Cool Climate Oenology & Viticulture Institute

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Best Management Practices for Reducing Winter Injury in Grapevines

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Best Management Practices for Reducing Winter Injury in Grapevines – An Overview

Growing grapes in cool climates is a challenging task. Vineyard health and productivity is a function of the local site and climatic conditions during the growing season AND the dormant period. Successful vineyards are those that are productive and sustainable over multiple years (where sustainable is defined as producing an annual crop at economically viable levels for the grape grower each year). The potential for vine injury due to low temperatures during the dormant period adds another level of vine management to be undertaken. Not only must a vineyard operator manage the vines to produce a high quality crop based upon the weather conditions of the current growing season, practices must be employed to ensure that vines achieve optimum health to withstand cold winter temperatures during the dormant period.

This best management practices manual for reducing winter injury in grapevines has been developed as a result of 5 years of research and practices in commercial vineyards across Ontario. The information is for existing vineyards and will provide guidance for preventing winter injury and suggested practices for responding to winter injury. The manual does not provide guidelines for assessing new vineyard locations.

Glossary

Acclimation – a complex process during which plants develop cold tolerance. It begins during late summer when shoots stop growing and become brown and woody or "harden off". Tissues acquire increased cold hardiness through a number of factors and mechanisms. *V. vinifera* grapevines acclimate in response to both short days and low temperatures.

Advective freeze – characterized by a massive passage of cold air during which little stratification of air temperature occurs with elevation changes.

Bud – compound structure from which shoots arise from in the spring. Fruiting buds are composed of large central primary bud, a smaller secondary bud and even smaller tertiary bud. Generally the primary bud is the most fruitful but often the least winter-hardy.

Cane – a mature woody shoot (one year old wood).

Cold Hardiness – the ability of grapevine tissue to survive during exposure to low temperatures

Cold/Winter Injury – the killing of some part of the vine by low temperatures

Cold Tolerance – the capability of a plant to withstand or survive low temperature conditions

Cold Avoidance – ways to avoid cold injury. These include site selection, elevation/slope, and cultivar selection as well as freeze protection strategies such as wind machines or burying of canes.

Cryoprotectant – a compound that protects biological tissue from freezing

Deacclimation - the process when grapevines lose hardiness and are ready to resume growth. It is the transition from a cold hardy to a cold tender state.

Dew (frost) Point – the temperature at which water vapour in the air condenses from a gas to a liquid. It is an important concept in the sense that when the dew point is below critical damaging temperatures, grapevine tissue can be more susceptible to cold injury.

Differential Thermal Analysis (DTA) – a technique to conduct research on the mechanisms of freeze tolerance and also to predict lethal freezing temperatures for grapevines. Temperature differences are recorded between grapevine tissue and a reference over time under identical thermal cycles. Differential temperature changes over time provide data about when freezing events have occurred to grapevine tissue.

Dormancy – time between the end of commercial harvest and bud break with absence of visible growth.

Double pruning – extra buds are retained after an initial pruning early to mid-winter. A second pruning is done after assessing bud damage and the threat of frost injury is minimal.

Extra cellular – outside of the cell or the area/spaces between cells

Geotextiles – are permeable fabrics used to protect plants and soils

High Temperature Exotherm (HTE) – heat released when supercooled water freezes extracellularly (in the intercellular spaces); extracellular freezing is considered non-lethal.

Intracellular – within the cell

Kicker cane – extra cane(s) retained during dormant pruning for subsequent removal during the growing season.

Leaf water potential (ψ) – a measurement commonly used to determine the water status (or stress) of a plant. It is commonly measured using a pressure chamber (“pressure bomb”) to determine the osmotic pressure of xylem sap. The more negative the value, the more stress the plant is under.

Lignification – the process where vine organs accumulate lignin that allows more resistance to cold and water loss. Lignin is incorporated into a complex tissue called periderm on the surface of grapevine canes.

Low Temperature Exotherm (LTE) – heat released when supercooled water freezes intracellularly (within the cytoplast & vacuole); Intracellular freezing is lethal.

