Vineyard Frost Protection

Cain Hickey, Erick Smith, and Pam Knox

Introduction

Frost is the deposition of ice crystals on the surface of an object. In vineyards, frost can occur on many objects (e.g. vineyard floor, roof of the equipment shed, etc.), but the objects of major concern are sensitive swollen buds or green vine tissues. Frosts can occur on many occasions throughout the year, and often throughout the dormant season. However, dormant season frosts are not necessarily a threat to vineyard health and crop potential as the dormant vine buds are not as susceptible to injury at this stage compared to when buds are breaking dormancy in the spring. In the spring, vines begin to de-acclimate from colder winter-time temperatures. De-acclimation culminates in bud break, also termed budburst, which has been defined by the modified Eichorn and Lorenz grapevine growth stage system as stage 4: “leaf tips visible” (Fig. 1; Dry and Coombe 2004). In fact, the stage of grapevine phenology influences frost damage susceptibility; it has been shown that Pinot noir tissue damage can occur at growth stage 2/3 at 26 °F, at stage 4 at 28 °F, at stage 9 at 29 °F, and at stage 11 at 30 °F (Sugar et al. 2003). Further, there may be small differences in cultivar-specific susceptibility to cold injury (Johnson and Howell 1981). Regardless of the relative cold susceptibility of tissues at a certain growth stage or of a specific cultivar, grapevine bud break can often occur far in advance of the last frost-free date, putting grapevines at high risk of frost tissue damage. Since buds contain future flower and leaf tissues, frost can greatly impact the annual economic situation of vineyard and winery enterprises.

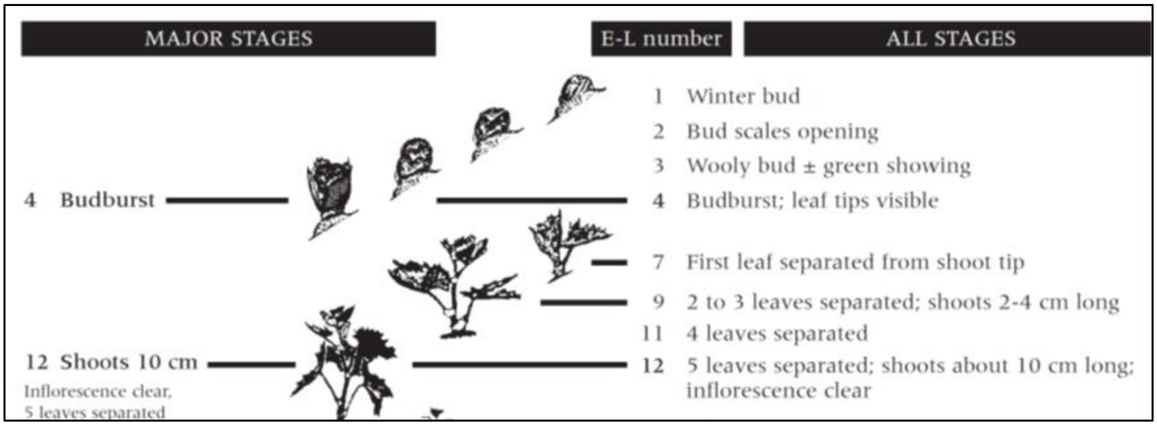

Figure 1. Grapevine growth stages 1-12 from the modified E-L system; adapted from Dry and Coombe (2004).

For this reason, this extension publication focuses on spring frosts, and the term “frost” will be used synonymously with “spring frost/freeze”. The word “freeze” refers to the damage caused by frost, and the damage caused by a freeze event (commonly known as an “advective freeze”). Last, this publication focuses on damage to de-acclimated and, thus, sensitive grapevine buds and green tissues as opposed to cold injury to dormant buds and woody tissues. This is partially to maintain a distinction between frost and cold injury, but also because producers can actively attempt to manage spring frost. For an in-depth tutorial of vineyard frost and freeze protection, please see the Workshop Proceedings from Understanding and Preventing Freeze Damage in Vineyards, held on December 5-6, 2007 at the University of Missouri, Columbia, MO (R.K. Striegler et al. 2007) (available online at: https://extensiondata.missouri.edu/pub/pdf/winegrape/wg1001.pdf).

