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 subsequently decreased yield and fruit quality. Severe frost injury is capable to destroy a whole vintage. In areas such as the Southeast, in which spring frosts are common, tools to prevent frost injury are essential to maintain the longevity and economic sustainability of a vineyard. However, while wind machines and sprinkler systems can save a crop during a frost event, implementing those methods is costly and technically challenging. Here we discuss possible methods of prevention and frost protection, management and implication of frost injury in grape vines.

1. Introduction:

Late spring frosts are common in the southeastern US, capable costing several million dollars (Poling, 2008; Zabadal et al., 2007). However, in contrast to many other high value crops, frost protection methods for wine grapes are rarely deployed, due to high cost and management challenges. However, the damage than can occur after severe frost events can be devastating, making large investments for frost protection methods more attractive on the long run. 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.

It is crucial to understand the differences between 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 events 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 that are forming on surfaces. Another common frost type is black frost, that occurs on days with low humidity, missing the typical ice crystals. Frost generally occurs, when the temperature of a surface is equal or lower of a dew point of 32F. This is often the case on clear, cloudless cooler nights that promote radiation (Poling, 2008; Centinari, 2018; Fiola, 2020). Radiation occurs when warmer temperature over day is heating up plants and soil, but cloud free skies and cooler temperatures at night cause heat to radiate off from surfaces. Frost then can build up on plant surfaces (shoots, buds), causing injury

Table 1. Classification of cold events

Cold Event	Wind Speed	Temp (F)	Cause
Frost	Below 5 mph	> 32	Radiation
Frost/Freeze	Below 10 mph	32	Mix of radiation and weather event
Freeze	Above 10 mph	Below 32	Weather event (cold front, wind shifts etc.)

through dehydration and physical damage. Especially clear nights with minimum air temperatures of 40 F or lower, and dew-points of 32 F or lower, are high risk night for frost.
Frost/Freeze events are a short-lasting mix of radiation and weather events, often characterized by lower air temperatures (around freezing) and higher wind speeds. Pure 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 years and bring significantly colder temperatures at a time when the crop is most vulnerable. One of the most memorable spring freeze events as the April Freeze of 2007, when nearly 5 days of freezing weather had a significant impact on farming all across the East Coast, including Florida (Poling, 2008). On grapevines, freezes cannot just cause the loss of buds and shoots, they also can lead to damage on trunk and cordon structure. Vines that are affected by severe physical damage 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. Most of the mentioned mitigation and prevention measures will not help in the rare case of a freeze. However, the prevention of frost injury in a vineyard can be partly achieved through the use of active measures such as vineyard wind machines, sprinkler systems or vineyard fires, and passive measures such as delayed pruning.

2. Preventing Spring Frost Damage

We will cover four different methods of preventing frost damage, all are deployed in some extend in Southeastern vineyards. Active frost protection methods such as wind machines, sprinkler systems or vineyard fires are expensive, while the passive frost protection method of delayed pruning is cheaper, but less effective.

a) Wind Machines

Figure 1: A stationary wind machine in North Carolina. (Photo: Eric Case)

Vineyard or orchard wind machines are 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 15-75ft height. This weather condition is called inversion and is fairly common during spring frost events. Wind machines then pull warmer air from above the vineyard into the lower air layers, effectively pushing colder air out of the vineyard, and therefore preventing frost. Wind machines protect

only during temperature inversions, which require low wind speeds and warm air layers in 15-75ft heights. The use of a wind machine during frost/freeze events or during less stable inversions might increase the amount of cold air and therefore damage in the vineyard and 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 (such as AWIS weather services) should consulted frequently to better predict the use of wind machines. Wind machines can be either portable or permanently installed (Figure 1), 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 can create quite some noise, and we recommend to talk to your neighbors before purchasing and installing a wind machine.

b) Overhead Sprinkler Systems
Frost protection with overhead sprinklers requires 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 2). This will build up a layer of ice over the tissue. The constantly applied water will keep the ice temperature around 31-32 F, keeping bud and shoot temperature slightly above that.
Vineyard overhead sprinkler systems require a large water source, pumps, reliable operation conditions under cold temperatures, fast rotation times and high uniformity (Table 2).

Figure 2: Frost protection with sprinkler systems in a vineyard (Photo: Darryl Kirby, Frosty morning in the vineyard. | A relic from archived file… | Flickr. CC 2.0)

The choice of equipment is therefore highly important. Sprinklers with rotation times of less than 30 seconds are recommended to be installed in a vineyard. Conventional or hybrid impact sprinklers with a mechanical braking system are recommended to handle difference 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 uniformly 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 that are easy to assemble nozzles that are easy to replace are highly recommended. The frost protection success of a sprinkler system relies on the frequent and uniform distribution of water throughout the night.

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 threats need fewer turns.

Overhead sprinkler systems only can be used during low-wind speeds. We recommend to install sprinkler systems in blocks with early bud-breaking cultivars.

c) Preventative Vineyards Fires
Controlled fires for frost protection are used especially to protect vines from radiation frost injury. Frost protection fires work best with a strong temperature inversion. The smoke generated by 'smudge pots', wood piles (Figure 3) or candles will keep the heat that is radiated from the vineyard as well as the heat generated by the fires in the lower air layer, effectively keeping the temperature in the vineyard above 32F.
Vineyard fires need to be started at dawn and need to keep burning throughout the night. We recommend to use a fire every 15-20 feet in every other row (Figure 3).
Vineyard fires are labor intensive to install and maintain. Smudge pots need to be frequently refilled, which requires a reservoir of enough fuel (diesel). We recommend to have candles/wood/smudge pots as well as fuel tank and canisters ready and stored close to the vineyard. However, compared to sprinkler systems and wind machines, controlled vineyard fires are a cost effective method, recommended in areas that experience spring frosts not very frequent.