LTE 10 – the temperature at which 10% of the primary buds will be killed
LTE 50 – the temperature at which 50% of the primary buds will be killed
LTE 90 – the temperature at which 90% of the primary buds will be killed

Periderm – bark which is thick waxy and brown that consists of phellogen (cork cambium), phellem (cork) and phelloderm.

Phloem – vascular tissue that transports sugars and other solutes throughout the plant.

Pith – central part of cane.

Radiational freeze – occurs when freezing temperatures develop during calm and clear sky conditions. Radiant heat is lost from the earth because there is no cloud cover to trap radiant heat or wind to mix the air. This results in very cold conditions at the surface.

'Spare Parts' viticulture – the use of multiple trunks, retaining suckers, double pruning to compensate for any winter injury that may have occurred.

Spur – a short cane pruned to 1 to 4 nodes.

Supercooling – the ability to withstand very low temperatures where the contents of the cell can remain liquid during subfreezing temperatures. Buds supercool to avoid freezing injury.

Temperature Inversion – the reversal of the normal behaviour of air temperature in which a layer of cooler air at the earth's surface is overlain by a layer of warmer air. Under calm, winter conditions, ambient temperature is warmer above the ground than at the surface.

Vascular cambium – tissue of canes and older wood that generates new phloem and xylem annually.

Xylem – vascular tissue that primarily transports water and minerals.

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1. WINTER INJURY

1A. Define and Describe

Freeze injury is probably the greatest threat to long-term successful grape growing in Ontario. Freeze injury can occur any time during the dormant period. Low temperature injury after bud break in the spring and before normal leaf fall is often referred to specifically as frost damage and is a type of freeze injury. Consequences of freeze injury include:

- Loss of fruiting buds
- Uneven or poor vegetative growth
- Inability to achieve vine balance
- Disease incidence (crown gall)
- Loss of vine growth uniformity in a block or vineyard
- Loss of consistency of production
- Loss of vines
- Additional input costs for renewing and retraining vines
- Reductions in yield, quality and income

Winter injury to grape vines can take multiple forms. There can be injury to the buds, injury to the canes and also to trunks. Bud injury is the easiest to assess during the dormant period through the sampling of dormant canes and then cutting the buds open to examine the growing tip to determine if it is alive or dead. Cane injury and trunk injury may not be readily visible until well into the growing season and the vines undergo additional stress (high temperatures, dry conditions, maturing a large crop, etc.).



Figure 1.1a Bud injury Figure 1.1b Vine trunk death Figure 1.1c Vine cane injury

Water is the critical factor that can lead to winter injury as ice crystals can form within (intracellular) and between (extracellular) cells. The formation of ice crystals can result in cell membrane injury and cell death. When numerous cells are damaged, the structure and function of the vine can be impaired. For buds, injury to the meristem (growing point) will not allow for bud growth and shoot development. Injury to the canes conductive tissue (phloem and xylem) can restrict movement of water and nutrients leading to shoot collapse and failure of cluster growth while injury to the trunks may result in outright vine death or the development of diseases such as Crown Gall which can impair vine growth and may lead to vine death in future years.

