Prevention and Management of Frost Injury in Wine Grapes

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Summary:

Late spring frost events can cause severe injury to grapevines, often leading to the loss of fruitful buds and subsequent decreased yield and fruit quality. Severe frost injury has the potential to destroy a whole vintage. In areas such as the Southeast, in which spring frosts are common, both passive and active frost control techniques are essential to maintain the longevity and economic sustainability of a vineyard. However, while active control techniques such as wind machines and sprinkler systems can save a crop during a frost event, implementing those methods is costly and technically challenging. Here we discuss recommended methods of prevention and frost protection, management and implication of frost injury in grape vines. Please refer to the North Carolina Winegrape Grower's Guide, Chapter 11 for a broader discussion of spring frost control measures.

1. Introduction:

Late spring frosts are common in the southeastern US, capable of costing several million dollars (Poling, 2008; Zabadal et al., 2007). In contrast to many other high value crops, frost protection methods for wine grapes are less frequent deployed, due to high cost and management challenges. However, the damage that can occur as a result of severe frost events can be devastating. Large investments such as the purchase of wind machines are economically sustainable if frequent frosts (every 5-6 years) occur (Poling, 2008). For example, after two frost events in late April and one in mid-May of 2020, more than 70% of North Carolina wine grape vineyards suffered significant crop loss, with some losing close to all fruit for the year. Such losses are devastating if experienced frequently. An integrated approach of preventative measures, management and pruning can help to mitigate short- and long-term implications of late spring frost damage.

Table 1. Classification of cold events

Cold Event	Wind Speed	Air Temp (°F)	Cause
Frost	Below 5 mph	32 and below	Caused by rapid radiational loss of heat
Frost/Freeze	Below 10 mph	32 and below	Caused by a combination of rapid radiational heat loss and persistent winds (in the range of 5-10 mph)
Freeze	Above 10 mph	Below 32	Also called wind-borne or advective freeze with winds above 10 mph

It is crucial to understand the differences among cold events that can occur in spring. Frost events are caused by radiation, while freeze events are caused by moving air masses, cooling surfaces (advection). Generally, cold events can be characterized into three different categories (Table 1): Frost events, frost/freeze events and freeze events. Frost events are by far the most common during spring in the Southeast, characterized by clear nights and low wind speeds (< 5mph). Hoar frosts are accountable for over 90% of all frost events in the Southeast, indicated often by water crystals forming on surfaces. Another common frost type is black frost that occurs on days with low humidity and, therefore, is missing the typical ice crystals. Frost generally occurs when the temperature of a surface is equal to or lower than a dew point of 32 °F. This is often the case on clear, cloudless cooler nights that promote radiation (Poling, 2008; Centinari, 2018; Fiola, 2020). Radiation occurs when warmer temperatures during daylight hours heats up plants and the soil. Cloud-free skies and cooler temperatures at night cause heat to reradiate from surfaces. Frost then can build up on plant surfaces (shoots, buds), causing injury through dehydration and physical damage. Clear nights with minimum air temperatures of 40 °F or lower, and dew-points of 32°F or lower, are at high risk for frost. While the National Weather Service might issue a frost warning at temperatures above 32 °F, that does not mean that a radiation frost will occur and damage a specific vineyard.

Frost/freeze events are typically longer in duration (longer than 10h), caused by a mix of radiation and persistent winds. Crop protection is made very difficult by sustained winds of more than 5 mph.

Windborne (advective) freeze events are caused by moving air masses, bringing cold air from northern weather systems into the Southeast. While this happens frequently in winter, spring freeze events are rare. However, they can be very dangerous, last for several days and bring significantly colder temperatures at a time when the crop is most vulnerable. One of the most memorable spring freeze events was the April freeze of 2007, when 5 days of freezing weather had a significant impact on farming all across the East Coast, including Florida (Poling, 2008). On grapevines, windborne freezes may not just cause the loss of buds and shoots, but they may also lead to damage on trunks and cordons. Vines suffering severe cold injury can either die, or if they survive, often show deep cracks in the permanent wood structure and have to be removed later in the year.

