Assessing and Managing Cold Damage in Washington Vineyards

WASHINGTON STATE UNIVERSITY EXTENSION • EM042E

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By Michelle Moyer, Lynn Mills,
Gwen Hoheisel, and Markus Keller

Introduction

During the winter, grapevine varieties require some degree and duration of low temperature exposure in order to fulfill plant chilling requirements. Adequate chilling is critical to uniform and timely budbreak the following spring. However, in northern production areas, vines can be exposed to very low temperatures, or sudden drops in temperature that are outside of their range of adaptation. When temperatures fall below the level of vine cold hardiness, there can be damage to buds, canes, cordons, trunks, or roots, and even death of the vine. In addition to sudden temperature drops below cold hardiness thresholds, prolonged low temperature durations that are above these thresholds can often result in cold-related damage symptoms on the vine. The damage from this type of cold exposure is a result of tissue dehydration. For further detail regarding the definition and identification of grapevine terms used here, please see WSU publication EB2018E, entitled "Canopy Management for Pacific Northwest Vineyards."

Damage or death of buds has a variety of consequences. A dormant grape bud, called a compound bud, is actually comprised of three smaller buds, each of which represents a compressed shoot capable of growth (Fig. 1). The primary bud is the largest and contains the most preformed flower clusters. (Clusters on this year's vine were actually formed last year.) The secondary bud is less developed and may or may not contain flower clusters. The tertiary bud generally only contains a shoot. The secondary and tertiary buds usually only grow out if the primary and secondary buds have been damaged. Unfortunately, the primary bud is generally the first to die when exposed to cold, followed by the secondary and tertiary buds. Therefore, knowing the extent of primary bud damage is critical in determining pruning strategies and estimating crop potential for the upcoming growing season.

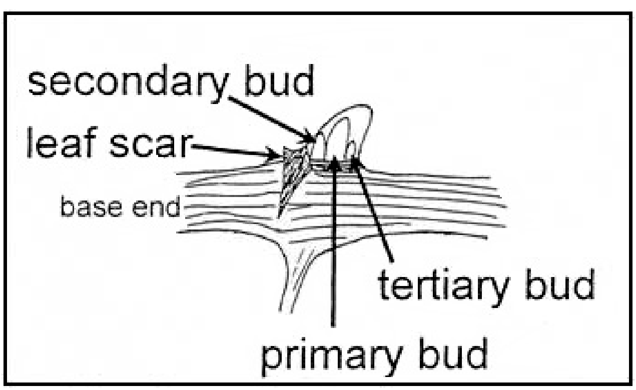

Figure 1. A visible grapevine bud is actually a composite, consisting of three internal buds as shown. The primary bud in Vitis vinifera *tends to be the most fruitful, followed by the secondary bud. The tertiary buds have a tendency to be vegetative (no clusters are produced). Drawing by Lynn Mills.*

Cold damage to canes and trunks occurs in the vascular tissue: the phloem and the xylem. The phloem is the nutrient-conducting tissue in the inner bark, whereas the xylem is the water-conducting tissue in the wood. Severe phloem damage may take time to repair, but research at WSU has demonstrated that vines can recover from phloem damage (Keller and Mills 2007). Xylem damage is more destructive. If severe or complete damage occurs in the xylem, vines cannot adequately transport water to the developing canopy, causing vine collapse with possible death. Damage specific to canes can result in stunted shoots or potential shoot collapse, depending on the extent of the damage. Damage to trunks can induce excessive suckering (shoots developing near the soil line), crown gall development, trunk splitting, or vine death. Trunk damage is common just above the soil line due to cold air pooling near the vineyard floor. This causes a girdling effect on the vine, which can then mimic water and nutrient deficiencies later in the season do to the restricted movement of sugar, water, and nutrients through the vascular tissue.

