4.1 Maintaining Young Vines

Once the vine has been planted, (see 3.3 Planting Grapevines) care must be taken to ensure a healthy plant. The first shoots from a young plant are fragile. Each plant will produce a number of shoots from the scion. Early careful removal of all except the single strongest most upright shoot will help ensure a good start for the young plant.

Young plants should be protected with milk cartons or plastic tubes, be kept weed free around the plant base and never suffer water stress. Water stress should not be considered for at least the first two years and sometime three depending on the strength of growth. Irrigation sets should be frequent and of short duration ensuring that there is always adequate moisture to a point just below the furthest extent of the rootzone. It is not necessary to irrigate well past the rootzone as this wastes water and leaches nutrients out of the rootzone.

As the young plant grows tying should be done every 10 – 15cm of growth to help ensure a straight and non damaged trunk. The vine is tied to a stake that is affixed to the cordon wire. If growth is slow, removal of the axial shoots at the base of each leaf will encourage more growth.

Continual monitoring for pests, disease and nutrient deficiencies will help the vine achieve its maximum growth potential. Young plants should be included in a standard mildew prevention program similar to adult plants. Cutworms can be a significant problem in young plantings and should be monitored carefully in the first 3 years.

See section 5.3 Pests and Diseases.

If the plant is grafted an inspection of each plant should be done later in the season in both the first and second year to remove any scion roots having grown past the graft.

The second year is much like the first year in many respects. The vine is kept free of weeds around the base, all trunk suckers continually removed and treated as an adult plant for mildew and disease. If the cane has achieved at least pencil thickness above the cordon wire, the vine can be tied to the cordon wire and 4 buds left below the cordon. In cases of exceptional growth where the cane is at least pencil thickness 60 cm above the cordon, the vine can be tied down on the cordon.

The amount of fertilizer used in the second year is dependent on the growth in year one. The type of the fertilizer should be based on the soil analysis. If the soil was balanced with amendments prior to planting, minimal additions will need to be added.

See 4.3 Nutrition for further reading.

Vine Rejuvenation

Severe winter temperatures (below -20°C) or very cool temperatures during the shoulder season (below -12°C) can cause substantial damage to the fruiting buds of many varieties. If bud damage is suspected, the severity of bud damage should be assessed by bud dissection. Pruning methods should be changed based upon the number of dead buds and the age of the vine. For mature vines more buds should be left in order to compensate for dead buds. On spur pruned vines it is important to leave renewal buds below the cordon as it may be necessary to replace the cordon in the following year if too many spur positions are lost.

If the fruiting wood is severely damaged the trunk and the roots can still be functioning. A dead fruiting structure can trigger very vigorous re-growth from the base of the vine and from the trunk area.

The objective is to absorb the strength of the root system and create a new trunk and fruiting wood capable of surviving through next winter. Excessive vigor produces canes that are particularly susceptible to cold winter injury. Begin by removing the dead plant structure, although the dead trunk or what remains of it could be used to train the new shoots. Allow most or all of the new shoots to grow and tie them as with first year growth, ensuring a straight trunk for the future. Do not fertilize the plant as the growth will be very lush without any help. Disease control for powdery mildew is very important as the new growth is particularly susceptible. Water control may also be an option in order to slow the growth and ripen the wood for winter..

4.2 Canopy Management for Pacific Northwest Vineyards

Mercy Olmstead, Kathleen Willemsen, and Markus Keller

Growing grapes in the Pacific Northwest can be challenging and rewarding, and depending upon your location, vegetative growth and management will differ. Growers need to carefully assess their vineyard site including soil characteristics, annual precipitation, and precipitation timing in addition to researching potential grape varieties in order to assess potential vine vigor.

Vineyard location can have a large effect on vine growth. Those located in maritime climates may be concerned with controlling vegetative growth and increasing fruit exposure; while those in inland Pacific Northwest vineyards may need to adjust their vegetative management to optimize their canopy and fruit exposure. However, proper canopy management can lead to good profits for the grower and high quality fruit for the winemaker.

Management of grapevine canopies has changed over the years, and throughout the world. Many European countries have adopted a tightly spaced, minimal height vineyard, with no trellis support, while some New World countries have moved to a wider spacing and trellis system. Benefits can be realized for both types of systems, and those in between, depending upon grape variety characteristics and climate. However it may behoove us to define some terms before talking specifically about canopy management for Pacific Northwest vineyards.

Definitions of Canopy Components

Canopy, as defined in this publication, contains all vegetative and reproductive plant parts that are above-ground. This includes the trunk, cordons, canes, spurs (Fig. 4.1), shoots, fruit, and leaves. The management of this canopy involves the manipulation of these components in order to achieve a balance between vegetative and reproductive growth for optimum yield and fruit quality.

Shoots are comprised of vegetative and reproductive growth containing the length from the basal end to the growing tip. The growing tip is where leaves are initiated during optimum growing conditions, and can be used as an indicator of vine stress. Shoots originate from buds, which occur on canes, spurs, cordons; trunk and even underground (emerge as suckers).

Canes are mature, lignified wood from the previous season's growth. Canes and shoots are comprised of ***nodes*** (Figure 4.2), with spaces between nodes defined as ***internodes***.At each node is a bud containing three sets of buds (primary, secondary, and tertiary). The primary bud is the most fruitful, while the tertiary bud is the least fruitful. Buds can be dissected before pruning to aid in determining the potential crop load and help with decisions about pruning severity.

Pruning weight is determined by the amount of wood that is pruned off one vine in a single season. This can be used in formulas to determine how many buds should be removed and/or left on the vine as part of balanced pruning techniques (Reynolds, 1988). The amount of pruning wood is determined by how the canopy is managed throughout the previous season. Thus, if a vineyard is on a particularly vigorous site, then a large amount of pruning wood can be accumulated. However, on a low vigor site the canopy may be fairly small, leading to thinner canes and lower pruning weight.

Crop load is used to describe the ratio of yield to the pruning weight or leaf area. Potential crop yield before bloom can be determined by analyzing the primary, secondary, and tertiary buds (Morrison, 1991). This can then be used to adjust the pruning strategy to achieve optimum balance for fruit quality.

The ***vigor*** of the vine describes the growth rate and depends on a combination of factors, including soil type, texture, depth, water availability, and variety choice. Inherently, some grape varieties are more vigorous (e.g., Syrah or Shiraz, Sangiovese) than others. Canopies of vigorous varieties can produce an excess amount of leaf area when compared to recommended levels and may require more intense management.

Most canopy management is directed at the manipulation of the canopy ***microclimate***, which is the

Figure 4.1 A typical cordon-trained grapevine and its associated sections before spur pruning

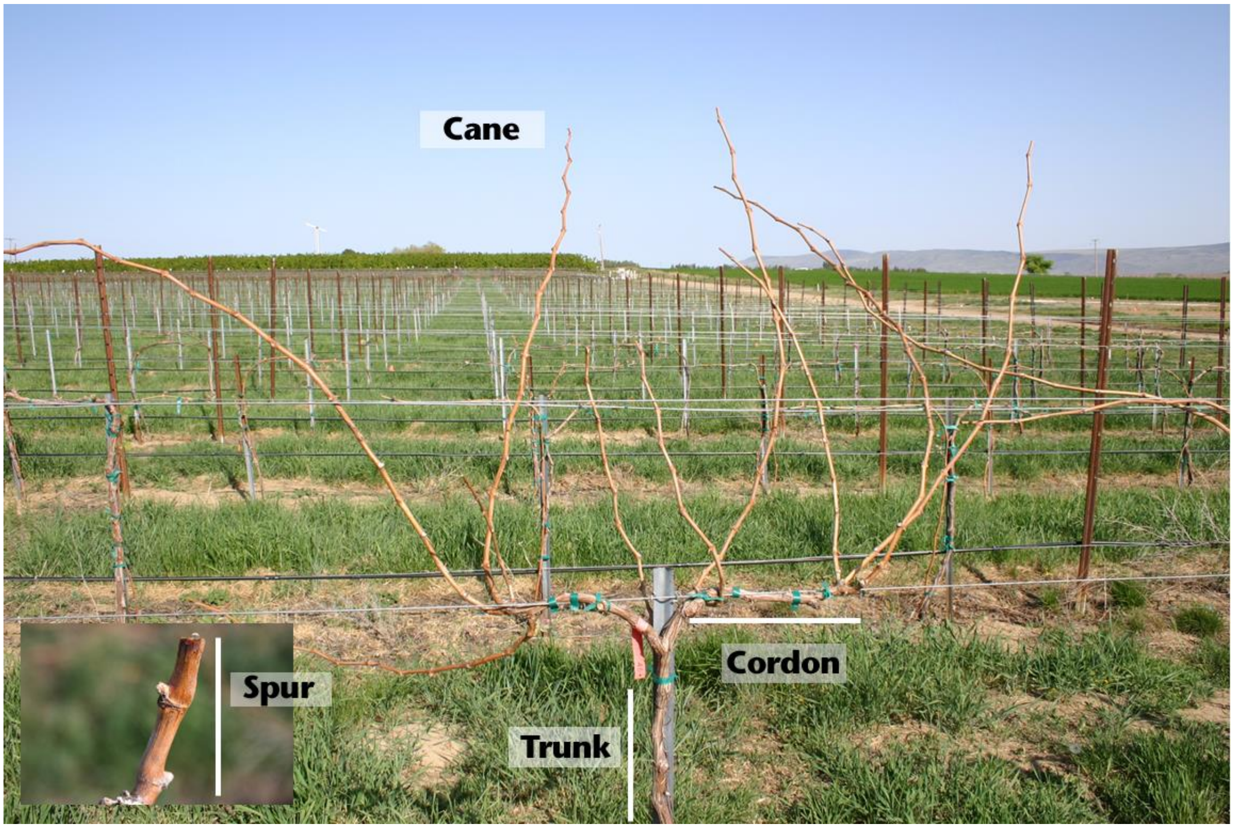
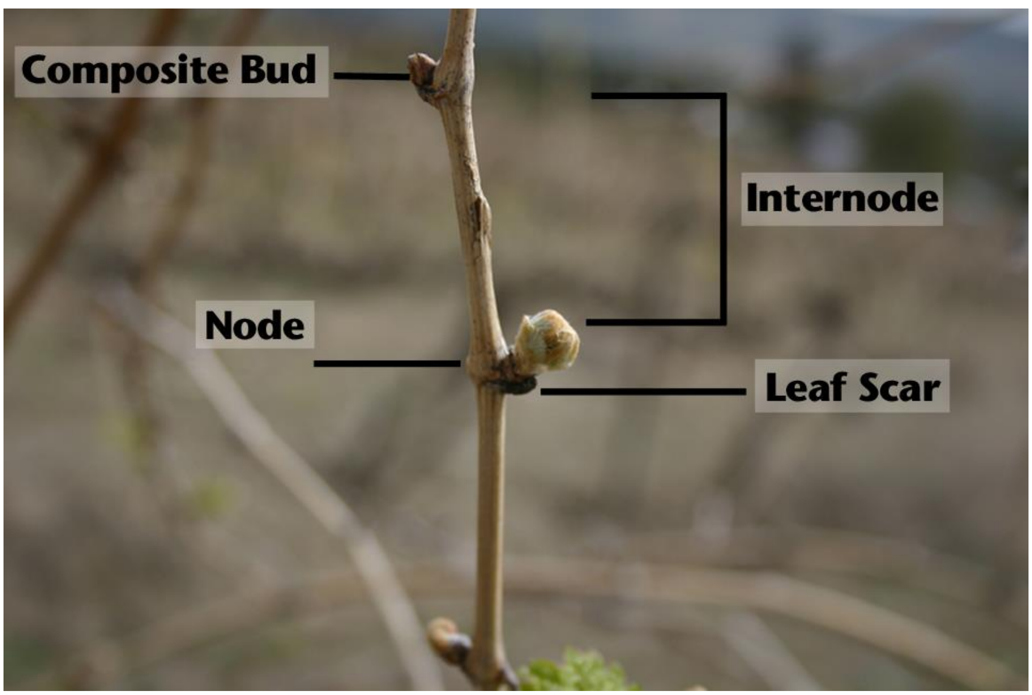


Figure 4.2 Shoot anatomy showing nodes, internodes, composite bud, and leaf scar.



climate surrounding and within the canopy (Tarara, 2005). Microclimate includes a number of factors including solar radiation, temperature, wind speed, humidity, and evaporation rates. Because leaves tend to alter these factors, the canopy microclimate depends upon the number of leaves and their spatial arrangement within a defined area (Smart, 1985).

Goals of Canopy Management

- Establish and maintain vine shape into one which facilitates uniformity in growth and fruit production
- Maintain vine shape to utilize mechanical means of vineyard tasks
- Produce optimum quality fruit through manipulation of vegetative growth
- Control crop load
- Promote continuous production of fruitful buds where desired (depending upon trellising system)
- Mitigate cold damage through the proper allocation of carbohydrate resources

Light and Temperature Effects of Canopy Manipulation

In order to understand how light and temperature affects vine growth, a brief review of some basic plant physiology is necessary. Plants fix carbon from the atmosphere through a process called photosynthesis. This process takes carbon dioxide from the atmosphere in addition to water and, using light energy, builds a carbohydrate molecule while giving off oxygen.

$$6CO_2 + 6H_2O \xrightarrow{\text{Light Energy}} C_6H_{12}O_6 + 6O_2$$

Through photosynthesis, carbohydrate is fixed (sugars are produced), and energy is produced via respiration, which occurs continuously. During respiration, some of this carbon that has been fixed is used to make energy to drive other processes in the plant.

Plants need a certain quantity of light (measured in µmol photons/m²s) in order to achieve their maximum sugar production. In grapes, about 40% of full sunlight (800 µmol/m²s) satisfies the maximum photosynthesis requirement (Smart, 1988; Keller et al., 1998). For comparison, a bright sunny day in most of the Pacific Northwest will have about 2000 µmol/m²s, although this may vary according to your specific latitude and time of season. Light quality is also an important factor in plant growth, as leaves strongly absorb at peaks in the blue (430 nm) and red (660 nm) range . The range of the spectrum that plants use for photosynthesis is called photosynthetically active radiation (PAR), which is approximately the visible light range from 400-700 nm.

Grape leaves are very efficient at absorbing solar radiation, with over 85% of PAR absorbed by the outer layer of the canopy (Figure 4.3; (Smart et al., 1985). The remaining 15% is either transmitted through the leaf or reflected up to the atmosphere. Canopy structure determines the amount of light intercepted by exterior leaves. Beyond the first layer of leaves, only 10% of the PAR is reaching the interior, and further into the canopy, less than 1% of the sunlight reaches the interior of the vine (Smart, 1991). Sunlight interception by leaves can be via direct or diffuse radiation. Direct radiation interception by exterior leaves drives canopy photosynthesis more efficiently than interception of diffuse radiation (Smart, 1984; Smart et al., 1988). Leaf orientation within a canopy (i.e. perpendicular to angle of solar radiation) must be optimal to efficiently intercept solar radiation.

Measurements of shade can be assessed by looking at the red:far red (R:FR) ratio. As mentioned above, leaves absorb red light (660 nm) and reflect light in the far red (730 nm) range (~41%) (Smart et al., 1988). As grapevine canopies become more shaded, a greater proportion of the light that reaches the interior leaves is far red light (Smart et al., 1982). Thus, the lower the R:FR ratio, the less efficient the leaves in the interior are at photosynthesis.

Effects on Low Light Quantity on Grapevines:

- Decrease shoot growth, but increase lateral growth
- Decrease fruit set
- Delay in fruit maturity
- Reduction in fruit color
- Reduction in acid degradation
-

- Reduction in fruit cluster initiation for subsequent seasons
- Increase in disease incidence
- Increase in certain pest populations (e.g., leafhoppers)
- Increase in internode length

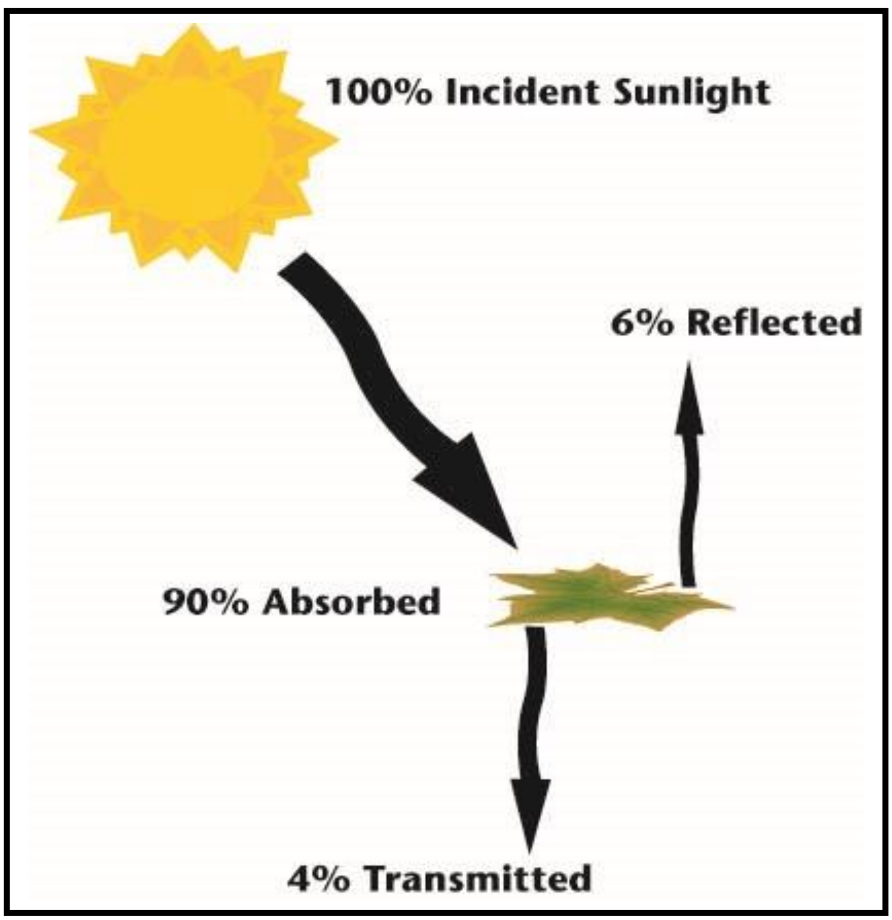
(Morgan et al., 1985; Keller et al., 1998; Keller and Hrazdina, 1998; Petrie et al., 2003)

Temperature can also have a significant effect on shoot growth and fruit quality. Grape clusters and leaves in direct sunlight can experience temperatures 13-15°C higher than ambient temperatures (Spayd et al., 2002). This is why during a 40°C day summer day, fruit ripening slows down or can even stall. Typically, as temperatures increase, the rate of shoot growth increases. However, high temperatures (>35°C) can decrease shoot growth by shutting down photosynthesis (Ferrini et al., 1995).

Low temperature (<10°C) can also decrease grapevine growth by slowing photosynthesis. This can have a cascading effect on fruit set, fruit development and ripening, and storage of reserves in the grapevine for subsequent growing seasons.

Knowledge of the temperature differences between sites can be useful for matching site to variety and also determining ripening times. It is more important to grow appropriate varieties for specific sites than to grow mediocre quality grapes on inappropriate sites. Separate vineyards can be planted to stagger ripening times to ensure that deliveries to wineries will be handled in a timely fashion. This underlines the importance of site selection and communication between the grower and the winery.

Figure 4.3. Balance of solar radiation absorbed, transmitted, and reflected from a Gewürztraminer grape leaf.



Effects of Low and Very High Temperatures on Grapevine Canopies:

- Decrease photosynthesis, possibly leading to reduced sugar accumulation and reserves
- Decrease shoot growth
- Delayed ripening
- Decrease fruit set

Canopy Assessment Methods

Shading Indices

In upright canopy systems, the surface area of the vine is determined by the height and width of the full grown canopy. The greater the surface area, the more solar radiation is intercepted for growth processes. One thing to consider when assessing canopies is volume, which is determined by the height and width of the vines trained to a specific trellising system. The larger the volume, the greater the number of leaves, and shading may be a concern. One easy way to determine fruit exposure is to calculate the surface area to volume ratio. This can be easily done with a meter stick or measuring tape to derive the exterior canopy dimensions.

Point Quadrat

This method is another tool that can be used in conjunction with calculating shading indices and sunfleck analysis to assess canopy density. Point quadrat method requires a thin metal rod that is randomly inserted into the canopy. As with measuring leaf layer number (LLN), each leaf or other vine parts that touch the rod are recorded on a spreadsheet. Multiple areas within the canopy should be assessed, at least 50 to 100 times in order to get good, representative data (Smart, 1991). Be sure to avoid bias by choosing a uniform random method of inserting the rod throughout the vineyard row or block (e.g., every X number of steps). Record each leaf, cluster and canopy gap that the rod passes through from one side of the canopy to the other.

Once you have recorded your information from the canopy assessment, you can calculate percent gaps (rod does not touch anything), leaf layer number, percent interior leaves, and percent interior clusters (Smart, 1991).

- % gaps = total gap #/# of insertions x 100
- LLN = total # of leaf contacts/# of insertions
- % interior leaves = # interior leaves/total leaf # recorded x 100
- % interior clusters = # interior clusters/total cluster # recorded x 100

Ideal numbers for this method should be 20-40% canopy gaps, LLN of 1.0-1.5, % interior leaves <10%, and % interior clusters <40%.

Sunfleck Analyses

This method assesses the amount of canopy gaps, and can be done throughout the season. Estimate the proportion of gaps in the canopy, especially around the fruiting zone. There should be adequate light reaching the fruiting zone from the top or exterior portion of canopy to the cordon or cane. An easy way to measure this is to set a sheet or tarp underneath the canopy under the fruiting zone and assess canopy gaps within a defined area. This defined area can be drawn on the sheet (e.g., $1m^2$). When completed, the percentage of sun reaching the ground for vertical canopies should be between 2- 10% (Smart, 1973).

Techniques for Canopy Manipulations

Training System

Training and trellis systems that allow for upright positioning of shoots (i.e., Vertical Shoot Positioning – VSP) generally allow adequate light penetration and air movement through the canopies of most grape varieties grown in the Pacific Northwest. However, these systems can allow too much fruit exposure in high-solar radiation inland areas, causing sunburn. In these areas, a system that allows for more shading (e.g., simple sprawl) can optimize fruit exposure. Divided canopy systems with hanging shoots, like Geneva Double Curtain or Scott-Henry are more apt to have more leaf area with a well-exposed fruit zone due to the positioning of shoots upwards and downwards, depending upon the specific system. Scott-Henry systems are especially good for those varieties and sites that can be particularly vigorous. However, when a divided canopy is used, yields increase due to the higher number of buds on the vine. In these cases, crop load must be carefully balanced with vegetative growth for optimum fruit quality.

When laying out the vineyard, be sure to optimize light absorption by equalizing the height of the trellising system and the width between rows. This should result in a 1:1 ratio between rows and trellis height (Smart, 1982). This avoids the 'bleeding' through of light and inefficiencies in the vineyard regarding the capture of sunlight. However, if vineyard rows are too closely spaced, it is possible to get cross-row shading, which can lead to shaded leaves close to the fruiting zone.

Pruning

Grapevines have a fixed capacity – that is one vine can ripen a certain amount of fruit and support a certain amount of shoots. One of the main goals of pruning is to ensure that there is enough potential vegetative growth to ripen the crop and enough fruitful buds to provide an adequate crop load. Large canopies can negatively affect fruit quality, with other negative effects on canopy quality (e.g., disease incidence and penetration of fungicides and pesticides). In addition, getting light into the canopy will help with forming fruitful buds for the following year, and help in hardening the canes off for the winter in the fall.

Specific pruning recommendations will depend on your training system (i.e., spur or cane-pruned system), variety (e.g., some varieties do not produce fruitful basal buds and are cane-pruned), and vine vigor. In cordon-trained systems, 2-3 bud spurs should be evenly spaced along the cordon (Figure 4.4). In cane-pruned systems, be sure to choose canes that have adequate spacing between nodes for fruiting wood. Distinguish between count and non-count buds; only buds that are one finger width above the cordon should be counted in the final bud count for that spur (Figure 4.5). Buds close to the cordon are basal buds and usually remain dormant. Potential crop load can be determined by sectioning buds and is most often used before pruning to give an idea of buds that may be damaged by winter temperatures.

Balanced pruning may be used as a tool to adjust cropload in areas of variable vigor. This technique incorporates prunings from several representative vines and estimates the vines' capacity based on the weight of these prunings. Thus, if a vine had weak growth the previous season, less buds would be left to encourage the vigor of the remaining shoots. A vigorous vine would benefit from a lighter pruning (more buds), thus balancing leaf area and crop load while decreasing the vigor of the remaining shoots.

The bud number to be retained is usually a minimum per vine plus a certain number for each pound. For winegrape varieties, numbers for balanced pruning will depend upon the variety (Smart, 1991). As a rule of thumb, leave about 30 buds per kg (15/lb) of pruning weight.

One more thing to consider is the crop to pruning weight ratio. In much of the research literature, these ratios have been given for well-watered vines. It can be calculated from the kg/vine of fruit and dividing that by the kg/vine of pruned canes. This will give an idea of the balance of the vine. If this number is too low (<5), then the vine may be able to support more crop load than what was harvested from it last year, and bud numbers/vine can be increased per vine. If it is too high (>10), then perhaps the crop may need some thinning, or the bud number may need to be reduced per vine.

Figure 4.4 Evenly spaced spurs in a vertically-trained, cordon system.

Figure 4.5 Non-count buds are those less than one fingers width from the cordon as seen here in a spur-pruned, cordon-trained system.

Goals of Pruning

- Maintain a balance between vegetative growth and fruit growth (including regulation of bunch number and size)
- Produce high quality fruit
- Select nodes that produce fruitful shoots
- Allow for easy access of farm equipment and vineyard traffic

Shoot Thinning

Often after bud break, a number of shoots will emerge from latent buds in the cordon in spur trained systems, or bud position may not be optimum in cane-pruned systems. Shoot thinning can be used to help improve the light penetration into the canopy later on in the season. This can also be used to adjust crop load by thinning fruitful shoots to reduce the crop, or thinning non-fruitful shoots to increase the leaf area to crop ratio.

Shoots can be removed once they have pushed out at least 10-15 cm in order to adjust the spacing between shoots. Spacing between shoots should be about 7 cm, with spurs remaining at 10-15 cm in order to get good light and air movement through the canopy.

Shoot Positioning

Although pruning is used to manipulate shoot position, shoot positioning can be used to direct shoot growth upwards or downwards. Shoots are usually tucked under a number of catch wires, depending upon your trellis design. The main goal of shoot positioning is to expose the fruit for color development (in red varieties) and increase air movement around the cluster to reduce disease incidence. The earlier berries and clusters are exposed, the less chance there is of inducing "sunburn". Earlier exposure can induce the skins to develop secondary metabolites which are similar to melatonin production in human skin (a.k.a. your 'suntan'), that protects the berry from harsh UV solar radiation. Be cautious of doing shoot positioning or leaf removal too late into the season, otherwise sunburn can be a problem, especially with white varieties.

Cluster Thinning

There are many opportunities in the life of a vineyard to adjust crop load (Table 4.1). Site selection, vine spacing, training system, and pruning technique are just a few things that can influence crop load. Vines that may be overcropped due to a small canopy size can benefit from cluster thinning to bring the vine back into balance. At least 30-40% of the crop must be removed in order to observe any differences when the fruit is harvested.

Proper timing can influence whether the benefits of cluster thinning are realized or not. The earlier thinning is practiced, the larger the berries will be due to redistribution of resources in the vine. Flower thinning will allow for more open clusters in the fruit zone; however caution should be exercised so that fruit set is not negatively affected. Early cluster thinning after fruit set may encourage shoot growth, but can reduce bunch compactness and botrytis susceptibility (Keller, 2001). If clusters are removed at veraison, maturity can be advanced in the remaining clusters, especially if lagging clusters are removed. Finally, late cluster removal will reduce yield.

Cluster thinning should not be a long-term practice in the vineyard, and if vines are continuously overcropped, pruning and shoot thinning strategies should be revisited.

Table 4.1 Influences of vineyard establishment and management on grapevine yield components

Component	Determined During	Management Options
Vines / acre Nodes / vine	Planting Winter pruning	Density / Trellis design Pruning level
Shoots / node Clusters / shoot	Budbreak - Early previous season and current season	Pruning level, short thinning, nutrition, canopy management
Flowers / cluster Berries / cluster	Fruit set	Nutrition, canopy management, irrigation, nutrition
Berry weight	All season	Irrigation, nutrition, crop thinning

Methods to Improve Fruit Exposure

Hedging

Canopies that are overly vegetative and large can reduce air flow and increase disease incidence, reduce light quantity, change light quality, and reduce fruit quality. Hedging can be used to remove the top portions of the canopy (10-20%) in order to reduce shoot growth and young leaves which can act as a strong sink for carbohydrates. However, timing is very important, as vines can compensate for the reduction in leaf area by compensating in growth elsewhere in the vine (i.e., lateral shoot growth) (Candolfi-Vasconcelos and Koblet, 1990; Candolfi-Vasconcelos et al., 1994). If hedging is done midway through fruit development (i.e., lag phase), then the vine has a better chance of developing those newly developed leaves to produce sugars, than later in the season (Cartechini et al., 2000). Late hedging will direct the vine's energy to a new flush of lateral shoot growth, rather than to the developing fruit which can delay ripening. As with cluster thinning, if repeated hedging is necessary, it is time to revisit your pruning and crop load strategies.