In this article, we mainly will talk about prevention and management of spring frost events in established vineyards. Most of the mentioned mitigation and prevention measures will not help in the case of windborne freezes. The prevention of frost injury in an established vineyard can be partly achieved through the use of active measures such as vineyard wind machines or sprinkler systems, and passive measures such as delayed pruning. *However, the best practice to avoid frost and cold damage in a vineyard begins before planting, with the selection of the correct site, suitable cultivars and the best training systems.*

2. Preventing Spring Frost Damage during Vineyard Establishment

While this article focuses on the prevention and management of frost injury in established vineyards, the **best prevention is to select a proper field site and the correct cultivars.**

The choice of vineyard site and cultivar has a large impact on the occurrence of frost injury. Sites that frequently show frost on grass, vegetation or other structures should be avoided, as they usually also do not show very good airflow (Figure 1). Vineyards located at higher elevations, relative to surrounding topography, will be affected by fewer radiational frosts. In addition, the better air movement in higher elevation vineyards helps to lessen disease pressure. Vineyard floor management programs comprised of a vegetation-free strip under the vines, along with close mowing of vegetation between rows and around the perimeter of the vineyard may provide a slight increase in air temperatures within the vineyard as compared to tall, un-mowed vegetation or freshly cultivated soil. Promoting good air drainage out of the vineyard by limiting or removing any possible obstructions to air flow below the vineyard will likewise help to limit frost damage.

Early bud breaking cultivars should also be avoided. However, market demands often determine the choice of cultivars, with the early breaking 'Chardonnay' and 'Merlot' on the top of the consumers list. We highly recommend double pruning or delayed pruning techniques (see below) on those cultivars.

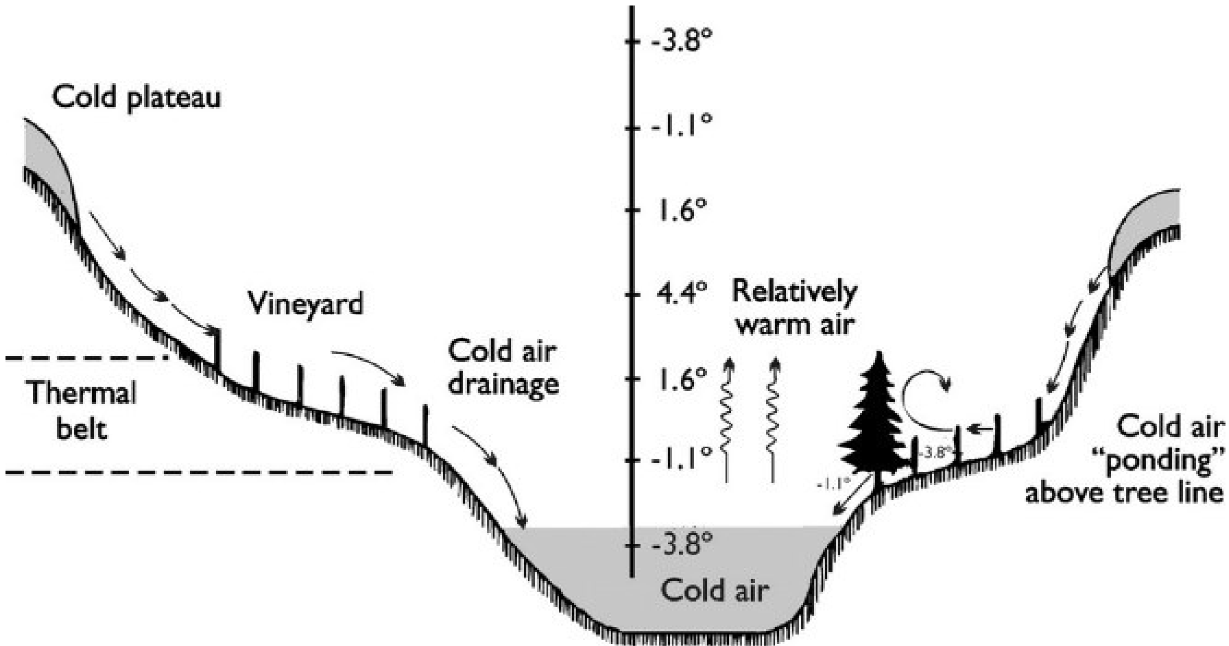

Figure 1: Effect of vineyard site and topography on air flow (Poling, 2008).