Initial Steps in Assessing Cold Damage in Vineyards

Vineyard assessment of cold damage can be a laborious process and an unnecessary one if cold damage has not occurred. Prior to making assessments, check local weather data and compare to WSU's grape cold hardiness data (available from http://wine.wsu.edu/extension/weather/cold-hardiness/)

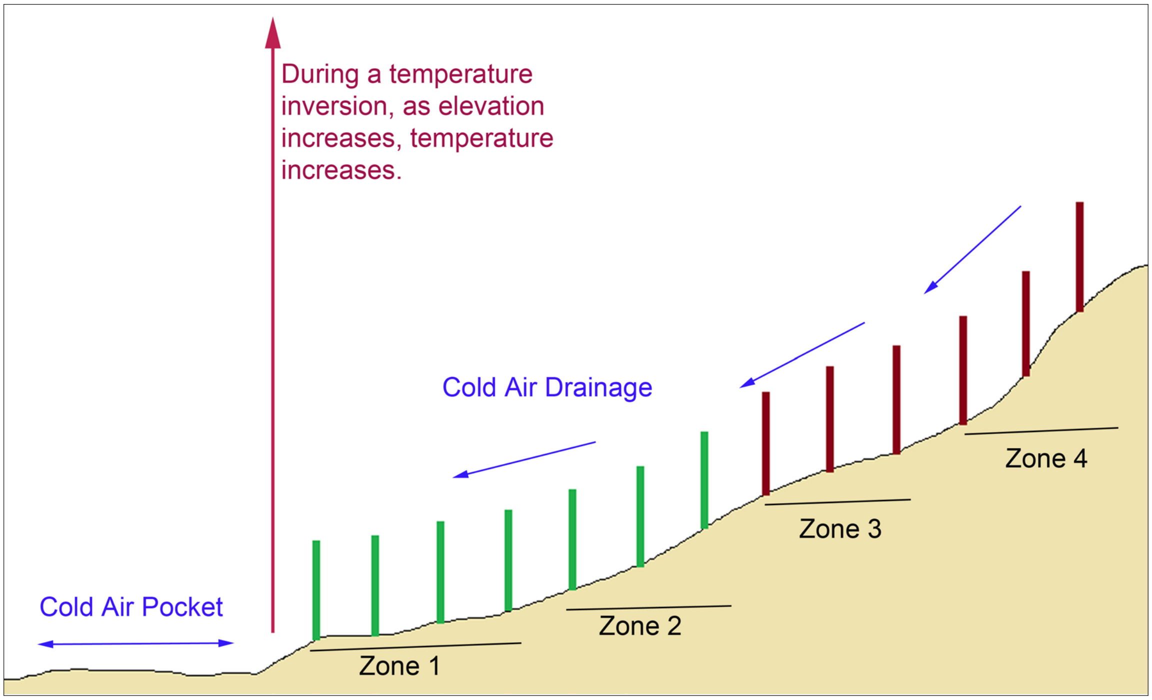

Figure 2. When selecting "zones" for cold damage assessment, consider varietal, climate, and topography differences of your vineyard blocks. In particular, choose zones within a block (delineated by vertical colored lines in the image) to represent the temperature gradients due to air drainage and elevation. As cold air sinks, it will drain to a low point. Temperature inversions (when the atmosphere is stable) do not allow this cold air pocket to readily dissipate.

to see if critical temperature thresholds for damage have occurred. If these thresholds have been met, then proceed with damage assessment.

To properly assess damage, divide the vineyard into zones based on grape varieties and landscape characteristics. Factors which should be used to determine a zone include different grape varieties, changes in elevation, structures inhibiting airflow (windbreaks, roads, and surrounding agriculture), general air drainage, soil variation, and vineyard size. Select zones that are representative of the potential different microclimates within a vineyard (Fig. 2). Once you have determined how to divide your vineyard, you can begin bud, cane, and trunk assessments as described below. This is one area where random sampling of your vineyard may not be the most appropriate and efficient means to assess cold damage. If you know that a given zone has a history of cold damage, focus assessment efforts there.

