When early spring warming is followed by below freezing temperatures, grape growers keep their fingers crossed hoping to escape freeze injury.

In this article, we will review some basic concepts related to post-budbreak freeze injury and frost protection options available for grape growers.

Freeze and Frost

We often use the terms “frost” and “freeze” interchangeably to describe a meteorological event, specifically related to air temperature dropping below 32°F (0 °C). However, “frost” and “freeze” definitions reported in the literature are variable and sometimes confusing. I like the definitions used in the book: Frost protection: Fundamentals, practice, and economics [Food and Agriculture Organization of the United Nations (FAO), 2005; 1]. In this book frost is defined as “the occurrence of an air temperature of 0°C or lower, measured at a height of between 1.25 (49.2 in) and 2.0 m (78.7 in) above soil level, inside an appropriate weather shelter”, while freeze “occurs when water within the plant freezes”.

In other words, a frost becomes a freeze event if ice forms within the plant tissues.

Keep in mind:

- It is the ice formation inside the plant tissue rather than low temperatures per se that cause the damage.
- The formation of ice crystals can be either inter-cellular (space between cells) or intra-cellular (within the protoplasm of cells), the latest causing cell death [1] (Figure 1). The general hypothesis is that during spring frosts, freeze injury is mainly caused by inter-cellular rather than intra-cellular ice formation [1, 2]. The formation of inter-cellular ice crystals produces a water vapor deficit/gradient between the interior and the exterior of the cells. As a result, water migrates from the inside to the outside of the cells and deposits on the ice crystals formed in the inter-cellular spaces. If ice continues to grow, the cells become more desiccated and lose their turgor [3]. Freezing-induced dehydration can also permanently damage the structure of cell membranes and other cellular components. This usually causes flaccidity and/or discoloration of the damaged tissue [4]. Thus, the current view is that dehydration injury is the main cause of frost damage. [2].

Figure 1. Ice formation in the extra-cellular space. Image Source
Water within plants doesn’t always freeze during a frost event. Plants have developed avoidance strategies to avoid ice formation in the tissues, for example, by supercooling, and tolerance strategies (e.g., the solute content of the cells) to survive inter-cellular ice formation without irreversible damage of the plant tissue [1].

**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” [5]. Many factors affect the temperature at which damage occurs including the type of plant tissue, stage of phenological development of the bud/shoot, dew point and surface moisture, a probability of an ice nucleation event, and pre-frost environmental conditions [6].

**Why is budbreak considered the onset of the most susceptible period for cold injury?**

Growing organs have a high water content, which makes them susceptible to the formation of ice at freezing temperatures. Air temperature of –2, –3°C can permanently damage green tissues [6]. Early spring growth is particularly susceptible to freeze injury. Freezing tolerance remains low during the most of the growing season and gradually increases late summer and fall (cold acclimation) and reaches its maximum peak in midwinter [6]. In midwinter, grapevines are able to tolerate freezing temperature through a complex process called deep supercooling. For example, the cells within the dormant bud become resistant to lower temperature through dehydration (i.e., movement of water to inter-cellular spaces) and accumulation of so-called cryoprotectant (e.g., soluble sugars and proteins). Those compounds lower the freezing point of the water within the plant tissue and stabilize cell membranes [6] making the dormant buds able to survive temperatures well below freezing. Also, during the dormant season buds are thought to be disconnected or weakly connected to the vine’s vascular tissues, which limit their potential to take up water [7].

**There are two main types of frosts**

**Adventive frost**

An adventive frost is usually a regional weather event. It occurs when strong, cold winds (colder than the critical temperature) blow into a region day and/or night. The rapid, cold air movement “steals away the heat in the plant causing freeze damage” [5]. Unfortunately, there is very little which can be done to protect against an adventive frost. For example, wind machines are useless during an adventive frost event.

**Radiation or radiative frost**

A radiation frost is the most common type of frost for many grape growing regions. Luckily, a radiation frost is also the easiest to protect against during a frost event. It occurs when a dry, cold air mass moves into an area when there is almost no cloud cover and no wind at night. Because plants and soil are warmer than the sky temperatures, they will “radiate” heat back to their surrounding space and become progressively colder than the air [5].

Radiative and advective frosts may occur simultaneously; the classification depends on which is one is dominant (Table 1).