Types of freezes/frosts [adapted from UGA Extension Bulletin 1479 (Smith et al. 2017); Poling (2007)]:

There are two weather patterns with which vineyard managers should be familiar when considering frost protection of grapevine tissues: advective freezes and radiation frosts (see Table 1 for a comparison of traits of these patterns).

Table 1. Traits of advective freezes and radiation frosts; adapted from Poling (2007).

	Temperature (°F)	**Wind**	**Temperature inversion?**	**Active frost protection methods effective?**
Advective freeze	Below 32	> 10 mph	No	No
Radiation frost	Above 32*	calm	Yes	Yes

*Temperatures in an inversion can be below 32 °F at the surface, but above 32 °F with increasing elevation.

Advective freezes are typically associated with the movement of a weather front into an area. Cold and dry air replaces the warmer air that was present before the weather change. An advective freeze front is associated with moderate to strong winds, no temperature inversion, and low humidity. The winds associated with advective freezes blow added heat away and cause ice to form poorly, thereby limiting the effectiveness of active frost protection methods. *Radiation frosts* occur when the sky is clear and there is little or no wind. Radiation frosts occur because of heat loss in the form of radiant energy. Objects on the earth's surface (i.e. vines) lose heat to the atmosphere during radiation frosts. Radiation freezes are often associated with a temperature inversion (Figure 2) in the atmosphere. A temperature inversion occurs when air temperature increases as elevation increases. A weak inversion occurs when temperatures aloft are only slightly warmer than near the surface. A strong inversion is noted by rapidly increasing temperature with elevation. *Active frost protection methods are far more effective during radiation frosts compared to advective freezes, and are especially effective in strong inversion conditions.*

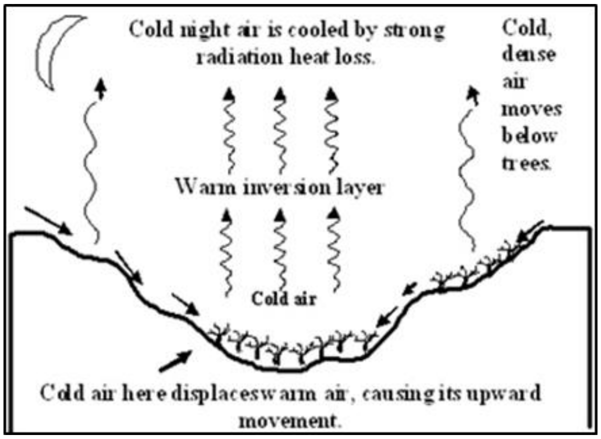

Figure 2. Depiction of a radiation frost event; adapted from UGA Extension Circular 877 (Taylor 2012).

Ways to avoid frost: passive and active frost protection

Passive frost protection methods involve those that do not modify the vineyard climate and typically do not require energy input into the system (as do wind machine or heaters). Passive methods include site selection, cultivar selection, and cultural practices. In general, these methods do not afford as many degrees of protection relative to active frost protection methods (discussed below), but these methods are nonetheless critical as they have saved the season's crop for many industry stakeholders in the past. Further, a degree or two can make the difference between a full crop and a substantial crop loss.