Leaf Removal

In vineyards where there is excess vigor or lateral growth, leaf removal can be practiced to increase fruit exposure to light and better balance vine and fruit growth. With this technique, leaves are removed in the bottom portion of the canopy (~30 cm), by either hand or mechanical means (Figure 4.7).

Excess removal of leaves around the fruiting zone however, may delay ripening and reduce sugar accumulation. Leaves immediately around the cluster are important for sugar accumulation, and there is a period of adjustment in the vine to source sugars from other leaves further above on the shoot. Thus, timing of leaf removal is very important. Under warm conditions (e.g. interior PNW), timing of leaf removal has been shown to not affect yield components or fruit composition (Kliewer and Bledsoe, 1987).

Early leaf removal soon after fruit set seems to be the best time in order to get maximum benefit of increased exposure. Late leaf removal (i.e., around veraison) can increase the risk of sunburn in grape berries, because berries do not develop protective compounds to deflect harmful UV rays. Damage from UV rays can lead to reduced anthocyanin production and delayed ripening (Spayd et al., 2002). In addition, leaf removal should be concentrated on the east side of the vine in rows oriented north-south to avoid cluster overexposure on the west side of the vine.

Figure 4.6 Hedging

Figure 4.7 Leaf removal can be employed to get better light exposure and air movement into the fruit zone. Extreme leaf removal, if too late in the season as seen here, can leave clusters open to sunburn and may delay fruit ripening.

The Ideal Canopy

Based on a number of recommendations by Richard Smart (Smart, 1991), the ideal canopy can be defined by a number of characteristics.

- 1:1 canopy height to row width to avoid cross-row shading and optimize sunlight interception
- North-south row orientation
- Vertical training systems to maximize sunlight interception
- 21,000 m^2/ha of canopy surface area
- Leaf area/surface area = < 1.5
- Leaf layer number = 3.0
- 7-14 cm^2 leaf area per gram of fruit
- 1.0-1.5 m shoot length
- Internode length = 60-80 mm
- Yield : pruning weight = 5-10
- 20-40% canopy gaps

Although these recommendations are a good guide, be sure to take into consideration your vineyard site, grape variety, and vigor before comparing your canopy to the "ideal" canopy. Use your experience with particular varieties on particular sites to adjust or fine-tune these numbers as needed. The goal in any case should be to have the proper balance of vegetative and reproductive growth to optimize fruit quality and yield.

Concluding Remarks

Canopy management must start with proper site selection, soil evaluation, and variety choice. There are multiple points in the establishment of a vineyard to manipulate a number of factors that can enhance fruit quality.

References and Useful Literature

Candolfi-Vasconcelos, M. C. and W. Koblet. 1990. Yield, Fruit Quality, Bud Fertility and Starch Reserves of the Wood as a Function of Leaf Removal in Vitis Vinifera - Evidence of Compensation and Stress Recovering. Vitis. 29: 199-221.

Candolfi-Vasconcelos, M. C., W. Koblet, G. S. Howell and W. Zweifel. 1994. Influence of Defoliation, Rootstock, Training System, and Leaf Position on Gas Exchange of Pinot Noir Grapevines. Am. J. Enol. Vitic. 45(2): 173-180.

Cartechini, A., A. Palliotti and C. Lungarotti. 2000. Influence of Timing of Summer Hedging on Yield and Grape Quality in Some Red and White Grapevine Cultivars. Acta Horticulturae. 512: 101-110.

Ferrini, F., G. B. Mattii and F. P. Nicese. 1995. Effect of Temperature on Key Physiological Responses of Grapevine Leaf. American Journal of Enology and Viticulture. 46(3): 375-379.

Keller, M. 2001. Principles to Have in Mind When Deciding on a Thinning Strategy. Australian Viticulture. 5: 27-29.

Keller, M., K. J. Arnink and G. Hrazdina. 1998. Interaction of Nitrogen Availability During Bloom and Light Intensity During Veraison. I. Effects on Grapevine Growth, Fruit Development, and Ripening. American Journal of Enology and Viticulture. 49(3): 333-340.

Keller, M. and G. Hrazdina. 1998. Interaction of Nitrogen Availability During Bloom and Light Intensity During Veraison. Ii. Effects on Anthocyanin and Phenolic Development During Grape Ripening. American Journal of Enology and Viticulture. 49(3): 341-349.

Kliewer, W. M. and A. M. Bledsoe. 1987. Influence of Hedging and Leaf Removal on Canopy Microclimate, Grape Composition, and Wine Quality under California Conditions. Acta Horticulturae. 206: 157-168.

Morgan, D. C., C. J. Stanley and I. J. Warrington. 1985. The Effects of Simulated Daylight and Shade-Light on Vegetative and Reproductive Growth in Kiwifruit and Grapevine. Journal of Horticultural Science and Biotechnology. 60(4): 473-484.

Morrison, J. C. 1991. Bud Development in Vitis Vinifera L. Botanical Gazette. 152(3): 304-315.

Petrie, P. R., M. C. T. Trought, G. S. Howell and G. D. Buchan. 2003. The Effect of Leaf Removal and Canopy Height on Whole-Vine Gas Exchange and Fruit Development of Vitis Vinifera L. Sauvignon Blanc. Functional Plant Biology. 30: 711-717.

Reynolds, A. G. 1988. Response of Riesling Vines to Training System and Pruning Strategy. Vitis. 27: 229-242.

Smart, R. E. 1973. Sunlight Interception by Vineyards. American Journal of Enology and Viticulture. 24(4): 141-147.

Smart, R. E. 1984. Some Aspects of Climate, Canopy Microclimate, Vine Physiology, and Wine Quality. Proceedings of the First International Cool Climate Viticulture and Enology Symposium., Oregon State University, Corvallis.

Smart, R. E. 1985. Principles of Grapevine Canopy Microclimate Manipulation with Implications for Yield and Quality. A Review. American Journal of Enology and Viticulture. 36(3): 230-239.

Smart, R. E. 1988. Shoot Spacing and Canopy Light Microclimate. Am. J. Enol. Vitic. 39(4): 325-333.

Smart, R. E. 1991. Sunlight into Wine: A Handbook for Winegrape Canopy Management. Adelaide, AU, Winetitles.

Smart, R. E., J. B. Robinson, G. R. Due and C. J. Brian. 1985. Canopy Microclimate for the Cultivar Shiraz. I. Definition of Canopy Microclimate. Vitis. 24: 17-31.

Smart, R. E., N. J. Shaulis and E. R. Lemon. 1982. The Effect of Concord Vineyard Microclimate on Yield. I. The Effects of Pruning, Training, and Shoot Positioning on Radiation Microclimate. Am. J. Enol. Vitic. 33(2): 99-108.

Smart, R. E., S. M. Smith and R. V. Winchester. 1988. Light Quality and Quantity Effects on Fruit Ripening for Cabernet Sauvignon. Am. J. Enol. Vitic. 39(3): 250-258.

Spayd, S. E., J. M. Tarara, D. L. Mee and J. C. Ferguson. 2002. Separation of Sunlight and Temperature Effects on the Composition of Vitis Vinifera Cv. Merlot Berries. Am. J. Enol. Vitic. 53(3): 171-182.

Tarara, J. M. 2005. A Climatology Refresher for Vineyard Managers and Winemakers. WSU Wine and Grape Research and Extension Newsletter. Prosser, WA. 15: 2-5.

Pruning

Pruning is the single most influential activity affecting vine growth, fruit quality and winter survival. The objective of pruning is to balance the development above ground to the vigor and development of the root system, maintain the vine shape while replacing injured or warn out areas.

Each vine has a fixed capacity potential to ripen a given quantity of fruit and wood depending on the vine's root system, vine size, leaf area, number of fruitful shoots, variety, climate, soil, trellis system and vineyard management. Overpruned vines produce less fruit, excessive vigor causing shading and are prone to injury from cold temperatures. Light pruned vines produce large numbers of shoots, large numbers of bunches and poor quality of fruit.

There are various types of trellis systems as shown in Section 3.5 but only two methods of pruning. These differ in the length of one year old wood retained after pruning. Cane pruning retains long fruiting canes filling the space between plants. Spur pruning utilizes short canes (1-2 buds) originating from a cordon system that fills the space between plants.

The decision of which system of pruning to employ will be dependent, in part, on the fruitfulness of the basal buds vs. the fruitfulness of the buds occurring in mid-cane.

Prior to the beginning of pruning it is useful to check for primary bud damage. This is accomplished by using a thin blade and cutting through the bud parallel to the cane. A live bud is green while a dead bud is brown dark in color. Care should be taken not to cut too deep or the green tissue underneath the bud will be exposed. This can be green even if the bud is dead. Buds should be checked on a number of long canes to get an understanding of any winter damage.

When pruning, select canes of pencil thickness, uniform diameter, and uniform color and free of disease. Canes must also be well hardened and have grown with good sun exposure. It has been shown that late pruning delays bud break. This is useful if any areas are prone to late season frosts.

A guide to bud numbers is to use the fruit weight to pruning weight ratio. (This concept is explained in Vine Physiology Section 2 and Canopy Management Section 4.2) A low ratio of 4-5 suggests more buds should be left and a high ratio suggests fewer buds should be left.

Cane Pruning

The canes should originate close to the main trunk and 10-20 cm below the fruiting wire. Canes growing directly from old wood should be avoided if possible as they are not as fruitful. A single short spur in good position near the main trunk can also be left to grow the fruiting canes for next year.

The number of buds left depends on vine spacing, the number of buds producing in the previous year and the growth attained. If the growth is weak, leave fewer buds and if strong, leave a few more buds.

Canes are cut through the last node when pruning to facilitate typing. Some individuals prefer to wrap the cane around the wire to reduce the amount of tying required. Cane pruned vines must be tied each year.

Spur Pruning

Spur pruning is restricted to vines which are cordon trained. Spurs consist of 1-2 buds not including the very basal bud. Two to 3 spurs can be left if increased crop is desired. These nodes produce the shoots and fruit for the current season's growth. Basal buds may often be unfruitful if they are shaded or if shoots are over vigorous. Spur pruned vines require good leaf and shoot management to expose basal buds to sunlight during the period of fruit bud initiation (around bloom and a few weeks after bloom). Good light conditions are required for these buds to develop the flower clusters and flower parts for the next year's crop. Spur pruning can be used for any variety with fruitful basal buds.

Spur pruning is quicker and more economical. However it is easy to over crop vines and to create shading and crowding of fruit clusters when too many nodes are left. Summer shoot thinning may be required to correct 'mistakes'.

Spurs are usually left in a vertical position, except for vines trained to the Geneva Double Curtain or spur pruned Scott Henry system. Tying of spur pruned vines is required only when new cordons are established or when an arm breaks free of the original tie.

Cordon trained vines use the same trellis system as cane pruned vines.

4.3 Nutrition

Soil Management

The Ministry of Agriculture and Lands has produced several reference publications that will assist people in the management of soils. These publications are called ***Soil Management Handbook for the Lower Fraser Valley*** and ***Soil Management Handbook for the Okanagan and Similkameen Valleys***.

These handbooks complement the soil descriptions contained in Ministry of Environment (MOE) Technical Report #18 *Soils of the Okanagan and Similkameen Valleys* and *Soils of the Langley-Vancouver Map Area RAB Bulletin* 18 (Vol. 1-5). For the Vancouver Island area, MOE Technical report #15 *Soils of Southeast Vancouver Island Duncan-Nanaimo Area. These maps are no longer available to the public, but may be available from some Ministry of Agriculture and Lands offices.*

Soils most suitable for commercial grape production have the following characteristics:

- well drained
- no ground water within 2 metres of the surface
- no restriction to root development
- pH of 6 to 7.5 in the top 40 cm
- nil to slight calcariousness in the top 40 cm and slight to moderate calcariousness beyond 40 cm
- non saline
- preferably medium to high cation exchange capacity
- medium to warm soil temperature
- site which has a slight slope (3 to 4%) to the south or southwest.
- are mineral soils with a minimum of 1% organic matter or more in interior soils and 4% or more organic matter in coastal soils

Soils differ greatly in the proportions of organic matter, clay, silt, sand, and rock; water holding ability; bacterial and other animal life. Soils change with time. Farmed soils can change rapidly. Good soil management promotes grape production by encouraging a favourable environment for grape roots. All vineyard practices that involve the soil will affect plant growth in some way.

Soil Texture

Soil texture is an important property affecting vine growth and soil management. Soil texture refers to the combination of mineral particle sizes in the soil. A soil can be coarse, medium, or fine textured; each is dependent upon the combination of the individual mineral particle sizes which are grouped into four particle sizes as follows:

1. Gravel – size 2 mm to 80 mm, generally rounded and loosely compacted;
2. Sand – size 0.05 mm to 2 mm, sub-rounded primarily quartz or feldspar minerals;
3. Silt – size 0.002 mm to 0.05 mm, rounded and not sticky when moist or wet; and,
4. Clay – size <0.002 mm, flat secondary minerals, sticky and plastic when wet or moist.

Most soils are mixtures of these four particle sizes and in addition, some also contain organic matter.

Individual soil texture classes are placed into five main soil textural groups. Common properties related to each group are found in the following table.

For additional reading:

Parnes, R. (1990). Fertile Soil: A Grower's Guide to Organic and Inorganic Fertilizers. Davis, California

Table 4.2 – Main Characteristics of Soil Textural Groups

Textural Group	Soil Textures	Characteristics
Coarse	gravels (G) sand(S) loamy sand (LS)	Generally single grained loose and very friable when moist, loose and soft when dry; many large pores; very low water holding capacity; and rapid perviousness; loose sands tend to wind blow; good bearing strength and trafficability when moist.
Moderately Coarse	sand loam (SL)	Very friable when moist, moderate to low water holding capacity; good trafficability and bearing strength when moist.
Medium	loam (L) silt loam (SiL) silt (Si)	Friable when moist; slightly sticky and plastic when wet; many medium to small pores; high water holding capacity; moderately good trafficability and bearing strength when moist.
Moderately Fine	clay loam (CL) silty clay loam (SiCL) sandy clay loam (SCL)	Hard to very hard when dry; sticky and plastic when wet; friable to firm when moist; high proportion of small pores; high water holding capacity; poor trafficability when wet.
Fine	silty clay (SiC) sandy clay (SC) clay (C) heavy clay (HC)	Very hard when dry; very sticky and plastic when wet; firm when moist; many small pores; moderately high water holding capacity; very poor trafficability when wet.

Available Water Storage Capacity (AWSC) Affected by Soil Texture

The capacity of a soil to store water depends upon the particle size composition of the soil (texture) and the soil particle arrangement (structure). It is also dependent upon organic matter and content of coarse fragments.

The available water in soils is generally considered as that held between field capacity and the wilting coefficient. Below are typical moisture holding capacities of different soil textures.

Table 4.3 – AWSC Values for Soil Textures in the Okanagan and Similkameen Valleys

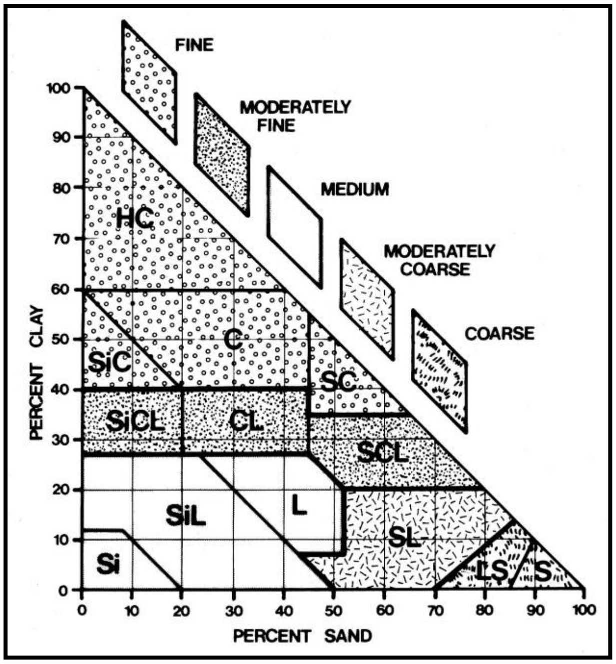
Texture Class	AWSC* mm/cm of Soil	Relative AWSC Rating
Gravel	0.2 – 0.6	Very low
Sand	0.8	Very low
Loamy Sand	1.0	Low
Sandy Loam	1.2	Moderate
Loam	1.7	Moderate
Silt Loam	2.1	High
Clay Loam	2.0	High
Clay	2.0	High
Organic	2.5	Very high

* AWSC values are given for the less than 2 mm size fraction only.
For gravelly soils with coarse fragments, the AWSC values are correspondingly reduced. Also the whole profile water holding capacity is much less on shallow soils.

In the soil texture triangle, pure sand (S), silt (Si) and clay (C) soils are shown near the triangle corners while soil textures of loam (L) or clay loam (CL) near the centre have various amounts of each.

Figure 4.8 – The Composition of Textural Groups.

Percentage of clay and sand in the main textural classes of soils; the remainder of each class is silt



The texture classes of the soil are: Sand (S), heavy clay (HC), silt (Si), Loam (L), or combinations of various forms as silt loam (SiL) The symbols within the triangle are meant to group these classes into similar coarseness classes from fine to coarse.

Good Soil Management

Before planting a vineyard:

1. Disturb the soil as little as possible during land clearing except in cases where shallow soils overlay clay or silt soils or where clay or silt soils overlay sands or gravels.
2. Have the soil analyzed at depths of 0-20 cm and 20 to 40 cm.
3. Incorporate large amounts of organic matter or grow a (deep rooted) green manure crop (e.g. fall rye) for several years before planting.
4. As grapes are a deep rooted crop, incorporate any recommended nutrients, lime, organic matter etc., as deep as possible.
5. Before planting, break up any hard pan with a deep ripper at least in the location where vines will be planted. It is better to use two way and close spacings in the ripping operation. Organic matter could be dropped into the trench created by the slip plow during this operation so that the organic matter and any soil amendments are placed deep into the soil profile.

After Planting a Vineyard — Good Management Should

1. Provide adequate amounts of water and plant nutrients for optimum crop growth.
2. Avoid excessive uptake of nitrogen, particularly late in the season, thereby promoting winter hardiness.
3. Prevent soil erosion, by wind or water through the use of temporary cover crops planted in the late summer and incorporated in the spring or through the use of permanent cover crops.
4. Improve or maintain soil structure.
5. Extend root development.
6. Increase or maintain soil organic matter.
7. Avoid working on wet soils, especially clay or silt soils
8. Keep the number of tractor trips in the vineyard with wet to moist soil to a minimum to avoid soil compaction. (compact soil has a bulk density greater than 1.4)
9. Maintain a cover crop on alternate rows in clean cultivated vineyards with heavy soils for tractor traffic.

9. Plant deep rooted cover crops to keep the soil open.

Poor Soil Management Will Result In

1. Decreased soil air content and water infiltration rates (e.g. by frequent, deep cultivations)
2. Decreased soil organic matter levels (e.g. by not growing cover crops or adding organic matter to the soil).

Erosion Control

Water and wind erosion should be reduced or eliminated. Water erosion damage is most severe on slopes where grapes are grown up and down the slope. Wind erosion is severe when light sandy soils are left bare.

Winter cover crops, permanent grass, and drainage systems all help to reduce erosion. The use of fall seeded cover crops can provide good water and wind erosion control. Wind erosion in the summer months on sandy soils can be reduced through the use of summer cover crops.

Organic Matter

Soil organic matter is a very small part of a mineral soil, but plays a very important role. Proper management of the organic matter influences the vineyard long term productivity. About 40% to 45% of the soil organic matter is very stable and resists decomposition. Another 40% to 45% is moderately stable (half life of 20 to 40 years). This portion is held within the soil particles and is very important to soil fertility accounting for 40% to 50% of the nutrients released each year. The remaining 10% to 15% decomposes easily and is composed of living and dead organisms (bacteria, algae, fungi, earthworms, nematodes etc.).

Excessive tillage, soil erosion and poor cover crop management will speed the loss of organic matter, especially in the interior where irrigation and cultivation, combined with hot summers, "burns" the organic matter very quickly.

In addition to the inorganic fertilizers available, there are organic fertilizers that can be used with advantage in vineyards. Some of these are listed in Table 4.2. There are several considerations that must be made when dealing with organic fertilizers. These are:

(a) the nutrients they contain are usually in an insoluble form (except potassium) and must be broken down by soil microorganisms. Organic fertilizers are therefore more effective if they are incorporated into the soil

(b) organic fertilizers are usually bulky and expensive to transport. The use of green manure crops and cultivating these into the soil may be a good substitute for some forms of organic fertilizer.

Organic matter improves the physical condition of the soil, increases soil moisture-holding capacity, improves aeration and serves as a source of nitrogen and other plant food. It supports bacteria and fungi which aid in the release of plant nutrients.

Most vineyard soils are low in organic matter. The organic matter level can be increased through the addition of green manure crops, barnyard manure, grape prunings, manure, and hay. Maintaining or improving soil organic matter will benefit the soil and grape plants.

Methods of Improving Soil Organic Matter

(a) Green Mature Crops

Organic residues from green manure crops maintain the soil in a more desirable physical condition, helping water and air movement into the soil.

Green manure crops provide a source of nitrogen that is released slowly throughout the growing season.

Green manure crops can be planted in March or April, after the fall cover has been removed. It will mature in two months. It can then be incorporated and the vineyard prepared for the fall cover crop that is planted at the end of July. A green manure crop of oats, Austrian winter peas and vetch at 78, 45 and 22 kg/ha, respectively, or clover at 15 to 20 kg/ha in combination with cereals such as barley and oats will enrich the soil with nitrogen and organic matter when they are turned under.

A temporary nitrogen deficiency may occur for a short time after ploughing in more mature green manure crops.

Grape pomace composed of seeds, skins and stems can be used as a source of organic matter. Pomace is usually quite acid. On heavy soils it may help to improve soil pH and structure. Do not use rates over 3 tonnes/ha.

Grape prunings are a cheap source of organic matter. Mulching these with a rotary mower, followed by incorporation into the soil, will provide more than a tonne of organic matter per hectare in most vineyards.

(b) Temporary Cover Crops

All vineyards, regardless of age, should have some form of cover crop during the period of August 1 to April 1. Cover crops, if properly managed, will add much-needed organic matter to the soil, reduce soil erosion, hasten fruit and vine maturity, improve water penetration during the fall and winter, and provide winter protection to the roots.

Fall cover crops should be planted up to the trunk of the vines for the greatest benefit.

Fertilizers to aid in cover crop establishment should be applied only if the cover crop is to be a permanent one.

Adequate soil moisture is needed for good seed germination and cover crop growth.

Spring cereals such as barley and oats or winter cereals such as winter wheat or fall rye should be seeded at 100 to 170 kg/ha.

Temporary cover crops should be turned under while still green. If the growth is too mature, vine growth can be reduced and soil nutrients tied up for three to five years before being released with decomposition. Apply 75 to 100 kg/ha of 34-0-0 to a heavy cover crop just before working it under to aid decomposition.

Temporary cover crops should be planted by the end of July.

(c) Application of Manures

The positive results of manure applications to vineyards have in most cases, been greater than the addition of the plant nutrients contained in the manure would warrant. Manures help to improve soil organic matter, soil structure and nutrition. There are also other beneficial effects when manures are added to soil.

Manures should be added to vineyards before working the soil in the spring. The next best time is in the fall, before the soil freezes.

Cow and poultry manures are commonly used. Each type differs in nutrient content. Manures supply plant food over a period time, but in the year of application each ton of manure should supply approximately the amount shown in Table 4.2. Recommended rates of N, P2O5, and K2O can be adjusted downward, depending upon the amount of manure applied.

Some chemical fertilizers should be used, even when heavy applications of manure are made.

Cow manure may be applied up to 35 tonnes per hectare. Poultry manure may be applied up to 15 tonnes per hectare.

Table 4.4 Fertilizer value of cow and poultry manure

			Kilograms per tonne of manure	
Type of manure	**Quality**	**N**	**P_2O_5**	**K2O**
Cow manure	Good	2.5	1.5	4
	Poor	1	0.5	3
Poultry manure	Good	5	3	4
	Poor	3	2	3

* Good quality refers to properly stored manure, containing little litter. Poor quality refers to exposed, leached manure with considerable litter.

Non-Nutritional Causes of Low Vine Vigour

Grape vines that do not produce enough leaf area to fill the trellis are not capable of producing optimum yields of grapes. Such plants have a scarcity of leaf area. The vigour of such plants needs to be improved. Usually there are factors other than nutrition at work. Some of these factors are listed in

Fertilizers and Mineral Elements

Plant Nutrients

Present information shows that 16 elements are essential to good plant nutrition. Three of these – carbon, hydrogen and oxygen – are taken from air and water. The other 13 are normally absorbed from soil by roots. Nitrogen, phosphorus, potassium, calcium, magnesium and sulphur are required in larger amounts, and are therefore called major nutrients. Zinc, iron, manganese, copper, boron, molybdenum and chlorine are required in small amounts, and therefore called micro nutrients.

Table 4.5 Causes and possible remedies of low vigour

Cause of Low Vigour	Possible remedy
Shallow or deep, dry soils	Add more organic matter to the soil, improve irrigation
Overcropping	Balance pruning and/or bunch thinning
Root injury caused by deep cultivation	Shallow cultivation
Winter injury to the roots	Replant
Poorly drained soil drain soil	Reduce irrigation, shallow cultivation
Insects and disease	See appropriate sections of the guide
Low or high pH	Apply lime or sulfur products according to soil test recommendations
Herbicide injury	Reduce rates, trim vine tips near the ground, change to a safer herbicide, do not spray on vine trunks until pruning or suckering wounds have healed

In the interior alkaline soils there is a reduced availability of manganese, iron, copper and zinc. Alkaline soils that are also sodic will express very high levels of sodium in addition to the low availability of manganese, iron, copper and zinc. In the coastal acid soils there is an increased availability of aluminum and manganese, and these elements together with copper may become toxic. Aluminum toxicity causes severe stunting of roots which become short and stubby, relatively unbranched and dark coloured, relative to well branched roots in good soils. The availability of most nutrients is reduced at low pH. Calcium and boron may be in short supply in acid soils. A boron deficiency causes root distortion, and death of root tips. Growth is restored when the availability of boron is restored.

Carbon is obtained from carbon dioxide in the air. Hydrogen and oxygen are supplied mainly by water. These nutrients are used to build parts of the vine.

They are also the major source of energy for growth.

Table 4.6 Nutrients essential to plant growth

Major Elements	Secondary Element	Micro Elements
Carbon		Boron
Hydrogen	Magnesium	Zinc
Nitrogen	Calcium	Copper
Oxygen	Iron	Manganese
Phosphorous	Sulphur	Molybdenum
Potassium		Chlorine

Table 4.7 Usual visual expressions of nutrition disorders

Elements	Seasonal Appearance	Shout Position
Boron	Early	Apical
Zinc	Early	Apical-mid
Iron	Early	Apical-mid
Manganese	Mid-season	Basal
Magnesium	Late	Basal
Potassium	Mid-late	Basal
Nitrogen		Not diagnostic

The following descriptions of nutrients and some of the symptoms of nutrient deficiencies provide some guidance for diagnosing plant nutrient needs. These are only a guide and should be confirmed by chemical analysis.

Table 4.8 Nutritional deficiencies

Common	Less Common	Not Observed
Boron	Manganese	Chloride
Nitrogen	Phosphorous	Sulphur
Potassium	Magnesium	Copper
Zinc	Iron	Molybdenum
	Calcium	

Table 4.9 Nutritional excesses

Common	Not Observed
Boron	Calcium
Nitrogen	Chloride Copper Iron Magnesium Manganese Molybdenum Phosphorous Sulphur

Nitrogen

Nitrogen is the most widely used, and most difficult nutrient to manage, in vineyards. Plants use nitrogen to form proteins that make up the protoplasm, the living substance in plant cells.

Grapes, compared to many other crops, have a low nitrogen requirement. Shortages of nitrogen are not detected easily. Generally, fruit yields are reduced before visual symptoms such as stunted growth, thin shoots, or pale green leaves are seen. Reduced fruit bud development, resulting in lower yields, can be caused either by excess or deficient nitrogen levels.

Basic nitrogen fertilizer recommendations are difficult to provide because vine growth is also largely affected by soil type, the rate of breakdown of organic matter (mineralization), vigour of a variety, irrigation practices and conditions of the root system. Generally, sandy soils require frequent small nitrogen applications while loamy, silt or clay soils may not require any fertilizer. Vigour in newly planted vineyards will be influenced by the previous cropping history of the land.