Figure 3: Wood to be burned in a vineyard in Germany to protect from frost (Photo: Jutta M. Jenning, Weinberg - Vineyard | Wegen Kälte und Frost schützen die Win… | Flickr, CC 2.0)

d) Delayed pruning
Delayed pruning is a widely used method to delay bud break and 'trick' late spring frosts. It is sometimes also referred to as 'double pruning'. Especially one-year old wood of early bud breaking cultivars that are trained on a bi-lateral cordon system (such as a Vertical Shoot Positioning) can be mechanically pre-pruned at the catch wire. Such a cut usually leaves about 8-12 buds per shoot. After removal of the wood, the vines will remain like this until bud-break. A final prune to the desired number of spurs and buds per vine will then be performed manually in early spring. 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.
Delayed pruning can be useful to delay bud break up to two-three weeks. However, if the final manual pruning step is delayed, this pruning method has the potential to reduce crop load and/or lead to delayed fruit maturation (Hickey & Hatch 2019).

e) Other Methods of Frost Protection:
The choice of vineyard site and cultivar has a large impact on the occurrence of frost injury in a vineyard. Sites that frequently show frost on grass, vegetation or other structures should be avoided. Those sites usually also don't show very good airflow (Figure 4). Early bud breaking cultivars should also be avoided. However, market demands often determine the choice of cultivars, with the early braking 'Chardonnay' and 'Merlot' on the top of the consumers list. We highly recommend double pruning techniques on those cultivars. There are several other active measures of frost prevention, that are rarely practiced in the Southeast: 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). All those measures as well as the above mentioned active prevention measures rely on the deployment of a temperature invasion. In the case of real spring freeze events, a vineyard almost is defenseless and the above mentioned methods are less effective or technically not workable.

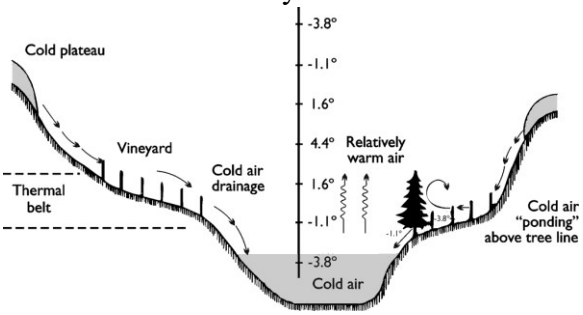

Figure 4: Effect of vineyard site and topography on air flow (Poling, 2008).

3. Managing Spring Frost Damage:

a) How to assess injury
Usually two types of tissue are likely to be injured after a spring frost event: buds and shoots. Very uncommon are damages to the permanent structure of the vine after a spring frost event. However, injuries to trunk, head, cordon or spurs are more common if cold sensitive cultivars are planted in locations that lack good airflow, or after a strong freeze event (Figure 4).

Assessing bud injury: The assessment of bud injury is very common in the Southeast and we recommend this method as a routine in

early bud breaking cultivars every year. 60-100 buds/acre/cultivar will be sacrificed either before pruning or after a late spring frost to assess viability of primary and secondary bud. 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 the chapter 'References' for more guidance on bud injury assessment.

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 5). For more images of shoot frost injury, please visit the Ontario GrapeIPM website. Young succulent shoots will wilt once the frost thaws, but older more hardened shoots will take a few days to show symptoms.

Figure 5: Shoots affected by wilting and browning after a spring frost in 2020 (Photo: Eric Case)

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 (see below).

Assessing trunk injury: Trunk injury can occur without directly visible symptoms. Results are weak growth in the following seasons. Phloem can be injured, but no splitting may have occurred. Please see this article. **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, sometime no action is the best management option. Most grape cultivars have fruitful secondary buds which will produce 50-70% 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 damage of buds after 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.

4. **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. 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.

5. Resources:

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).

6. Literature:

- Centinari, M. 2018. Understanding and Preventing Spring Frost and Freeze Damage to Grapes. Extension Bul. ART-5334. Pennsylvania State University.
- Fiola, J.A. 2020. Grapevine Frost/Freeze Damage I: Background and Prevention. Extension Bul. 05042020, Univ. of Maryland. https://extension.umd.edu/sites/extension.umd.edu/files/_docs/articles/GrapeFrostFreezeDamageIBackgroundPrevention_05042020_0.pdf
- Hickey, C. and Tremain, H. 2019. Dormant Spur and Cane Pruning Bunch Grapevines. Extension Bul. 1505. University of Georgia.
- Poling, B. 2008. Spring Cold Injury in Winegrapes and Protection Strategies and Methods. HortScience 43(6):1652-1662. https://journals.ashs.org/hortsci/view/journals/hortsci/43/6/article-p1652.xml
- Rain Bird 2011. Vineyard Frost Protection – 3 key requirements for effective protection with overhead sprinklers. https://www.rainbird.com/sites/default/files/media/documents/2018-01/wp_VineyardFrostProtection.pdf
- Zabadal, T.J., Dami, I.E., Goffinet, M.C., Martinson, T.E. & Chein, M. K., 2007. Winter Injury to grapevines and methods of protection. Ext. Bul. E2980, Michigan State University.