Assessment of Bud Damage

Allow at least 24 hours after a potentially damaging cold event before you sample any buds. After following bud collection methods described in the next few paragraphs, allow buds to warm up to room temperature (65°F or warmer) prior to doing bud assessments. This allows damaged tissues to brown. If buds are assessed too soon after a cold event, damaged tissue can resemble non-damaged tissue. As a general rule, begin by sampling 100 buds randomly throughout the entire zone. Removal of entire canes for sampling is also effective, as you are obtaining multiple cane internodes to assess phloem and xylem damage, in addition to multiple buds. Sampling along the entire length of a cane will also pinpoint where on that cane any damage has occurred.

If you notice high levels of variation in bud damage, you need to either sample another 100 buds or reassess how you are defining your zones. Continue this process until you have a fairly consistent assessment of bud damage per zone. If you are worried about removing too many buds, then cut the sample canes above the second or third node rather than at the base. The cold hardiness is usually similar in buds from the base of a cane out to at least node position 10 or beyond.

Assessing bud damage during dormancy is the most practical way to gain valuable information to guide subsequent pruning with respect to bud retention. As mentioned above (Fig. 1), there are three buds inside every compound grape bud, so assess them accordingly. Use a sharp razorblade to make three cuts perpendicular to the long axis of the compound bud (Fig. 3). What are the colors of the buds? Green

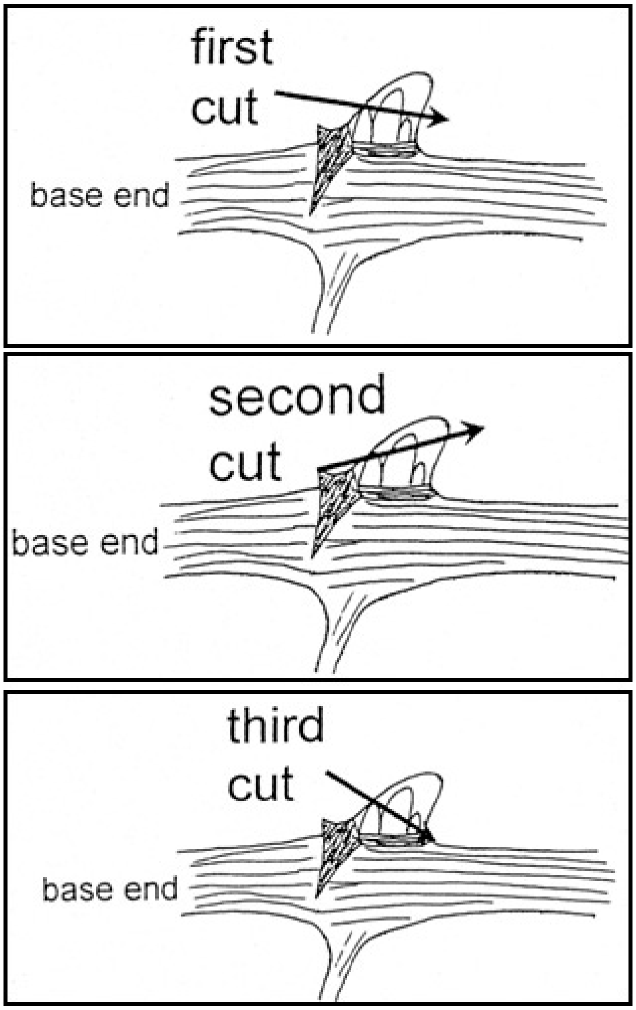

Figure 3. To accurately assess bud damage, primary, secondary, and tertiary buds should be visible. This is accomplished by making three consecutive cuts through the composite bud, as shown in this figure. The first cut exposes the primary bud, the second exposes the secondary bud, and the third exposes the tertiary bud. Note of caution: these cuts are very thin; cutting too deeply exposes the cane xylem. Drawing by Lynn Mills.

is a good indication that the bud is alive and healthy. Dark green-brown or brown indicates bud damage or death (Fig. 4). Be careful not to cut the bud too deeply; xylem tissue directly below the compound bud may be alive and viable (and therefore, green) when the individual buds are dead. Cutting too deep is a common mistake when doing bud assessments for the first time.