Excess Nitrogen

Excess nitrogen stimulates vegetative growth and may delay wood maturity. Excess nitrogen may also create shading conditions which contribute to lower bud fruitfulness and increased powdery mildew and *Botrytis*.

Nitrogen vs. Cold Hardiness

It is not true that applications of nitrogen will reduce cold hardiness of vines. Vines low in vigour and low in production as a result of nitrogen deficiency need applications of nitrogen to become more vigorous and more productive. Excess vigour as a result of excess nitrogen leads to succulent growth and poor wood maturity which in turn is not winter hardy.

Nitrogen Soil Application

Established Plantings

A restricted nitrogen program may be necessary to reduce vigour, hasten fruit maturity, and promote winter hardiness. Vine growth and yields are often adequate without application of nitrogen fertilizer.

Efficient Fertilizer Use In Vineyards

The most efficient use of nitrogen fertilizer occurs if it is applied after bloom but before veraison. Early maturing varieties may have three or four weeks of time after harvest before leaf fall and may benefit from nitrogen after harvest, provided this does not stimulate new growth.

The availability of nitrogen varies with the type of fertilizer used. Urea for example takes a long time to become available in a cool, wet soil. Local research has shown that nitrate based fertilizers such as calcium nitrate provide nitrogen almost immediately and provide soil solution nitrate for a limited time. Ammonium based fertilizer such as ammonium sulphate required almost 30 days before it became available and then persisted in the soil solution for a longer period of time depending on soil type and irrigation or rainfall. Timing of fertilizer applications to influence specific responses at specific times of the vegetative growth or at fruit formation is therefore more controllable with nitrate based fertilizers. The longer lasting ammonium based fertilizers must also therefore be used with caution late in the season when winter hardiness of the grape vine is of concern.

The splitting of nitrate based fertilizers during the growing season will provide better control of the soil solution nitrate than large applications of fertilizers applied all at once. Slow release N formulations can also be used to apply nitrogen over a longer period of time.

The concentration of the soil nitrogen solution is also affected by the frequency and duration of irrigation or rainfall.

It takes about 3.7 kg of pure nitrogen to produce one ton of fresh grapes, with 1.6 kg stored in the clusters and 2.1 kg in the vegetative growth. This ratio of nitrogen storage holds true for all varieties, regardless of age. Nitrogen needs can therefore be calculated for a four or five ton grape crop if there is no breakdown of organic matter in the soil (mineralization).

A crop of four tons of grapes would therefore require (3.7 x 4) = 14.8kg of actual N. However, a process called mineralization releases plant nutrients including ammonia. Ammonia is quickly converted to a nitrogen source for plants, depending on soil oxygen content, soil temperature, soil moisture and soil pH. It is therefore difficult to calculate precisely how many kg of nitrogen it would take to produce the four-ton grape crop.

Nitrogen Foliar Applications (Urea)

Foliar applications of urea are not generally recommended. However, they can be used under special circumstances when additional nitrogen is required. To avoid the delay of wood maturity, do not apply foliar nitrogen after the end of July. Some urea products contain an impurity called biuret. Foliar injury can result if the biuret content of urea exceeds 2 percent.

Nitrogen Fertilization at Related to Soil pH

Urea is an excellent source of nitrogen for plants when utilized on soils that have a pH of 7.0 or less. However, on soils with a higher pH, it may not be the most efficient N-source when surface applied because N-losses through ammonia volatilization are likely to be quite high. On alkaline soils (those having a pH higher than 7.0), ammonium sulfate (21-0-0) or ammonium nitrate (34-0-0) will have lower ammonium volatilization, and calcium nitrate will not have any. The first two fertilizers will acidify soils under irrigated conditions. The actual acidification rate depends on the physical and chemical properties of the soil as well as on the level of water percolating through the soil and the amount of fertilizer applied in excess of that used by plants. However, ammonium sulphate also contains 24°C, plant available sulphur which may be advantageous on soils containing insufficient levels.

The preferred sources of nitrogen fertilizer on acid soils in decreasing order of their effect on soil pH are calcium nitrate, urea, ammonium nitrate and a mixture of ammonium sulphate and urea sold as 34- 0-0-11 on soils poorly supplied with plant available sulphur. Ammonium sulphate should probably be avoided on these soils except when correcting a sulphur deficiency or to reduce high pH.

Table 4.10 Amount of fertilizer needed to supply various amounts of nitrogen in kilograms per hectare

Actual Nitrogen Kg/ha	Urea 46-0-0	Ammonium nitrate 34-0-0	Ammonium sulphate 21-0-0	Calcium * nitrate 15-0-0
30	65	88	142	200
40	87	118	190	267

* Calcium Nitrate may be applied to the soil where the pH is low. It tends to maintain pH levels whereas other nitrogen fertilizers lower the pH.

Assessing Nitrogen Needs

There is no single method that serves well as a guide to nitrogen requirements for grape vines. Nitrogen needs are determined during the growing season, and through the use of indicators such as crop load, amount of winter pruning, assessing canopies and by checking bloom time petiole analysis. In addition there are visual symptoms.

Calculation of Fertilizer Rate for Ground Applied Fertilizers

Fertilizers are labeled according to the percentage of nitrogen (N), phosphate (P_2O_5) and potassium (K_2O) and other nutrients when these are present. The rest of the ingredients in the fertilizer are carriers such as oxygen and hydrogen.

General Formula:

The amount of fertilizer required:

$$= \frac{\text{recommended rate x 100}}{\text{\% fertilizer analysis}}$$

Example A

Recommended rate of potassium is 135 kg/ha
Fertilizer analysis is 0-0-60

Amount of fertilizer to apply:

$$= \frac{\text{135 kg/ha x 100}}{60}$$

= 225 kg

Example B

Example: if 250 kg/ha of 13-16-10 was applied amount of nitrogen would be:

$$\frac{\text{225 kg/ha x 13}}{100} = \text{29 kg}$$

amount of phosphorous would be:

$$\frac{\text{225 kg/ha x 16}}{100} = \text{36 kg}$$

amount of potassium would be:

$$\frac{\text{225 kg/ha x 10}}{100} = \text{22.5 kg}$$

Phosphorus and Potassium

The application of P and K should be based on soil test recommendations.

Unnecessary soil applications of potassium may interfere with the uptake of calcium and magnesium. It is important to monitor soil potassium values and to carefully control potash fertilizer applications on low magnesium soils.

Phosphorus

The major role of phosphorus in plants is for energy transfer. Phosphate influences root, flower, seed and fruit formation. Deficiencies can result in stunted growth, small leaves, poor fruit set and a generally weak plant condition. Deficiencies are corrected with phosphate fertilization. The availability is also improved by maintaining soil pH in the optimal range (6 to 7.5). On acid soils (low pH), phosphorus combines with aluminum and iron to form insoluble compounds.

Potassium

Potassium is needed to form sugars and starches, proteins, acids and colouring materials, odour and taste of grapes and wine. Potassium also increases plant winter hardiness, and drought resistance. Foliar symptoms of potassium deficiency usually occur in mid summer. Leaves in the centre of the new shoots develop yellowing or a lighter green. This starts at the leaf edge and gradually moves to the centre of the leaf. Brown spots and dead areas may develop. The spots may fall out and leave holes in the leaves. Leaves may become brittle. Fruit ripens unevenly. In cases of advanced deficiency, the leaves have a scorched appearance and may turn black. Shoot growth is reduced, vine vigour is low, and berry set and yields are also low in severe cases. **Excess amounts of potassium will result in decreased uptake of calcium and magnesium and increased pH values in grape juice.**

Magnesium

Magnesium is a major part of chlorophyll, the green material in leaves. Magnesium is also involved with phosphate uptake and movement in the vine. Deficiencies are sometimes related to land leveling operations, exposing soils containing either low magnesium or high potassium levels. **Grape stem drying may be caused by magnesium deficiency.**

Soils with low magnesium values require magnesium applications. Dolomitic limestone is an effective means to supply soil applied magnesium if low pH values are present. Magnesium sulfate or Sul-Po-Mag can be used if pH values are above pH 6.5.

Most vineyards require multiple sprays to maintain adequate magnesium levels to a maximum of 36Kg/ ha. Magnesium sprays can be combined with sprays of boron, zinc chelate or urea.

Symptoms of magnesium deficiency in green fruited varieties begin with a yellowing of basal leaves that gradually progresses to younger leaves. The yellowing begins at the leaf edge and gradually moves into the leaf between the veins. Yellow areas eventually turn white and die. Browning of the leaves may eventually occur. In red fruited varieties the discolouration pattern is the same, except that the leaf becomes red or purple. In both the green and the red fruited varieties, the veins remain green. The leaves will drop prematurely in very severe cases. High calcium supplies relative to magnesium may induce magnesium deficiencies. Deficiency symptoms may be induced by low magnesium and/or high potassium levels in the soil and/or high nitrogen uptake by the roots.

Table 4.11 Fertilizer sources of sulphur and magnesium

Formulation	% sulphur	% magnesium
Sulphur products	90	0
Sul-Po-Mag	22	11
Gypsum	18	0
Espsom salts	18	10
13-16-10	13	0
16-20-10	14	0
21-0-0-	24	0
Dolomic limestone	0	0

Boron

Boron influences cell differentiation, cell growth, pollen germination and growth of pollen tubes.

Vineyards require regular soil applications of boron.

Boron uptake is related to soil moisture during the growing period. Drought induced boron deficiency is not uncommon during the spring growing period if vineyard soil moisture was inadequate the preceding fall. Where soil applications have been overlooked, a temporary restoration of boron levels may be obtained with one or more foliar applications, especially when poor set is anticipated.

Soluble boron sprays may be combined with some pesticides such as wettable powders but not with oils or liquid pesticides. Soluble boron products may be added to herbicide tanks (check labels) and then sprayed onto weeds and soil. Avoid spraying vine trunks with this mixture due to the toxic effects of boron in this mixture to grape vines. Boron can be combined with other elements such as zinc chelate, magnesium or urea.

Petiole and soil tests provide a useful guide to boron requirements.

Too much boron is very toxic to grape plants. Do not exceed recommended rates. Soil applications should be broadcast evenly over the entire vineyard area and should not be made within one month of lime applications.

Symptoms of boron deficiency

Symptoms of boron deficiency may be noticeable on the fruit clusters, shoots or leaves, and may occur at different times of the year. Drought induced deficiency may be present if new leaves are small, misshapened, cupped, puckered, wrinkled and, sometimes, have missing lobes. Terminal buds stay dormant. Numerous lateral shoots appear. Shoots may be stunted and dwarfed after bud break with zigzag growth and more than normal lateral growth. Flowers and flower clusters may dry up. Some small round berries may appear mixed with normal sized berries. Later in the year, leaves may have interveinal yellowing or the yellowing may appear in patches. Internodes on new shoots may become shorter during the growing season, followed by dying of shoot tips and development of swollen areas that become corky and split. Severe cases of boron deficiency result in no new shoot growth or failure of flowers to set.

Soils where boron deficiencies are likely to occur

1. Soils which are leached
2. Soils low in phosphates
3. Soils high in potassium or heavily limed soils
4. Sandy or gravely soils
5. High pH soils

Table 4.12 Percentage equivalents and conversion factors for some plant food boron materials

Amount of material required to supply 1 kg boron/hectare

Kind of boron product content	% boron content	kg product required
Borate 40	12.5%	8.0
Solubor	20%	20.0

Calcium

Calcium influences good root formation, protein formation and carbohydrate production. Calcium is used to build cell walls and helps "cement" cells together. Calcium controls the uptake of water, alters the availability of nutrients and prevents the toxic effects of others. A deficiency may produce young leaves that are distorted and small with irregular leaf margins. Leaves may turning yellow between the veins and at the leaf margins, followed by the appearance of pinhead sized spots near the leaf margins. Vine tips die. There appears to be a sensitive balance between calcium, magnesium, potassium and boron. An imbalance causes abnormal performance of plant functions. A **lack of calcium is associated with berry shrivel and drying and brittleness of stems.** Soil calcium levels are maintained by liming soils to the recommended pH.

Soils in which a calcium deficiency may occur

1. Acid soils
2. Sandy soils, especially in coastal areas
3. Soils which are subject to leaching through excessive irrigation or rain
4. Soils which have accumulations of excessive amounts of potassium as a result of potassium applications when they are not needed, or continued use of high rates of manures.
5. High nitrogen or potassium applications to a range of soils may contribute to calcium deficiency.
6. Foliar application of Calcium can be used to correct Ca deficiency.

Zinc

Zinc influences berry set, pollen development, normal leaf development, the elongation of internodes, starch and chloroplasts.

Zinc should be applied when zinc levels are low. Use both foliar symptoms and petiole tests to determine zinc levels. Zinc may be combined with sprays of boron, magnesium or urea.

The principal symptoms of zinc deficiency (Little Leaf) are a failure of shoots to grow normally, small and chlorotic leaves, straggly clusters, a widened angle formed by the two basal lobes of the leaf blade where the leaf stem or petiole is attached and a lightening or green colour between the veins of the leaf.

Vines grafted onto some rootstocks such as Freedom, Harmony and C-1613 are more susceptible to zinc deficiency.

Types of soils where zinc deficiencies commonly occur

1. Acid soils that are leached, sandy or where total zinc is low
2. Alkaline soils with a high pH
3. Old corral sites
4. Land that has been levelled (95 % of available zinc is in the top 15 cm or soil).
5. Soils which are over limed
6. Soils that are very low or very high in organic matter (muck soils)
7. Cold wet springs
8. Soils with excess phosphorous

Zinc Fertilization of Soils

Generally, zinc is more available to plants in acid than in alkaline soils. However, zinc deficiencies do not occur on all alkaline soils and are observed quite often in acid soils. Zinc is a relatively immobile nutrient in soils and therefore should not be expected to move rapidly through the profile. It is advised that soil levels be determined before planting when an addition can still be easily worked into the root zone. When soil test values are 1 ug/mL (1 ppm) or less, it is recommended that 10 kg Zn be applied per hectare (about 30 kg/ha of zinc sulphate monohydrate (35% Zn) or 45 kg/ha of zinc sulphate heptahydrate (23% Zn). Such an application to the root zone will correct a zinc deficiency for a period of two to three years.

Soil applications of zinc are expensive and are not always successful because zinc is easily tied up in the soil. Soil applications in existing vineyards should be applied only in localized, severely deficient areas.

Foliar applications of zinc are more economical and effective.

Table 4.13 Fertilizer sources of zinc

Formulation	% Zinc
Zinc sulphate (monohydrate	35
Zinc sulphate (heptahydrate)	23
Zinc 50 "neutral zinc	5
Zinc chelate	14

Iron

Iron is needed for development of chlorophyll, activation of enzyme systems and the formation of complex organic compounds.

Iron deficiency develops first on young leaves. Leaves develop yellowing between the veins, progressing to small veins and gradually to the main veins until the entire leaf is yellow. These symptoms are more pronounced than those of zinc or manganese deficiency. Yellow leaves eventually die.

Iron chlorosis, also known as lime induced iron deficiency, usually occurs on seepage sites and in grape varieties sensitive to high pH soils. Grape rootstocks listed under Phylloxera Control will aid in minimizing lime-induced iron deficiencies in scion varieties. Foliage of iron deficient plants may be made green by foliar application of iron chelates. This is a temporary measure and does not correct the basic cause. Iron sprays may have to be repeated several times to see results. Do not combine iron with other pesticides or minerals.

Soils Where Iron Deficiencies are Likely to Occur

1. Soils with high pH and free calcium carbonates
2. Poorly drained soils (poor soil aeration)
3. Soils very high in manganese
4. Oxygen deficient soils (compact soils)
5. Soils with low or very high temperatures
6. Land that has been leveled or where erosion occurs
7. Where high phosphate applications have been made.
8. Iron is not normally applied to the soil. See table for foliar application rates.

Manganese

Manganese assists in the formation of chlorophyll and activates enzymes.

Deficiency symptoms begin on basal leaves as a yellowing between veins. Manganese deficiencies are easily confused with iron or zinc deficiencies. Petiole analysis will help to separate these deficiencies.

Deficiencies of manganese are possible in soils with pH values above seven. Manganese deficiencies sometimes occur with iron deficiencies. See foliar tables for materials and rates.

Copper

Copper is an important part of several plant enzymes and is involved in photosynthesis and chlorophyll formation. Copper influences leaf shape, size and colour, fruit set and yield, root growth and terminal growth. Copper will enhance the flavour, storage and shipping of some fruits and vegetables as well as increase their sugar content. Failure of flowers to set and seed to form are symptoms of copper deficiency in some annual crops.

Deficiency symptoms for copper would most likely occur on soils high in organic matter. Deficiency symptoms include poor root development, small pale leaves with burnt tips and margins, downward cupped leaves, rough bark on canes, petioles and veins, wilt and death of shoot tips, flower caps that turn straw yellow and do not fall off, short canes and short internodes, plus reduced yields due to a failure of flowers to set and a lack of seed development.

NOTE: See use of copper for post harvest sprays in the diseases section of this guide. Copper toxicity to vines may result from repeated applications of copper to soils or vines.

Sulphur

Sulphur is applied to grapes for the control of powdery mildew. Replacement of sulphur with other fungicides may result in the need for sulphur applications in some areas.

Sulphur is part of protein and of some volatile components. It is involved with the formation of chlorophyll. Deficient vines may have deficiency symptoms which are very similar to a nitrogen deficiency in the early stages. This progresses in more severe cases to restricted shoots. Shoots may be thin, stiff and upright. Terminal leaves are light green. There is a yellowing and sometimes orange and red tinting of terminal leaves together with some black (necrotic) spots or spotting between the veins.

Table 4.14 Sources of sulphur

Formulation	% sulphur
Ammonium thiosulphate	26
Ammonium sulphate	24
Potassium sulphate	18
Sulphate of potash-magnesia	18 to 22
Epsom salts Mg SO_4	10
Elemental sulphur	90-99
Gypsum	16 to 18

Sulphur is a minor element which is sometimes not present in the soil in adequate amounts. High pH soils (over 8.5) may require acidification (see write-up on soil acidification). Sulphate-sulphur is the only form that is directly available to vines. It is therefore the form of sulphur that should be used to correct nutrient deficiencies. Some fertilizers contain sulphate-sulphur as a secondary ingredient; e.g. ammonium sulfate (21-0-0), Epsom Salts (magnesium sulphate), potassium sulphate (0-0-50), gypsum (calcium sulphate). Generally, the use of acidifying fertilizers such as 21-0-0 on soils with a high pH, and the use of non-acidifying fertilizers such as gypsum or epsom salts on acid soils, will ensure sufficient sulphur for adequate nutrition.

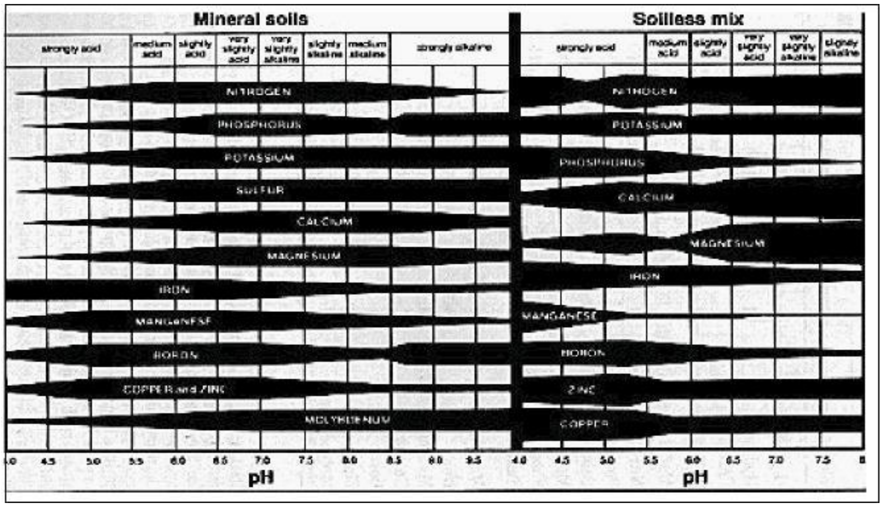
Soil Reaction and Influence of pH Availability of Nutrients

Figure 4.8 illustrates the relationship between pH and the availability of various plant nutrients. Each element is represented by a band as labelled. The width of the band at any particular pH value indicates the relative availability of the element at different pH values; the wider the band, the more favourable the uptake. The total amount present is not indicated, however, since this is influenced by additional factors, such as cropping, fertilization, and the chemical composition of soil minerals. Molybdenum, an essential element, has not been thoroughly investigated. Indications are, however, that liming and high pH promote its availability.

Lime Applications to the Soil

Poor vine growth may result where soils have become too acidic (pH below 6.0). Lime applications are required to correct these low pH values. Most virgin soils in the British Columbia Interior

Figure 4.8 How Soil pH Affects Availability of Nutrients



are neutral or alkaline (i.e. pH 7.0 or higher). However, the use of nitrogen fertilizers and continued irrigation for many years favours the development of acidic conditions which are caused by leaching calcium, magnesium and other elements. Such effects are most pronounced in coarse textured soils and are often restricted to areas where fertilizers have been applied. Frequent determination of soil pH is recommended so that corrective liming can be implemented. Failure to take quick action may result in low pH values deep in the soil profile that are difficult to correct.

The need for liming must be determined by a lime requirement test.

Allow about one month between applications of fertilizer and applications of lime. Lime should not be applied to the soil immediately following or preceding a fertilizer application because the lime will cause ammonia to be released into the atmosphere and the effect of the fertilizer will be reduced.

These rates are for agricultural lime materials with a neutralizing value or calcium carbonate equivalent to 100. Rates for other materials must be adjusted according to the calcium carbonate equivalent.

For example, calcium hydroxide (hydrated lime), as used fresh, has a calcium carbonate equivalent of 135%. Therefore, if fresh hydrated lime is used, multiply the amounts in the soil test report by 0.74.

It may be advantageous to supply part of the total lime requirement as dolomite, which contains both calcium and magnesium. However, do not use high magnesium (dolomite) lime for routine soil pH correction unless large amounts of magnesium are needed.

In cases where dolomite is used it should comprise half, or less, of the total lime requirement. For example, if the lime recommendation is 2 t/ha, apply dolomite at 1 t/ha, or less with the balance comprised of agricultural lime, well pulverized C.A. storage lime or hydrated lime.

The lime must be broadcast evenly between the rows and must be incorporated to be effective. The effectiveness of any liming material depends upon the particle size. The finer it is ground, the greater the reacting surface and the more rapid the effect upon the pH level. Extremely coarse materials are so slow that they are not recommended.

Pulverized lime that can pass through a #60 sieve is considered fine ground (a #60 sieve has wires spaced 0.25 mm apart).

Soil Acidification

Sometimes it is desirable to lower soil pH in order to increase the availability of some plant nutrients. Acidification may be required on soils that have a pH above 8.0. Lowering soil pH involves the same cultural practices and considerations as liming, except that different products are required. The principal agents used to lower soil pH are elemental sulphur, sulphuric acid, aluminum sulphate, and iron sulphate (ferrous sulphate). Ammonium sulphate, ammonium phosphate, and other ammonium containing fertilizers are also quite effective in reducing soil pH, though they are primarily sources of plant nutrients.

For large areas, elemental sulphur (or a mixture of it and bentonite to improve its stability and safety when handled in confined spaces) is probably the most economic product. However, elemental sulphur has to be oxidized by soil micro-organisms (*Thiobacillus* species) to sulphuric acid to effect a reduction in soil pH. The rate at which soil pH will decrease is related to the activity of the soil micro organisms. Sulphuric acid can of course also be used but it is unpleasant to handle as well as very corrosive. Generally, elemental sulphur when fully converted to sulphuric acid will react with three fold its applied weight of residual carbonate. As with limestone applications, limiting the maximum rate of applied sulphur at any one time (about 2 tonnes per hectare) will lower the pH gradually while preventing or minimizing the chance of salt build-up. The soil test laboratory will determine the total soil acid and sulphur requirement to attain desired soil pH upon request.

Fertigation

Fertigation is the application of fertilizers through an irrigation system by the use of "T" tape, drippers, microjets, sprinklers, etc.

Advantages

- Fertigation ensures the fertilizer will be carried directly to the root zone; amounts and timing of fertilizer application can be precise.
- Avoids problems of inadequate rainfall to move fertilizer in when using trickle type irrigation.
- Studies have shown that less fertilizer needs to be used due to direct application to root zones and therefore less to be leached as potential pollution.
- Savings in labour

Disadvantages

- Increased capital costs
- Uniformity of application depends on uniform water distribution. Poor system design, plugged lines and emitters mean poor distribution.
- Amounts cannot be varied to suit individual vine requirements.
- Not all types of fertilizers can be used.
- Potential for salts and pH problems in soil.
- Irrigation system can become corroded.

Table 4.15 Examples of Fertigated Nitrogen products

Type		Solubility
Urea	46-0-20	440 gm/L of solution or 4.4 lb/gal of solution
Ammonium nitrate	34-0-0	590 gm/L of solution or 5.9 lb/gal of solution
Calcium nitrate	15.5-0-0	950 gm/L of solution or 9.5 lb/gal of solution

Phosphorus

Not all forms of phosphorus are acceptable. For example, treble super phosphate 0•45•0 changes spontaneously to dicalcium phosphate and precipitates out, clogging lines and emitters.

Acceptable forms are: 10-34-0
0-55-0 (phosphoric acid)
10-52-10
20-20-20
10-45-10

Fertilizer formulations such as ammonium polyphosphate (10-34-0) or phosphoric acid (0-55-0) can be used without forming precipitates. Precipitate problems can occur even with these forms of phosphorus, particularly with water high in Ca or Mg (above 300 ppm) or when mixing fertilizer. A test should be done if water analysis shows calcium and magnesium are above 300 ppm.

A test to determine whether precipitation will occur should be done by mixing the fertilizer solution with a sample of irrigation water in the same proportions as they would be if injected into the irrigation line. If the mixture turns cloudy, the fertilizer solution concentration is not high enough to prevent fertilizer from precipitating in the irrigation lines.

This problem can occur if injection occurs at the same time as certain other types of fertilizers, particularly calcium nitrate, or even if one is followed by another.

Micro Nutrients

Chelates or sulphates of most minor elements can be safely applied, but they may be more efficiently applied as foliar sprays.

Equipment

A backflow prevention device is required to be placed in line before any injection equipment.

Injectors: Venturi injectors require at least a 20% pressure drop between the inlet to the Venturi (prior to a pressure reducing valve) and the outlet to the Venturi. Some growers have noted difficulty in injecting the amounts of liquid per minute that charts specify. The Venturi unit must be sized for your system. If there are too few emitters to create enough flow, too much of the flow has to go through the Venturi and the pressure differential is reduced and the required suction will not take place. If it is too low there may be no suction at all. If the flow is too low for the smallest Venturi device, you will have to use a different injection system.

Other injector methods are:

- Sprayer pump
- Electric metering pump
- Hydraulically driven ratio feeder
- Bypass feed tank
- Feed line into pump suction side (for systems which use a pumped water supply)

Timers: Some growers have experienced problems with power surges and/or strikes from lightening. A basic surge suppressor or power bar used for plugging in computers will eliminate surges or spikes in voltage when power lines are struck in the vicinity. If the surge is too great, it may fry the metal oxide rectifiers in the power bar and still affect your clock. The bar will then be acting as an ordinary outlet and will not suppress surges and the rectifiers will need replacing.

Grounding: Your clock must be properly grounded. If it is connected to your house system with a proper ground it should be fine, but if the clock is out in the field it must still be grounded properly. Use an eight foot grounding rod which must be placed no further than 12 feet from your clock. It is wise to check with an irrigation company that is familiar with proper lightening and surge protection equipment.

Fertigation Practices

Check out this website below for information regarding tree fruit fertigation practices and information http://www.al.gov.bc.ca/treefrt/product/ fertigation2001.pdf.

This information may be useful when considering grape fertigation.

The information presented in this website applies directly to orchard nursery stock and 1 year old trees in the orchard. It is included here as an example of considerations and the approach taken to fertigate young trees. The same type of consideration could be given to young vines, taking care not to stimulate them too much, ensuring that they mature and harden before the end of September.

Injection

Fill the lines for at least five minutes before starting injection. When injection is completed, continue running the irrigation for l/2 hour to ensure all the fertilizer solution is cleared, to ensure even distribution and to avoid clogging lines and emitters.

The amount of time required to evenly distribute the fertilizer and to clear all lines is approximately l/2 hour of zone run time after injection has been completed.

Injection time

$$\text{injection time} = \frac{\text{volume of solution}}{\text{injection rate}}$$

e.g.

- volume of solution = 2 gal of mix
- injection rate
- a figure from an injection chart usually available with the injector with an inlet pressure of 100 psi and an outlet pressure of 60 psi using a model 384 Mazzei injector, the suction rate (injection rate) is 8.2 gal/hr.

