruit do not attain the desired sugar levels. Buds exposed to sunlight during their development are more fruitful than those that are shaded. However, severe water stress reduces the fruitfulness of developing buds and thus reduces crop yields in the subsequent season. Thus, the intent of irrigation is to supply no more water than is needed to achieve the desired results of maintaining adequate vegetative growth and berry development.

Water use increases in proportion to the leaf area of the vine. Large vines require more water than do small vines. However, water stress is usually more severe in a young vineyard because the young vines have less-well-developed root systems and cannot draw moisture from as large a volume of soil as can large vines. Thus, the best time to install an irrigation system in the vineyard is at or before the time it is established.

Finally, the presence or absence of weeds and cover crops also affects the vines’ need for supplemental water. Cover crops compete with the vines for water. This competition can be minimized by keeping the cover crop mowed short or by using cover crops that become dormant during hot, dry weather. Weeds also compete with vines for critical moisture. Weeds should be excluded from the area under the trellis by mechanical or chemical means. Irrigation should *never* be used as a remedy for poor weed control. The elimination of weeds might go far towards alleviating the vines’ water stress.

Avoiding Vine Water Stress with Irrigation

A properly functioning irrigation system ensures that vines have adequate moisture. As stated earlier, the objective of irrigation is to supplement natural precipitation so that vines achieve adequate vegetative growth and berry development. Vineyards can be equipped with a sprinkler, drip, or trickle irrigation system; each has its particular advantages and disadvantages. A drip irrigation system uses lightweight plastic tubing and fittings to make frequent applications of small amounts of water directly to the plant root zone. Drip irrigation is generally preferred over sprinkler irrigation for these reasons:

- ❑ less water is used (1/3 to 1/2 less with proper management)
- ❑ less energy is required because less water is delivered at lower operating pressures
- ❑ leaves remain dry during irrigation, reducing the incidence of disease
- ❑ the solid-set nature of the drip system results in lower labor and operating costs
- ❑ field operations can continue while irrigating
- ❑ the need to control weeds or to cultivate and mow between rows is reduced
- ❑ less fertilizer is needed if it is injected directly

into the irrigation water

- ❑ less runoff occurs on hilly terrain, reducing soil erosion
- ❑ no wind interference occurs
- ❑ the system can be easily automated.

Drip irrigation systems also have several disadvantages:

- ❑ system components can be damaged by insects, rodents, and laborers
- ❑ the small emission orifices may be easily clogged
- ❑ the system offers no frost protection.

Drip irrigation systems are similar to sprinkler irrigation systems in that they require a pumping station to deliver water, a main line to move water from the source to the vineyard, submains to distribute water throughout the vineyard, and laterals with emitters, which replace the sprinklers. The lateral tubing and emitters may be suspended from a trellis wire, laid directly on the ground, or buried in the root zone of the vines.

Water Supplies

The primary difference between drip irrigation and sprinkler irrigation systems is the consideration that must be given to water quality with drip irrigation. Particulate matter such as sand, silt, and algae can easily clog the small orifices of emitters. Therefore, a water filtration system must be installed between the pumping station and the vineyard. For groundwater supplies such as wells and protected springs, an inexpensive screen filter is usually adequate. When streams or ponds are used, sand media filters are recommended. Sand filtration systems designed for drip irrigation are relatively expensive. For small systems, however, standard swimming pool filters may be substituted. The use of self-flushing emitters is highly recommended if the water quality is questionable. When water is of extremely low quality, microsprinklers, another form of low-volume, low-pressure irrigation, should be considered. The water quality of the potential water source should be analyzed before any substantial expenditures are made for an irrigation system. Many private water testing firms offer a standard irrigation water quality analysis. Additional tests should be requested if specific contaminants are suspected. Water sources with little or no recharge should contain from 6 to 9 acre-inches of water for each acre to be irrigated during the season. Sources such as streams or wells will need to yield 5 to 10 gallons per minute for each acre irrigated at a time. Zones smaller than 1 acre might be possible for smaller systems, thereby requiring even lower flow rates.