When assessing buds, count how many primary and secondary buds fall into the viable or damaged categories. Tertiary buds can be inspected, but are not fruiting so are generally ignored except as an indication of potential canopy recovery. It is also important to keep track of where on the cane you are assessing buds, and where you see damage. An example worksheet for buds and cane/trunk assessments is appended to this manual. During spur pruning, workers generally leave buds that are closer to the cordon, and remove buds higher on the cane. However, if all the buds close to the cordon are dead, and the only living buds are 5–10 nodes from the cordon, it is important to leave longer spurs/canes when pruning. If all the buds are dead near the ends of the canes, but alive near the cordon, you can leave shorter canes/spurs.

Assessment of Cane Damage

Cane and trunk phloem is sometimes more hardy than buds during early and late winter; however, it is typically less hardy than buds in midwinter. In many varieties the xylem is usually more hardy than either the buds or the phloem. In some varieties, however, the xylem tends to be somewhat less hardy than the buds in midwinter. To get a more complete picture of the damage level in a vineyard, an assessment of cane damage is also needed. Damage to tissue can be random and irregular throughout the cane. The key to properly quantifying cane damage is to assess different cane areas on a larger number of samples.

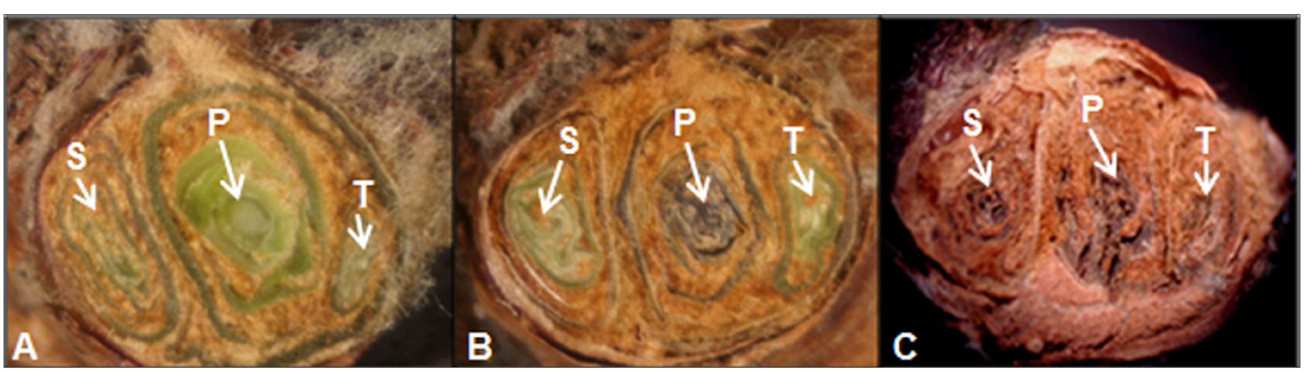

Figure 4. Cross sections of grapevine compound buds showing the location of primary (P), secondary (S), and tertiary (T) buds. A) All three buds are alive; B) P bud is dead, while S and T buds are alive; C) All three buds are dead. Photos by Lynn Mills.

Figure 5. A series of thin, longitudinal cuts along the cane exposes the phloem (P) and xylem (X). While there is some slight discoloration in the phloem (olive green), the xylem is healthy (bright green). Photo by Michelle Moyer.

Similar to buds, begin by sampling approximately 25 canes randomly throughout the zone; sample more if you notice near equal counts of dead and alive tissue area.

When assessing canes, look for damage to the phloem and xylem. To do this, make a series of thin longitudinal (parallel with the length of the cane) slices that reveal possible damage (Fig. 5). The first cut should expose the phloem by removing only the thin cork layer that forms the outer bark. An additional deeper cut will expose the xylem. If the tissue is healthy, it should be bright green. If there is cold damage, the color will range from dark brown-green to completely brown (also seen in trunk damage, Fig. 6).