Therefore,

$$\text{injection time} = \frac{\text{2 gallons}}{\text{8.2 gallons/hour}}$$

$$= \text{.24 hours or 15 minutes}$$

Note Back Flow Prevention

Farmers that have cross connection control devices installed must have them tested every year in order for the devices to be considered acting and in working order. **Contact your water purveyor for information regarding the installation and testing of these devices.**

Petiole and Soil Analysis

Petiole Analysis for Bearing Vineyards

Both petiole and soil analyses are the most reliable guides to fertilizer requirements for bearing vineyards. To be of greatest value, petiole analysis should be made on an annual basis. Paired comparison, one from normal and one from the abnormal condition, are frequently helpful. Using petiole analysis only when nutritional problems are suspected will not yield the greatest benefit from the analysis service. Deficiencies of various nutrients produce characteristic visual symptoms in grapes. Diagnosis of visual nutritional deficiencies can be difficult, especially if more than one element is deficient. Petiole analysis allows for a more accurate diagnosis of such problems The following general guidelines are approximate tissue values based upon available information to date, and are subject to change as more information becomes available. These values are based on grape leaf petioles taken opposite basal flower clusters at full bloom. *See Table 4.14.*

Procedure for Sampling Vineyards for Grape Petioles

Important

A petiole sample is only as good as the method of taking the sample. The results that are provided are only as good as the sample.

When to Sample – Bloom time.

Fee Schedule per Sample

Consult soil and tissue laboratory for up-to-date fee schedules.

How to Sample

1. Sample only vines of the same variety and same age.
2. Sample only the leaf petiole that is opposite the first or second flower cluster towards the base of the shoot.
3. Take only one petiole from each plant. Collect sufficient petiole sample to produce 30 grams of dry matter (100 to 300 petioles), depending on petiole size. Varieties with large petioles, require about 100 petioles per sample. Varieties with smaller petioles require 300 petioles per sample.
4. Dot not sample plants that have been sprayed with fertilizer.
5. Separate the leaf blade from the leaf petiole and save the petiole only.
6. Use an X pattern wherever possible for each variety. Avoid outside rows and vines covered with soil dust.
7. Remember to place sample information cards inside each sample bag. Complete the application forms and attach these, plus payment, to the bags.

TABLE 4.16 Adequate nutrient range for grapes based on bloom time petiole analysis

Nutrient	Method of expression	V Vinifera		
Nitrogen	% Low vigour	0.5	to	1.2
	% Med vigour	0.55	to	1.3
	% High vigour	0.60	to	1.5
Magnesium	%	0.3	to	1.5
Phosphorus	%	0.15	to	0.5
Potassium	%	2.5	to	4.5
Calcium	%	1.0	to	3.0
Boron	ppm	30.0	to	100.0
Zinc	ppm	25.0	to	100.0
Iron	ppm	40.0	to	300.0
Manganese	ppm	30.0	to	150.0
Sulphur	%	0.1	to	0.5

Variety Vigour

Low Vigour	Medium Vigour	High Vigour
Auxerrois	Cabernet Franc	Bacchus
Gamay Noir	Chasselas	Barbera
Kerner	Ehrenfelser	Cabernet Sauvignon
Ortega		Chenin Blanc
Schonburger	Muscat Ottonel	Chardonnay
	Optima	Gewürztraminer
	Peral of Csaba	Madeline Angevine
	Pinot Gris	Madeline Sylvaner
	Pinot Meunier	Merlot
	Pinot Noir	Muller Thurgeau
	Semillon	Pinot Blanc
	Siegerrebe	Riesling
	Vidal	Sangiovese
		Sauvignon Blanc
		Syrah

Soil Analysis

Soil analysis before planting a vineyard is important to determine the soil fertility and to incorporate any soil amendments that may be required. Soil sampling must be done carefully and accurately to be representative of the various soils in the proposed vineyard site. Soils tests after vineyard establishment provide reliable information relating to organic matter content, pH, degree of salinity and relative quantities of available plant food. Soil tests for physical or other chemical characteristics can be requested from most labs as well. All of this information is useful in establishing a fertility management program. Soil tests will not tell you the value of your land, the variety of grape to grow, or how often you should irrigate.

Soil Testing Philosophies

Differences in interpretations of soil analysis by various soil test laboratories are based on differences in philosophy. There are three different concepts used by different organizations doing soil testing. These are:

1. **Nutrient Ratio Concept:** An ideal soil will have the following distribution of exchangeable base nutrients as a percentage of base saturation: 65 to 75% calcium, 10 to 15% magnesium, 4% potassium; or calcium/magnesium ratio of 4:1.
2. **Fertility Management Concept:** Irrespective of soil test values, the amounts of nutrients that should be added to a soil should be equal to the amount removed by the crop.
3. **Nutrient Sufficiency Concept:** A sufficient amount of a nutrient should be present in the soil to obtain optimum yield. Applying more of that nutrient will not further increase yields.

Fertilizer studies done in various parts of North America have shown that the first philosophy is irrelevant. The second philosophy does not apply to soils that have more than enough of the nutrients needed for optimum yield. The greatest promise, therefore, for having economic use of fertilizer lies with the third philosophy. It is the most conservative of the 3 approaches and recognizes the contribution made to plant nutrition by not only the surface soils, but also by the deeper soils.

The British Columbia Ministry of Agriculture and Lands uses the third philosophy in its recommendations

Soil Sampling Methods for Vineyards

Important

A soil sample for soil tests is only as good as the methods of taking the sample. The results that are provided are also only as good as the sample.

Fall is the best time to sample soils.

Submit samples for analysis at least 6 to 8 weeks before the results are needed. If samples are taken in the spring, do so before fertilizer is applied in time for results to be available.

Avoid Contamination of the Sample

How to Sample

1. Make a map of the vineyard.
2. On the plan
   - separate varieties
   - indicate areas that are different from each other (e.g. slope, surface soil colour, drainage, soil texture).
3. Sample fields separately if the fertilizer use is historically different in different areas.
4. Keeping in mind points 2 and 3, take enough samples from each area to give a good cross section of that area.
5. Where special problems exist, sample from good and bad areas, keeping these samples separate.
6. Sample in the area where the fertilizer has been applied.
7. Use a clean soil auger or clean shovel. Clear away surface grass or litter, and dig a hole 40 cm deep.
8. Take a slice 2 to 3 cm thick and 6 cm wide, down one side of the hole, to a depth of 20cm. Trim the sides of the slice and place the slice in a pail. All soils in the same sample area are treated this way. Mix the soil in this pail thoroughly, breaking any lumps and remove large stones. Then fill the sample box. Each sample should represent a composite of soil from 5-6 locations within each sample area.
9. Sample the rest of the hole (e.g. 20 to 40 cm) and place these samples in a second pail. Follow a similar procedure.

10. Mark the location of the hole and each sample on the map. Mark the soil sample boxes in the same way. Fill the soil sample box. Use a separate box for each sample.

Soil Testing Laboratories

Norwest Soil Research Inc
104-19575 55A Ave
Surrey, BC V3A 8P8
Tel: 604-514-3322 Fax: 604-514-3323

Pacific Soil Analysis Inc.
11720 Voyageur Way,
Richmond BC V6X 3G9
Tel: 604-273-8226 Fax: 604-373-8082

Soilcon Laboratories Ltd.
275-11780 River Rd,
Richmond BC V6X 1X7
Tel: 604-278-5535 Fax 604-278-0517

M & B Research and Development Ltd
10115C McDonald Park
Sidney, BC
Tel: 250-656-1334 Fax 250-656-0443

A&L Canada Laboratories Inc
2136 Jetstream Road
London ON N5V 3P5
Tel: 519-457-2575 Fax: 519-457-2664

Compatibility Chart

It is very difficult to generalize because solubility depends on a number of factors, the most important is pH, the concentrations of the solutions and solution temperature. Any concentration of more than three products will have reduced solubility over two materials alone. This chart is only a guide, and when you may have questions do a trial mix in a bucket using representative amounts of material and water.

■ *Incompatible*
▨ *Reduced Solubility*
(blank) *Fully Compatible*

	Urea	Ammonium Nitrate	Ammonium	Calcium nitrate	Potassium nitrate	Potassium chloride	Potassium	Ammonium	Fe,Zn,Cu, Mn	Fe,Zn,Cu, Mn	Magnesium	Phosphoric acid	Sulfuric acid	Nitric acid
Urea														
Ammonium nitrate														
Amonium sulphate														
Calcium nitrate			■											
Potassium nitrate														
Potassium chloride			▨	■		▨								
Potassium sulphate				■										
Ammonium phosphate				■										
Fe, Zn, Cu, Mn, sul-				■			▨	■						
Fe, Zn, Cu, Mn, che-				▨				▨						
Magnesium sulphate				■			▨	■						
Phosphoric acid				■						▨				
Sulphuric acid				■			▨							
Nitric acid										■				

Certain chemicals that are used for formulating custom liquid fertilizers are incompatible in concentrated fertilizer stock solutions. This compatibility chart illustrates some of the combinations that should be avoided in the same stock solution. (*Modified from Soil and Plant Labs Inc. Bellevue, WA*)

4.4 Irrigation

Water Management Principles and Practices for Vineyards

Pat Bowen, Pacific Agri-Food Research Centre, Summerland BC

Vineyard water management can be the most influential cultural practice that determines grapevine vigour, yield, fruit quality and general vine health. It is also a practice that, to be effective, requires tailoring to suit site conditions (soil type and depth, terrain and climate), current vine size (canopy leaf area, rooting depth) and vine spacing and variety, and to achieve other management goals including cover crop maintenance, frost protection and disease and pest control.

For most crops, irrigation principles are aimed at attaining maximum crop growth and yield while minimizing water waste. The principles guide the selection of irrigation equipment and the placement and amount of water applied in order to closely match water delivery to uptake from the root zone. In vineyards, irrigation principles differ because water management is used, much like pruning and training, to manipulate vegetative growth, berry development and fruit exposure so as to achieve high fruit quality for winemaking. These manipulations often rely on the creation of mild to moderate water stress after fruit set. The divergent goals of attaining maximum fruit quality and maintaining vine growth, development, and productivity (yield) can be difficult to achieve. The greater importance of fruit quality over yield may emphasize the desire to create stress. However, growers should be aware that deficit irrigation methods intended to improve fruit quality can result in excess vine stress, poor fruit quality, damaged or abscised leaves and weakened vines that are susceptible to winter injury and perform poorly in the following growing season. Irrigation management should be based on local experience and with a goal to balance vine health with vigour control.

Irrigation Systems

There are various irrigation systems to consider. All have advantages and disadvantages depending on site conditions, water availability and cultural goals.

High-volume, High-pressure Sprinkler Systems

An overhead sprinkler system uses up to 50 times more water than a drip system, but is simple to maintain, applies large amounts of water in a short period, and can be used for frost protection. Another advantage of sprinkler irrigation is the water applied between planted rows helps to maintain cover crop growth throughout the growing season. A disadvantage is that large areas of the vineyard are watered at the same rate, sometimes including areas that do not require water. Sprinkler systems are thus most suitable for large sites with level terrain, little variation soil types, and uniform vine vigour. The system should be designed to apply water evenly over the field surface. It is important to know the rate of water application per area for calculating the amount of time required to wet through the vine rooting depth. A run time that is too short will deprive deeper roots of water and may lead to buildup of salts within the root zone. A run time that is too long may leach fertilizers, particularly nitrate, from the root zone.

The appropriate water application rate may be limited by the rate of water absorption by the soil. Water infiltration through soils is influenced by the soil bulk density and texture (i.e. coarse-textured soils have higher infiltration rates). Infiltration is substantially reduced by the presence of a shallow water table or hardpan. It is also influenced by the condition of the soil surface. Surface crusting and puddling can result from frequent cultivation without addition of organic matter; cultivation of fine textured soils when wet; and extreme water application rates. Cover crops can greatly improve soil surface permeability. Without surface impedances, water application rates should not normally exceed 5 mm (0.2 in.) per hour on fine-textured soils, or 10 mm (0.4 in.) per hour on coarse-textured soils.

Low-pressure systems

There are two main types of low-pressure irrigation systems: drip or trickle systems and micro-sprinkler systems. Drip systems can be installed above or below ground, but above-ground systems are most common and are easier to access for maintenance. Both systems can be installed to vary water application rates according to variations in soil texture or vine vigour within the vineyard. Other advantages and some disadvantages of each system are:

Drip Systems:

a) Drip irrigation wets a discrete soil volume within which root growth is restricted unless significant rainwater is retained by the soil or the wetted volume is in contact with high water table. The restricted wetted soil volume and size of the root system can provide an advantage in controlling canopy vigour. This may be particularly useful in vineyards with deep, fine-textured soils. However, a root system that is too small may not take up sufficient water to satisfy canopy requirements during hot, dry weather. If prolonged, this water stress can result in permanent leaf damage both from lack of water and overheating. A shallow root system is also particularly prone to winter freeze damage. Thus it is important to install a drip system with appropriate emitter numbers, spacing and delivery rates, and to operate the system at run-durations that lead to a wetted soil volume appropriate for the vine canopy size. Because only a very small area of the soil surface is wetted by drip systems, fertilizers broadcast onto the soil surface will not be carried to the root system except by rainfall. Thus fertilizers must be applied to the soil surface well before spring rainfall is complete, or by injection into the drip system. Applying fertilizer to just below the drip emitter can be effective but care must be taken not to over-apply or else a high concentration of dissolved salts will be carried to the root system and lead to root damage or vine stress.

b) Application of acidifying fertilizers such as ammonium through the drip system can reduce soil pH to below optimal and lead to leaching of nutrients, particularly boron, potassium and phosphorous from the root zone.

c) Choice of cover crop species and timing of their planting must be coordinated with natural rainfall if the drip system is the sole source or irrigation water.

d) A drip irrigation system must have a filtration system to help prevent emitter plugging. However, even with an installed filtration system, emitters can become partially or fully plugged leading to uneven water application. Emitters can also over-apply water if faulty or damaged. Thus drip system emitters should be frequently inspected.

e) Drip system designs must account for differences in vineyard elevation to ensure even application of water.

Micro-sprinkler systems:

a) Micro-sprinkler systems operate under low pressure but use emitters with flow rates higher than that of drip emitters. Higher water application rates are thus achieved with fewer emitters.

b) Water is applied over a larger surface area with a micro-sprinkler or micro-jet emitter than with a drip emitter. Thus, micro-sprinkler systems overcome the limitations of drip systems in fertilizer application and cover crop maintenance.

c) There are micro-sprinkler systems designed to be installed above the crop canopy and operated for frost protection. Growers should ensure that the water distribution area and flow rate of these systems is adequate for their canopy size.

For further information on low-pressure system designs and operation see the BC Trickle Irrigation Design Manual, or contact irrigation equipment suppliers.

Seasonal Water Requirements – Phenology and Climatic Conditions

Vineyard water requirements over the growing season are estimated to be between 25 and 75 cm, depending mainly on vine canopy size and climatic conditions, which determine total transpiration. The amount of water transpired by the cover crop and evaporated from the soil surface can increase water requirements substantially. Water uptake during different periods of the growing season is generally related to crop transpiration during that period. From budbreak to flowering, water consumption is only 5% of the total for the season because air temperatures are generally cool and the average leaf area over the period is relatively low. From flowering through fruit set, leaf area and temperatures rise, which increase water consumption for the period to about 15% of the season's total. During the long period from fruit set to veraison, active leaf area and air temperatures are highest and water consumption is about 60% of the total. Over the shorter period from veraison to harvest, the active leaf area remains high but cooler temperatures prevail reducing the water consumption to about 20% of the total. After harvest, temperatures drop further and leaf activity declines until leaf-fall so water consumption is only about 5% of the total.

Rainy periods that provide extended cloud cover and raise air humidity will reduce evapo-transpiration and the rate of soil dry-down. Rainfall that penetrates to the root zone will offset irrigation requirements.

Soil Type and Plant-available Moisture

Soil type and condition, particularly soil texture and bulk density, affect the water holding capacity and pressure with which water is held by the soil. The field capacity of a soil is the maximum water content the soil can retain when allowed to drain freely. Soil water holding capacity is usually expressed as the percent moisture at field capacity. Storage capacity is the difference between field capacity and the low limit of plant-available water, known as the permanent wilting point. The difference between the soil water content and the permanent wilting point is considered to be the plant-available water. However, a vineyard can suffer from water stress at soil moisture levels significantly higher than the permanent wilting point. Finer-textured soils, containing silt and/or clay, have larger storage capacities (Table 4.15) and therefore require larger water applications than sandy or gravely coarse-textured soils to wet a given soil volume to field capacity. Soils that are shallow, above a shallow water table, or with coarse subsoil require less water to wet the root zone to field capacity.

Table 4.17 Approximate Water Storage Capacity for Different Soil Textures

Soil Type	Coarse	Medium	Fine
Permanent wilting point	3%	6%	14%
Field Capacity	7%	16%	28%
Storage Capacity	4%	10%	14%
Storage Capacity per Meter (mm)	100-300	145-210	200
Storage Capacity per Foot (inches)	1.0-1.3	1.5-2.2	2.2

The amount of water applied during irrigation should be sufficient to wet the targeted soil volume (usually the root zone unless partial root zone drying is implemented) to field capacity. If all irrigations are applied when the soil in the root zone reaches the same threshold water content, the amount of water required per application will always be the same. However, if regulated deficit irrigation (see below) is implemented, the threshold soil water content is varied with phenological stage and this changes the amount of water required to thoroughly wet the root zone.

A problem encountered in many vineyards is variable soil texture. Under such conditions, irrigating as appropriate for the coarsest-textured soil in the vineyard block will be adequate for the finer-textured soils that will likely have a larger moisture reserve. However, such a situation may lead to variable vigour within the vineyard, often due not only to differences in moisture availability but to associated differences in nutrient availability. Ideally these conditions should be dealt with in the irrigation design and with precision management of fertilizers.

Irrigation during Vineyard Establishment

Young, newly planted grapevines have small root systems that access moisture in a very limited soil volume. Growers should irrigate young vines frequently to replenish the moisture in the root zone while progressively wetting a larger volume to encourage expansion of the root system to the targeted volume. Even mild water stress should be avoided in young vineyards since the goal is to promote strong vegetative growth for vine training rather than to manage vigour and attain high fruit quality, which are water-management goals in mature vineyards. However, with frequent irrigation it is important that the soil in the root zone is well drained and has sufficient air-filled pore space to provide oxygen to the roots. Over-application of water can leach nutrients, especially nitrogen, from the root zone. Frequent, low-rate applications of fertilizer are recommended for young vines, particularly when establishment is on coarse-textured soils.

Availability of Water

If the water supply to the vineyard is less than vineyard requirements during critical periods, an on-site reservoir may be needed. If the total water supply is limited or costly, a deficit irrigation technique should be considered (see below).

Water Quality

Irrigation water should be analyzed if there is any doubt about the alkalinity or salinity of the water.

Irrigation Scheduling Methods

Root Zone Replenishing

The simplest scheduling method is to apply water when the total available moisture in the root zone reaches a low threshold. For example, irrigating when 40% of the available water remains in the root zone in coarse-textured soils or when 50% of the available water remains in fine-textured soils will provide adequate water to satisfy vine requirements while avoiding excess drainage to below the root zone. Although this method is effective for preventing vine water stress, it may result in excess vigour and delayed fruit ripening, particularly on deep, fine-textured soils. Two methods are used for estimating available moisture in the root zone: measurements of soil moisture content, and estimates of crop water consumption.

Replenishing based on measured soil moisture levels. Methods and instruments for measuring soil moisture content are:

- **Gravimetric method**. This method is time consuming. Soil samples must be taken at specific depths, weighed, oven-dried, and then re-weighed to determine percent moisture. Knowledge of the location and size (breadth and depth) of the root system is needed so that representative soil samples can be taken.
- **Squeeze test**. Although a person can learn to determine the approximate wetness of a soil from its tactile properties, this takes considerable experience. As with the gravimetric method, representative soil samples must be taken from the root zone.
- **Conductivity block**. These include gypsum and Watermark blocks. Buried in the soil, these blocks change in conductivity with changes in soil moisture. Compared to tensiometers (see below), conductivity blocks are more reliable at very low soil water contents (moisture tensions less than 1 bar).
- **Tensiometers**. A tensiometer is a sealed water-filled tube with a porous cup at the bottom end and a small air space at the top. A pressure gauge attached to the top measures the pressure of the air space. The tensiometer is buried with the cup at site of interest. Water moves out of or into the tube through the ceramic cup depending on the soil moisture until the moisture tension (the pressure with which water is held by the soil) is equal to the pressure of the air space. Thus the pressure gauge shows the pressure (matric potential) or tension with which water is held by the soil. This moisture tension increases as the soil dries down. The pressure units on the gage are usually centibars and equate to other units as follows: 100 centibars = 1 bar = approx. 1 atmosphere = 0.1 megapascal (MPa) = 100 kilospascals. (KPa) The pressure gauge range is usually 0 to 100 centibars. For a given percent moisture cosp:ntent, soil moisture tensions are higher for finer-textured than for coarser-textured soils. A moisture tension of 75 centibars may correspond to 90% available moisture

depletion for a sandy soil but only about 30% depletion for a silt loam. Tensiometers should be located on the major soil types in a vineyard.

- **Time domain reflectometer (TDR).** Once used only by researchers, these systems have been simplified and are now affordable to growers. TDR systems use buried probes or sensors to measure soil moisture at a fixed point, or employ access tubes into which a sensor probe can be inserted to measure moisture at several depths. TDR systems measure the soil water content rather than the moisture tension, which is more relevant to the crop.
- **Neutron probes.** These instruments are used mainly by researchers because they are expensive, employ a radiation source, and require training to operate. Also, because there is a radiation hazard, an operator's license is required. Measurements are based on the amount of hydrogen in the soil. Access tubes are used in a way similar to that for TDR systems (above). Neutron probes must be calibrated for soil type.

Recent research conducted in a sprinkler-irrigated vineyard on a deep, fine-textured silty soil near Penticton revealed the importance of properly locating soil moisture monitors. The study found that when moisture measured through the soil profile down to 60 cm depth was depleted to well below 15% over more than three weeks, leaf stomatal conductance and photosynthesis rate remained as high as when irrigation had been applied at a soil moisture threshold of 15%. These results indicate that a significant portion of the root system was below 60 cm depth. In such a vineyard, soil moisture monitors should be placed deep within the profile where the active roots are located. Determining the optimum placement depth for monitors may require excavation to determine the depth of the active root system, and a study of the relationship between monitored moisture at different depths and signs of vine water stress.

Replenishing based on estimated crop consumption. Vineyard water consumption or evapotranspiration (ET_c) can be estimated using the following relationship:

$$K_c = ET_c/ET0 \text{ \underline{or} } ET_c = K_c \times ET0$$

where ET_0 is the evapotranspiration of a short green crop completely shading the ground, and K_c is the crop coefficient (the fraction of water a non-stressed crop uses in relation to that ET_0).

K_0 varies through the growing season as vines develop active leaf area. There have been tabulated values of K_0 published for grapevines, and these can be modified depending on the vigour level of a vineyard. At the beginning of the growing season before bloom, K_0 is often around 0.2. At around bloom, K_0 rises to about 0.4 then increases further to 0.8 just before veraison. During ripening Kc may increase to about 0.9, then decrease to 0.5 or lower after harvest and before leaf fall.

To calculate ET_c, using tabulated values of K_c, growers need current ET_0 values. One method to determine ET_0 uses a black Bellani plate atmometer. This is an inexpensive flat, black, porous plate which is kept wet. The amount of water evaporating from its surface is used to calculate ET_0. Current ET_0 values can also be obtained by contacting a local weather office that provides daily Class "A" pan evaporation data. This is used to calculate ET_0 by using a pan coefficient which varies with wind speed, relative humidity and position of the pan.

Growers applying irrigations based on estimated crop water consumption should be aware that even when good data can be accessed for ET_0, estimates of K_c can be inaccurate and lead to poor estimates of ET_c. If ET_c is overestimated and excess irrigation is applied, excess vigour and an increased risk of nitrate leaching may result. If ET_c is underestimated, moisture deficits may become progressively worse through the season and lead to delayed ripening and poor fruit quality.

Xylem water tension threshold

Another irrigation scheduling method uses a measured indicator of vine water status as a threshold, rather than soil water content or estimated water consumption. This technique may overcome the problem of not knowing whether soil moisture measurements are representative of the whole root zone or whether estimated consumption estimates are accurate. Measurements of petiole xylem water tension, known as the leaf water potential, are taken at a specific time of day (i.e. solar noon). Irrigating at a midday threshold of -1.0 MPa for white varieties or -1.2 MPa for red varieties is recommended to avoid water stress and to ensure adequate water is provided to

satisfy vine requirements. Growers should be aware of their soil dry-down dynamics (speed with which soil moisture is being depleted) and the corresponding effects on vine water status to ensure the crop is monitored at the appropriate frequency to catch threshold vine water potentials. Also, the time of day when leaf water potential measurements are taken may be critical. Recent research conducted in a vineyard on sandy soil in the Oliver-Osoyoos area found that mid-day leaf water potential measurements can be a poor indicator of vine water status. The study found that when soil moisture deficits were prolonged for a week beyond when irrigation was normally applied, mid-morning and early-afternoon leaf water potential measurements were not significantly different from those taken on irrigated vines, even though stomatal conductance was reduced by one third and photosynthesis rate was halved. The explanation is that the reduced stomatal conductance in response to the soil moisture deficit reduced the leaf transpiration rate and decreased xylem water tension to the same level as the irrigated vines.

Deficit Irrigation Methods

Regulated Deficit Irrigation (RDI)

This technique makes use of the variable effects of vine water status at different phenological stages over the growing season. The goal is attain high fruit quality by optimizing vine vegetative growth, early cluster development and fruit set and then encouraging maximum resource supply to maturing clusters. In other words, water management is used to achieve vine balance. An additional benefit of RDI is improved water conservation compared with that of standard irrigation scheduling for root zone replenishment.

One strategy for achieving high-quality wine grapes is aimed at maintaining low to moderate vine vigour and small berries without delaying fruit ripening or reducing fruit-bud initiation for the following year. The recommendation begins with irrigating through the bloom-set period at a rate similar to vineyard evapotranspiration (ET_c). This ensures that fruit set and fruit bud initiation will not be hindered. After fruit-set and up to veraison, irrigation is held back until the crop is under mild water stress indicated by leaf water potentials of about 1.2 - 1.4 MPa, which corresponds to

about a 35% reduction in water applied com

pared to fully replenishing ET_c. At sites with fine-textured soil, partial rather than full irrigations are applied during this time so that periods of mild water stress are frequent. Only minor reductions in leaf stomatal conductance and photosynthesis occur with mild water stress, while growth of shoots and green berries can be reduced substantially. Because the supply of sugars is not reduced relative to the utilization by developing sinks, veraison is not delayed. On the contrary, with a reduced crop load, time of veraison may be advanced. After veraison, it is recommended that irrigation is increased to maintain high photosynthesis rates. However, recent research has found that there is little benefit from resuming irrigations at full ET. Scheduled irrigations should continue after harvest so vine carbon reserves are replenished and root systems are protected against desiccation and cold injury.

Caution is required while implementing RDI in vineyards, particularly for those on coarse-textured soils that have low moisture storage capacities or in drip-irrigated vineyards with small root systems. In such vineyards it is particularly important to monitor soil moisture and vine water status frequently and at several locations in the vineyard (see monitoring methods above). Both scion and rootstock varieties vary in their response to soil moisture levels, so experience is needed in setting irrigation thresholds. Excess water stress can reduce vine vigour and yield for several seasons. Too little stress may not produce the desired results. Controlled water stress can be enhanced by reducing the amount of water applied per irrigation and reducing the length of an irrigation cycle (increasing irrigation frequency).

Partial Rootzone Drying (PRD)

This irrigation technique was first developed in Australia to conserve water, but has been found to be effective in reducing vine vigour while maintaining vine water status. In some vineyards PRD has improved wine grape quality.

The theoretical basis for the benefits of PRD is that the positive effects of mild water stress and high vine water status are brought simultaneously via two parts of the root system. This is achieved by having part of the vine root system in moist soil and the other part in relatively dry soil. The roots in the drier soil produce less cytokinin and more abscisic acid than roots in moist soil. The lowered cytokinin levels reduce shoot growth while the increased ABA levels cause partial stomatal closure. The net effect is reduced vegetative growth and water consumption.

Another effect is enhanced root growth in the drier soil. Some growers believe that a larger root system will access more of the minerals needed for development of complex flavours, but there is currently no scientific basis for this theory.

There are several ways to implement PRD. In the Australian region where the technique was developed, vineyards have shallow soils and effective separation of the root system was achieved by drip-irrigating the area between pairs of vines down the row while the areas between the vines in each pair were allowed to dry. When the rate of soil drying in the non-irrigated areas slowed or stopped, these areas were then irrigated on a normal schedule while the previously irrigated areas were allowed to dry. Switching the irrigated versus non-irrigated areas was done to maintain the beneficial levels of cytokinins and ABA. The first PDR irrigation systems installed consisted of two drip lines per row, each corresponding to an irrigation zone. Currently on the market are double, fused drip tapes that ease installation and keep each zone's emitters properly separated.