3. Prevention Frost Injury in Established Vineyards

a) Wind Machines

Figure 2: A stationary wind machine in North Carolina. (Photo: Eric Case)

Vineyard or orchard wind machines may be effective tools to prevent or minimize frost injury during radiant frost events. Wind machines work on the principle that during night warm air will be radiated into higher air layers and 'trapped', preferably in 15-75 ft height. This weather condition is called inversion and is fairly common during spring frost events. The height of the inversion layer is referred to as the ceiling and the difference in temperatures at ground level versus the ceiling is called the strength of the inversion. Wind machines mix the warmer air below the ceiling with the colder air near the ground and by removing the coldest air close to leaves and replacing it with warmer ambient air. The amount of protection achieved is dependent on the strength of the inversion. The use of a wind machine during a frost/freeze or an advective freeze should be avoided. Usually wind speeds of 5 mph or more will disturb inversions and make wind machines less effective. The operation of a wind machine also depends on the microclimate in your vineyard, the terrain, reliable weather data and good weather predictions. A machine can cover as much as 10 acres of vineyard, depending on the terrain and vineyard layout. In the best-case scenario, a wind machine should be planned as integral part of vineyard establishment.
A weather station should be installed in the vineyard and online agricultural weather services (e.g. AWIS weather services) should consulted frequently to better predict the use of wind machines. Wind machines can be either portable or permanently installed (Figure 2), and should not be confused wind turbines, that are used to generate electricity. Wind machines have tall fans that are driven by propane, gasoline or electric engines. The cost of a wind machine can easily exceed $25,000. However, if frost injury frequently leads to loss of yield, the installation of a wind machine is a sustainable investment. The operation of a wind machine creates a lot of

noise, and is very loud. We highly recommend talking to your neighbors before purchasing and installing a wind machine.

b) Overhead Sprinkler Systems

Frost protection with overhead sprinklers requires maintaining a continuous water/ice interface, and an undisturbed tissue/ice connection. To achieve this, water needs to be supplied constantly from dusk until temperatures are high enough for the ice to thaw (Figure 3). This will build up a layer of ice over the tissue. Constant application of water will keep the ice temperature around 31-32 °F, slightly above critical levels for damage to buds and shoots.

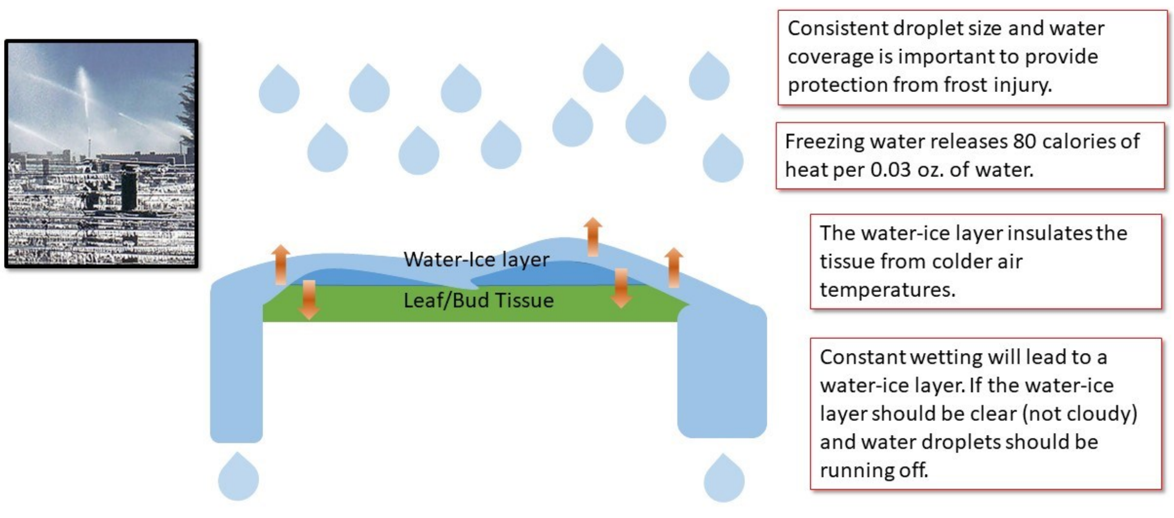

Figure 2: Protecting leaf and bud tissue from frost injury, using sprinkler systems, requires consistent droplet size and coverage. The water-ice layer on top of the tissue should always be clear (not cloudy or white), and you should see water droplets running of the sides.

Vineyard overhead sprinkler systems require large water sources, high capacity pumps, reliable operation under cold temperatures, fast sprinkler head rotation times and high uniformity in droplet size and distribution patterns. (Table 2).