Soils

Any soil suitable for vineyard establishment can accommodate a drip irrigation system. Since water is applied slowly, even soils with very limited infiltration properties are not a deterrent to the use of drip irrigation. The major soil consideration is that of lateral water movement. Generally, in a light-textured, sandy soil water will move primarily downward, whereas in heavy-textured, clayey soils water will tend to move laterally outward from the emitter. In the former case, more emitters per vine may be required to thoroughly wet the root zone.

Terrain

The terrain, or topography, of the vineyard must also be considered. If designed properly, drip irrigation systems can be used on relatively steep slopes. In such applications, pressure regulators must be installed to keep pressure variations throughout the vineyard at a minimum. The use of pressure-compensating emitters is also recommended. Whenever practical, vineyard rows should be laid out along the contour to minimize elevation changes along drip irrigation laterals and to minimize erosion associated with rain.

Pumps

Pumps for drip irrigation systems are considerably smaller than those for comparable sprinkler systems because the required flow rates and pressures are lower. Because the pressure is low, it is sometimes possible to use gravity feed from an elevated tank or reservoir. The major advantage of the smaller pumping unit requirement is that single-phase electric motors (under 7.5 horsepower) may be used to drive the pump in many cases. Electric pumping units are widely preferred for irrigation systems of this size and are well-suited to automatic control.

Injection Systems

Provision should be made for injection of fertilizer and chemicals into the irrigation water. Fertilizer efficiency can be greatly enhanced if the fertilizer is applied in this manner. In drip irrigation systems, an injection system is particularly helpful for introducing chlorine for algae control or acid for removal of bacterial slime or precipitated materials such as iron. Care must be taken to prevent environmental damage from accidental spills. Safety equipment to prevent backflow of chemicals into the water source or chemical storage tank includes some or all of the following, depending upon the method of injection: check valve, backflow preventer, vacuum breaker, low-pressure drain, and a power supply interconnected between irrigation pump and injector. In addition, proper installation calls for the use of corrosion-resistant components and injection away from water sources.

Water Management

Good water management is critical for proper drip irrigation operation. Tensiometers or electrical resistance blocks can be placed directly in the row to monitor the soil moisture conditions in the root zone of the vines. These "sensors" can be used to control pumping stations for fully automatic control of the irrigation system.

System Design

Crop irrigation systems are specialized in design, and it is beyond the scope of this publication to provide the detailed information needed to design, construct, and operate a system. If you are interested in irrigation, discuss your needs with reputable companies that specialize in irrigation system design, installation, and maintenance. These companies often advertise in trade publications and exhibit their systems at trade shows. For more information, contact your county Cooperative Extension Service agent or Consolidated Farm Service personnel.

References

Fereres, E. (Ed.). 1981. Drip Irrigation Management. University of California Division of Agricultural Sciences, Leaflet No. 21,259. 39 pp.

Neja, R. A. 1982. How to Appraise Soil Physical Factors for Irrigated Vineyards. University of California Division of Agricultural Sciences, Leaflet No. 2,946. 20 pp.

Kasimatis, A. N. 1981. Vineyard Irrigation. University of California Division of Agricultural Sciences, Leaflet No. 2,823. 9 pp.

Drip Irrigation Suppliers

Some of the full-service drip irrigation dealers that serve the region are:

Johnson & Co., Inc.
P. O. Box 122
Advance, NC 27006
(919) 998-5621

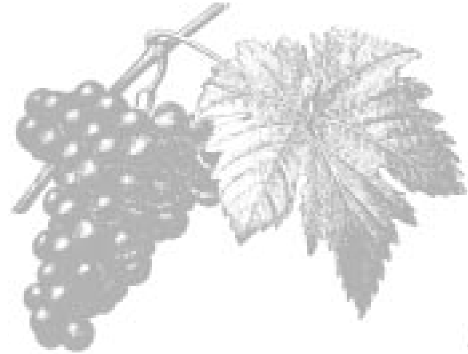
Mid-Atlantic Irrigation Co., Inc.
1803 W. Third St.
P. O. Box L
Farmville, VA 23901

Berry Hill Irrigation
Rt. 1 Box 245
Buffalo Junction, VA 24529
(804) 374-8082

Aquaculture, Inc.
Rt. 1 Box 242
Raphine, VA 24472
(703) 377-5866

Chapter 11

Crop Prediction



Crop prediction or estimation is the process of projecting as accurately as possible the quantity of crop that will be harvested. Why estimate the crop? The most obvious reason is to know how much crop will be present for sale or utilization. Beyond that fundamental reason, it is also important to know whether vines are undercropped or overcropped. In the absence of methodical crop estimations, the experienced grower can rely on past vineyard performance. This approach is subject to error, however, especially in grape regions subject to spring frosts or winter injury, which can greatly affect a vineyard's productivity from year to year.