In contrast to passive frost protection measures, *active frost protection* methods involve those that modify the vineyard climate and typically require energy input into the vineyard system. The vineyard climate is modified by active frost protection methods such as wind machines/helicopters, heaters, and sprinkler-applied irrigation water can also be used to protect vine tissues, as discussed in further detail below. While active frost protection methods cost additional money to employ, it is important to consider the economic value of the grape crop (and the wine that will be made and sold from that crop) that could be "saved" through their use. Poling (2007) estimated that investment in wind machines costs about $2,800 per acre, and may prove profitable if the site has a greater than a 20% chance of spring frost. Current grower-reported data support the cost estimates of Poling (2007), and that it may take around $120-150 per frost event to fuel the wind machine. If an average of four tons of grapes per acre were produced, and this crop was turned into wine that sold for $20/bottle, then the potential revenue loss is conservatively estimated to be approximately $48,000 per acre (this is for a *total* crop loss; secondary buds can produce fruit). Thus, it is important to consider the site and frost risk and evaluate if active frost protection via a wind machine is worth the upfront investment.

For the vineyard manager, historical meteorological data and resources available (capital, labor, deep well, pond, etc.) can help determine the appropriate active freeze protection system. Historical data of your site can be acquired from the University of Georgia's weather network (http://www.georgiaweather.net/). This historical meteorological data can help to predict the potential for freeze damage at your vineyard site location, which may influence the decision for risk aversion by employing an active frost protection system. However, keep in mind that the nearest weather station may not provide exact local weather conditions in terrain characterized by frequent and sharp changes in elevation, such as mountainous regions.

Passive frost protection

Site selection and cultivar selection are the passive frost protection methods that should be considered before vineyard establishment. Cold air follows the same drainage pathway that water does. Thus, under radiation type frost events, where there is virtually no air movement, the coldest air will pool at the bottom of a sloped and/or convex landform (Fig. 3). For this reason, choosing a vineyard site that is higher than surrounding land, and is planted on convex as opposed to concave landforms, will ensure that the coldest air will move away from the vines. It should be noted that cold air drainage is most likely to occur when a strong temperature inversion is created by no air movement.

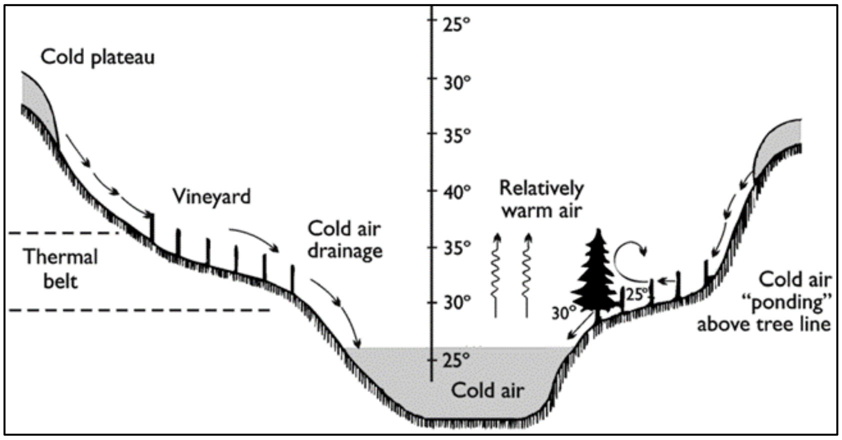

Figure 3. Depiction of the effect of topography on cold air drainage and "temperature inversion" – likely experienced during a radiation frost event; adapted from Poling (2006).

While planting vines on an "exposed" site that is higher than surrounding land helps protect from frost injury during radiation frosts, vineyards on such convex land forms are at a higher frost injury risk in advective freeze conditions as they are more exposed to prevailing cold winds than if they were planted in a protected valley. Fortunately, radiation frosts tend to be more common than advective freezes in the spring in the southeastern US. Further, planting grapevines on low-lying landforms poses greater risk for excessive vegetative growth and increased disease pressure. Vineyards with a southern aspect have potential to break bud earlier due to the greater amount of sun and heat when compared to vineyards with a northern aspect; this may be especially true when aspects are separated by extreme (i.e. greater than 25%) slopes. Thus, while southern-exposed vineyards may experience better seasonal vine growth and ripening capability, they may have a relatively greater risk of spring frost when compared to northern-exposed vineyards.