The choice of equipment is therefore highly important. Sprinklers with rotation times of a minimum rotation time of 30 seconds are recommended to be installed in a vineyard. Conventional or hybrid impact sprinklers with a mechanical braking system are recommended to handle differences in water pressure. If sprinkler systems use silicone, they might slow down in colder temperatures. Water needs to be distributed uniformly, and droplet size should be consistent over the area that is covered. Less uniformity or differences in droplet size can lead to areas in which plant tissue is not covered sufficiently, leading to subsequent cold injury. Hybrid impact sprinklers with an integrated nozzle and deflector design are recommended to achieve higher uniformity. Systems having nozzles that are easy to assemble and/or replace are highly recommended. The frost protection success of a sprinkler system relies on the frequent and uniform distribution of water throughout the night (Figure 2).

Table 2: Recommendation for overhead sprinkler systems (according to RainBird, 2011)

Requirement	Description
Rotation time < 30 sec	Mechanical spring/arm; water pressure flexible brake system
Uniformity in distribution and droplet size	Hybrid-systems designed to produce consistent coverage and droplets
Freeze tolerant	Spring and arm shielded from ice buildup
Low maintenance	Tool free replacement of sprinkler system. ACME threads need fewer turns.

Overhead sprinkler systems only can be used during low-wind speeds. We recommend installation of sprinkler systems in blocks with early bud-breaking cultivars. It is critical to have a water supply large enough to allow continuous irrigation over several hours and possibly for more than one night back-to-back. If pulling water from a stream, consider the stream flow during periods when frost control might be needed. If pulling from a pond, consider pond size and the recharge capacity of the pond. Sprinkler systems can cause flooding and saturated conditions on not well drained soils, leading to problems with disease and die-back later in the season. Overhead sprinkler systems for frost protection are recommended only if the water supply is adequate and soils have good internal and surface water drainage characteristics.

c) Delayed pruning

Delayed pruning and double pruning are widely used passive methods to delay bud break and ‘trick’ late spring frosts on spur-pruning systems. With double pruning, one-year old wood of early bud breaking cultivars trained on a bi-lateral cordon system (such as a Vertical Shoot

Positioning or a high-wire cordon system) can be mechanically pre-pruned at the catch wire, leaving about 8-12 buds per shoot. After removal of the wood, the vines will remain like this until bud-break. Cutting to fewer than 7 nodes above the desired points for bud break ~~could~~ may not result in adequate delay in the time of bud break. A final pruning to the desired number of spurs and buds per vine will then be performed manually in early spring, usually at growth stage EL4-5. The apical buds on the pre-pruned one-year old wood will break first, and in case of a late spring frost, will be 'sacrificed' for the still dormant basal buds, which will be retained after the final manual pruning step.

With delayed pruning, no pruning is done until bud break, at which time, selected shoots and cut back to the desired bud count and unneeded shoots are removed entirely. As a result, bud break may be set back up to two-three weeks as compared to shoots pruned earlier. If the final manual pruning step with either delayed pruning or double pruning is not done until a later growth stage, crop load reduction and/or delayed fruit maturation may result (Hickey & Hatch 2019).

d) Other Methods of Frost Protection:

There are several other active measures of frost prevention, including the use of helicopters to move air from the inversion zone into the vineyard, the use of hot stones or heaters to supply hot air in a vineyard, and the use of fans in lower elevation to move warmer air into the vineyard (Poling, 2008). The use of vineyard fires is only recommended if the users are fully aware of the risks. Vineyard fires are very work intensive and can cause severe damage to a vineyard if not maintained properly. All active frost protection measures rely on the presence of a temperature inversion. In the case of windborne freeze events, a vineyard almost is defenseless and the methods that are described are less effective, technically not workable or dangerous.

4. **Managing Spring Frost Damage:**

a) How to assess injury

Usually two types of tissue are likely to be injured during a spring frost event: buds and shoots. Damage to the permanent structure of the vine resulting from a spring frost event, while not common, can occur. However, injuries to trunk, head, cordon or spurs are more likely if cold sensitive cultivars are planted in locations that lack good airflow, or after a strong freeze event.