Basic Components of CropYield

Crop estimation is based on several pieces of critical information: (1) a good historical record of average cluster weights at harvest; (2) an accurate count of current bearing vines per acre or block; and (3) an accurate determination of the average number of clusters per vine at the time of the crop estimate. Of these variables, average cluster weight is most subject to variation from year to year.

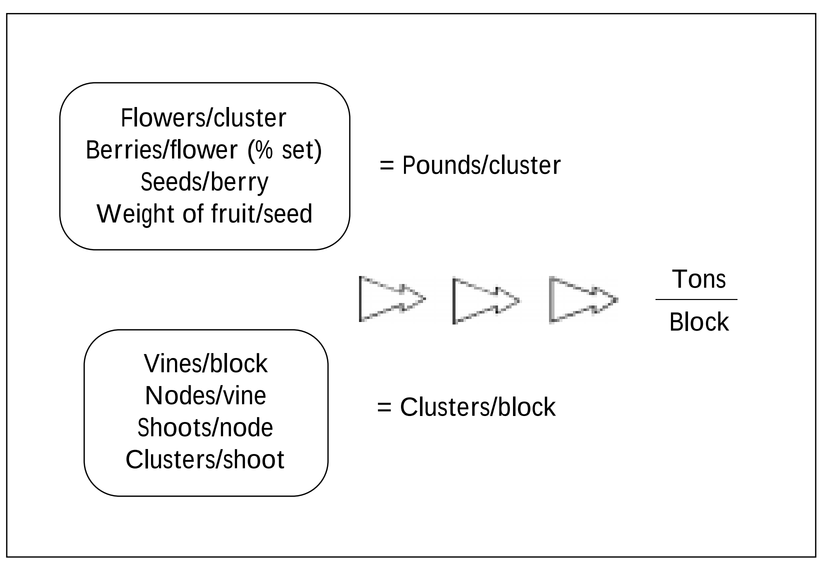
The theory of crop estimation is also based on an understanding of the components of vineyard yield. Those components are shown in Figure 11.1.

As this diagram illustrates, we can differentiate between yield components that contribute to the number of fruit clusters per block and those yield components that determine the average cluster weight. Variability in yield per acre can be traced back to variation in one or more of the many components that collectively determine yield.

Looking specifically at cluster weights (pounds per cluster in the diagram,) it is common to see yearly variation in the percentage of flowers that set fruit. Reductions in set may be due to poor weather during or immediately after bloom, poor vine nutrient condition, and possibly other factors such as pesticide phytotoxicity. Regardless of the cause, average cluster weight data from several years is more meaningful than a single year's data.

The number of clusters per block also varies from year to year. The number of (bearing) vines per block tends to decline through attrition as a vineyard ages unless the vineyardist is conscientious about vine replacement. The number of nodes per vine is a function of dormant pruning severity. The number of shoots per node varies

Figure 11.1. Basic components of crop yield.



with variety, vine vigor, and the use of shoot thinning as a canopy management practice. The number of clusters per shoot is affected by variety, the proportion of bud injury, and the growing conditions of the vine during the previous season. Compared to well-exposed shoots, shoots that develop in dense shade are more likely to have nodes with less fruitful shoots the following year.

Although the relationships shown in Figure 11.1 are helpful in understanding crop variation, it is not essential to consider each component of yield to estimate a crop. In practice, the following equation can be used to estimate crop with reasonable accuracy.