Cultivar selection is the other passive frost protection method to consider before vineyard establishment. Cultivars that have relatively late bud break are good choices to limit the chance of experiencing tissue damage due to a spring frost/freeze event. Chardonnay is the hallmark grapevine cultivar for early bud break. Unfortunately, this is the most widely-planted white-berried *vinifera* grapevine in Georgia; as such, the threat of spring frost is commonplace for those who grow this cultivar. Table 2, below, shows the bud break differential of common *vinifera* cultivars when compared to Chardonnay (ENTAV-INRA 1995). In general, white cultivars *tend* to break bud earlier than red cultivars; whites are also often harvested before reds. Some popular hybrids with Pierce's disease tolerance, widely planted in the Georgia piedmont, were observed to exhibit similar patterns to *vinifera* cultivars. For example, Blanc du Bois was observed to break bud earlier than Lenoir/Black Spanish and Norton. There are some exceptions to the "whites break bud earlier than reds" rule, however. Muscat Ottonel, Sauvignon blanc, and Marsanne (all whites) can break bud later than Pinot noir and Merlot (both reds) (Table 2). Hybrid cultivars can often break bud earlier than *vinifera* cultivars, and there are differences within hybrids. For example, Chardonel can break bud up to two weeks earlier than Vidal blanc (Striegler 2007). It would therefore be prudent to plant Chardonel on a low frost potential site. Muscadine grapevines have relatively low perennial frost damage potential in most of Georgia. However, muscadine growers in northern Georgia and in west/central North Carolina may be at greater frost risk due to cold weather patterns that can be experienced during bud break.

In practice, differences in bud break between cultivars may not be as evident – especially when the theoretical difference is only a few days, and especially on land with very similar slope and aspect. These cultivar bud break guidelines are not intended to prevent growers from planting early-bud breaking cultivars. However, it would be very smart to plant cultivars that bud break relatively early on the least frost-prone site (i.e. highest land and/or north-facing) on your land to reduce frost risk. Note that these considerations for bud break are not to be confused with a cultivar's bud and woody tissue cold hardiness, which is typically measured in dormant buds from acclimation in the late fall/early winter through de-acclimation in the late winter/early spring. For example, though Syrah and Mourvedre are late-bud breaking, they also are extremely cold-tender. Further, these varieties do not typically perform well under the climatic conditions of Georgia and the southeastern US.

Table 2. Relative Dates of Bud Burst of Selected *V. vinifera* Grape Cultivars (ENTAV-INRA 1995); adapted from Hellman 2015.

Cultivar	Time of Bud Burst (days)*
Chenin blanc, Chardonnay	0
Gewürztraminer, Viognier	1
Pinot blanc	2
Pinot gris, Pinot noir, Merlot	3
Petite Verdot, Tannat	5
Riesling, Cabernet Franc, Semillon	6
Grenache, Muscat Ottonel	7
Sauvignon blanc, Syrah, Tempranillo	8
Carignan, Marsanne	10
Counoise	13
Cabernet Sauvignon, Mourvedre	14

*The relative number of days that bud burst occurs in these cultivars *after* bud burst is observed in Chenin blanc and Chardonnay.

Cultural methods for frost protection include pruning, cultivation, and the application of chemical products advertised to delay bud break or improve tissue cold hardiness. Delayed, or double, pruning has potential to delay basal bud break as apical buds tend to break before basal buds (Figure 4). However, there has been little formal of evaluation of these pruning strategies to determine the number of apical buds required to delay basal bud break. Further, completely delaying pruning until one is “clear” from the threat of frost shifts time-consuming field labor into an already busy time of the season; this can make vineyard management difficult. Anecdotal observations also suggest that delaying pruning well into the spring can reduce the percent of basal bud break, which negates the originally intended purpose of employing delayed pruning – to “save” basal buds. Cane pruning may also slightly delay bud break date and phenological advancement when compared to spur pruning (Hatch 2015).