<table>
<thead>
<tr>
<th>Frost Type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation</td>
<td>Clear; calm; inversion; temperature greater than 0°C during day</td>
</tr>
<tr>
<td>Advection</td>
<td>Windy; no inversion; temperature can be less than 0°C during day</td>
</tr>
</tbody>
</table>

Table 1. Frost event terminology and typical characteristics [source FAO, 2005; 1]

**Options available to protect your vines from freeze injury**

**Passive or indirect methods (risk minimization)**

Passive methods are avoidance strategies, efforts to reduce the probability and risk of freeze damage.

**Site selection**

You have probably already heard this, but it cannot be said too many times: “The best time to protect your vineyard from frost injury is before it is planted” [5]. Cold air flows downhill, so mid-slope locations are warmer if there are no obstacles to cold air flow [8] (Figure2). Thus, when evaluating potential sites for establishing your vineyard, look for a site with good air drainage. Get historic records of low temperatures, number of frost-free days, and accurate information on percent slope, aspect or exposure, and elevation. You can contact your local county Extension office for information about site suitability for a vineyard.
Cultivar selection

Grapevine cultivars may vary in the average day of budbreak by up to two weeks [8]. To avoid or reduce the risk of freeze injury plant cultivars with early budbreak in the location within the vineyard with the lowest risk of frost.

Training system choice

Many factors related to fruit quality and economics influence the choice of a training system. With regard to the risk of freeze damage, a training system which places the buds high on the trellis may reduce frost hazard (Figure 3). Frost hazard is reduced by up to 0.36 °C each 10 cm (3.94 in) above the soil level [9].

Delaying budbreak by chemical means

Application of vegetable-based oils (e.g., Amigo oil) at nontoxic rates can slow bud de-acclimation and delay grapevine budbreak anywhere from 2 to 20 days depending on several factors including variety, number of applications and coverage [10,11]. Those oils are called “dormant oils” because they need to be applied when the buds are dormant. If you are interested in trying Amigo oil or a similar type of oil in your vineyard, begin with a small selection of vines. Be sure to record phenology, crop yields, fruit composition (Brix, pH, TA) and quality (fruit aromas and flavors, etc.) data for un-sprayed and sprayed vines. In this way, you can assess the impact of oil application on delaying budbreak as well as potential secondary effects on production and fruit quality parameters.

Middle-row management

Mowing ground cover short will increase the warming of soil during the day and release slightly more heat during the night [12]. Tall cover crops and weeds may also hinder cold air drainage.
Active or direct frost protection methods (frost management)

Active or direct frost protection strategies are efforts to modify microclimate conditions in the vineyard and increase temperatures above injury levels. Some of the most common active frost protection methods are:

Wind machines (or fans)

Wind machines are well suited for radiational frosts because they use the inversion of air temperature that develops during this type of frost event. Wind machines pull down warmer air, from above the inversion layer, which may provide from 1 – 3°F of warming [3]. The minimum size vineyard recommended for a wind machine is around 7-10 acres. Wind machines may become profitable on sites where there is a 20% (1 in 5 years) or higher probability of spring frost damaging events [3]. It is worth mentioning that wind machines have been noted to produce a loud noise. Operating costs are higher than for over-vine sprinkling systems but considerably lower than the use of return-stack oil heaters and standard propane heaters [3].

Over-vine irrigation

Over-vine sprinkler systems have been successfully used for frost protection since the 1940s [5]. Sprinklers provide a constant amount of water covering the buds and shoots. As water freezes, it releases a small amount of heat, which increases the temperature of the plant tissue. The level of protection is proportional to the amount of water applied [5]. If properly used, this method is very effective in protecting grapevines from freeze injury. It is the only active method that doesn’t rely on inversion strength during a frost event [5]. However, on the other hand, keep in mind that it requires substantial water resources, is labor intensive and if the system fails during the night/frost event, it can cause more damage than otherwise applying no frost protecting strategy.

Heaters

Heating the vineyard for frost protection is a very old practice. In ancient Rome (at least 2000 years ago) growers used to burn piles of pruned wood and other waste to heat their vineyard during spring frost events [5]. Fossil-fueled heaters are rarely used these days because of the high cost of fuel and labor, low heating efficiency and contribution to air pollution. Unfortunately, there is not a perfect strategy which can provide complete frost protection in every situation. Quite often the combination of different methods is the best option.

If you are looking for detailed information about active frost protections strategies, please check:

- Understanding and Preventing Freeze Damage in Vineyards. 2007. Workshop Proceedings. The University of Missouri Extension.

Literature cited