Equation 11.1

$$\text{Estimated Yield (tons/acre)} = \frac{1}{2{,}000\ \text{lb}} \times \frac{\text{Vines}}{\text{Acre}} \times \underbrace{\left[\frac{\text{Shoots}}{\text{Vine}} \times \frac{\text{Cluster}}{\text{Shoot}}\right]}_{\text{or } \left[\frac{\text{Clusters}}{\text{Vine}}\right]} \times \text{Average Cluster Weight (lb)}$$

As previously stated, the key elements needed to estimate the crop are: (1) the number of bearing vines per acre; (2) the average number of clusters per vine; and (3) average cluster weight at harvest. The 1/2,000 fraction converts pounds (used in expressing average cluster weight) to tons. There are more sophisticated procedures for estimating crop, but this equation provides a reasonably accurate prediction. The following sections present specific recommendations for determining the values of the three critical elements of the equation.

Number of Bearing Vines Per Acre

The maximum number of vines per acre is determined by the row and vine spacing. A full planted acre of vines spaced 8 feet apart in rows 10 feet apart will have about 545 vines. However, the actual number of bearing vines in most vineyards is somewhat less than the maximum possible. In poorly maintained vineyards, the actual number of vines may be less than 70 percent of the available vine spaces. Yield estimates can err significantly if estimates do not account for missing vines. To use an example, an estimate based on 545 bearing vines per acre might predict 4.9 tons of crop. Using the same average cluster weight (0.6 pound) and number of clusters per vine (30), the actual yield would be only 4.4 tons per acre if 10 percent of the vines were missing or were nonbearing. Unfortunately, it is not uncommon for 10 percent of the vines to be missing. Therefore, it is important to ensure that crop estimates are based on the actual number of bearing vines.

In some vineyards, the trellis spaces created by missing vines are filled in by extending cordons from adjacent vines. While this is a good practice to maintain vineyard productivity, it makes it more difficult to determine the number of vines per acre accurately and to estimate the crop successfully. An alternative is to count the number of panels (the distance between two consecutive posts in a row) per acre and to make counts of clusters per panel rather than clusters per vine.

Number of Clusters Per Vine

The average number of fruit clusters per vine is determined by counting clusters on representative vines and deriving an average figure from those counts. Crop can be estimated any time after all the flower clusters are exposed on the developing shoots. One advantage in waiting until after fruit set, however, is that the percentage of berry set can also be gauged. The vines on which clusters are counted should be selected methodically. One possibility is to sample on a grid — for example, inspecting every twentieth vine in every third row. The number of vines on which to count clusters depends on vineyard size and the uniformity of vines within the vineyard. In a 1- to 2-acre vineyard with vines of a uniform age, size, and training system, it might be necessary to sample only 10 or 15 vines. In larger, nonuniform vineyards, sampling should be stratified to account for variation between distinct areas of the vineyard. Bear in mind that the purpose of sampling is to determine the average number of clusters per vine for the entire vineyard. The larger the sample, the greater the likelihood that the sample average will be close to the vineyard average.

Average Cluster Weight

Cluster weights for each variety should be obtained annually at harvest and averaged. The results should then be averaged over all years for which data are available and used in making crop estimates. Clusters can be collected from picking bins after harvest, but the tendency in that sampling process is to select larger-than-average clusters. For each vine, record the total number of clusters picked, weigh them, and divide the weight by the number of clusters to obtain the average cluster weight. Subtract the weight of the empty picking bins from the total fruit weight. Picking all clusters from vines will ensure that you take into consideration the extremes in cluster size. Again, sampling 10 to 15 vines may be sufficient for a small, uniform vineyard.

Sources of Variation

After the number of bearing vines per acre (or block) and the average number of clusters per vine have been determined, these data can be combined with the average cluster weight to predict the crop yield per acre (or block). Unfortunately, the above discussion oversimplifies the crop prediction process somewhat. Even with thorough sampling, accurate vine counts, and many years' average cluster weight data, the actual crop tonnage at harvest can vary significantly from that which is predicted only two months before harvest. Many experienced producers are satisfied if the difference between predicted and actual yields is less than 15 percent. The most uncertain component of the crop prediction equation presented in this chapter is the average cluster weight. That uncertainty results from variation in the cluster weight components listed in Figure 11.1. Furthermore, environmental conditions, diseases, and insect pests affect cluster weights. A dry summer, for example, tends to reduce berry size and thus decrease average cluster weight. As Table 11.1 illustrates, a 1/10-pound difference in average cluster weight can result in a yield difference of nearly 1 ton per acre. Furthermore, the predicted yield does not account for fruit lost to bunch rots, birds, deer, or other unpredictable factors.