Figure 4. A delay-pruned Chardonnay vineyard displaying advanced apical relative to basal bud development in the spring (photo courtesy of Clark MacAllister).

Soil wetting and soil cultivation practice (bare vs. vegetation) can impact soil heat conductance and absorbance, and therefore may have minimal impact on the microclimate around the vine as it relates to frost risk. Anecdotal observations suggest that cover crops have not increased frost damage incidence, but Donaldson et al. (1993) found that herbicide treatment resulted in warmer temperatures, and shorter duration at critical temperatures, at cordon height when compared to disking or mowing. Thus, it is recommended to maintain your vineyard floor to complement your site – if it is well-sloped or highly vigorous, then cover crops may help limit soil erosion and attenuate vigor. However, herbicide treatment may provide *slight* benefit to frost protection.

Commercial chemical spray products such as oils, anti-transpirants, and cryoprotectants have produced varied results in their ability to effectively protect cold-sensitive grapevine tissues. Centinari et al. (2016) found that the application of potassium-based salt fertilizer (KDL) 24 hours before low temperature exposure did not impact shoot mortality in Noiret. It was also reported that dormant-applied Amigo oil (a vegetable based adjuvant) delayed bud break for a longer period in *vinifera* (six to 11 days) compared to hybrid cultivars (two to four days), but that neither product resulted in reduced freeze damage of the hybrid cultivars. Dami (2007) reported that dormant season-applied oils had no effect on mid-winter bud hardiness, but delayed bud break – sometimes to extreme and undesirable lengths (i.e. 19 days). Further, it was reported that oils can be phytotoxic (damaging to green tissue) at rates at or above 10% (v/v) (Dami 2007 and Centinari et al. 2017), that stylet oil is more phytotoxic than soybean oil (when applied at the same rate) and that crop yield was reduced with high application rates (≥ 10%) (Dami 2007). The take home for these studies is that the specific product, application rate, cultivar being treated, and frost occurrence date all affect the success of frost protection with commercial oils and cryoprotectants. Further, that undesirable side-effects, such as reduced crop yield, may occur if phytotoxic rates are used. Clearly more work in this area is required before well-defined, dependable recommendations can be made for the use of these products.

Active frost protection

Vineyard heaters have been used to prevent cold injury for centuries. A common commercial heater is called a return stack fuel oil heater and it is suggested that 40 units (pots)/acre be placed in an orchard. Heaters are becoming less popular tools for active frost protection in vineyards for the following reasons. While effective at raising air temperature in a strong inversion, fuel heaters lose effectiveness under windy conditions. Further, the use of heaters in tandem with air mixing by wind machine can help protect vines under extremely cold radiation frost events. The cost of fuel oil and labor needed to tend the heaters may additionally prohibit the use of vineyard heaters as an economical frost protection measure. One of the few vineyards known to employ the use of fossil fuel heaters in northern Georgia commented that it takes roughly 90 gallons of diesel fuel per acre at each frost threat event; as the cost of diesel fluctuates, so will the cost of using the heaters. An additional comment was made about the large amount of labor required to deploy and remove heaters from the vineyard. As alternative sources of heat to fossil fuel-burning heaters, growers have burned dead plant material such as dormant cane prunings and brush during freeze events.