On deep or fine-textured soils where vines have extended root systems, the configuration of wet and dry zones between and within pairs of vines in the planted row may not be effective for splitting vine root systems. Root systems can extend well into the space between planted rows and beyond neighbouring vines within the row. An effective PRD drip system developed for use in this type of vineyard has three zones: one in the planted rows, another halfway between every second planted row, and the third halfway between the remaining planted rows. The three zones are irrigated one at a time.

It is important that vineyards be well established before implementing PRD. Growers should watch for signs of significant water stress (see table below) and adjust the frequency of irrigations and switchover events to avoid levels of stress that lead to reduced vine performance. In vineyards with deep-rooted vines on rich, fine-textured soils, it may be difficult to achieve an effective zone of dry soil. It may be worthwhile to first try PRD on a small area to observe whether there are benefits before converting an entire vineyard.

Recent research comparing deficit irrigation techniques has found no benefit of PRD over RDI. It is thought that both techniques create mild water stress and result in portions of the root zone in wet and dry soil over the course of irrigation cycles. Further research is needed to gain a better understanding of how these techniques affect the distribution of soil moisture within the root zone and the development and physiology of vines growing on a range of soil textures and depths.

Water Management for Table Grapes

Water management for table grapes should promote production of large clusters with large berries. Water stress should be avoided though the growing season and deficit irrigation techniques should not be used. Growers should frequently monitor vineyards for water-stress symptoms (see below) and increase irrigation frequencies if stress is detected.

Grapevine Water-Stress Symptoms

1. Leaves "feel" thick, soft (not turgid) and warm.
2. Tendrils and/or shoot tips begin to droop.
3. New internodes on shoots are short.
4. New leaves and shoots appear grayish-green.
5. Leaves curl back.
6. Lower, well-exposed leaves turn yellow.
7. Berry set and berry size are reduced.
8. Margins of terminal leaves and tendrils are dry.

Irrigation Equipment

The following is a brief description of the most common equipment used to irrigate today's vineyards. More details are available from your irrigation dealer.

Sprinkler (overhead) irrigation

Until about twenty years ago most overhead systems utilized impact sprinklers. These have now been replaced mostly by rotating sprinklers (rotators). Having only one moving part, they are generally more reliable than impact sprinklers and need less maintenance.

Overhead systems meet the water demand of the crop and maintain an actively growing cover crop, but generally use more water than any other system.

Micro sprinklers

Micro sprinklers (or spinners) are low pressure, low volume sprinklers positioned overhead or below the cordon. They use relatively little water compared to impact sprinklers, but water distribution is not very uniform under windy conditions. Due to the small droplet size, a substantial proportion of the water may evaporate in hot, low relative humidity conditions. They also need relatively frequent checking, as they tend to plug easily when the water is not clean or when algae grow in the lateral lines. Like overhead systems, they supply water to both the vine and the cover crop.

Drip

There are a number of options to consider when installing drip for vineyards. The most common system these days is based on flow controlled (pressure compensating) emitters. The emitters are either in-line (manufacturer integrated into the drip line) or externally inserted into punched holes. External emitters are easily replaced if they are plugged, but are now less common than the integrated emitters.

Flow controlled drip lines assure even water distribution in steep terrain. They also allow for longer line runs as friction loss in the tubing is less of a concern.

Non flow controlled drip lines are suitable for vineyards on flat ground and with shorter row lengths. They are less common now, but used to be very reliable.

Recommended emitter spacing is now usually between 45 to 60 centimeters (18 to 24 inches) depending on soil conditions. Flow rates per emitter range from less than 2L/hour to 4L/hour.

Sub-soil drip lines or soaker hoses have been installed in some vineyards. They are buried about 10 cm below the surface, thereby eliminating "puddling" (pooling of water below the drip line). They also reduce some weed growth. The major disadvantage is the difficulty in monitoring evenness of discharge rate. They may also be damaged by rodents (pocket gophers).

Drip systems in coarse soils tend to limit the root system of the vine to the actual wetted area. They are usually not suitable for supporting the growth of a cover crop, but use less water per acre than overhead systems.

Water filtration

All drip systems using surface water require a good filtration system to avoid premature plugging of emitters. Filtration is also recommended for well water systems.

Self flushing sand filters are very efficient at removing debris from the water supply and are appropriate for surface water. Apart from periodic change of the filtration media (sand), they require little maintenance. Depending on the size of the system, they can be relatively costly.

There are a number of disk filters on the market, which are less costly, but require more maintenance. They are suitable for relatively clean well water.

Fertigation

A number of different systems are available for injecting fertilizer or other water soluble materials into the drip irrigation (some fertilizers can also be applied through overhead irrigation systems, but depending on materials and concentration, there is a risk of phytotoxic effect).

Venturi based injectors require no external power source as they are based on the Bernoulli principle. They are commonly used where only smaller quantities of liquid are injected into the system.

Injector pumps are used where power is available and where larger volumes of fertilizer need to be applied in shorter time. Piston pumps are very accurate and are not affected by variations in line pressure. A inexpensive alternative is the use of a crop sprayer to inject soluble materials into the irrigation system.

Automatic timers

A broad range of timers are on the market from simple lawn irrigation timers to very sophisticated devices able to use sensors for automated decision making. Most timers connect to household current, but operate the valve control signals at 24 volt AC.

Inexpensive lawn irrigation timers are well suited for use with drip systems. Most of them allow for season adjustment of irrigation length of time and are usually fairly simple to program. The limited maximum length of watering time for each zone however makes some of these timers less suitable for overhead systems. All these relatively inexpensive systems need two wires for each electric valve; a common and a control wire. Wire can become a fairly substantial portion of the expense for large acreages or for blocks remote from the controller. All these timers come with a master valve control, which allows automatic pump start when an irrigation cycle starts (useful for systems with their own delivery pumps).

For mid-range timers there are some interesting new developments. One is a timer programmed from a computer connected to the controller through wireless communication (requires line of sight from computer to controller; maximum range is about 300 meters). This controller also comes with a wireless manual remote control, which is very handy for testing and troubleshooting the system. Programming abilities with these systems are almost unlimited in terms of length of watering cycle and cycle frequency.

Another new timing device available uses the same two wires to control a large number of zones, considerably reducing wire cost.

Most of the mid range timers allow for the use of soil moisture and/or rain sensors to automatically suspend irrigation when a certain threshold is reached. The use of sensors however adds complexities which require more than average tech savvy from the operator. Familiarity with soil and crop variability and appropriate siting of the sensors can improve the effectiveness of using these timers. Many mid and high end timers (with the appropriate add-ons) can be controlled from a cell phone.

There are new systems on the market which control the electric valves wirelessly through radio signals. These systems, still under development, can be very expensive.

Automatic timers play an important role in water conservation, since each zone will only run for a predetermined length of time.

Add a zone

"Add a zone" is a device that allows the splitting of a zone controlled by one electric valve into two separate zones, without having to add an extra wire. This is useful where blocks originally serviced by drip systems are converted to overhead, or where flow rates in a drip system are increased by the reduction of emitter spacing. They require an additional, unused zone on the controller to work.

Moisture Sensors

A wide array of soil moisture sensors is available including the expensive neutron probe; time domain refractometry (TDR) sensors; sensors based on electrical conductivity or resistance; and tensiometers. All these sensors have their advantages and drawbacks; but interpretation of the collected data requires experience and skill. The simplest and cheapest tool for assessing soil moisture is still the shovel, used for digging pits in various locations in the vineyard, along with tactile and visual observation of the soil.

Other methods for determining whether the plants need water are visual cues (tendrils, basal leaf coloration), thermal indicators (leaf temperature at predetermined times of day) or pressure based measurements (stem or leaf water potential) taken with a pressure bomb.

4.5 Vineyard Floor Management

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Growing quality grapes for wine making should take into consideration the entire ecosystem as part of a sustainable production system. Vineyard floor management can have a large impact on the abiotic (e.g., temperature, wind, precipitation) and biotic (e.g., beneficial insects, pests, and disease) factors in the vineyard, especially microclimate modifications and soil health. Decisions about what system to use should take into account the overall vineyard management system.

Types of Floor Management Systems

Resident Vegetation – While this option requires little input, this system has both advantages and disadvantages. Resident vegetation consists of all plant species that are growing within the vine row and alleyways. These plant species can consist of both native plants and invasive weed species, with the diversity of native plant species determined by individual regions of viticulture production.

Management of resident vegetation usually consists of mowing to reduce plant height for vineyard traffic. Mowing frequency will be determined by the type of plant species present in the resident vineyard vegetation. In vineyards using conventional or sustainable systems, the area under the vine may be kept weed–free with an herbicide application in the spring. This system essentially has minimal costs, primarily for equipment costs to occasionally mow vegetation.

***Clean Cultivation* –.** In conventionally managed systems, vineyard alley rows are disked or sprayed with herbicides to reduce in-row vegetation, while in organically farmed systems, mechanical means or approved organic products are used to keep vineyard rows weed free. This can result in the exposure of bare soil, which will reduce competition with the grapevine for water and nutrients, but can increase the possibility of soil wind and/or water erosion in prone areas. Slopes are particularly vulnerable to topsoil loss in clean cultivated systems. Tillage and equipment travel through vineyard alleys over time can contribute to root zone compaction and problems with water infiltration.

Cover Cropping – Cover crops can be managed in a number of different ways in the vineyard. Most commonly, crops are seeded in every alleyway to provide cover throughout the vineyard. They can also be planted in alternate rows, each with a solid stand of a different cover (e.g., grass and legume), or simply clean cultivation in one alley row and a cover crop in the adjacent alleyway. In some vineyards using sustainable management, the area immediately underneath the vine is kept clean with herbicide applications or cultivation to reduce any possible impacts on vine growth from competition for water and nutrients, especially with drip irrigated systems. Those vineyards with an organic management strategy must utilize mechanical means, due to strict regulations regarding the application of synthetic chemicals.

Cultivation – Depending upon the cover crop choice, tillage or mowing may be required. Annual cover crops such as a number of grass and grain covers may need to be mowed a couple of times per year in order to facilitate access throughout the vineyard, or for frost protection in the spring. Tillage is another option, especially for some annual legumes and forbs that can release nitrogen in the soil and may be available for vine uptake. However, timing of tillage and knowing the decomposition rate is important to ensure that nitrogen release coincides with an appropriate vine growth stage. With perennial cover crop systems, mowing may also be necessary as some cover crops can reach heights of three feet. Tillage can also be applied to perennial cover crop systems as stands diminish and need to be reseeded.

Benefits of Utilizing Cover Crops in Vineyards

- Reduce soil erosion due to wind and water
- Protect the soil surface during high traffic events during the growing season
- Increase water infiltration
- Reduce insect populations (pests)
- Increase beneficial insect populations (predators)
- Reduce chemical use

- Reduce weeds depending upon the competitive nature of the cover crop
- Reduce vine vigor
- Recycle nutrients within the soil ecosystem
- Prevent nutrient leaching
- Increase organic matter
- Alter microclimate

Potential Problems

- Negatively alter microclimate
- Increase in vertebrate pest populations
- More expensive to incorporate than resident vegetation depending upon cover crop choice
- Nutrient release may not coincide with vine uptake or demand
- Frost risk during early spring and late autumn

Using Floor Management Wisely

Floor management systems, particularly cover cropping, can impart a number of benefits to the production of premium quality grapes. Vineyard age should be considered, as vigorous cover crops can compete with young vines for water and nutrients. This can reduce vine growth and possibly delay vine development in the early stages of establishment. Once a vineyard is established and vines are mature (> 4 years old), cover crops may be used in areas of excessive vigor to reduce canopy size and maintain an optimal balance between the vegetative and fruiting sections of the vine.

One of the biggest impacts of cover crops is the protection of the soil surface. Wind and water erosion can strip the upper soil layers, up to 5 cm in a growing season. Conversely, soil accumulates in areas that contain vegetative cover (Coldwell et al., 1942). Cover crops, especially grasses, protect the soil by minimizing the dislodging impact of raindrops and reducing water runoff (Goulet et al., 2004; Stredansky, 1999). During the growing season, cover crops can help to reduce soil compaction and soil erosion from equipment traffic (Kaspar et al., 2001), and increase traction for vineyard traffic. This can be especially important when Pacific Northwest harvesting extends later into the autumn season, after precipitation begins to fall.

Cover crops can also reduce surface crusting and improve rainfall penetration, important on soils that may be subject to saline conditions or with higher percentages of clay (Folorunso, et al., 1992; Gulick et al., 1994). Those plant species with large root systems like oilseed radish (*Raphanus sativus* or *R. sativus* var. *oleiferus*) have been proven successful at penetrating hard pans to improve water infiltration and drainage (Cline, 1992). Plants with extensive root systems aerate the soil as roots decompose, leaving pores that can increase infiltration.

Increasing soil organic matter and nutrient availability is a popular reason for utilizing cover crops in vineyards. However, the impact of cover crops on actual levels of organic matter and its use to solely supply nutrients to the vines is highly dependent upon the soil type, temperature, and rainfall. Many of the microorganisms involved in the decomposition of organic material need some type of moisture to maintain their activity. Therefore, in semi-arid and arid regions, it is very difficult to greatly affect the percentage of organic matter in the root zone unless there is supplemental irrigation in the vineyard alleys.

Mycorrhizal fungi are symbiotic fungi, also known as arbuscular mycorrhizal fungi (AMF) that colonize grapevine roots. Be cautious when using mycorrhizal supplements, as existing research under field conditions has not definitively shown consistent benefits. If you do choose to use mycorrhizal supplements, be sure that the source is a reputable vendor and that some type of plant material is part of the supplement. Mycorrhizae require living roots in order to grow and reproduce. It may be fairly expensive to inoculate an entire vineyard with AMF, thus inoculating individual vines when establishing a vineyard is more practical. Mycorrhizae can improve water status in grapevines and has been shown to increase some nutrients in other crops (Kaya et al., 2003), a benefit for vineyard sites with marginal soil status (Augé, 2001; Biricolti et al., 1997; Linderman and Davis, 2001). Simply the presence of a cover crop can increase the population of Vesicular Arbuscular Mycorrhizae (VAM) fungi in vine alleys, but colonization of grapevine roots by VAM requires that the roots be in contact with the colonized cover crop roots in vine alleys, although there is some colonization by other types of mycorrhizal fungi

(Baumgartner et al., 2005). Planting a cover crop that is a host for AMF fungi has been shown to boost resident populations in other crops (e.g., Kabir and Koide, 2002), however research in vineyards is limited. To gain the most benefit from mycorrhizal inoculations, do not fumigate prior to planting (unless there is a preexisting condition necessitating fumigation), reduce high inputs of phosphorus fertilizers, and reduce tillage practices to avoid disrupting existing AMF colonies (Schreiner, 2004).

Insect populations can be increased or decreased, depending upon cover crop choice. For example, some vineyard pests (e.g., cutworms) prefer broadleaved covers rather than grasses, and the presence of broadleaf covers in the alleyway can reduce the number of bud strikes observed during the early spring season. Having some type of cover can also aid in reducing dust and spider mite populations, as dusty, dry conditions encourage these populations. However, cover crops can also increase populations of vineyard pests, especially voles, moles, and gophers.

Cover Crop Choices and Their Management

Seed Bed Preparation

Different cover crop choices may require different methods of seeding; however seed bed preparation is fairly standard. The seed bed should be moist (via natural precipitation or irrigation), well-mixed, and free of existing plant material. Depending upon the soil profile, shallow ripping or rotovation (25-30 cm) of the soil may be necessary to ensure optimal establishment conditions. When ripping in the vineyard, be sure to select a time period when the soil is fairly dry to ensure good mixture of the soil profile with small particles, not large chunks. Water, in the form of precipitation or supplemental irrigation, should be applied before and after seeding for good germination. The vineyard alleyways are disked and leveled to provide a firm seed bed, and then seeded. Seeding depth will depend upon the size of the seed, but generally, smaller seeds will require a shallower planting depth. This is especially important with many of the clovers and medics.

Seeds can be drilled with a seed drill or may be broadcast with a broadcast seeder. Many cover crops can be seeded either by drilling or broadcasting, however, check with the seeding equipment manufacturer, as broadcasting usually requires a higher seeding rate than drilling. In addition, some cover crops establish more uniformly when drilled than broadcast. Most cover crops in the Pacific Northwest are planted in the autumn to take advantage of winter precipitation.

Cover Crop Selection

Choosing a cover crop will depend largely upon the objectives that you want to address in the overall vineyard management plan. There are three main categories of cover crops – grasses, legumes and forbs.

Grasses

Many grasses tend to form a large, fibrous root system, which is beneficial in windy areas to prevent soil erosion. In vigorous vineyards, it can take up nitrogen and tie it up over time. Unlike legumes, nitrogen in the grass plants is not readily available to vines for uptake when the plants decompose. Grass cover crops can also provide a substantial amount of biomass that, over time, may aid in increasing vineyard soil organic matter.

Grasses like cereal rye, oats, barley and triticale are often used as annual cover crop systems. Typically these are planted in the autumn and tilled under or mowed in the spring for frost protection. Mowing grasses can leave stubble in the vineyard alleys, which can serve to reduce dust, provide traction for field equipment, and compete with weed species. Grasses are usually more competitive than legumes or forbs with existing weed populations.

Legumes

Legumes are broad leaved, annual or perennial species that are known for their ability to fix nitrogen. Nodules colonized on the roots are the ‘factories’ that house nitrogen-fixing bacteria (*Rhizobium* spp.) that form a symbiotic relationship with legume roots. However, legume seeds must be inoculated with the proper strain of bacteria in order to effectively fix the nitrogen. Nodules that are actively fixing nitrogen will appear pink when cut in half. Nitrogen is released and available for mineralization processes after the cover crop begins to decompose.

When legumes are mowed, some of the roots die in order to keep the plant in balance between the shoot and root systems, thus a proportion of the colonized roots die and release nitrogen as well. Root sys tems of legumes have a tap root based system that can aid in increasing water infiltration. Legumes can attract a number of rodents to the vineyard, thus are often used only in established vineyards to avoid damage to young root systems.

Forbs

Forbs are broad leaved, flowering plants and can consist of annual and/or perennial species. A number of forb species make up wildflower mixes that are available from a local cover crop seed supplier. Forbs can be attractive and some studies indicate that they may be able to increase beneficial insect populations, depending upon the diversity of species in the mix. Wildflower mixes can be difficult to establish if the mix contains species that are not appropriate for the region in which the vineyard is located. Establishment can be enhanced by breaking up the soil prior to seeding or broadcast seeding. Seed contact with the soil surface is increased by running a ring roller through the vine alleys. When using these mixes, be sure to contact your local extension agent or weed specialist to determine if any of the components may be listed on your province's noxious weed lists. A number of introduced species have become noxious weeds in the past and are very difficult to control (e.g., Yellow Starthistle, Purple Loosestrife).

Annual Cover Crop Choices for Tilled Vineyards

- Annual Ryegrass
- Barley
- Oats
- Triticale
- Wheat
- Cereal Rye
- Field Pea
- Mustards and *Brassica* spp.
- Various vetch species

Annual Cover Crop Choices for No-Till Vineyards

- Clovers (*Trifolium* spp.)
- Red
- Crimson
- Subterranean
- Medics (*Medicago* spp.)
- Bur
- Barrel
- Black

Perennial Cover Crop Choices

- Fescues
  - Tall
  - Hard
  - Red
  - Sheep
- Meadow Barley
- Perennial Ryegrass
- White Clover
- Various bunch-type wheatgrasses
- Crested Wheatgrass
- Pubescent Wheatgrass
- Wildflower/Forb mixes

Annual Systems

Annual Ryegrass – *Lolium multiflorum*. Annual ryegrass is also known as Italian ryegrass, and is a cool-season bunch grass (Sattell, 1998). As with many of the grasses, it has an extensive fibrous root system, useful in areas with excess water or nitrogen. In vineyards with marginal nutrient status, annual ryegrass can compete with the vine during bloom and early shoot growth. This grass is quicker to form a good stand than perennial ryegrass which is slower to establish (Verhallen et al., 2001). Annual ryegrass tends to perform better on finer-textured soils (e.g., silty or clayey), although sandy soils may be adequate for growth. Annual ryegrass matures between June and September, is typically seeded in the autumn, and tilled in late spring or early summer (Ingels et al., 1998).

Cereal Cover Crops – Barley (*Hordeum vulgare*), oats (*Avena sativa*), triticale (*Triticosecale hexaploide*), and wheat (*Triticum aestivum*) are known as cereal cover crops and can be interplanted with vetches because their stems are often strong enough to support the vine-like growth (Sattell, 1998). Care should be taken when choosing varieties that are resistant to diseases that could infect nearby fields of grain crops. Barley and wheat are more drought tolerant than oats or triticale. Cereal crops are often tilled into the vineyard in early summer, but can be mowed for extra frost protection in the spring. Cereal crops form a fibrous root system, adequate for reducing soil erosion and removing excess nitrogen. Cereal crops are planted in the autumn, to take advantage of winter moisture for germination.

Cereal Rye – *Secale cereale* L. Cereal rye or winter rye can be used to increase organic matter and can produce about 3,500-11,000 kg/ha in dry biomass (Satell, 1998). It has an extensive fibrous root system that can take up excess water and nitrogen present in the vineyard. It can be combined with any of the vetch species to increase residue in vine alleys, and can be helpful to degrade certain herbicide residues (Zablotowicz et al., 1998). It is normally planted in the autumn or early spring and mowed before it begins to senesce. Cereal rye is a very cold tolerant cover crop, enduring temperatures down to -34°C.

Clovers – Crimson clover (*Trifolium incarnatum*), rose clover (*Trifolium hirtum*), and subterranean clover (*Trifolium subterraneum*) are annual clovers often used in vineyards that are managed without tillage. Crimson and rose clovers can reach a height of 15-20 cm; however subterranean clovers exhibit a low, prostrate growth habit (Ingels et al., 1998; Sattell, 1998). Unlike other clover species, subterranean clovers produce seed underground, perhaps lending some advantage to providing a continual stand. As with many clovers and medics, a large quantity of hard seed is produced which will germinate over multiple years. Clovers perform best when part of a mix, which often includes multiple clover and medic species. In soils with poor nutrition, it may be difficult to establish a good stand, thus adequate phosphorus, calcium, and sulfur is necessary. Amendment of the soil before planting can ensure good establishment.

Field Pea – *Pisum sativum*. Field pea has been used in a number of vineyards in eastern Pacific Northwest vineyards as a winter/spring annual and tilled or mowed in early summer to supply organic matter and release nitrogen. Stems of the plant are succulent and breakdown rapidly, providing a burst of nitrogen in the soil. Much of the biomass is accumulated in the early spring, and is often a component of cereal crop mixes.

Medics – *Medicago* spp. Bur medic (*Medicago polymorpha*), barrel medic (*Medicago truncatula*), and black medic (*Medicago lupulina*) are cover crops that were originally used for establishing pastures. All are considered a reseeding annual or a short-lived perennial. Bur medic performs well on soils with pH > 6.5, establishes with relatively little seed (~5.5 kg/ha), and produces large quantities of hard seed for future season's growth. Seed pods from bur medics are often spiny, although some cultivars such as 'Santiago' have no spines on seed pods. Bur medic performs well in vineyards with minimal irrigation in vine alleys, provided winter rains are adequate. Barrel medic prefers soil pHs that range from neutral to alkaline, and requires about 300 mm of precipitation to adequately establish (Schnipp and Young, 2004). It too produces a large number of hard seeds, maturing in mid-spring. Black medic performs well on soils similar to barrel and bur medic. The cultivar 'George' was developed for dryland production with approximately 375 mm of precipitation per year. It is easily controlled with mowing and herbicide applications.

Mustards – *Brassica* spp. Mustards are part of the forbs family and are often grown for their ability to produce certain chemicals called glucosinolates. These compounds break down via microbial degradation to isothiocyanide, which can act as a soil fumigant and weed suppressant. Mustard cover crops can be grown and incorporated before a vineyard is established (Figure 4.12) if a chemical fumigant is not desired. If grown in vine alleys in an established vineyard, it is treated as a reseeding annual and should not be mowed until seeds have set. Both white mustard (*Sinapsis alba*) and oriental mustard (*Brassica juncea*) have shown success in drier environments. *Brassica napus* can also be grown as a cover crop; however it is mainly grown for oilseed production.

Vetches – *Vicia* spp. This group of covers include hairy vetch (*Vicia viiosa*) and common vetch (*Vicia sativa*). Vetches are commonly seeded or are present as volunteer plants in vineyards. They can be seeded in stands alone, or with grain crops to provide a structure for climbing. Hairy vetch is more prone to climbing beyond the vine alley, into trellises, especially on deep soils. Vetches are fairly shallow rooted plants, unlike many of the tap-rooted legumes (Ingels et al., 1998b). Both types of vetches have bluish-purple flowers during bloom (Figure 4.13) and can be an effective cover for attracting beneficial insect populations as well as pure aesthetics. Hairy vetch is more cold tolerant than common vetch with most of the biomass production in the early spring and summer. Allow vetches to reseed if a continuous stand is desired.

Perennial Systems

Fescues – *Festuca* spp. This group includes tall fescue (*Festuca arundinacea*), sheep or hard fescue (*Festuca ovina*), and red fescue (*Festuca rubra*). Sheep and hard fescues are bunchgrasses, while red fescues can have a slow, spreading growth habit.

Many turf type fescues can form a dense mat of growth in vine alleys, providing excellent weed suppression and traction. During the summer, the reduction in precipitation and/or irrigation will induce dormancy, providing a layer of mulch. Fescues are well suited for dryland vineyards, and should be autumn-seeded to take advantage of available precipitation. Some varieties of fescue can produce large root systems, which may make it difficult to eradicate. Most fescues are prolific seed producers which will contribute to the following season's stand.

Indian Ricegrass – *Orzyopsis hymenoides* or *Achnatherum hymenoides*. This grass is native to western North America, and is often used for erosion control on sand dunes and soils with large percentages of sand. Although green in the spring, it is a summer-dormant species that retains its hold on soil particles, making it useful for sandy, windy sites. It is a very drought tolerant, cool season cover crop choice.

Meadow barley – *Hordeum brachyantherum*. Meadow barley is a perennial grass that performs best in wetland or riparian areas. It is also known as California Barley and can tolerate clay with low calcium and low water holding capacity or serpentine (high magnesium) soils well. Serpentine soils are most commonly found in California and not readily found in the Pacific Northwest. Meadow barley is a poor competitor with weeds and some type of control measure should be taken before planting meadow barley.

Perennial Ryegrass – *Lolium perenne*. Perennial rye is a cool-season, moderately drought-tolerant bunchgrass that can be competitive when overseeded. It establishes relatively quickly and germinates early in the growing season (Hannaway et al., 1999). Because of its early germination, it is an ideal candidate forgrass mixes in which the germination of other species is staggered. This will provides a green cover for a longer period during the growing season than a monoculture of perennial rye. Perennial rye is especially good for preventing soil erosion, because of its extensive fibrous root system. In areas with mild winters, perennial rye can be seeded into vineyard rows; in areas with potentially cold winters, it should be seeded during the late summer. Seeds should not be planted deeper than 1.25 cm to establish a good stand.

Wheatgrasses – This group of grasses includes Crested Wheatgrass (*Agropyron cristatum*), Standard Crested Wheatgrass (*Agropyron desertorum*), and Pu bescent wheatgrass (*Agropyron trichophorum*), including a number of other species. These grasses are known for their drought tolerance and persistent stand (5-7 years). With good early establishment, they can significantly reduce the weed population in vineyard alleys. They can be seeded in combination with forb mixes to aid in attracting beneficial insect populations, but be careful of competition with forbs in establishment.

White Clover – *Trifolium repens*. White clover is a perennial cover that performs better on heavy soils than on lighter, sandy soils because it is not as drought tolerant as other clovers like subterranean clovers. It is considered a short lived perennial that may require replanting every 3-4 years depending upon stand establishment. Plants are hardy to about -8°C (Brandsæter et al., 2002). White clover seeds are small (Table 1) and seed/soil contact must be maximized to get good stand establishment. Seeding depth should be no more than 0.5 cm, thus a properly prepared seed bed is required.

Wildflower and Forb mixes – These mixes often consist of various varieties of native flower and grasses to enhance ecological diversity. Choosing native varieties will ensure sufficient germination and persistence from year to year. Check with your local extension or agriculture office to get a list of native wildflowers for your area. Also, be sure to inquire about any component of the mixture that may become an invasive species. A mixture of species may necessitate a broadcast application within the vineyard rows due to the variance in seed size. After broadcast seeding, a press wheel or cultipacker may be useful to maximize the seed/soil contact; however seeds should not be pressed into the soil too deeply.

Concluding Remarks

Vineyard floor management should take into consideration your overall goals for vineyard management and the surrounding area. Vineyard sites may require cover crops that help in vigor control, compete with the existing weed population, and control soil erosion by wind and water. Keep in mind that sustainable grape production must take into consideration labor concerns, economics of the management system, and ecological impacts.

References and Useful Resources

Augé, R.M. 2001. Water relations, drought, and vesicular-arbuscular mycorrhizal symbiosis. Mycorrhiza. 11:3-42.