Assessment of Trunk Damage

Trunk damage is the most difficult to assess. Like the cane, damage can be irregular in its location on the trunk and throughout the vineyard. Begin by selecting 20 vines within an area of the vineyard where vines are most likely to suffer the greatest damage. If there is no significant trunk damage at this location in the vineyard, it is unlikely that damage has occurred elsewhere, and further sampling is unnecessary. However, if approximately 50% of the trunks show damage at the "high-risk" location, additional trunk samples are needed to determine the extent of damage throughout other areas of the vineyard. The key to efficient and accurate assessments of trunk damage is to spread subsequent samples out across the vineyard and choose those parts of the trunk most likely to be damaged: near the soil line or within an area that

Figure 6. Trunk damage mimics cane damage. A) Dead phloem but healthy, green xylem is visible; B) Dead phloem and damaged (milky-white) xylem; C) Both the phloem and xylem are dead. Photos by Michelle Moyer.

was covered by grow tubes. Also, make note of whether there was measurable snow coverage and how long this snow coverage lasted, as this can have an insulating effect on trunks, protecting them from cold damage below the snow line. Conversely, light reflection from the snow surface can warm the southern side of trunks during sunny days, which can predispose trunks above the snow line to cold damage at night. (Peña Quiñones et al. 2019)

Assessment cuts should be carefully made in order to avoid girdling the vine. Make certain that any single cut on a trunk encompasses no more than one fourth of the vine circumference. As with cane assessments, make a series of thin longitudinal cuts to assess the color of the phloem and xylem (Fig. 6). Healthy tissue will be green. Damaged xylem will have a milky-white to brown hue, and damaged phloem tissue will be olive-green to brown.

Managing and Avoiding Cold Damage

Plant Cold Hardening or Acclimation

In the autumn, grapevines undergo physiological changes to prepare tissues for overwintering (Keller 2015). In most regions, this usually begins in August with the cessation of shoot growth, the gradual beginning of leaf senescence, and dormancy of overwintering buds. In addition, cane maturation is occurring as the shoots turn brown due to the deposition of cork in the outer bark (periderm). The latter is a prerequisite for subsequent bud and cane cold acclimation; green shoots cannot cold-acclimate. In areas subject to low winter temperatures or early fall frosts, using cultural practices that enhance hardening-off is encouraged. This is often done by withholding water before véraison to accelerate periderm formation. Despite their reputation, however, crop load, delayed harvesting, and leafroll disease have little impact on periderm formation and cold acclimation, at least so long as the crop load is not excessive (Halldorson and Keller 2018; Keller et al. 2014; Lefebvre et al. 2015).

Cold Air Pockets in the Vineyard

The variable terrain across Washington makes predicting the level of cold temperature extremes challenging. Cold air pockets often form in narrow valleys or bowls, where cold air is trapped and cannot drain from the site (Fig. 1). These cold air pockets can be as small as a swale in a vineyard block, noticeable by frost development in spring and fall, or as large as entire regions such as those situated in river basins. One way to reduce cold air pocket formation is to aid air movement by planting vineyards on slopes above the valley floor. Avoiding swales and plant away from physical structures (buildings, large rocks, windbreaks, etc.) that impede free air drainage. Even unharvested crops, such as corn, beneath a vineyard can make the difference between little and severe cold damage (Keller and Mills 2007).

Use of Wind Machines

When a thermal inversion exists (Fig. 2), wind machines can be used to mix the warmer air from higher elevations with the colder air near the ground level. At low ambient wind speeds (<5 ft/sec), deploying a wind machine can result in a 2.5–6°F increase in air temperature up to 100 ft from the machine (Davenport et al. 2008). The stronger the difference in the thermal inversion, the more likely the temperature will increase with air mixing. Because of the connection with thermal inversions, air needs to be stable (i.e., no to low-speed natural winds) in order for wind machines to be effective.