Wind machines/helicopters are likely the most common active frost protection methods used in the vineyard industry. These active frost protection methods are only effective in strong inversions with minimal to no wind. Wind machines (Figure 5) or helicopters can be used to mix air of the top (warmer) and bottom (cooler) layers of an inversion. Mixing the inversion layers hopefully results in a moderated temperature around the grapevine buds to at least the minimum temperature required to prevent grapevine tissue damage. In a strong inversion, the air temperature may be warm enough to protect the plants. However, if the wind machine is operated in a weak inversion or advective freeze conditions**,** the air movement could cause greater damage to the grapevine tissues through evaporative cooling. One wind machine can raise the temperature 1-3 °F and cover a 12-acre portion of vineyard (Hellman 2015). While 1-3 °F of protection may not seem great, wind machines are effective for managing the most common frost-related weather event after bud burst – radiation frosts (Poling 2007). Helicopters are not used as frequently as wind machines, but do have the advantage of adjusting to the height of the inversion layers when wind machines may not. The estimated cost for flying a helicopter over a vineyard was $825 per hour in 2006 (Poling 2007), and recent communications with growers suggest this number has dropped to roughly $600 per hour today. Based on the earlier-mentioned economics of potential revenue lost due to a killing frost, this may be an economical option to save a crop. *For in-depth discussion of operating wind machines, helicopters, and heaters for frost protection, please review Poling (2007).*

Figure 5. A wind machine in a young Chardonnay vineyard during the post-harvest period.

Irrigation is the least common active frost protection method used in the vineyard industry. This is perhaps because of the several factors that play into the success of this frost protection method, such as system issues (pumps not working, broken sprinkler heads, miscalculated pump rate to fully cover vine tissues, etc.) and the need to know the air and dew point temperature and type of prevailing weather patterns (i.e. advective freeze vs. radiation frost). Frost protection using water is utilizing latent heat of fusion to protect vine tissues. This scientific term simply means that heat is released when ice freezes, and this heat protects underlying tissues by maintaining temperatures at or slightly above 32 °F. If the wind is blowing, air mixes with the water to form air pockets, which forms cloudy ice. This significantly decreases the effectiveness of frost protection. Clear ice is an indication that you have good freeze protection. Irrigation should be applied at a rate that ‘keeps up’ with freezing conditions so that the ice is consistently wet and forms a clear layer. Approximately 6800 gallons of water per hour may need applied for successful protection of an acre of grapes. These necessary water resources, coupled with the potential need to pump water up steep slopes, make frost protection via irrigation a fiscally-intensive pursuit. Further, it is possible that the weight from ice may damage the trellis. For the above-mentioned reasons, irrigation is not highly recommended for vineyard frost protection. *For in-depth discussion of operating an irrigation system for frost protection, please review UGA Extension Bulletin 1479 (Smith et al. 2017).*

After the frost…

Once a frost has occurred, there are some practical considerations. Grapevines have three buds-primary, secondary, and tertiary. The primary bud carries the greatest crop potential, but is also the most susceptible to frost injury. When the primary shoot is killed (Fig. 6), a secondary bud can break and often bear some crop. While the secondary bud is certainly less fruitful and carries a lower crop than the primary bud, the secondary bud can bear 50% or more of the crop carried by the primary bud in some French hybrid cultivars (Hellman 2015). This, in turn, could be an important cultivar consideration if the vineyard is in a frost-prone site. Regardless of severity of frost injury, it is probable that vines will survive. It is important to care for any secondary and tertiary shoots that emerge (just as you would care for the primary shoots) and implement the perennial management tasks of shoot positioning and training system maintenance. This will ensure good leaf exposure for photosynthesis and maintain spur positions for the following season. If there is a small crop, its maturity may be slightly delayed due to the late growth initiation and reduced leaf area. Use your chemical and sensory measurements to determine when to harvest the fruit and what it can be best used for in the winery (i.e. less-ripe fruit is often a good candidate for a rosé or sparkling wine, or used to boost acidity in other wines). Disease management is also an important post-frost injury consideration. According to Schilder (2010), the fungal management plan depends on a few different scenarios concerning the harvestable crop amount and the tandem interest in reducing inoculum buildup. In general, if the crop is harvestable, then the spray program should proceed as if the frost injury didn’t occur. However, it is important to keep leaf area healthy regardless of crop level to ensure good carbon gain throughout the remainder of the season.