Baumgartner, K., R.F. Smith, and L. Bettiga. 2005. Weed control and cover crop management affect mycorrhizal colonization of grapevine roots and arbuscular mycorrhizal fungal spore populations in a California vineyard. Mycorrhiza. 15:111- 119.

Biricolti, S., F. Ferrini, E. Rinaldelli, I. Tamantini, and N. Vignozzi. 1997. VAM fungi and soil lime content influence rootstock growth and nutrient content. Am. J. Enol. Vitic. 48:93- 99.

Brandsæter, L.O., A. Olsmo, A.M. Tronsmo, and H. Fykse. 2002. Freezing resistance of winter annual and biennial legumes at different developmental stages. Crop Sci. 42(2):437-443.

Burton, C.J. and P.J. Burton. A manual for growing and using seed from herbaceous plants native to the northern interior of British Columbia. Symbios Research and Restoration. Smithers, BC. 168 pp. symbios@bulkley.net

Cline, R.A. 1992. Soil management for orchards and vineyards. Ontario Ministry of Agriculture and Food Fact Sheet #92-120. Accessed online 10/14/2005. http://www.omafra.gov.on.ca/ english/ crops/facts/92-120.htm

Coldwell, A.E., P.R. Loewen, and C.J. Whitfield. 1943. The relation of various types of vegetative cover to soil drift. J. Am. Soc. Agron. 34:702-710.

Folorunso, O.A., D.E. Rolston, T. Prichard, and D.T. Louie. 1992. Cover crops lower soil surface strength, may improve soil permeability. Cal. Agric. 45(6):26-27.

Goulet, E., S. Dousset, R. Chaussod, F. Bartoli, A.F. Doledec, and F. Andreux. 2004. Water-stable aggregates and organic matter pools in a calcareous vineyard soil under four soil-surface management systems. Soil Use Mgt. 20:318- 324.

Gulick, S.H., D.W. Grimes, D.S. Munk, and D.A. Goldhamer. 1994. Cover-crop-enhanced water infiltration of a slowly permeable fine sandy loam. Soil Sci. Soc. Am. J. 58(5):1539-1546.

Hall, M. H. White Clover. Agronomy Facts 22. The Pennsylvania State University Cooperative Extension. Accessed Online 10/14/2005. http://cropsoil.psu.edu/Extension/Facts/ agfact22.pdf

Hannaway, D., S. Fransen, J. Cropper, M. Teel, M. Chaney, T. Griggs, R. Halse, J. Hart, P. Cheeke, D. Hansen, R. Klinger, and W. Lane. 1999. Perennial Ryegrass. PNW 503. Accessed online 10/14/2005. http://eesc.orst.edu/agcomwebfile/ edmat/html/pnw/pnw503/pnw503.html

Ingels, C.A., R.L. Bugg, G.T. McGourty, and L.P. Christensen. 1998a. Cover Cropping in Vineyards: A Grower's Handbook. Univ. of Calif. Div. Agr. Nat. Res. Publication #3338. 162 pp.

Ingels, C.A., K.M. Scow, D.A. Whisson, and R.E. Drenovsky. 2005. Effects of cover crops on grapevines, yield, juice composition, soil microbial ecology, and gopher activity. Am. J. Enol. Vitic. 56:19-29.

Kabir, Z. and R.T. Koide. 2002. Effect of autumn and winter mycorrhizal cover crops on soil properties, nutrient uptake and yield of sweet corn in Pennsylvania, USA. Plant and Soil. 238:205-215.

Kaspar, T.C., J.K. Radke, and J.M. Laflen. 2001. Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. J. Soil Water Conserv. 56:160-164.

Kaya, C., D. Higgs, H. Kirnak, and I. Tax. 2003. Mycorrhizal colonization improves fruit yield and water use efficiency in watermelon (Citrullus lanatus Thunb.) grown under well-watered and water-stressed conditions. Plant and Soil. 253:287-292.

Linderman, R.G. and A.A. Davis. 2001. Comparative response of selected grapevine rootstocks and cultivars to inoculation with different mychorrhizal fungi. Am. J. Enol. Vitic. 52:8-11.

McGuire, A. 2003. Mustard. EB1952E. Washington State University Extension, Pullman, WA. Available online at: http://grantadams.wsu.edu/agriculture/covercrops/pubs/ eb1952e.pdf

Sattell, R. 1998. Using Cover Crops in Oregon EM 8704. Oregon State University Extension Service, Corvallis, OR.

Schnipp, A. and R. Young. 2004. Barrel Medic. Agnote DPI-264. New South Wales Department of Primary Industries. Accessed online 10/14/2005. http://www.agric.nsw.gov.au/ reader/pasttemplegume/dpi264.htm

Schreiner, R.P. 2004. Mycorrhizas and mineral acquisition in grapevines. Proceedings of the Soil Environment and Vine Mineral Nutrition Symposium. San Diego, CA. American Society for Enology and Viticulture. pp. 49-60.

Stredansky, J. 1999. Reduction of wind erosion intensity by vegetation cover. Ekologia 18:96- 99. University of California SAREP Cover Crop Database. Accessed 10/14/2005. http:// www.sarep.ucdavis.edu/ccrop/

Verhallen, A., A. Hayes, and T. Taylor. 2001. Cover Crops: Ryegrass. Accessed online from the Ontario Ministry of Agriculture 10/14/ 2005. http://www.omafra.gov.on.ca/english/crops/facts/cover_crops01/ryegrass.htm

Zablotowicz, R.M., M.A. Locke, and R.J. Smeda. 1998. Degradation of 2, 4-D and fluometuron in cover crop residues. Chemosphere. 37:87- 101.

Seed Sources

** Listing of companies is not an endorsement for a particular vendor*

- Landmark Seeds, N. 120 Wall St. Suite 400, Spokane, WA 99201
  http://www.landmarkseed.com/index.html
- West Coast Seeds, 925 64th Street, Delta, B.C.,V4K 3N2
  http://www.westcoastseeds.com/
- Peaceful Valley Farm and Garden Supply, P.O. Box 2209, Grass Valley, CA 95945
  http://www.groworganic.com/default.html
- S & S Seeds, P.O. Box 1275, Carpinteria, CA 93014-1275 (805) 684-0436
  http://www.ssseeds.com/index.html

4.6 Frost Protection

Considerations for Protecting Grapevines from Low Temperature Injury

Robert G. Evans [1]

Introduction

Attempts to protect grape vines from cold temperature injury began at least 2000 years ago when Roman growers scattered burning piles of prunings, dead vines and other waste to heat their vineyards during spring frost events (Blanc et al., 1963).

The protection of vines against cold temperature injury is still a crucial element in commercial viticulture in many areas of the world. It is estimated that 5 to 15 percent of the total world crop production is affected by cold temperature injury every year. However, because of the extreme complexity of the interactions between the varying physical and biological systems, our current efforts to protect crops against cold temperature injury can be appropriately characterized as more of an art than a science.

The need to protect against cold injury can occur in the spring, fall and/or winter depending on the location and varieties (Evans, 1991). Frost protection activities on grapes in the spring are to protect new leaves, buds and shoots (and later the flowers) from cold temperature injury. However, it is often necessary to frost protect *V. vinifera* vineyards in the fall in areas like the inland Pacific Northwest (PNW) to prevent leaf drop until after harvest so that sugar will continue to accumulate in the berries, accumulate carbohydrates and better prepare vines to withstand winter temperatures. Sometimes protection measures must be initiated during very cold temperature events during the winter periods on *V. vinifera* vines and some perennial tree crops (i.e., peaches, apricots) in colder regions. Winter cold temperatures can injure roots and trunk/cane injuries (splits, wounds, tissue damage). Injuries can also increase the incidence of certain "secondary" diseases such as crown gall and Eutypa (spring) by providing entry points at injury sites. Usually, only a couple of degrees rise in air temperature is sufficient to minimize cold injury at any time of year. However, all frost protection systems will fail when environmental conditions exceed their capacity. The adopted level of protection is an economic decision based on risk assessments by the grower.

The terms frost and freeze are often used interchangeably to describe conditions where cold temperature injury to plants result as a consequence of subfreezing temperatures (< 0^{o}C). This discussion will generally refer to frost and to frost protection systems for the wide variety of countermeasures growers may use to prevent cold temperature injury to plant tissues.

Types of Frosts

There are basically two dominant types of frost situations which will be encountered. These are radiant frosts and advective freezes. Both types will usually be present in all frost events, but the type of frost is characterized by the dominant type.

Radiation Frosts: A radiation frost is probably the most common in grape growing areas around the world. It is also the easiest type of frost to protect against and the main reason that site selection is so important. Almost all frost protection systems/ methods available today are designed to protect against radiant-type frost/freezes.

Both *radiative* losses and *advective losses* (wind) must be counteracted in radiative frost conditions plus enough heat added to increase air temperatures, if necessary to keep plant tissues above their critical temperatures. All objects radiate heat into the environment in proportion to their relative temperature differences. For example, exposed objects will lose heat at a faster rate when exposed to a clear night sky which has an

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effective temperature around -20°C, but will not lose heat as rapidly to clouds which are relatively much warmer depending on cloud type and height. With respect to the plant, heat is lost by upward long-wave radiation to the sky, heat is gained from downward emitted long-wave radiation (e.g., absorbed and re-emitted from clouds), air-to-crop (advective) heat transfers, and heat can either be gained or lost soil-to-plant (radiative) heat transfers.

Radiant frosts occur when large amounts of clear, dry air moves into an area and there is almost no cloud cover at night. During these times, the plants, soil, and other objects which are warmer than the very cold night sky will "radiate" their own heat back to space and become progressively colder. In fact, the plants cool (by radiating their heat) themselves to the point that they can cause their own damage. The plant tissues which are directly exposed to the sky become the coldest.

These radiation losses can cause the buds, blossoms, twigs, leaves, etc. to become 1 - 2°C colder than the surrounding air which radiates very little of its heat. The warmer air then tries to warm the cold plant parts and it also becomes colder. The cold air settles toward the ground and begins slowly flowing toward lower elevations. This heavier, colder air moves slowly ("drifts") down the slope under the influence of gravity (technically called "katabatic wind"), and collects in low areas or "cold pockets." Drift, typically moving 1 - 2 meters per second (m/s), can carry heat from frost protection activities out of a vineyard and replace it with colder air. It can also carry heat from higher elevation heating activities into a vineyard. The amount of heat lost to wind drift is often at least equal to radiative heat losses that are in the range of 10 to 30 watts per square meter (W/m^2) or more. Consequently, the replacement heat must be greater than the sum of both radiative and advective heat losses during "successful" frost protection activities (i.e., 20-70+ W/m^2 depending on climatic variables and time of year).

Concurrent with the radiative processes and with very low wind speeds (< 1.5 - 2 m/s), a *thermal inversion* condition will develop where the temperature several tens of meters above the ground may be as much as a 5 - 8°C warmer than air in the vineyard. Springtime temperature inversions will often have a 1.5° - 3°C temperature difference (moderate inversion strength) as measured between 2 and 20- meters above the surface. Many frost protection systems such as wind machines, heaters and undervine sprinkling rely on this temperature inversion to be effective.

The general rate of temperature decrease due to radiative losses can be fairly rapid until the air approaches the *dew point temperature* when atmospheric water begins to condense on the colder plant tissues (which reach atmospheric dew point temperature first because they are colder). The *latent heat of condensation*[2] is directly released at the temperature of condensation (dew point), averting further temperature decreases (at least temporarily). Thus, the exposed plant parts will generally equal air temperature when the air reaches its dew point. At the dew point, the heat released from condensation replaces the radiative heat losses. Because the air mass contains a very large amount of water which produces a large amount of heat when it condenses at dew point, further air temperature decreases will be small and occur over much longer time periods. A small fraction of the air will continue to cool below the general dew point temperature and drift down slope.

Thus, having a general dew point near or above critical plant temperatures to govern air temperature drops is important for successful, economical frost protection programs. Economically and practically, most cold temperature modification systems must rely on the heat of condensation from the air. This huge latent heat reservoir in the air can provide great quantities of free heat to a vineyard. Severe plant damage often occurs when dew points are below critical plant temperatures because this large, natural heat input is much too low to do us any good and our other heating sources are unable to compensate. There is little anyone can do to raise dew points of large, local air masses.

[2] When water condenses from a gas to a liquid, it releases a large amount of heat (2510 KiloJoules per liter at 0EðC compared to 335 KJ/l released when water freezes.)

Advective Freezes: Destructive cold temperature events under advective conditions are often called freezes rather than frosts. These freezes occur with strong (> 3 m/s), cold (below plant critical temperatures) large-scale winds persisting throughout the night (or day). They may or may not be accompanied by clouds and dew points are frequently low. Advective conditions do not permit thermal inversions to form although radiation losses are still present. The cold damage is caused by the rapid, cold air movement which convects or "steals" away the heat in the plant. There is very little which can be done to protect against advective-type freezes. However, it should be pointed out that winds greater than about 3 m/s that are above critical plant temperatures are beneficial on clear-sky radiative frost nights since they keep the warmer, upper air mixed into the vineyard, destroying the inversion and replacing radiative heat losses.

Critical Temperatures

The critical temperature is defined as the temperature at which tissues (cells) will be killed and determines the cold hardiness levels of the plant. There are other presentations at this symposium dealing with critical temperatures and supercooling, however, this is a poorly understood phenomenon by many growers and it is surrounded by a substantial body of myths.

Critical temperatures vary with the stage of development and ranges from below -20^{o}C in midwinter to near 0^{o}C in the spring. Shoots, buds and leaves can be damaged in the spring and fall at ambient temperatures as high as -1^{o}C. Damages in the winter months can occur to dormant buds, canes and trunks and will vary depending on general weather patterns for 7-14 days preceding the cold temperature event and physiological stages. Cold hardiness of grapes (and their ability to supercool) can be influenced by site selection, variety, cultural practices, climate, antecedent cold temperature injuries and many other factors (Johnson and Howell, 1981a, 1981b).

Critical temperatures are most commonly reported for the 10%, 50% and 90% mortality levels, and very often there is less than one degree difference between the values. These are not absolute values but they give the grower confidence in implementing frost protection activities and can reduce unnecessary expenses. Knowledge of the current critical temperatures and the latest weather forecast for air and dew point temperatures are important because they tell the producer how necessary heating may be at any stage of development and how much of a temperature increase should be required to protect the crop.

It is important to note that critical temperatures determined in a laboratory are done in carefully controlled freezers with slow air movement. The air temperature in the freezer is lowered in small predetermined steps and held there for 20 to 30 minutes or more to allow the buds to come into equilibrium. This practice has given rise to the common misconception that buds have to be at a temperature for 20 - 30 minutes or so before damage will occur. The truth is that whenever ice forms in the plant tissue there will be damage regardless of how long it took to reach that point. Plant tissues cool at a rate dependent on the temperature difference between it and its environment. Thus, if the air suddenly drops several degrees (as may be the case with "evaporative dip" when overvine sprinklers are first turned on) the tissues can rapidly cool below critical and cold injury will occur. In addition, mechanical shock from falling water droplets or agitation of the leaves and buds by wind machines can stop supercooling and quickly initiate ice crystal formation resulting in damage even if the tissues are above the laboratory-determined critical temperature values. However, the laboratory values (if available for a site and variety) provide a good ballpark figure as to when and what frost protection measures need to be implemented.

General Cold Temperature Protection Strategies

The objective of any crop cold temperature protection program is to keep plant tissues above their critical temperatures. Programs for protection of grape vines from cold temperature injury can be characterized as combinations of many *small measures* that incrementally achieve relatively *small increases* in ambient and plant tissue temperatures.

Any crop can be protected against any cold temperature event if economically warranted. The selection of a frost protection system is primarily a question of economics. Fully covering and heating a crop as in a greenhouse are the best and also the most expensive cold protection systems, but they are usually not practical for large areas of vineyards, or chards and many other small fruit and vegetable crops, unless other benefits can also be derived from the installation.

The questions of how, where, and when to protect a crop must be addressed by each grower after considering crop value, expenses, cultural management practices and historic frequency and intensity of frost events. These decisions must be based on local crop prices plus the cost of the equipment and increased labor for frost protection activities. It is not economically feasible to protect for all freeze conditions. Thus, these decisions must be balanced against risk assessments of both the annual and longer term costs of lost production (including lost contracts and loss of market share) and possible long-term vine damage.

Avoidance of cold temperature injury to vines can be achieved by passive and/or active methods (Reiger, 1989). Passive methods include site selection, variety selection, and cultural practices that can greatly reduce potential cold temperature damages as well as labor and other expenses for active frost protection measures. Active methods are necessary when passive measures are not adequate and include wind machines, heaters and sprinklers that may be used individually or in combination. Most successful frost protection programs are a mix of passive and active measures. Full consideration of several potential passive and active scenarios in the initial planning before planting will make active frost protection programs more effective and/or minimize cost of using active methods while not significantly increasing the cost of vineyard establishment.

Passive Frost Protection Strategies

Passive or indirect frost protection measures are practices that decrease the probability or severity of frosts and freezes or cause the plant to be less susceptible to cold injury. These include site selection, variety selection and cultural practices, all of which influence the type(s) and management of an integrated passive and active frost protection program.

Site Selection

The best time to protect a crop from frost is before it is planted. The importance of good site selection in the long term sustainability of a vineyard operation cannot be over emphasized (Stergios and Ho well, 1977b). It will influence the overall health and productivity of the vines through: soil depth, texture, fertility and water holding capacities; percent slope, aspect (exposure), subsurface and surface water drainage patterns; microclimates; elevation and latitude; and, disease/pest pressures and sources.

In windy (advective) situations, lower lying areas are protected from the winds and are usually warmer than the hilltops. However, under radiative frost conditions, the lower areas are cooler at night due to the collection of cold air from the higher elevations. Since frost injury is more common under radiative conditions, the best sites are usually located on hillsides with good cold air drainage conditions. Good deep soils with high water holding capacities will minimize winter injury to roots. In short, a good site can minimize the potential extent and severity of cold temperature injury and greatly reduce frost protection expenses and the potential for long term damage to vines.

Good site selection to minimize cold temperature injuries from radiation frost events must include evaluation of the irrigation (and frost protection) water supply, cold air drainage patterns and sources, aspect (exposure) and elevation. Long term weather records for the area will provide insight to the selection of varieties and future management requirements. Rainfall records will indicate irrigation system and management requirements. Assessment of historic heat unit accumulations and light intensities will help select varieties with appropriate winter cold hardiness characteristics that will mature a high quality crop during the typical growing season. Prevailing wind directions during different seasons will dictate siting of windbreaks, locations of wind machines, sprinkler head selection and spacings, and other cultural activities. Sometimes it is necessary to install the necessary weather stations and collect these data for several years prior to the installation of a vineyard.

Air Drainage: The importance of defining the sources and patterns of cold air drainage in determining frost protection strategies is poorly understood by many vineyard planners and is often neglected. This ignorance leads to many potentially avoidable frost problems. Minimizing cold air movement (drift) into and out of a vineyard during radiative frost events is absolutely critical to the long term success of the vineyard production. Obtaining a good site with good air drainage, especially in a premier grape growing area, can be very expensive, but it is an investment that with a very high rate of return.

Cold air movement during radiative conditions can often be visualized as similar to molasses flowing down a tilted surface: thick and slow (1-2 m/s [2-4 mph]). Air can be dammed or diverted like any other fluid flow. Row orientation should be parallel to the slope to minimize any obstruction to cold air as it flows through the vineyard. A relatively steep slope will help minimize the depth of cold air movement and reduce potential cold injury with height.

The major sources of cold air movement in a vineyard are usually either up slope or downslope from the site. Cold air can from above can flow into and/or back up and submerge a vineyard with cold air that has ponded below the site. Thus, all the sources of cold air and their flow patterns must be determined early in the planning process. As explained above, the cold air density gradients flow down slope and collect in low areas. Air temperatures in depressions can be 6 - 8°C cooler than adjacent hill tops (Blanc et al., 1963). Consequently, a vineyard site at the bottom of a large cold air drainage system may experience severe frost problems even if it is located on a "good" hillside location. A study of past cropping patterns and discussions with local residents will usually provide insight for defining the coldest areas.

The potential vineyard site must also be evaluated for impediments (natural and man-made) to cold air drainage both within and downslope of the vineyard that will cause cold air to back up and flood the vineyard. There is little than can be done for most natural impediments, however, the placement of man-made barriers may be either beneficial or extremely harmful. It is possible to minimize cold air flows through a vineyard, reduce heat losses (advective) and heating requirements with proper siting or management of man-made obstructions. Conversely, improper locations of barriers (windbreaks, buildings, roads, tall weeds or cover crops, etc.) within as well as below the vineyard can greatly increase frost problems.

Windbreaks are often used for aesthetic purposes, to reduce effects of prevailing winds or to divide blocks with little or no thought about their frost protection consequences. They can be advantageous in advective frost conditions, but they often create problems in radiative frosts. Windbreaks, buildings, stacks of bins, road fills, fences, tall weeds, etc. all serve to retard cold air drainage and can cause the cold air to pond in the uphill areas behind them. The size of the potential cold air pond will most likely be 4 to 5 times greater than the height of a solid physical obstruction, depending on the effectiveness of the "dam" or diversion. Thus, the proper use and placement of tree windbreaks and other barriers (buildings, roads, tall weeds or cover crops, etc.) to air flow in radiative (most common) frost protection schemes is very important.

The basal area of large tree windbreaks at the downstream end of the vineyard/orchard should be pruned (opened) to allow easy passage of the cold air. Windbreaks at the upper end should be designed and maintained, if possible, divert the cold air into other areas, fields, etc. that would not be harmed by the cold temperatures.

Aspect **–** Aspect or exposure is the compass direction that the slope faces. A north facing slope in the northern hemisphere is usually colder than a south facing slope in the same general area (opposite in the southern hemisphere). A northern exposure will tend to have later bloom which can be an advantage in frost protection, but conversely may have fewer heat units during the season and there may be problems maturing the crop with some varieties.

A southern exposure is usually warmer causing earlier bloom and a longer growing period. However, winter injury may be accentuated in southern exposure due to rapidly fluctuating trunk and cane temperatures throughout warm winter days followed by very cold nights. Dessication of plants due to heat and dry winds may be problematic on south facing slopes depending on the prevailing wind direction.

A southwest facing slope will have the highest summer temperatures and may be desirable for varieties that are difficult to mature in some areas. However, as southwest slope may be a problem with trunk burn (injury from reflected sun) in areas that typically have snow cover during the winter.

Elevation and Latitude **–** Air temperature is inversely related to altitude. Temperatures decrease about 10EðC for every kilometer of elevation. Higher elevations and higher latitudes both have a lower thickness of atmosphere above them and have higher nocturnal radiative cooling rates. Due to day length fluctuations throughout the year, higher latitudes will be colder. Thus, both higher elevations and high latitudes generally bloom later and have shorter growing seasons than lower altitudes and lower latitudes. The cooler environment may be offset by a warmer (southern) exposure; however these factors will have tremendous influence on variety selection and irrigation/soil water management as well as the type and extent of frost protection strategies.

Natural Heat Sources **–** Nearby large bodies of water will tend to moderate extremes in temperature throughout the year as well as reducing the frequency and severity of frost events. The "lake effect" is evident in western Michigan which is affected by Lake Michigan as well as the Napa-Sonoma grape growing areas in California which are moderated by "coastal effect" from the cold waters of the Pacific Ocean. Large cliffs, buildings or outcroppings of south facing rock will absorb heat from direct solar radiation in the day and release it at night thereby warning nearby vegetation.

Variety Selection

Fitting the best variety to the site is often more a matter of luck than science. It is known that some varieties will perform better under certain exposures, slopes and soils than others in the same area, but this information is lacking for most varieties in most areas (Anderson et al., 1980; Howell and Shaulis, 1980; Stergios and Howell, 1977b). However, selecting a variety which will consistently produce high yielding and high quality grape is every bit as important as (and dependent on) site selection. Different varieties will behave differently under the same circumstances. It is known that the sensitivity to frost for many deciduous trees is greatly influenced by root stocks, but this has not been demonstrated in the literature on grapes. Johnson and Howell (1981b) detected small but consistent difference in cold resistance from three varieties at the same stages of development.

Considerations will include evaluations of varietal differences in the tendency to break dormancy or de-harden too early to avoid the probability of frost injury. The susceptibility of a variety to potential winter damage in the region must be assessed. A variety with a long growing season (high heat unit requirement) may require more frost protection activities in the autumn.

Cultural Practices

Proper cultural practices are extremely important in minimizing cold injury to vines (Howell, 1988, 1991; Swanson et al., 1973; Winkler et al., 1974). It is obvious that healthy vines will be more resistant to cold temperature injury. Selecting the proper cultural practices for each location and each variety will encourage good vine health. Over cropping, excessive canopy shading, poor irrigation practices (over- or under-irrigation), improper timing of irrigations and over-fertilization can decrease hardiness and lower carbohydrate reserves leading to excessive cold temperature injury.

Cultural practices generally provide at most an equivalent 1^{o} to1.5^{o}C increase in air temperature. They must be carefully and thoughtfully integrated into a complete package of passive and active frost control measures, and they include: trellis height, soil fertility, irrigation water management, soil and row middle management (cover crops), pruning and crop load management, canopy management (training systems), spray programs and cold temperature monitoring networks. In addition, other practices such as covering graft unions between vines and rootstocks (if used) with soil prior to winter conditions and avoiding mechanical injuries to trunks are essential to long term production.

Trellis height – Because the coldest air is closest to the soil surface under radiative frost conditions, the trellis (bearing surface) should be has high a practical. Considerations will include pruning and the passage of over-the-crop mechanical harvesters, sprayers, and other equipment.

Fertility – High soil fertility levels by themselves have little effect on cold hardiness of vines. However, when high fertility is combined with high soil water levels late in the season *V. vinifera* vines may fail to harden-off early enough to avoid winter injury. This does not appear to be a problem in *Concord* and some other American cultivars or French hybrid varieties. The general recommendation is to adopt conservative plant nutrition programs that keep soil levels at the low end of fertilizer guidelines in frosty areas.

Irrigation – Irrigation systems have been used for frost protection since the early part of the 20th century (Jones, 1924). Selecting the proper irrigation system is crucial in frost protection strategies, disease management strategies and long term production. In arid areas, irrigation management is the largest single controllable factor in vineyard operation that influences *both* fruit quality and winter hardiness of vines. Additional detail on irrigation system design and management considerations for grapes is presented in Evans (1999).

Irrigation management can play a major role in preparing (harden-off) *V. vinifera* vines for cold winter temperatures in some arid regions. For example, in the inland arid areas of the PNW, the primary reason that they can successfully and consistently grow high quality *V. vinifera* grapes, as compared to other "high" latitude areas like Michigan and New York, is that they can and do control soil moisture throughout the year. Early season regulated deficit irrigation techniques as well as late season controlled deficit irrigations have both been effective in hardening-off vines in arid areas (Evans, 1999).

Overvine sprinkler systems have been used for bloom delay (evaporative cooling in the spring) on deciduous fruit trees such as apples and peaches in the spring which ostensibly keeps the buds "hardy" until after the danger of frost has passed. It does delay bloom, however, it has not been successful as a frost control measure on deciduous trees because of water imbibition by the buds which causes them to lose their ability to supercool. This results in critical bud temperatures that are almost the same as those in non-delayed trees. In other words, although bloom is delayed, but critical bud temperatures are not and, thus, no frost benefit. However, if the buds are allowed to dry during a cool period when the bloom delay is not needed or after a rain, they can regain some of their cold hardiness. There are no data on this practice in grapes.

After Harvest Irrigation – In areas with cold winters (i.e., temperatures below -10^{o}C) it is advisable to refill the soil profile to near field capacity after harvest to increase the heat capacity of the soils so that vine roots are more protected from damage from deep soil freezing and reduce the incidence of crown gall through injury sites. This practice also helps inhibit vine dessication from dry winter and spring winds.

Soil and Row Middle Management (cover crops) – Management of the soil cover in row middles in a vineyard can affect vineyard temperatures during a frost event. Historically, it has been recommended that cover crops not be used in frost prone vineyards. This California-based guideline was to keep soil surfaces bare, tilled and irrigated to make it darker so as to absorb more heat from the sun during the day. Some of this heat is then released during the night into the vineyard and may provide as much as 0.6^oC air temperature increase over cover cropped areas if soil temperatures are relatively high with a strong thermal inversion. Cold soils contribute less. It is important that the top 10 cm of the soil be kept wet to take advantage of this heat source since damp soils will conduct stored heat from lower soil levels much faster than dry soils. The contribution of the irrigation itself to heating of soils is small unless the water is above 15^oC. Bare soils are not beneficial if a grower is using sprinklers for frost protection.

Current information is that soil with cover crops will still contribute about 0.6^oC as long as they are kept mowed fairly short (< 5cm). Snyder and Connell (1993) found that the surface of bare soils was 1- 3^oC warmer than soils with cover crops (higher than 5 cm) in California almonds at the start of a cold period. However, after several days of low solar radiation and/or strong dry winds (soil surface drying), the areas with cover crops were warmer. There was no difference in covered soil surface temperatures once the cover crop exceeded 5 cm in height.