1B. Examples of Freeze Injury in Grapevines

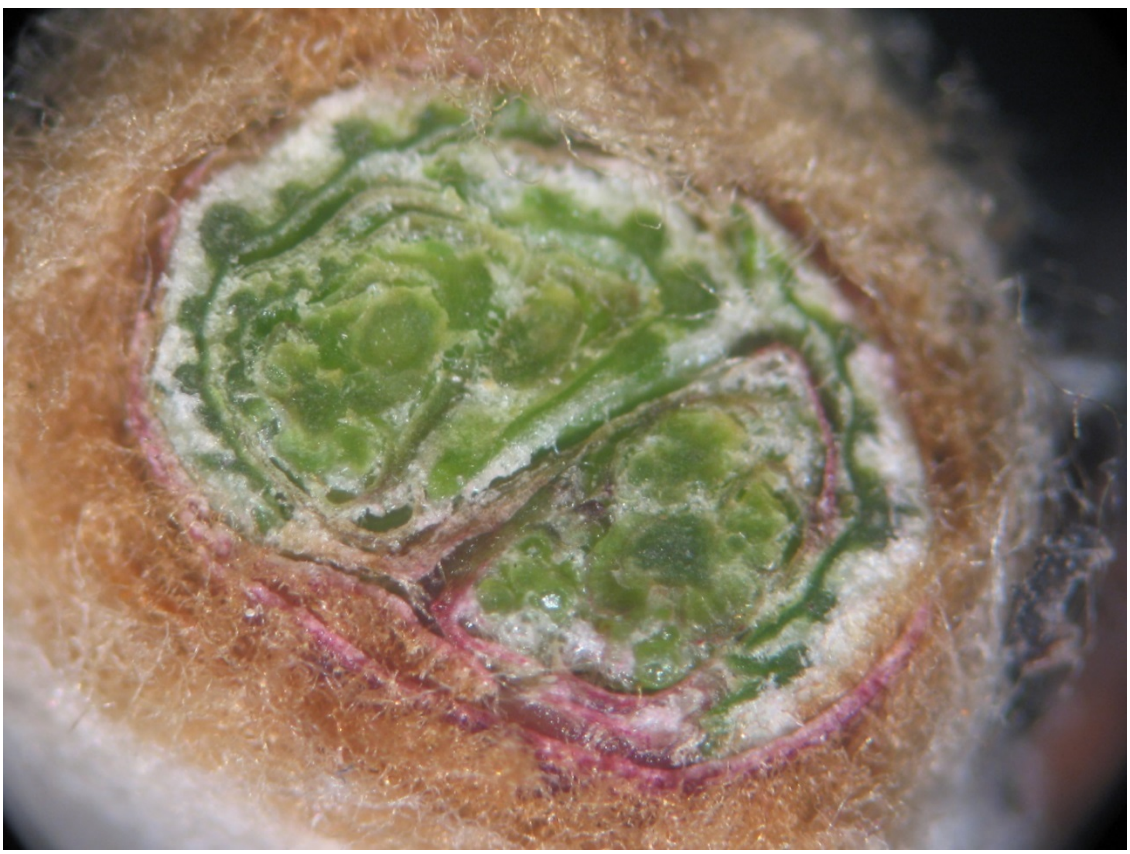

Figure 1.2. Grapevine bud cross-section depicting healthy live primary and secondary buds