Late-Season Irrigation

Replenishing the top 2–3 ft of soil to field capacity late in the growing season is one way to help mitigate winter damage to grapevine roots (but do not apply excess water where it would cause pooling and run-off). Direct damage to roots can occur if soil temperatures drop below 22°F; adequate soil moisture acts as a buffer to these low temperatures and reduces the depth of frost penetration (Gale and Moyer 2017). Dry soil conditions also exacerbate symptoms of cold-induced damage, as they may prevent repair of air bubbles that usually form in the xylem in winter. If air bubbles form in the xylem, the ability for water to move upward in the plant is limited or stopped, shoot desiccation can occur, and in years with substantial above-ground cold damage, a lack of water can severely limit tissue recovery. Under normal conditions, root pressure associated with springtime activation (seen as sap flow or bleeding) of the plant will eliminate these air bubbles (Keller 2015). However, root pressure in the spring may be insufficient if there is inadequate water in the soil. In years with low winter precipitation, the only available water content prior to spring irrigation is the carry-over from the previous season (Davenport et al. 2008).

Variety Selection

Of the many factors that influence the grape variety selected for production at a particular site, cold hardiness should be strongly considered. An incorrect choice may result in the need for retraining, or in the worst case, replanting entire blocks, in addition to lost crop production.

Cold hardiness and short-season/cool-season tolerance (or ability to ripen early) should not be confused. While cold hardiness refers to the plant's ability to withstand low winter temperatures, short-season/cool-season tolerance is the ability for a variety to ripen a crop during a cooler growing season (i.e., relatively low heat accumulation), or in locations with short growing seasons (i.e., short duration between frost-free dates in the spring and fall). While some varieties are both cold hardy and cool-season/short-season tolerant, many are not (e.g., Cabernet Sauvignon is relatively cold hardy for *Vitis vinifera* but requires a long, warm growing season).

In general, the biggest influencing factor for a particular cultivar's cold-hardiness is its parentage. Most native North American *Vitis* species, often found as rootstocks, juice grapes, or as a parent in many hybrids, are more cold-hardy than their European *Vitis vinifera* counterparts. Among *V. vinifera* cultivars, those originating from more northern climates tend to be more cold-hardy than their southern counterparts (Keller et al. 2014). However, the "northeners" also tend to have earlier budbreak than the "southerners," which makes them somewhat more vulnerable to spring frosts. In addition to differences among cultivars of *Vitis vinifera*, there are clonal selections within many of the cultivars that may be slightly more cold-hardy and/or cool-season/short-season tolerant than other clones (Clore et al. 1974).

Table 1 lists selected wine, juice, and rootstock varieties according to their mid-winter hardiness as observed in Prosser, WA. Predicting cold hardiness is difficult because certain varieties can have different levels of cold hardiness depending on the time of the season (Ferguson et al. 2011, 2014). Some may be slow to acclimate in the fall (e.g., Cabernet Sauvignon), making them susceptible to early winter cold events. Others may deacclimate quickly in the spring (e.g., Concord, Chardonnay, Malbec), making them susceptible to late winter/early spring cold events.

Cold Hardiness Program at WSU

Washington State University, with funding from the Washington Winegrowers Association, the Washington State Concord Grape Research Council, and the Washington State Grape and Wine Research Program, maintains a program that measures the cold hardiness of various grape varieties in eastern Washington (Mills et al. 2006). Throughout the dormant season, this program provides updates on the critical temperatures that will result in bud, phloem, and xylem damage. This information can be used to determine the need to run wind machines and whether cold events might lead to vine damage. You can use this information to monitor the development of cold hardiness in vines throughout the season, as well as when they start to deacclimate from the cold in the spring. This information is available at http://wine.wsu.edu/extension/weather/cold-hardiness/. Because such measurements only apply to the site where the tissue samples are collected, a mathematical model that simulates the changes in bud cold hardiness from fall to spring (Ferguson et al. 2011, 2014) is provided on WSU's AgWeatherNet website at http://weather.wsu.edu. The model is run using daily temperature data from AgWeatherNet, a network of weather stations across Washington, which extends the hardiness data collected in Prosser throughout the state.