Assessing bud injury: The assessment of bud injury is very common in the Southeast and we recommend it as a routine practice in early bud breaking cultivars every year. This technique requires the sacrifice of 60-100 buds/acre/cultivar either before pruning or after a late spring frost to assess viability of primary and secondary buds. These assessments will either determine the pruning strategy (e.g. how many buds to retain on the final cut if delayed pruning was performed) or will help to assess potential damage and estimated crop load after a late spring frost. Please refer to section 6 'Resources' for more guidance on bud injury assessment.

Figure 3: Shoots affected by wilting and browning after a spring frost in 2020 (Photo: Eric Case)

Assessing shoot injury: Frost damage on shoot causes symptoms of browning and wilting. Frost damage may not be immediately noticeable on shoots and symptoms may appear more clearly after a few days (Figure 3). Young succulent shoots will wilt once the frost thaws, but older more hardened shoots will take a few days to show symptoms. Frost damage of shoots can greatly reduce yield, and lead to uneven ripening, depending on the severity of wilting. The management of shoot injury depends on the severity of the injury and the growth stage of the plant. For more information on shoot frost injury, please refer to the chapter 'Resources' below.

Assessing trunk injury: Trunk injury can occur without directly visible symptoms. Results are weak growth in the following seasons. Phloem tissue can be injured, but no splitting may have occurred. **Trunk/Cane splitting is a very severe cold injury and requires attention.** If trunk/cane splitting remains unattended, crown gall and grapevine trunk disease are often the result, leading to expensive losses and decay in subsequent years.

b) Managing frost injury

After frost injury has occurred, no action may be the best management option. Some grape cultivars, especially French-American hybrids, may have fruitful secondary buds which will be able to produce 40-70% of a full crop. Trying to maximizing crop loads after cold injury may lead to less crop the coming year, depending on severity and type of damage.

No action:

- In the case of bud damage after the final pruning, no action is still be best action to take.
- If **incomplete kill of shoots occurs,** no action might be the best approach. Once the vines reach a certain stage (E-L 15, see the E-L scale), taking no action is the best approach. However, no actions means: **There is increased risk of disease due to the dead material retained.**

Removal:

- Before E-L 12, buds can be rubbed off to force the growth of secondary buds. However, it is unclear of this will have an advantage over no action.
- ***Moderate shoot injury****:* Cutting the tops off the green shoots stimulates bursting of secondary buds lower down. However, this is not recommended: extra lateral growth that can be an issue, and late ripening, secondary crop can cause issues at harvest.
- ***Severe shoot injury:*** Removing all shoots back to the cordon may be considered **if E-L 12** or lower and if higher quality pruning material for next season is desired. This action will force dormant buds to break. ***Yields in this season will be* less *than no action!*** The later the shoot removal is conducted, the greater the reduction in bud fruitfulness for the following season.

- If visible damage, trunks/canes need to be removed. They can be removed at the end of season, depending on overall health of trunk. Keeping injured trunks and canes in the vineyard over several seasons will cause large problems with crown gall and trunk diseases.

5. Conclusions:

Late spring frosts are a challenge for Southeastern viticulture. Injury caused by such frost events can lead to uneven ripening and yield loss. However, several methods are available to prevent and manage late spring frost damages, many of which are expensive and/or labor intensive. . A grower must consider a number of economic as well as practical considerations when deciding whether to invest in an active cold protection system or method, and difficult tradeoffs are generally involved. However, those methods are the only tools currently available to mitigate frost damage in vineyards and should be deployed in locations with higher risks for late spring frosts.

6. **Resources:**

North Carolina Winegrowers Guide: Spring Frost Control

Assessment of bud damage:

- NCSU Presentation (pdf)
- Youtube video
- Web-resource University of Maryland
- Fact Sheet (Cornell)

Assessment of shoot damage and frost protection:

Dami, I. 2014: Guide to Assess Freeze Damage in Grapevines in Early Summer; Ohio State University

Hellman, 2019: Frost Injury, Frost Avoidance and Frost Protection in the Vineyard; Texas A&M.

Jones et al. 2010: Effect of frost damage and pruning on current crop and return crop of Pinot Noir; New Zealand Journal of Crop and Horticultural Sciences 38(3): 209-216.

Ontario Grape IPM: Frost in Grapevines.

Striegler et al. 2012: Understanding and Preventing Freeze Damage in Vineyards;

Walton et al. 2009: Grapevine Growth Distortions; Oregon State University (pdf).

7. **Literature:**

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