Table 11.1. Variation in Yield Estimate with a 1/10-Pound Change in Average Cluster Weight

Number of Vines per Acre	Number of Clusters per Vine	Average Cluster Weight (lb)	Yield (tons/acre)
545	30	0.60	4.91
545	30	0.50	4.10

The crop prediction model can be refined to provide a more accurate estimate of actual crop yield if the grower is willing to invest extra time. The process involves repeated measures of cluster weight during the growing season. Those measures are then used to adjust the average harvest cluster weight predicted at harvest. Seasonal cluster weight data can be fitted to a regression model and that model can then be used to predict the harvest cluster weight. Regression analysis is a tool used to describe how a unit change in one variable (for example, number of days after bloom) affects another dependent variable (for example, average cluster weight). However, to derive a meaningful model (one in which the regression model accounts for a significant proportion of variation in cluster weight), it is necessary to sample cluster weight on a number of days during the growing season. This process is somewhat tedious and destructive.

An alternative approach, suggested by researchers at Oregon State University, involves determining the average cluster weight at the "lag phase" of cluster development and using that single measure to adjust the average harvest cluster weight. For this method, a historical average lag-phase cluster weight must be developed for the vines in a vineyard. The lag phase of cluster growth corresponds to the lag phase of berry expansion that occurs with seed hardening. It can be measured as a temporary slowing of the otherwise linear increase in cluster weight throughout the season. The lag phase occurs about midway between bloom and harvest. Much but not all of the variation in harvest cluster weight is determined by this stage. Collect about 300 clusters during the lag phase, weigh them, and derive an average lag-phase cluster weight in the same manner used in determining the average harvest cluster weight. The crop prediction model is then modified to use both a historical average lag-phase cluster weight as well as the average lag-phase cluster weight for the current season to adjust the average harvest cluster weight as follows:

Equation 11.2

$$\text{Estimated Yield (tons/acre)} = \frac{\text{Vines}}{\text{Block}} \times \frac{\text{Clusters}}{\text{Vine}} \times \frac{S}{A} \times H$$

where:

S = lag-phase cluster weight for current season

A = historical average lag-phase cluster weight (several years' data)

H = average harvest cluster weight (several years' data)

Fitting some hypothetical numbers into this refined model will illustrate how a small change in the cluster weight during the lag phase will correspond to a change in the average harvest cluster weight.

Timing the lag phase of berry development is a potential source of variation with this technique. In Oregon, the cluster lag phase occurred about 55 days after first bloom, a period when the seeds of developing berries could no longer be cleanly cut with a sharp knife without the seed crushing the adjacent tissue of the berry.

Even using lag-phase cluster weights, it is necessary to take into account seasonal changes in water surpluses or deficits that can measurably affect cluster weights very close to harvest.

In conclusion, consider the following points:

❑ Good average cluster weight data are essential to predict the crop accurately. Do not rely on average cluster weight data from other vineyards. Long-term data will be more meaningful than a single year's data.

❑ Cluster-to-cluster variability is thought to be greater than vine-to-vine variability. Sample entire vines to develop the average cluster weights.

❑ Nonuniform vineyard blocks (for example, those where variations in soil, topography, vine age, or vine training occur) should be divided into uniform subblocks.

❑ The accuracy of yield estimates depends on representative sampling.

❑ Sampler variation can be significant. Use the same person each year to estimate crop.