Pruning Techniques to Deal with Cold Damage

As a general rule, if there is significant bud damage in the vineyard, it is better to leave too many buds at pruning at the expense of an additional pass-through after budbreak rather than leave too few buds and risk poor canopy development and yield (Keller and Mills 2007, Gohil et al. 2019). There are some calculations (Tables 2 and 3) that facilitate more accurate determination of the number of buds that should be retained per vine based on the amount of damage that is present (Wolfe 2000).

Vines are able to recover from up to 100% phloem damage, but xylem damage often means that vines

Table 1. Mid-winter cold hardiness of selected wine, juice, and rootstock grape varieties as observed by the WSU cold hardiness program in Prosser, WA. There are many additional factors that can influence cold hardiness within a variety: site, plant age, plant health, irrigation status, and vigor are a few.

Cold Hardy	Intermediate Hardiness	Cold Sensitive
Riesling, Chardonnay, Gewürztraminer, Cabernet franc, Cabernet Sauvignon, Lemberger, Alvarino, Auxerrois, Pinot gris, Pinot blanc, Concord*, rootstocks*, hybrids*	Merlot, Syrah, Malbec, Zinfandel, Pinot noir, Barbera, Nebbiolo, Sauvignon blanc, Viognier, Muscat blanc	Grenache, Mourvedre, Sangiovese, Tempranillo, Semillion, Chenin blanc

*These varieties/species are generally more cold hardy than *Vitis vinifera* classified in this category.

Table 2. Pruning strategies based on primary bud damage.

If you have ...	Then ...
Under 25% primary bud damage	Prune normally.
25–75% primary bud damage	Use the adjustment calculation. (**Table 3**)
Over 75% primary bud damage	Hedge the vine, leaving 5–6 buds per cane. If you suspect severe damage, prune after budbreak, or not at all.

Table 3. Calculating adjusted bud number with 25–75% primary bud damage (Wolfe 2000).

Step 1:	
Determine Crop Potential	Crop Potential = $\frac{\text{(\% alive Primary Buds)} + (0.25 \times \text{[\% alive Secondary Buds]})}{100}$
Step 2:	
Determine Adjusted Bud Number	Adjusted Bud Number = $\frac{\text{The number of buds you normally leave}}{\text{Crop Potential}}$

Example	
Step 1: After assessment, you found that only 30% of your primary and 60% of your secondary buds are alive.	**Crop Potential** = $\frac{30 + (0.25 \times 60)}{100} = \frac{30 + 15}{100} = 0.45$
Step 2: In most years you would leave 24 buds/vine at this particular site.	**Adjusted Bud Number** = $\frac{24}{0.45}$ = 53 buds for this year

have to be retrained. The decision to retrain depends on the level of damage, and should be made as late as possible, preferably between budbreak and 10 inches shoot growth on healthy vines. If you are unsure about the extent of xylem damage, wait until after budbreak to see how much growth there is from latent buds on the cordon. The decision to retrain is a difficult one, as you will likely not have a harvestable crop the first year, and may want to reduce cropping for 2–3 years.

Deciding whether to retrain a few vines or an entire block is even more difficult. Generally, if damage is limited to a small percentage of vines, then individual vine retraining is recommended. However, if damage is significant enough to cause substantial vine-to-vine variation in the block, retraining that entire block is recommended for vineyard economy and efficiency. In older blocks that have sustained severe or repeated cold damage and suffer from crown gall, replanting may be the more economical option compared to retraining, as crown gall persists in the plant and may continue to be a management problem.