Figure 6. Primary shoots killed by frost (photo courtesy of Fritz Westover)

Considering region in Georgia

A frost can occur from Young Harris all the way to Thomasville, GA. In fact, the threat of vineyard frost was very high in both of those locations in 2017, a very "early" year. Thus, it may be remiss to say that planting in southerly locations reduces the threat of frost. However, March and April (when grapevine bud break occurs) are generally milder in Region 3 compared to Regions 1 and 2 of Georgia (Fig. 8). Thus, Region 3 may be a "safer" place to plant to avoid a spring frost. However, cultivar suitability to Regions 2 and 3 is limited to only Pierce's disease (PD) tolerant bunch grapes and muscadine grapes. Thus, frost becomes a lesser concern when the grapevine cannot survive in the first place. Suffice it to say that regional cultivar suitability is primarily determined by susceptibility to limiting diseases (such as PD) and cold hardiness, both of which vary across *Vitis* species and latter of which has been tabulated (Dami 2007). For more information on grapevine cold injury, please see Chien (2014), Fiola (2014), and Zabadal et al. (2007). Nonetheless, muscadine grapes are primarily grown in Region 3 and some in Regions 1 and 2, while bunch grapes for wine production are primarily grown in Region 1 and some in Region 2. A future extension publication is anticipated to discuss the regional suitability of specific grapevine cultivars throughout Georgia in greater depth.

Figure 8. Georgia Grape Horticultural Areas. 1. Mountain 2. Upper Piedmont 3. Lower piedmont, middle and South Georgia; adapted from UGA Extension Bulletin 807 (Krewer 2006)

Summary

Due to the frequency of perennial frost threat in the spring, frost protection is an important consideration in vineyards in Georgia and the rest of the eastern US. For passive methods, the hierarchy of importance for avoiding frost may look like this: site ≥ cultivar > pruning > soil cultivation. Chemical spray products are not recommended at this time due to inconsistent research results. Active methods are primarily effective with radiation frosts, which are fortunately (unfortunately?) more common than advective freezes during seasonal grapevine bud break in the eastern US. Wind machines are by far the most widely-used active frost protection method in vineyards due to their relative effectiveness and ease of implementation when compared to other active methods. If your site is at risk of frost on a perennial basis, and your fiscal situation permits the purchase of an active frost protection method, the presented economics suggest the investment could quickly "pay for itself" by saving valuable crop.

References and resources

Centinari, M., M.S. Smith, and J.P. Londo. 2016. Assessment of Freeze Injury of Grapevine Green Tissues in Response to Cultivars and a Cryoprotectant Product. HortScience 51: 856-860.

Centinari, M., D.M. Gardner, D.E. Smith, and M.S. Smith. 2017. Impact of Amigo Oil and KDL on Grapevine Post-Budburst Freeze Damage, Yield Components, and Fruit and Wine Composition. Am. J. Enol. Vitic. *in press*.

Chien, M. 2014. Cold injury in grapevines. eXtension online article, April 30, 2014. http://articles.extension.org/pages/63372/cold-injury-in-grapevines

Constantinidou, H.A., O Menkissoglu, and H.C. Stergiadou. 1991. The role of ice nucleation active bacteria in supercooling of citrus tissues. Physiologia Plantarum. 81:548-554.

Dami, I.E. 2007. Freezing and Survival Mechanisms in Grapevines. *In* Proceedings from Understanding and Preventing Freeze Damage in Vineyards. R.K. Striegler et al. (organizing committee) pp. 13-20. University of Missouri, Columbia, MO.

Dami, I.E. 2007. Delaying Grapevine Bud Burst With Oils. *In* Proceedings from Understanding and Preventing Freeze Damage in Vineyards. R.K. Striegler et al. (organizing committee) pp. 89-91. University of Missouri, Columbia, MO.