Do not be discouraged if first attempts at crop estimation are inaccurate. The more experience and data acquired, the more accurate the estimates will become.

acclimation — phase during late summer when shoots stop growing and become brown and woody, and tissues acquire increased cold hardiness.

advective freeze — temperatures below 32°F, caused by the passage of large frontal systems of cold air. Little stratification of air temperature occurs with changes in elevation.

apical dominance — ability of shoots near the distal end of the cane to produce hormones that retard development of more basal shoots.

aspect — compass direction toward which the slope faces.

balanced pruning — pruning system that determines the number of nodes to retain based on weight of one-year-old canes removed at dormant pruning.

basal — in the direction of the roots or base of vine; see distal.

bud — usually consists of three partially developed shoots with rudimentary leaves or with both rudimentary leaves and flower clusters. A base bud is not borne at clearly defined nodes of canes. Compound buds have several growing points.

bud fruitfulness — ability of the bud to produce fruit; usually the most fruitful are located toward the exterior of the canopy.

cane — a woody, mature shoot after defoliation.

canopy — shoots of a vine and their leaves. Canopy management entails decisions regarding row and vine spacing, choice of rootstock, training and pruning practices, irrigation, fertilization, and summer activities.

cliestothecia — overwintering sexually produced structures of some fungi.

clone — one or more vines that originated from an individual vine, which was in some way unique from other vines of the same variety.

cordon — long, horizontal extension or two-year-old or older wood.

crop load — the ratio of crop weight to cane pruning weight for a given year.

cultivar — a named, cultivated variety.

distal — end of the stem towards the growing tip; see basal

dormancy — time between leaf-fall in autumn and bud break in the spring; absence of visible growth.

dormant pruning — annual removal of wood during the vine's dormant period.

double pruning — one pruning cut in late winter or early spring followed by a second pruning cut after the threat of frost is past but before appreciable shoot growth has occurred. Practiced where spring frosts are common.

evapotranspiration — the combined transpiration, or loss of water through stomata, and evaporation of water from the soil surface.

farm winery — classification in Virginia where at least 51 percent of the grapes used in winemaking must be grown at the farm, up to 25 percent may be purchased elsewhere in Virginia, and up to 24 percent may be purchased from other states.

graft union — where the rootstock is joined to the scion.

head — upper portion of vine consisting of the top of the trunk(s) and junction of the arms.

headland — area at the end of the rows used for vehicle turning.

hedging — pruning during the growing season, ususally removing only shoot tops and retaining only the nodes and leaves needed for adequate fruit and wood maturation.

hilling — protecting the graft union and a portion of the trunk with mounded soil in the fall.

internode — the portion of the stem between nodes.

macroclimate — climate of a large geographical region, such as a continent.

mesoclimate — climatic conditions within 10 feet of the ground and peculiar to a local site.

microclimate — environment within a specific small area, such as a grapevine canopy.

necrosis — death.

node — conspicuous joints of shoots and canes. Count nodes have clearly defined internodes in both directions on the cane.

pedicel — stem of an individual berry or flower.

periderm — bark.

phloem — food-conducting tissue. (Material generally flows from the shoots to the roots.)

pith — central part of a shoot or cane.

point quadrats — canopy transects or multiple transectional probes of the vine canopy.

pollinator — vine planted to supply pollen.

primordia — growing points of a bud.

pycnidia — fruiting structures of some fungi; pycnidia produce and release spores.

radiational freeze — Temperatures below 32°F that occur during calm, clear weather. Cooling ground cools the air immediately next to the ground. Lower spots will have lower temperatures.

renewal region (of canopy) — part of the canopy where buds for next year's crop develop (usually the fruiting region).

rootstock — variety used to supply roots to the vine.

scion — above-graft part of a grafted vine, including leaf- and fruit-bearing parts.

self-fruitful — able to set fruit with pollen of the same variety.

shoot — succulent growth arising from a bud, including stem, leaves, and fruit.

sporangia — specialized spores of certain disease-causing fungi.

spur — cane that has been pruned to 1 to 4 nodes.

stomata — leaf pores that allow gas exchange between leaves and the environment.

summer pruning — hedging or removing vegetation during the growing season.

tendril — stringlike, twining organs of shoots, located opposite leaves at nodes, that can coil around objects and provide shoot support.

trunk — vertical support structure that connects the root system with the fruit-bearing wood of the vine.

vascular cambium — tissue of canes and older wood that generates new xylem and phloem cells annually.

véraison — the period or stage at which fruit begins a third stage of ripening characterized by softening, color change, and perceptible increases in sugar and decreases in acidity.

vine vigor — rate of shoot growth.

xylem — water-conducting tissue of wood. (Fluids generally flow from the roots to the shoots.)