If you decide to retrain, there are several options available to renew damaged cordons (Gohil et al. 2019). If the trunk is still viable but spurs have become dysfunctional, then renewing spur positions by removing old spurs can be done. Alternatively or additionally, several short canes (kicker canes) can be laid down on the cordon to increase yield. However, if the cordon and/or trunk are severely injured, cut the trunk off a few inches above the ground. If roots have not been injured by cold temperatures, suckers (shoots from the trunk base) are likely to grow vigorously. It is often advisable to divert this vigor into multiple suckers, as allowing excessive growth will result in canes that are several degrees less cold hardy than non-vigorous canes (Todaro and Dami 2017). Moreover, long internodes will set the vine up for poor spur positioning in the future. Two shoots should be selected and trained along the cordon wire to the required new cordon length rather than simply letting them grow upright through the old canopy (Wolfe 2000). Tipping each shoot once it has reached the desired length on the wire will promote lateral shoot growth, and these laterals will become the spurs for the next year. Remaining suckers can either be removed at the end of the growing season or the following spring pre-budbreak. Delaying their removal until the following year will allow retraining as potential cordons in case additional injury occurred during that first winter.

If the vineyard has a history of excessive vigor, leaving renewal canes may be a viable option to divert this energy. However, these canes can produce fruit, and if this fruit is not removed, it may significantly alter yield estimation if not counted. Generally, a single renewal cane should not be maintained more than two years (sucker/shoot in year one, cane in year two). If a continuous production of renewal canes is needed to divert energy or for a cordon replacement reserve, maintain new suckers each year. If you are retraining from suckers, it is advisable not to crop the vine or suckers within the first training year unless excess vigor needs to be diverted.

Conclusion

While extreme cold temperature events may not be an annual occurrence, understanding and responding to cold damage is important in maintaining the long-term health of your vineyard. Systematic sampling of your vineyard before pruning, especially during years with damaging cold events, is recommended as a part of good viticulture practices.

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Cold Injury Assessment Worksheet (Buds)

Date:

Location:

Zone Descriptions:

Bud Assessment: Count the number of dead primary and secondary buds for each vineyard sampling zone, within each segment of a cane. Lower Cane—within approximately 6 nodes of the cordon; Middle Cane—between approximately 6–10 nodes; Upper Cane—approximately node 10+. To calculate **% Dead Buds** for each type of bud, add up the dead buds found on the whole cane, and divide by the total number of compound buds sampled on that cane.

Variety	Zone	Vine #	Cane #	*Lower Cane* Dead Buds		*Middle Cane* Dead Buds		*Upper Cane* Dead Buds		*Total* Dead Buds		Total Compound Buds	% Dead Buds		Notes:
				Pri	Sec	Pri	Sec	Pri	Sec	Pri	Sec		Pri	Sec	

Cold Injury Assessment Worksheet (Canes and Trunks)

Date:

Location:

Zone Descriptions:

Cane Assessment: One or more cane per vine can be assessed. **Damage Location:** Make an assessment near the base and top of the sampled cane. **Damage to Cane:** Defined as the presence of any damage (yes/no) in the cut area. To get **% Damage** for the Xylem and Phloem, add up the number of "Yes's" in the respective columns and divide by the total number of Canes assessed.

Trunk Assessment and **Damage Location:** Make 2 assessments of the trunk, one near the soil line (base), and one near the head (top). You don't need to assess every trunk you take cane samples from. **Damage to Trunk:** Defined as the presence of any damage (yes/no) in the cut area. To get **% Damage** for the Xylem and Phloem, add up the number of "Yes's" in the respective columns and divide by the total number of Trunks assessed.

					Damage to Cane (Yes/No)		Damage to Trunk (Yes/No)		Notes:
Variety	Zone	Vine #	Cane #	Location	Phloem	Xylem	Phloem	Xylem	
				Base					
				Top					
				Base					
				Top					
				Base					
				Top					
				Base					
				Top					
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By **Michelle Moyer**, **Lynn Mills**, **Gwen Hoheisel** and **Markus Keller**. Moyer, Mills, and Keller are at the WSU Irrigated Agriculture Research and Extension Center, 24106 North Bunn Road, Prosser, WA. Hoheisel is at Benton-Franklin County Extension, 1121 Dudley Ave, Prosser, WA.

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