Thus, areas with cold soils in the spring and winter (i.e., in the PNW) will have very little, if any, frost benefit from bare soils. Irrigations with cold water (less than the soil temperature) are also unlikely to have much vineyard warming effect. However, maintaining bare soils or very short cover crops may be important in the fall frost protection events if water-based methods are not used. In general, it is not practical to depend on bare soil heat contributions as a significant part of a cold temperature protection program. Cover crops and mulches can offer cultural advantages of reduced soil erosion, lower dust levels, providing habitats for beneficial insects and reduced weed populations that often outweigh any "frost" benefits from bare soils. On the other hand, use of cover crops to delay bud break because of colder soils will also have limited effect.

Weed control can have a significant impact on vineyard temperatures (Donaldson et al., 1993). Tall cover crops (and weeds) will have a soil heat insulating effect and, more importantly, may hinder cold air drainage and increase the thickness of the cold air layer resulting in more cold temperature injury to the vines. However, taller cover crops will provide a greater freezing surface undervine sprinkler frost protection systems and additional heat in the vineyard, but should be kept no more than 25 - 30 cm in height during the frost season.

Pruning and Crop Load Management – It is well known that pruning too early can accelerate bud break which may result in more frost damage than later pruning (Stergios and Howell, 1977a; Winkler et al., 1974). Heavy crop loads the previous year may reduce carbohydrate accumulations, weaken the vines and reduce cold hardiness making the vines more susceptible to cold temperature injury.

There is usually not complete crop loss on grapes from severe frosts. Unlike tree fruit species which only have primary buds, grape vines have primary, secondary, tertiary and latent buds (Kasimatis and Kissler, 1974; Proebsting and Brummund, 1978; Winkler et al., 1974). The secondary buds will break after the primary buds have been damaged by frosts. Secondary buds are fruitful but only produce a 25% to 50% crop, and their berries take longer to mature than primaries because of the later bud break. Thus, mixtures of fruit from both primaries and secondaries will be significant concerns in both harvesting and overall juice quality. In addition, maturation of berries from secondary buds may be problematic in areas with short growing seasons. Tertiary and latent buds can break after damage to primaries and secondaries, but they are mostly vegetative with low yields, if any. The removal of injured shoots after frost injury has not been found to be beneficial in improving yields (Kasimatis and Kissler, 1974).

The general recommendation is delay pruning until after the danger of temperatures < 10^oF (-12^oC) is past which it typically mid-February in south central Washington. Less severe pruning and fruit thinning to desired crop loads resulted in increased cold hardiness of *Concord* grapevines (Stergios and Howell, 1977a). Because buds at the end of a cane will open first, another option that delays basal bud break by 7 to 10 days is to delay pruning (if there is time) until the basal buds are at the "fuzzy tip" stage (just starting to open). Thus, a general recommendation for grape vines in a spring frost prone area is to delay pruning as late as possible and to prune lightly. Crop load adjustments can be made later by additional pruning or thinning clusters after the danger of frost is past. However, late pruning just prior to a springtime rain may increase the incidence of Eutypa die back disease.

Growers in some warm areas with hot summer nights may not care about loss of primary buds to frost and some managers may actually plan to use secondary buds to delay harvests until cooler fall periods for better juice balance. In these cases it may be advisable to delay pruning (or even knocking off primary buds) to get desired crop loads and juice character.

Canopy Management **–** Maintaining a good canopy light environment by selecting the proper trellis and training systems for each variety and location will be beneficial. Good pruning practices, shoot positioning, leaf removal and other activities that open the canopy to sunlight will increase carbohydrate reserves and the vine's ability to withstand cold temperatures and provide for vigorous growth in the spring. Training up multiple trunks may be an advantage for sustainable yields in some areas where winter trunk injuries are common.

Controlling the size and density of a canopy by pruning and soil water management can have substantial benefits on the cold hardiness of the vines during the following winter. Early season regulated deficit irrigation and alternate row irrigation techniques potentially results in reduced vegetative to reproductive growth ratios and better light penetration into the canopy. In addition, canes exposed to direct solar radiation during the growing season were more cold hardy (Howell and Shaulis, 1980).

Spray Programs **–** The use of chemical sprays (e.g., zinc, copper, etc.) to improve frost "hardiness" of vines has been found to offer no measurable benefit in limited scientific investigations. Likewise, sprays to eliminate "ice nucleating" bacteria have not been found beneficial because of the great abundance of "natural" ice nucleators in the bark and dust which more than compensate for a lack of bacteria. There is no reported research on grapes using cryoprotectants or antitranspirants for prolonging cold hardiness or delaying bud break.

There is very little information on the use of sprays to delay bloom in grapes and thus reduce the potential for frost injury. Some chemical sprays (such as spring applied AVG, an ethylene inhibitor) have been reported to delay bud break on some fruit crops with exact timing (Dekazos, 1979; Dennis et al., 1977). Fall-applied growth regulators (ethylene releasing compounds: ethephon or ethrel) have also been reported to delay bloom the following spring and increase flower hardiness on *Prunus* tree fruits but there were some phytotoxic effects on the crop (Proebsting and Mills, 1969, 1973, 1976). Giberillic acid (GA) was less successful on deciduous fruit trees in delaying bloom (Proebsting and Mills, 1974).

One report (Weaver, 1959) found that GA prolonged dormancy in *V. vinifera.* Applications of a growth retardant (paclobutrazol) showed promise in improving hardiness on *Concord* grapes with applications of 20,000 ppm applied the previous spring and summer. (Ahmedulla et al., 1986).

New research on the use of alginate gel (Colorado, Virginia and Georgia on peaches and/or grapes) and dormant oil/soy oil (Virginia, Illinois and Tennessee on peaches and/or grapes) coatings that are sprayed on the plants 6 to 10 weeks prior to bud break shows promise in prolonging hardiness and delaying bloom by several days. It is hypothesized that the coatings retard respiration and thus inhibit bud break, providing a frost benefit. However, the coatings need to be reapplied after rain events and the economics is unknown.

Frost Monitoring Systems **–** Reliable electronic frost alarm systems are available that alert the grower if an unexpected cold front has moved into the area. These systems can ring telephones from remote locations, sound an alarm or even start a wind machine or pump. The sensor(s) should be placed in a regular thermometer shelter and its readings correlated with other "orchard" thermometers that have been placed around the block(s) to set the alarm levels (after considering the critical bud temperatures). It is important to have enough thermometers and/or temperature sensors to monitor what is actually happening across the entire vineyard.

Thermometers and sensors should be placed at the lowest height where protection is desired (e.g., cordon height in grapes). They should be shielded from radiant heat from fossil-fuel fired heaters (a very common mistake that gives misleading high readings). Thermometers and alarm systems should be checked and re-calibrated each year. Thermometers should be stored upright inside a building during the non-protection seasons.

Active Frost Protection Strategies

Active or direct frost protection systems are efforts to modify vineyard climate or inhibit the formation of ice in plant tissues. They are implemented just prior to and/or during the frost event. Their selection will depend on the dominant character of an expected frost event(s) as well as passive measures used in the vineyard establishment and operation.

Active frost protection technologies will use one or more of three processes: 1) addition of heat; 2) mixing of warmer air from the inversion (under radiative conditions); and 3) conservation of heat. Options for active frost protection systems include covers, fogging systems, various systems for overcrop and under-canopy sprinkling with water, wind machines, and heaters.

In selecting an active system to modify cold air temperatures that may occur across a block, a vineyard manager must consider the prevailing climatic conditions which occur during the cold protection season(s). Temperatures and expected durations, occurrence and strength of inversions, soil conditions and temperatures, wind (drift) directions and changes, cloud covers, dew point temperatures, critical bud temperatures, vine condition and age, land contours, and vineyard cultural practices must all be evaluated. The equipment must be simple, durable, reliable, inexpensive and non-polluting.

Covering a vineyard (conservation of heat) with a woven fabric for frost protection is one of the best systems but is very expensive ($20,000 to $30,000 per hectare) and will not be discussed further. Likewise, there are also experimental soy oil-based, gelatin-based or starch-based spray-on foams that are applied five to ten cm thick just prior to a frost event (Choi et al., 1999) which will not be addressed, but are being investigated as temporary thermal insulators for plants. Thus far these have had limited success in tall crops like vineyards and orchards and they must be repeated at frequent intervals.

The total calculated radiant heat loss expected from an unprotected vineyard on a clear night is in the range of 2 to 3 million KJ/ha per hour (60-80 W/ m^2). The "heating" or frost protection system must replace this heat plus heat lost to evaporation. It is estimated that to raise air temperature one degree Celsius in a 2-meter high vineyard will require that about 25 W/m^2 after all losses (or at 100% efficient). Artificial (active) vineyard and orchard heating systems will supply anywhere from 1.3 to 18.2 million KJ/ha per hour (36 to 510 W/m^2) of heat although it is usually about 7.8 to 13 million KJ/ha per hour (220 to 360 W/m^2). **Table 4.16** presents some relative heat values for oil, propane and water. These show that a 2.0 mm/hr application of water releases a total of 190 W/m^2 (3.35 million KJ per mm of water per hectare) if it all freezes. However, unless this water freezes directly on the plant, very little of this heat is available for heating the air and thereby protecting the plant. By comparison, a system of 100 return stack oil heaters per hectare supplies a total of about 315 W/ m_2 (11.3 million KJ/ha/hr) which can potentially raise the temperature as much as 12°C with a strong inversion at 100% efficiency (however, conventional heaters are only 10% to 15% efficient and much of the heat is lost leaving about 30-50 W/m^2 which would raise the whole vineyard temperature only about two degrees Celsius).

Over-vine Sprinkling

Overcrop or overvine sprinkler systems (addition of heat) have been successfully used for cold temperature protection by growers since the late 1940's. Many systems were installed in the early 60's, however, cold temperature protection by overvine sprinkling requires large amounts of water, large pipelines and big pumps. However, use of water for frost protection in *V. vinifera* blocks is often not recommended when it is necessary to carefully manage soil water levels (e.g., central Washington state and north-central Oregon). It is often not practical because of water availability problems and, consequently, is not as widely used as other systems. Most of these systems are used for both irrigation and cold temperature injury (frost) protection in areas where precise soil water management is not critical for winter hardiness. Traditional "impact" type sprinklers as well as micro-sprinklers can be used as long as adequate water is uniformly applied.

Overcrop sprinkling is the field system which can provide the highest level of protection of any single available system (except field covers/green houses with heaters), and it does it at a very reasonable cost. However, there are several disadvantages and the risk of damage can be quite high if the system should fail in the middle of the night. It is the only method that does not rely on the inversion strength for the amount of its protection and may even provide some protection in advective frost conditions with proper design and adequate water supplies. The entire block is sprinkled at the same time. Cycling of water applications across a block is very risky.

Table 4.18 Approximate relative heat values of water in KiloJoules (KJ), No. 2 diesel heating oil and liquid propane (0.2778 KJ = 1 watt-hr; 10,000 m^2 per hectare).

Condensation (latent heat) of water at 0°C releases	2510 KJ/l
Evaporation of water at 0°C absorbs/takes	2510 KJ/l
Freezing or fusion of water (latent heat) to ice releases	335 KJ/l
10°C temperature change of water releases/takes	41.4 KJ/l
Oil burning produces	9,302 Kilocalories/l or 39,800 KJ/l No. 2 diesel
100 oil heater/ha @ 2.85 l/heater releases	11,343,00 KJ/hr/ha 3,151 KW/ha
Liquid Propane produces	6,081 Kilocalories/l or 25,500 KJ/l LP
160 LP heater/ha @ 2.85 l/hr/heater releases	11,343,000 KK/hr/ha 3,151 KW/ha

When applied water freezes, it releases heat (heat of fusion) keeping the temperature of an ice and water "mixture" at about -0.6°C. If that mixture is not maintained, the temperature of the ice-covered plant tissues may fall to the wet bulb temperature (approximately the dew point), which could result in severe damage to the vine and buds. The applied water must supply enough heat by freezing to compensate for all the losses due to radiation, convection, and evaporation. Water should slowly but continuously drips from the ice on the vine when the system is working correctly. The ice should not have a milky color, but should be relatively clear.

The level of protection with overvine sprinkling is directly proportional to the amount (mass) of water applied. The general recommendation for overvine systems in central California calls for about 7 l/s/ha or 2.8 mm/hr on a total area basis which will protect to about -2.5°C (Jorgensen et al., 1996). In colder areas such as the Pacific Northwest in the USA, adequate levels of protection require that 10 to 11.5 l/s/ha (3.8 - 4.6 mm/hr) of water (on a total area basis) be available for the duration of the heating period which protects down to about -4 to -4.4°C as long as the dew point in not less than -6°C. Generally, water application rates should be increased by 0.5 mm/hr for every dew point degree (E°C) lower than -6°C.

Since the heat taken up by evaporation at 0°C is about 7.5 times as much as the heat released by freezing, at least 7.5 times as much water must freeze as is evaporated. And, even more water must freeze to supply heat to warm the vineyard and to satisfy heat losses to the soil and other plants. Evaporation is happening all the time from the liquid and frozen water. If the sprinkling system should fail for any reason during the night, it goes immediately from a heating system to a very good refrigeration system and the damage can be much, much worse than if no protection had been used at all. Therefore, when turning off the systems, the safest option on sunny, clear mornings is to wait (after sunrise) until the melting water is running freely between the ice and the branches or if ice falls easily when the branches are shaken. If the morning is cloudy or windy, it may be necessary to keep the system on well into the day.

Targeting – "Targeting" overvine applications to only the vine canopy (e.g., one microsprinkler per vine or every other vine ~ every 2.5 to 4 m) can reduce overall water requirements down to about 2.15 - 5.5 l/s/ha depending on the percentage of area covered. For example, a 0.6 m wide strip using micro sprayers with long rectangular patterns on pruned vines in spring can reduce the rates to as low as 2.15 l/s/ha. However, the water applied on the vine must still be 2.8 mm/hr to 3.8 mm/hr (John, 1985; John et al., 1986; Jorgensen et al., 1996) depending on the amount of protection needed. Protection under advective conditions may require application rates greater than 2.6 l/s/ha depending on wind speeds and air temperatures. The entire block must be still sprinkled at the same time when targeted applications are used for cold temperature protection. A risk associated with targeted applications under low dew point conditions is that significant damage may result due to higher evaporation losses (cooling), especially when less than 50% of the total vineyard area is wetted.

Equipment **–** The application of water to the canopy must be much more uniform than required for irrigation so that no area receives less than the designated amount. A uniformity coefficient (UCC) of not less than 80% is usually specified. The systems for frost protection must be engineered for that purpose from the beginning. Mainlines, pumps and motors (7.5 - 12 BHP/ha) must be sized so that the entire vineyard or block can be sprinkled at one time. A smaller pump is often installed for irrigation purposes and the block watered in smaller sets.

Impact and other rotating sprinkler heads should rotate at least once a minute and should not permit ice to build up on the actuator spring or other parts of the sprinklers and stop the rotation. Pressures are typically 370 to 400 kPa and should be fairly uniform across the block (e.g., less than 10% variation). Many sprinkler heads will fail to operate correctly at temperatures below -7°C.

Evaporative Dip **–** There may be an "evaporative dip", a 15 to 30-minute drop in the ambient air temperature, due to evaporative cooling of the sprinkler droplets when the sprinkler system is first turned on. This dip can push temperatures below critical temperatures and cause serious cold injury. The use of warm water, if available, can minimize the temperature dip by supplying most of the heat for evaporation. The recovery time and the extent of this dip are dependent on the dew point temperature which can be approximated by the more easily measured wet bulb temperature. A low wet bulb temperature (low dew point temperature) requires that the overcrop sprinklers be turned on at higher ambient temperatures. Table 4.17 presents suggested system turn-on temperatures based on wet bulb temperatures. Wet bulb temperatures are measured by a simple web-dry bulb psychrometer.

Table 4.19 Suggested starting temperatures for overvine sprinkling for frost protection based on wet bulb temperatures to reduce the potential for low temperature bud damage from "evaporative dip."

Wet Bulb Temperature		Starting Temperature	
°F	°C	°F	°C
> 26	> - 3.3	34	1.1
24 to 25	- 4.4 to - 3.9	35	1.6
22 to 23	- 5.6 to – 5.0	36	2.2
20 to 21	- 6.7 to – 6.1	37	2.8
17 to 19	- 8.3 to – 7.2	38	3.3
15 to 16	- 9.4 to – 8.9	39	3.9

Water Supply **–** Large amounts of water are required for overvine (and undervine) sprinkling, so that many vineyard managers in frost prone areas are drilling wells and/or building large holding ponds for supplemental water. There are extra benefits to these practices in that the well water can be warmer than surface waters plus the ponds tend to act as solar collectors and further warm the water. If economically possible, growers should try to size the ponds to protect for as much as 10 hours per night for three or four nights in a row.

Because of insufficient water quantities, some vineyard managers and orchardists have installed overcrop microsprayer "misting" systems (not to be confused with very high pressure [ε1500 kPa] systems that produce thick blankets of very small suspended water droplets that fill a vineyard with dense "fogs" several meters thick) for frost protection. These mistings are not recommended because of the very low application rates (e.g., δ0.8 mm/hr or 2.25 l/s/ha). There is absolutely no scientific evidence that these misting systems trap heat, reflect heat or "dam" cold air away from a block. They do not apply adequate water amounts to provide sufficient latent heat for bud/flower protection that is necessary for overvine sprinkling conditions and some local irrigation dealers are facing significant legal problems as a result.

Undervine Sprinkling

Below-canopy (undervine) sprinkling is usually not an option with grapes crops depending on the trellising system because of the density of interference from trunks and trellis posts. However, one method that may have some promise is the use of heated water (Evans et al., 1996; Martsolf, 1989) applied under the vine canopy (never overvine) at application rates greater than 1 mm/hr (3 l/s/ha) at temperatures around 40-45°C.

Fogs

Special "fogging" systems which produce a 6 - 10-meter thick fog layer that acts as a barrier to radiative losses at night have been developed. They operate at very high pressures with small nozzles suspended about 10 m above the ground. However, they have been marginally effective because of the difficulty in attaining adequate fog thickness, containing and/or controlling the drift of the fogs and potential safety/liability problems if the fogs crossed a road.

Fogs or mists which are sometimes observed with both undercrop and overcrop sprinkler systems are a result of water that has evaporated (taking heat) and condenses (releasing heat: no "new" heat is produced) as it rises into cooler, saturated air. As the "fog" rises, into ever colder and unsaturated air, it evaporates again and disappears. The duration of fogs or mists will increase as the ambient temperature approaches the dew point temperature. Thus, the "temporary" fogging is a visual indicator of heat loss that occurs under high dew point conditions and does not represent any heating benefit. It has been shown that the droplet size has to be in the range of a 100-nanometer diameter to be able to affect radiation losses, and the smallest microsprinkler droplets are at least 100 times larger (de Boer, 1964).

Heaters

Heating for frost protection (addition of heat) in vineyards has been practiced for centuries with growers using whatever fuels were available. This is still true today in many areas of the world (i.e., Argentina) where oil prices are prohibitive. There are numerous reports of growers using wood, fence rails, rubbish, straw, saw dust, peat, paraffin wax, coal briquettes, rubber tires, tar and naphthalene since the late 1800s. However, these open fire methods are extremely in efficient because heating the air by convection due to the rising hot exhaust gases is very inefficient with most of the heat rising straight up with little mixing with cooler air in the vineyard. Therefore, current fossil-fueled heater technology which was developed in the early 1900's through the 1920's, was designed to maximize radiant heating by greatly increasing the radiating surface area. Since that time there have been relatively minor refinements and improvements to the return stack, cone and other similar designs. Propane-fired heaters made their appearance in the 1950s but suffer from many of the same problem, including poor efficiencies. Newer technologies such as electric radiant heaters have not proved economical.

Heaters were once the mainstay of cold temperature protection activities but fell into disfavor when the price of oil became prohibitive and other alternatives were adopted. They have made a minor comeback in recent years, particularly in soft fruits and vineyards where winter cold protection may be required, but are plagued by very low heating efficiencies, high labor requirements and rising fuel costs. In addition, air pollution by smoke is a significant problem and the use of oil-fired heaters has been banned in many areas.

Radiant heating is proportional to the inverse square of the distance. For example, the amount of heat 3 meters from a heater is only one-ninth the heat at 1 meter. Consequently, conventional return stack and other common oil and propane heaters have a maximum theoretical efficiency of about 25% (calculated as the sum of the convective and radiative heat reaching a nearby plant). However, field measurements reported in the literature (e.g., Wilson and Jones, 1969) indicate actual efficiencies in the range of 10-15%. In other words, 85 - 90% of the heat from both conventional oil and propane heaters is lost, primarily due to buoyant lifting and convective forces taking the heat above the plants ("stack effect"). Typically there are about 100 return stack oil heaters (without wind machines) or 160 propane heaters per hectare which produce about 29.6 million KJ of heat. If heaters were actually as much as 25% efficient, then only about 14.8 million KJ of heat would be required, a 50% savings in fuel.

Heaters are "point" applications of heat that are severely affected by even gentle winds. If all the heat released by combustion could be kept in the vineyard, then heating for cold protection would be very effective and economical. Unfortunately, however, 75-85% of the heat may be lost due to radiation to the sky, by convection above the plants ("stack effect") and the wind drift moving the warmed air out of the vineyard. Combustion gases may be 600°C to over 1000°C and buoyant forces cause most of the heat to rapidly rise above the canopy to heights where it cannot be recaptured. There is some radiant heating but its benefit is generally limited to adjacent plants and only about 10% of the radiant energy is captured. New heater designs are aimed at reducing the temperature of the combustion products when they are released into the orchard or vineyard in order to reduce buoyancy losses.

Many types of heaters are being used with the most common probably being the cone and return stack oil burning varieties. Systems have also been designed which supply oil or propane through pressurized PVC pipelines, either as a part of or separate from the irrigation systems. Currently, the most common usage of heaters in the Pacific Northwest appears to be in conjunction with other methods such as wind machines or as border heat (two to three rows on the upwind side) with undervine sprinkler systems.

The use of heaters requires a substantial investment in money and labor. Additional equipment is needed to move the heaters in and out of the vineyards as well as refill the oil "pots." A fairly large labor force is needed to properly light and regulate the heaters in a timely manner. There are usually 80 - 100 heaters per hectare although propane systems may sometimes have as many as 170. A typical, well-adjusted stand-alone heating system will produce about 11.3 million KJ/ha per hour.

Based on the fact that "many small fires are more effective than a few big fires" and because propane heaters can usually be regulated much easier than oil heaters, propane systems often have more heaters per acre but operate at lower burning rates (and temperatures) than oil systems. It is sometimes necessary to place extra heaters under the propane gas supply tank to prevent it from "freezing up."

Smoke has never been shown to offer any frost protection advantages, and it is environmentally unacceptable. The most efficient heating conditions occur with heaters that produce few flames above the stack and almost no smoke. Too high a burning rate wastes heat and causes the heaters to age prematurely. The general rule-of-thumb for lighting heaters is to light every other one (or every third one) in every other row and then go back and light the others to avoid puncturing the inversion layer and letting even more heat escape. Individual oil heaters generally burn two to four liters of oil per hour.

Propane systems generally require little cleaning, however, the individual oil heaters should be cleaned after every 20-30 hours of operation (certainly at the start of each season). Each heater should be securely closed to exclude rain water and the oil should be removed at the end of the cold season. Oil floats on water and burning fuel can cause the water to boil and cause safety problems. Escaping steam can extinguish the heater, reduce the burning rate and occasionally cause the stack to be blown off.

The combination of heaters with wind machines not only produces sizeable savings in heater fuel use (up to 90%), but increases the overall efficiency of both components. The number of heaters is reduced by at least 50% by dispersing them into the peripheral areas of the wind machine's protection area. Heaters should not be doubled up (except on borders) with wind machines and are not usually necessary within a 45 - 60-meter radius from the base of the full-sized machine. Heat which is normally lost by rising above the vine canopy may be mixed back into the vineyard by the wind machines. At the same time heat is also added from the inversion. The wind machines are turned on first and the heaters are used only if the temperature continues to drop.

Wind Machines

The first use of wind machines (mixing heat from the inversion) was reported in the 1920's in California, however, they were not generally accepted until the 1940's and '50's. They have gone through a long evolutionary process with wide ranges in configurations and styles.

Wind machines, or "fans" as they are often called, are used in many orchard and vineyard applications. Some are moved from orchards after the spring frosts to vineyards to protect the grapes against late spring, fall and winter cold temperature events.

Wind machines, large propellers on towers which pull vast amounts of warmer air from the thermal inversion above a vineyard, have greatly increased in popularity because of energy savings compared to some other methods and they can be used in all seasons. Wind machines provide protection by mixing the air in the lowest parts of the atmosphere

to take advantage of the large amount of heat stored in the air. The fans or propellers minimize cold air stratification in the vineyard and bring in warmer air from the thermal inversion. The amount of protection or temperature increases in the vineyard depends on several factors. However, as general rule, the **maximum** that the air temperature can be increased is about 50% of the temperature difference (thermal inversion strength) between the 2- and 20 meter levels. These machines are not very effective if the inversion strength is small (e.g. 1.3° C).

Wind machines that rotate horizontally (like a helicopter) and pull the air down vertically from the inversion rely on "ground effects" (term commonly used with helicopters, etc.) to spread and mix the warmer air in the vineyard. In general, these designs have worked poorly because the mechanical turbulence induced by the trees greatly reduces their effective area. In addition, the high air speeds produced by these systems at the base of the towers are often horticulturally undesirable.

A general rule is that about 12-15 BHP is required for each acre protected. A single, large machine (125- 160 BHP) can protect 4 - 4.5 ha or a radial distance of about 120 m under calm conditions. The height of the head is commonly 10 to 11 m in height in orchards and vineyards. Lower blade hub height for shorter crops is generally <u>not</u> advantageous since warmer air in the inversion still needs to be mixed with the cold surface air. Propeller diameters range from 3.6 to 5.8 m depending on machine age and engine power ratings. The propeller assembly also rotates 360° about its vertical axis every 4-5 minutes parallel to the ground. The blade assembly is oriented with approximately a 6° downward angle for maximum effectiveness over an area.

The current "standard" is a stationary vertical fan that is usually powered by gasoline or liquid propane engines that produce about 125 to 160 HP for the larger machines (lowered powered machines can be purchased for smaller areas.) Two 5.8 m blades rotate at about 590 to 600 rpm producing 400 to 500 m^3/s mass air flows. Improved blade design and the use of space age materials in their construction have resulted in major performance improvements in recent years.

Modern machines rely on the principle that a large, slow-moving cone of air to produce the greatest temperature modification is the most effective (propeller speed of about 590-600 rpm). A wind machine that does not rotate about its axis has an effective distance of about 180 m under calm conditions. The amount of air temperature increase decreases rapidly (as the inverse of the square of the radius) as the distance from the fan increases. In actuality, the protected area is usually an oval rather than a circle due to distortion by wind drift with the upwind protected distance about 90-100 m and the downwind distance about 130-140 m. Several wind machines are often placed in large orchard or vineyard blocks with synergistic benefits by carefully matching the head assembly rotation direction with spacing.

Many growers turn on wind machines at about 0°C which is appropriate for many radiative frost situations. However, if the forecast is for temperatures to drop well below critical temperatures and/or accompanied by low dew points (e.g., < -7°C), it is advisable to turn on the wind machines at +2 to +3°C to start moving the warmer air through the vineyard even with weak inversions. This will serve to reduce the rate of radiative heat losses and strip cold air layers away from the buds. Buds and other sensitive tissues will be kept relatively warmer for a longer period of time since they have more heat to dissipate. Hopefully, the cooling process can be delayed under these conditions long enough for the sun to come up and avoid reaching critical temperatures.

In response to the chronic need to increase cold temperature protection capability, several attempts have been made over the past 40 years to design or adapt wind machines so that the wind plume would distribute large quantities of supplemental heat throughout a vineyard. These efforts have been uniformly unsuccessful. The high temperatures (e.g., 750°C) of the added heat caused the buoyant air plume to quickly rise above the tops of the vines and mixing with the colder vineyard air was minimal. These designs have ranged from "ram jets" on the propeller tips to the use of large propane space heaters at the base of the wind machine. The added heat actually causes the jet to quickly rise above the tops of the trees and substantially decreases the radius of the protected area due to the increased buoyancy of the wind plume. These problems could be circumvented if large amounts of heat could be introduced and mixed at low temperatures (e.g., 3°C above ambient temperature) within 30 m of the wind machine.

Wind machines apparently work well when used in conjunction with other methods such as heaters and undervine sprinkling. They should **<u>never</u>** be used with overvine sprinkling for frost protection. If they are used by themselves, bare soil may be somewhat beneficial by providing about 0.6°C additional temperature rise. A grower planning on installing a wind machine will need detailed information on inversions in their locale. They may want to put up a "frost pole" or tower to measure the temperatures with height in the vineyard during springtime inversions. The wind machine should be located only after carefully considering the prevailing drift patterns and topographic surveys. Wind machines may also be located so as to "push" cold air out of particularly cold problem areas.