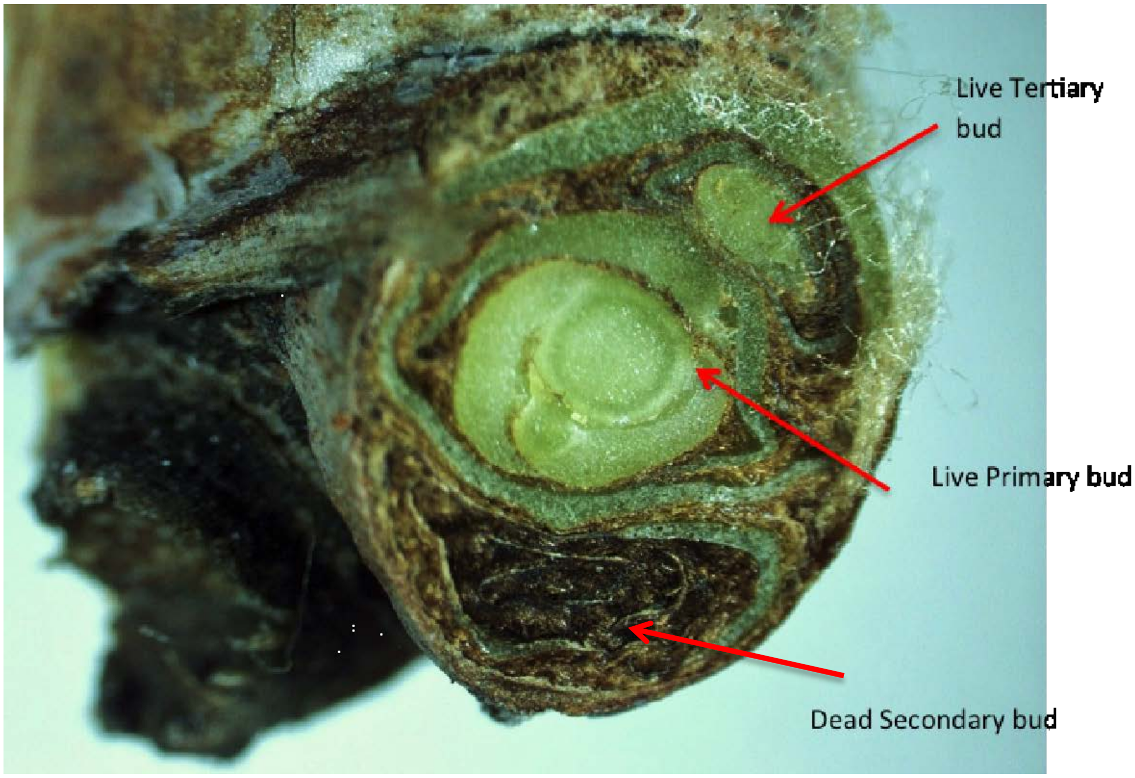

Figure 1.3. Bud cross section showing damaged secondary bud with primary and tertiary alive.