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

Dry, P., and B. Coombe, eds. 2004. Viticulture 1 – Resources, 2nd Ed. "Revised version of grapevine growth stages – The modified E-L system." Winetitles, Adelaide, Australia.

ENTAV-INRA. 1995. Catalogue of Selected Wine Grape Cultivars and Clones Cultivated in France. Ministry of Agriculture, Fisheries and Food. CTPS.

Fiola, J. 2014. Understanding grapevine bud damage. Timely Viticulture Newsletter Series, University of Maryland Extension. http://extension.umd.edu/sites/extension.umd.edu/files/_docs/articles/TimelyVitUnderstandingGrapevineBudDamage.pdf

Hatch, Tremain. 2015. A demonstration of head training/cane pruning to cordon training/spur pruning on Cabernet Sauvignon. Virginia Vineyards Association Winter Technical Conference, Charlottesville, VA, January 2015.

Hellman, E. 2015. Frost injury, frost avoidance, and frost protection in the vineyard. eXtension online article, Sep. 6, 2015. http://articles.extension.org/pages/31768/frost-injury-frost-avoidance-and-frost-protection-in-the-vineyard

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

Krewer, G.W. 2006. Home Garden Bunch Grapes. University of Georgia Extension Bulletin 807. http://extension.uga.edu/publications/detail.html?number=B807

Lindow, S.E., D.C. Arny, and C.D. Upper. 1978. Distribution of ice-nucleation-active bacteria on plants in nature. App. Env. Microbiology 36:831-838.

Perry, K.B., A. R. Bonanno, and D.W. Monks. 1992. Two putative cryoprotectants do not provide frost and freeze protection in tomato and pepper. HortScience 27:26-27.

Poling, E.B. (ed.) 2006. The North Carolina Winegrape Grower's Guide. North Carolina State University Publication AG-535. North Carolina State University, Raleigh, NC.

Poling, E.B. 2007. Overview of Active Frost, Frost/Freee and Freeze Protection Methods. *In* Proceedings from Understanding and Preventing Freeze Damage in Vineyards. R.K. Striegler et al. (organizing committee) pp. 47-64. University of Missouri, Columbia, MO.

Schilder, A. 2010. Disease control after freeze injury in grapes: what are the options?. Michigan State University Extension online article, May 25, 2010. http://msue.anr.msu.edu/news/disease_control_after_spring_freeze_injury_in_grapes_what_are_the_options

Smith E., T. Coolong, and P. Knox. 2017. Commercial freeze protection for fruits and vegetables. University of Georgia Extension Bulletin 1479. http://extension.uga.edu/publications/detail.html?number=B1479

Striegler, R.K. 2007. Passive Freeze Prevention Methods. *In* Proceedings from Understanding and Preventing Freeze Damage in Vineyards. R.K. Striegler et al. (organizing committee) pp. 39-46. University of Missouri, Columbia, MO.

Striegler, R.K., A. Allen, E. Bergmeier, and H. Caple (organizing committee). 2007. Understanding and Preventing Freeze Damage in Vineyards Workshop Proceedings. 108 pp. University of Missouri, Columbia, MO.

Sugar, D., R. Gold, P. Lombard, and A. Gardea. 2003. Strategies for frost protection. *In* Oregon Viticulture. E.W. Hellman (Ed.) Oregon State University Press. Corvallis, Oregon.

Taylor, K.C. 2012. Peach Orchard establishment and young tree care. University of Georgia Extension Circular 877. http://extension.uga.edu/publications/detail.html?number=C877

Zabadal, T.J., M.L. Chien, I.E. Dami, M.C. Goffinet, and T.M. Martinson. 2007. Winter injury to grapevines and methods of protection. Michigan State University Extension Bulletin E2930, 106 pp. http://www.emdc.msue.msu.edu/product/winter-injury-to-grapevines-and-methods-of-protection-685.cfm