Helicopters: Helicopters are an expensive (and sometimes dangerous) variation of a wind machine which can also be used under radiation frost conditions. They can be very effective since they can adjust to the height of an inversion and move to "cold spots" in the vineyard. The amount of area protected depends on the thrust (down draft) generated by the helicopter. Generally, the heavier (and more expensive) the helicopter, the better their protection capability during radiative frost events. A single large machine can protect areas greater than 20 hectares in size under the right conditions. However, due to the large standby and operational costs, the use of helicopters for frost protection is limited to special cases or emergencies. Helicopters should work from the upwind side of the vineyard making slow passes (2-5 m/s). One technique used with helicopters is to have thermostatically controlled lights in problem areas which turn on at a preset cold temperature. The helicopter then flies around the block "putting out the lights." There should also be two-way radio communications between the plane and the ground. A rapid response thermometer in the helicopter helps the pilot adjust the flying height for best heating effect.

Costs of Frost Protection Systems

It is quite difficult to present representative cost figures for frost protection systems since the installations are site-specific. Table 4.18 presents some "ball park" cost estimates for complete installed systems not including land value. The addition of wells and/or ponds is not included since these costs are extremely variable. The costs are additive if two or more systems are used. Economic comparison of estimated annual operating costs of the various frost protection systems are presented in Table 4.19 on a cost/hectare/hour basis.

Conclusions

The objective of any crop cold temperature protection program is to keep plant tissues above their critical temperatures. Programs for protection of grape vines from cold temperature injury consist of many *small measures* to incrementally achieve relatively *small increases* in ambient and plant tissue temperatures. These will be a mixture of passive and active measures that will cumulatively provide adequate protection levels. Passive methods include site selection, variety selection, and cultural practices. Active methods are necessary when passive measures are not sufficient and include wind machines, heaters and sprinklers that are used individually or in combination. Successful frost protection programs are usually a mix of passive and active measures. However, our ability to economically and practically protect crops during cold temperature events is more an art than a science.

Worldwide, vineyards are often severely affected frost damage to the canes, trunks, buds, shoots, flowers and leaves. In addition to lost production for that year, cold temperature injuries can also shorten vineyard life through increased incidence of crown gall and other diseases at injury sites on the plant. Frost protection systems are expensive due to purchases of supplemental equipment, labor and operation. Prevention of cold temperature injury is a significant part of annual vineyard production costs in many areas around the world.

There is no perfect method for field protection of crops against cold temperature injury. However, a blend of preplanned passive and active frost protection measures will be the most successful. The most important passive measure is good site selection, but it must be complemented by proper variety selections and cultural practices. Quite often combinations of active methods such as heaters and wind machines are advantageous. However, the capacity of any system or combined systems will always be exceeded at some point. In addition, a well-maintained and calibrated frost monitoring (thermometers and alarms) network will always be required.

Protection against advective (windy) freezes is much more difficult to achieve than protection against radiative freezes. Consequently, most of the methods/systems are practical and effective only under radiation situations. The formation of inversion layers is a benefit and many methods take advantage of an inversion to furnish, trap and/or recirculate heat.

A high dew point is probably the most powerful and effective mechanism available for reducing freeze damage to plants. This is due to the "heat pump" effect which replaces radiation losses with the latent heat of condensation. Any frost protection method which increases the water vapor content of the air is generally beneficial (but this is very difficult to accomplish!). Heat from water is more efficient than some other sources because it is released at low temperatures, is less buoyant (no "stack" effect), and may selectively warm the coldest plant parts.

Table 4.20 Estimated initial costs of installed frost protection systems common to Washington vineyards and orchards

Method	Estimated	Cost/hectare
Wind Machine (4-4.5)	$ 3,700	$ 4,500
Over-vine Sprinkler	$ 2,200	$ 3,000
Under-canopy Sprinkler	$ 2,200	$ 3,000
Over-vine Covers	$ 20,000	$ 37,000
Under-canopy Microsprinklers	$ 2,500	$ 3,700
Return Stack Oil Heat (100/ha) - used	$ 1,000	$ 1,100
Return Stack Oil Heat (100/ha) - new	$ 2,500	$ 3,000
Pressurized Propane Heaters (160/ha) - new	$ 6,200	$ 10,000

Table 4.21 Estimated approximate annual per hectare/hour operating costs *(including amortization of investment, but with O% interest and before taxes)* for selected cold temperature (frost) protection systems used 120 hrs per year.

Method	Estimated Cost/ha/hr
Return Stack Oil Heat (100/ha) *	$ 93.08
Standard Propane Heaters (154/ha) *	$ 103.98
Wind Machine (130 B-HP propane)	$ 0.92
Overcrop Sprinkling	$ 4.10
Under-canopy Sprinkling	$ 0.16
Frost-free Site	$ 0.00

* *equal total heat output*

In selecting a vineyard heating system to protect vines against cold injury, the manager/owner must consider the prevailing climatic conditions which occur during the cold protection season. Temperatures and expected durations, occurrence and strength of inversions, soil conditions and temperatures, wind (drift) directions and changes, cloud covers, dew point temperatures, critical bud temperatures, vine condition and age, grape variety, land contours, and vineyard cultural practices must all be evaluated. Both passive and active methods to protect against cold injury may be required. The equipment for active measures must be simple, durable, reliable, inexpensive and essentially non-polluting. Timing is critical.

There is a general need in agriculture, as in all natural resource industries, to conserve energy and other resources as well as to minimize negative environmental impacts, and frost protection activities must also move in that direction. Current technology for active frost protection is wasteful and inefficient in energy (i.e., heaters) and other resources. Development of new heater technologies (presently underway) that are at least 60% efficient (compared to 15% maximum now) would provide the same amount of heat in the vineyard as current heaters (i.e., return stacks) with one-fourth as much fuel which is a substantial savings in energy and expenses. Another example of the need for resource conservation is that sprinkler systems used for frost protection require large amounts of water at times when plant needs are very low causing water logged soils and leaching nutrients and other chemicals out of the root zone.

Conservation efforts will have to be aided by the improved ability to predict the severity and timing of frost events. Automated weather stations and a detailed knowledge of critical temperatures for different varieties in different areas throughout the year will be necessary. Mathematical models that combine accurate prediction of climatic conditions, plant physiology and resulting critical temperatures at any stage of growth will have to be developed and used to give growers more confidence in developing frost protection strategies and reducing expenses.

Literature Cited

Ahmedulla, M., A. Kawakami, C.R. Sandidge and R.L. Wample, 1986. Effect of paclobutrazol on the vegetative growth, yield, quality, and winter hardiness of buds of *Concord* grape. HortScience 21:273-274.

Anderson, J.A., G.S. Howell and J.A. Wolpert, 1980. Phenological development of different Vitis cultivars. Fruit Var. J. 34:5-7.

Blanc, M.L., H. Geslin, I.A. Holzbert and B. Mason, 1963. Protection Against Frost Damage. World Meteorological Org. Technical Note 51.

Choi, C.Y., W. Zimmit and G. Giacomelli, 1999. Freeze and Frost Protection with Aqueous Foam Development. HortTechnology 9(4):654-661.

de Boer, H.J., 1964. Comparison of Water Vapour, Water and Water Drops of Various Sizes, As a Means of Preventing Night Frost. Agricultural Meteorology. Elsevier. Vol 2:247-258

Dekazos, E.E., 1979. Effects of aminoethoxyvinylglycine (AVG) on bloom delay, fruit maturity and quality of 'Tifblue' and 'Woodard' rabbiteye blueberries. Proc. Fla. State Hort. Soc. 92:248-252.

Dennis, F.G., C.E. Crews and D.W. Buchanan, 1977. Bloom delay in stone fruits and apple with rhizobitoxine analogue. HortScience 12:386 (abstr.)

Donaldson, Dean R., R.L. Snyder, C. Elmore and S. Gallagher, 1993. Weed control influences vineyard minimum temperatures. Am. J. Enol. Vitic. 44(4):431-434.

Evans, Robert G., 1991. Frost protection techniques for trees in the Northwest. Proc. Frost Protection Strategies for Trees and Grapevines. Fresno, CA. Ca. Agr. Technol. Inst. Publ. 91 11104:85- 103

Evans, R.G. , 1999. AIrrigation choices for growing *V. vinifera* grapes in central Washington.@ pp. 57-74. In J Watson, editor. Proceedings of Growing Grapes in Eastern Washington. March 5, 1998, Richland, WA. The Good Fruit Grower, Yakima, WA.

Evans, R.G., M.O. Mahan and M.W. Kroeger, 1996. Utilization of Heated Water for Orchard Frost Protection. ASAE Tech. Paper 96-2041, Presented at Annual Meeting of ASAE . Phoenix, AZ. July 14-18. 15pp.

Howell, G. S., 1988. Cultural manipulation of vine cold hardiness. Proc. Sec. Intl. Cool Climate Vitic. and Enol. Symp.:p.98-102.

Howell, G.S., 1991. Approaches to solving the problem of low temperature damage to grapevines. Proc. Frost Protection Strategies for Trees and Grapevines. Ca. Agr. Technol. Ins. Publ. 91 11104:115-127

Howell, G.S., and N. Shaulis, 1980. Factors influencing within-vine variation in the cold resistance of cane and primary bud tissues. Am. J. Enol. Vitic. 31(2):158-161.

Howell, G.S., and J.A. Wolpert, 1978. Nodes per cane, primary bud phenology, and spring freeze damage to *Concord* grapevines. Am. J. Enol. Vitic. 29(4): 229-232.

John, P.H., 1985. Overhead Targeted Frost Protection. New Zealand Agricultural Engineering Institute, Lincoln College, Canterbury, New Zealand, Project Report Number 33.

John, P.H., P. Carran and I. Woodhead, 1986. Targeted Frost Protection-Orchard Trails. New Zealand Agricultural Engineering Institute, Lincoln College, Canterbury, New Zealand, Project Report Number 39.

Johnson, D.E., and G.S. Howell, 1981a. Factors influencing critical temperatures for spring freeze damage to developing primary shoots on *Concord* grapevines. Am. J. Enol. Vitic. 32(2):144-149.

Johnson, D.E., and G.S. Howell, 1981b. The effect of cane morphology and cultivar on the phenological development and critical temperatures of primary buds on grape canes. J. Amer. Soc. Hort. Sci. 106(5):545-549

Jones, E.H., 1924. Irrigation as frost protection in a citrus grove. Calif. Citrogr. 9(7):260.

Jorgensen, G., B.M. Escalera, D.R. Wineman, R.K. Striegler, D. Zoldoske and C. Krauter, 1996. Microsprayer Frost Protection in Vineyards. Ca Agr. Technol. Inst. Publ. No. 960803. Fresno, CA. 12 pp.

Kasimatis, A.N., and J.J. Kissler, 1974. Responses of grapevines to shoot break-out following injury by spring frost. Amer. J. Enol. Vitic. 25(1):17-20.

Martsolf, J.D., 1989. Heated Irrigation Cold Protection. Proc. Fla. State Hort. Soc. 102:64-69.

Proebsting, E.L., Jr., and V.P. Brummund, 1978. Yield and maturity of *Concord* grapes following spring frost. HortScience. 13(5):541- 543.

Proebsting, E.L., and H.H. Mills, 1969. Effect of growth regulators on fruit bud hardiness in Prunus. HortScience 4:254-255.

Proebsting, E.L., and H.H. Mills, 1973. Bloom delay and frost survival in ethephon treated sweet cherry. HortScience 8:46-47

Proebsting, E.L., and H.H. Mills, 1974. Time f giberellin applications determines hardiness of response of 'Bing' cherry buds and wood. J. Am. Soc. Hort. Sci. 99:464-466.

Proebsting, E.L., and H.H. Mills, 1976. Ethephon increases cold hardiness in sweet cherry. J Am. Soc. Hort. Sci. 101:31-33

Rieger, M., 1989. Freeze protection for horticultural crops. Hort. Rev. 11:45-109.

Schultz, H.B., and R.J. Weaver. 1977. Preventing frost damage in vineyards. Calif. Agr. Expt. Sta. Ext. Serv. Leaflet 2139

Snyder, R.L., and J.H. Connell, 1993. Ground cover height affects pre-dawn orchard floor temperatures. California Agriculture 47(1):9- 12. Jan-Feb.

Stergios, B.G., and G.S. Howell, 1977a. Effects of defoliation, trellis height, and cropping stress on cold hardiness of *Concord* grapevines. Am. J. Enol. Vitic. 28:(1):34-42.

Stergios, B.G., and G.S. Howell, 1977b. Effect of site on cold acclimation and deacclimation of *Concord* grapevines. Am. J. Enol. Vitic. 28:(1):43-48.

Swanson, F., P. Christensen, and F. Jensen, 1973. Preventing vineyard frost damage. Coop. Ext. Univ.of California.

Weaver, R.J., 1959. Prolonging dormancy in *Vitus vinifera* with gibberellin. Nature. 183:1198-1199.

Wilson, E.B., and A.L. Jones, 1969. Orchard Heater Measurements. Circular 511. Washington State University, Washington Agricultural Experiment Station. 18 pp.

Winkler, A.J., J.A. Cook, W.M. Kliewer and L.A. Lider. 1974. General Viticulture. 2nd ed. University of California Press, Berkeley, CA.

4.7 Crop Estimation

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Overview

Accurate crop estimation is critical for planning in both vineyards and wineries. Viticulturists require early season estimates to make decisions on canopy management, crop reduction and vine balance in order to optimize tonnages to maximize quality and productivity. Wineries rely on the crop estimate to ensure the grape intake requirements are sufficient, there is allowable tank space, and to order adequate enological supplies for the upcoming vintage. It is difficult to accurately assess the crop load as environmental factors, management practices and grapevine physiology all affect yield. Often crop estimates vary from the actual harvest up to and exceeding 30%. In general a good estimate will not vary by more than 10%. In order to provide a reasonable crop estimate the number of vines per block, the average number of bunches per vine and the bunch mass at harvest must be determined or predicted. Taking the time to properly estimate the potential crop load should result in an estimate that is accurate.

Determining the Number of Vines per Acre and per Block

In order to estimate the potential crop in a block the total number of vines per block must be determined. Most vineyards already have an accurate count of the number of vines per acre and block. If there is no record of plants per block, an accurate vine count is required. For most vineyards the number of vines per block is calculated based on planting density. Density is determined by multiplying the distance between vines (vine spacing) by the distance between rows (row spacing).

For example:

Vine spacing = 1.22m

Row spacing = 2.45m

Planting density is 1.22m × 2.45m = 1 vine per 2.94m²

Total area per hectare = 10000 m2

# of vines per hectare = 10000 ÷ 2.95 = 3364 vines per hectare

Vine spacing = 4 ft

Row spacing = 8 ft

Planting density is 4 ft × 8ft = 1 vine per 32 ft²

Total area per acre = 43560 ft²

# of vines per acre = 43560 ÷ 32 = 1361 vines per acre

The following gives the planting density in vines per acre and hectare for common vine and row spacing:

Table 4.22 Planting Density in Vines per Acre and Hectare

Vine Spacing (fr)	Row Spacing (fr)	Vines per Acre	Vine Spacing (m)	Row Spacing (m)	Vines per Hectare
3	7	2,074	0.9	2.1	5,126
4	7	1,556	1.2	2.1	3,844
3	8	1,815	0.9	2.4	4,485
4	8	1,361	1.2	2.4	3,364
5	8	1,089	1.5	2.4	2,691
4	9	1,210	1.2	2.7	2,990
5	9	968	1.5	2.7	2,392
6	9	807	1.8	2.7	1,993

Account for missing vines

Most vineyard blocks will have a slightly lower number of vines per acre than the calculated number due to missing vines from disease, winter injury, mechanical damage, replants, etc. These missing vines may cause an error in crop estimation if not accounted for. One method of accounting for the missing vines is to count the total number of missing vines in each block and subtract from the total plants per block. This requires spending the time to count all missing vines in every block in the vineyard. Another method is to include missing vines when counting the number of bunches per vine. In this situation record the plant as present, but with 0 bunches per vine. This eliminates the time required to count all missing vines in each block.

Determining the Number of Bunches per Vine

Bunch counting can be done during early shoot growth once the inflorescences are visible. It is best to count bunches as early as possible as they are much easier to see at this stage and takes less time. Secondary bunches are not visible at this time. It is more difficult to see bunches once the canopy is fully grown as leaves tend to obstruct ones view. If counting bunches later in the season it is important to count only primary bunches found on the primary and secondary shoots. The secondary bunches on lateral shoots should be ignored as they are not harvested.

Determining the number of bunches to count to get an accurate estimation of a particular block is dependent upon several factors. These include:

- The amount of variability within the block.
- The size of the block and planting density.
- The amount of error one is willing to accept in the sample.

Determining sample size

The accuracy of the estimate increases with the number of vines counted per block. The sample size should be determined by considering what level of variance is acceptable and how much time is to be allocated towards completing the crop estimation. In general, on very small blocks (blocks less than 1.5 hectares or 3 acres in size) 25 to 40 vines should be counted. On large blocks (2 to 4 hectares or 5 to 10 acres) a minimum of 100 vines should be counted.

For practical purposes it works well to count several vines (5 to 10) in a row every 6 to 10 rows. Randomly but uniformly select sections of vines for counting over the entire block. If there are sections with missing vines that have not been accounted for, record the vines 0 bunches per vine. If there is a section of a particular block that varies from the rest of the block (from frost damage or any other factor), it should be estimated separately.

Predicting Harvest Bunch Weights

The most difficult process in crop estimation is predicting the harvest bunch weight. The harvest bunch weight changes each year as it is influenced by many factors including vine physiology, vine nutrition status, vine water status, pest and disease pressure, environmental conditions, and vineyard management practices. Three commonly used methods of predicting bunch weight are:

- Historic bunch weight averages
- Lag phase weights
- Berry number counting

Each method has benefits and drawbacks to their use. Historic bunch weight estimates provide the first estimate in the growing season. The berry number and lag phase estimates account for the annual variation in bunch weights. A combined use of these methods over the growing season allows for early crop estimates which can be adjusted later on in the season to improve the accuracy of the estimate.

Historic Bunch Weights

Historic bunch weight (HBW) averages are useful in providing an early season crop estimate. This estimate should be completed in May, well before bloom. An average of at least 5 years of historic bunch weights by block or variety is required in order to give a reasonable crop estimate. It is important to collect bunch weights of all blocks in production on the day of or just prior to harvest each year. An assessment of the variation in the historic bunch weights will give a good indication of how accurate the crop estimation may be using the historic bunch weight. In order to estimate the crop load simply multiply the average number of bunches per vine by the total vines per block and the historic bunch weight.

HBW tonnes/hectare = $\frac{\text{avg. bunches/vine x vines/hectare x historic bunch weight (kg)}}{1000}$

HBW Crop Estimate (tonnes) = tonnes/hectare x hectares

HBW tons/acre = $\frac{\text{avg. bunches/vine x vines/acre x historic bunch weight (lbs)}}{2000}$

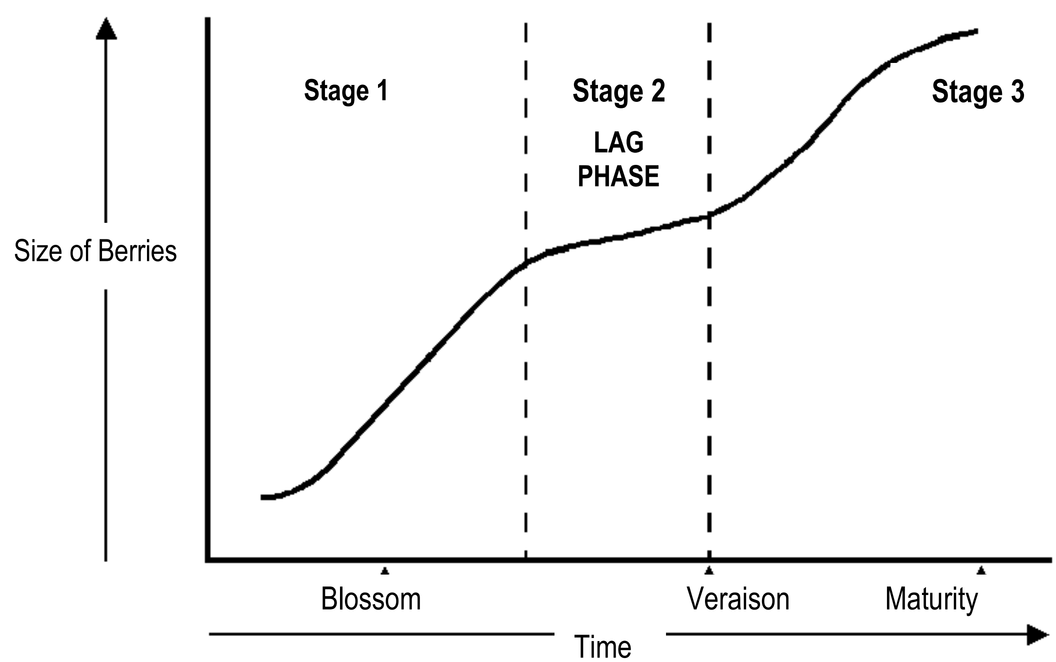
HBW Crop Estimate (tons) = tons/acre x acres

This estimate fails to account for the annual variation in bunch weights, which in some varieties and on younger vines can vary significantly. However, it does provide an early season estimate that serves as a good indicator of the crop potential in the vineyard.

Lag Phase Weights and Factors

Lag phase weights (LPW) involve sampling bunches during lag phase and determining the average bunch weights. These lag phase weights are multiplied by a factor to predict the final harvest bunch weight.

Figure 4.9 Growth Stages of a Grape Berry



Source: Jackson, D. and Danny Schuster, The Production of Grapes and Wine in Cool Climates, Buttwrworths of New Zealand (Ltd.), 205-207 Victoria Street, P.O. Box 472, Wellington, N.Z.

Lag phase occurs about halfway between bloom and harvest, and is identified by the hardening of the seeds. An increase in sugar production signals the end of lag phase and the onset of veraison. Lag phase is a useful time to collect samples to predict the harvest bunch weight which changes very slowly at this time. The lag phase weights are close to half of the actual harvest weight.

The benefit of lag phase crop estimation is that it takes into account the annual variation in bunch size, which can be as much as 100% of the bunch weight in some circumstances.

LPW tonnes/hectare = avg. bunches/vine × vines/hectare × LP weight (kg) × LP factor 1000

LPW Crop Estimate (tonnes) = tonnes/hectare × hectares

$$\textbf{LPW tons/acre} = \frac{\text{avg. bunches/vine} \times \text{vines/acre} \times \text{LP weight (lbs)} \times \text{LP factor}}{2000}$$

LPW Crop Estimate (tons) = tons/acre × acres

Sampling bunches at lag phase

When sampling it is important to accurately identify the exact stage of lag phase to ensure the samples are always taken at the same stage. Collect samples in a random but uniform pattern over the entire block. Sample bunches at random from the vine by taking bunches from the inside and outside portions of the canopy. The samples should be taken from alternating sides of the row. 5 to 6 bunches should be sampled each pass though the block. The passes through the block should be every 6 to 10 rows. A minimum of 40 bunches should be collected in an average sized block in order to obtain a sufficient sample. Increase the sample number in larger or more variable blocks.

Establishing lag phase factors

The lag phase factor is the difference between the lag phase weight and the harvest weight. Divide the harvest bunch weight by the lag phase weight to determine the factor. For example:

Chardonnay lag phase bunch weight: 0.076 kg

Chardonnay harvest bunch weight: 0.156 kg

Lag phase factor for Chardonnay:
0.156 kg / 0.076 kg = 2.05

The lag phase factors vary according to variety and stage of lag phase at which bunches are sampled. In general lag phase factors vary from 1.5 to 2.5. The factor for a particular variety will range from 1.9 to 2.5 at the very start of lag phase. This is indicated by the onset of hardening of the seeds in the grape. Dissecting the berry with a razor blade can test this. The berry is at the start of lag phase when the razor blade meets resistance when cutting due to the hard seeds. Later stages of lag phase can be determined by measuring the %Brix in the berries. The later stages of lag phase will have %Brix values from 6.0 to 9.0 % Brix. At this stage the lag phase factor will range between 1.5 and 1.9. It is critical that the lag phase at which the samples are taken are the same from year to year. This will help keep the lag phase factor consistent. Similar to historic bunch weights, an average of lag phase factors over 5 years will provide a good crop estimate using this method.

The lag phase method of bunch weight prediction is more accurate than the historic bunch weight method as it takes into account the annual variation in bunch weights. The disadvantage of this method is that the estimate cannot be completed until mid to late July. It is also critical to time the sampling of the blocks to the same stage of lag phase each year in order to improve the accuracy of the estimate.

Berry Number Averages

Another method of bunch weight prediction is to count the average number of berries per cluster. This number is multiplied by the historic average berry weight, which should be recorded at harvest for each block every year. It is best to use individual block berry weight values as they tend to be more accurate than variety averages. In the absence of individual block averages, varietal averages can give reasonable estimates.

Bunches can be sampled for berry counting once the berries have set. Sampling bunches should be completed in random fashion as described in the lag phase method. A minimum of 40 bunches should be collected in order to obtain a sufficient sample size. Once collected, one can count all berries from all of the bunches to determine the average berry number. Although very accurate, this method is extremely time consuming and in many cases may not be practical. An alternative method is to separate the bunches into tiers of similar sized bunches. Usually the bunches can be split into three to five tiers. From these tiers select three of the most representative bunches for berry counting. Using the average number of berries from each tier one can calculate the average berry number for the sample as shown in the following table.

Table 4.23 Calculating Number of Average Berries in each Tier

Tier	# of Bunches	Sample Size	Fraction of Sample	Bunch 1	Bunch 2	Bunch 3	Average Berry Number (ABM)	ABN * Fraction of Sample
1	5	50	0.1	223	213	209	215.0	21.5
2	9	50	0.18	175	190	182	182.3	32.8
3	17	50	0.34	156	148	143	149.0	50.7
4	13	50	0.26	128	139	122	129.7	33.7
5	6	50	0.12	76	85	90	83.7	10.0
							Sample average berry #	**148.7**

Notes:

- *# of bunches* refers to the number of bunches assigned to the particular tier
- *Sample size* is the total number of samples collected for the block
- *% of sample* is the fraction of the total sample *(# of bunches / sample size)*
- *Bunch 1, 2 and 3* are the 3 most representative bunches from each tier that are counted
- *Avg. Berry Number (ABN)* is the average of the counted bunches *(Bunch 1+Bunch 2+Bunch 3)/3*
- The *sample average berry #* is calculated by adding the *ABN* * the *% of sample* for each tier.
- The average berry # is then multiplied by the historic average berry mass. An additional 5% should be added to the value in order to account for the rachis weight.

Berry number tonnes/hectare = $\frac{\text{avg. bunches/vine} \times \text{vines/hectare} \times \text{avg. berry \#} \times \text{berry mass (g)} \times 1.05}{1{,}000{,}000}$

Berry number crop estimate = tonnes/hectare × acres

Berry number tons/acre = $\frac{\text{avg. bunches/vine} \times \text{vines/acre} \times \text{avg. berry \#} \times \text{berry mass (oz)} \times 1.05}{(2{,}000 \times 16)}$

Berry number crop estimate = tons/acre × acres

The berry number method of bunch weight prediction is valuable in estimating blocks where the set has been quite variable and there is a very large range of bunch sizes. The berry method can also produce a crop estimate at berry set earlier in the season than lag phase estimates.

Machine Harvesting Adjustments

It is necessary to adjust the crop estimate from the predicted value if the block is going to be machine harvested. The amount to adjust depends on the harvesting equipment, the variety, and the status of the canopy. There will be a reduction in tonnage due to some juice and fruit loss, and the elimination of the rachis which is left on the vine. In general, the rachis makes up approximately 5 % of the total bunch weight. The estimated % juice and fruit loss is added to the rachis value and subtracted from the total estimated tonnage. Industry standards use values averaging around 10% depending upon the block being harvested

Suggested timeline for crop estimation

1 - Early May – Pre-bloom

- Count bunches to determine the average number of bunches per vine.
- Complete the historic bunch weight crop estimate. (Estimate #1)

2 a - Berry Set (post shatter)

- Sample bunches to determine the average number of berries per bunch.
- Calculate the predicted harvest bunch weight using the berry number method.
- Adjust the historic bunch weight estimate using the predicted bunch weights. (Estimate #2)

OR

2 b - Lag Phase

- Sample bunches to determine the average bunch weight at lag phase.
- Calculate the predicted harvest bunch weight using lag phase factors.
- Adjust the historic bunch weight estimate using the predicted bunch weights. (Estimate #2)

3 - Harvest

- Collect bunch samples 1 or 2 days prior to harvest and record average bunch and berry weights. Determine the actual lag phase factor by dividing the harvest weight by the recorded lag phase weight.
- Adjust historic bunch weight averages, lag phase factor averages, and berry weight averages. Keep these records for use in future years.