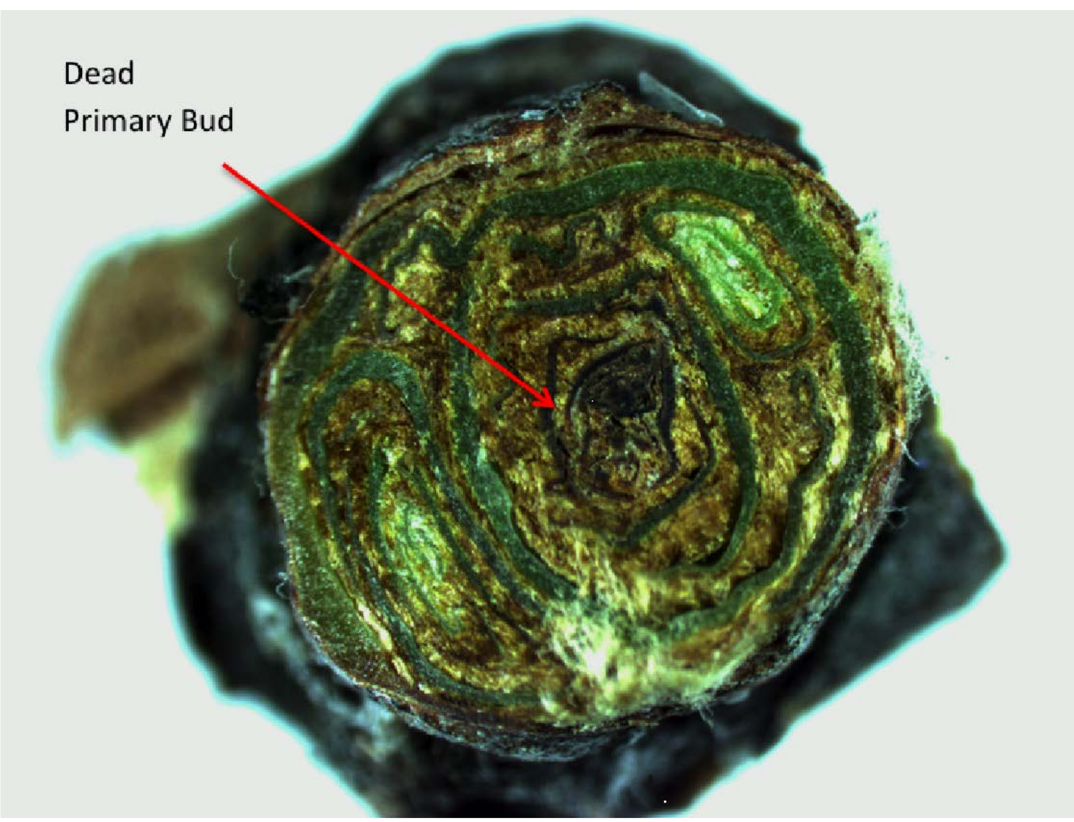

Figure 1.4. Grapevine bud cross section depicting dead primary bud

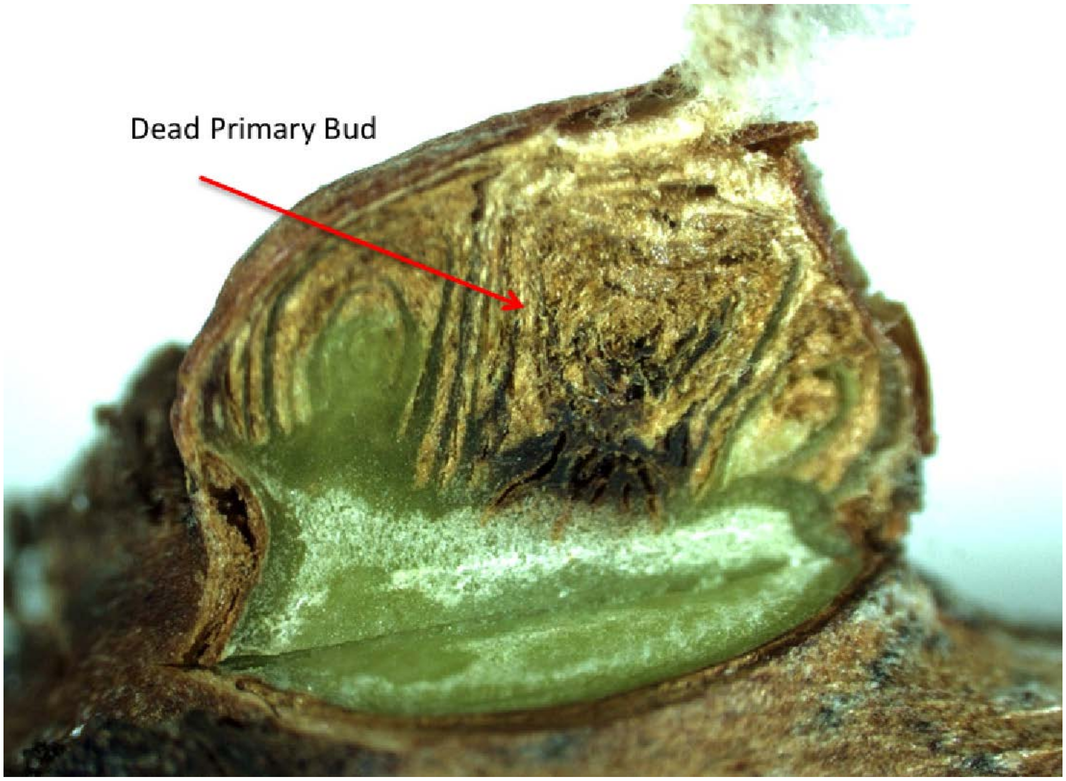

Figure 1.5. Longitudinal bud dissection showing dead primary bud

Figure 1.6. Severe winter injury of grapevines following a cold winter

Figure 1.7. Grapevine displaying truck damage following cold winter

Figure 1.8. Grapevine showing symptoms of Crown Gall - trunk split and callus cell formation

Figure 1.9. Grapevine showing signs of early shoot collapse due to vascular damage

Figure 1.10. Shoot collapse in Sauvignon blanc following fruit set

Figure 1.11. Freeze damage after budbreak in spring of 2012 in Vineland, ON.

Figure 1.12. Frost damage in grapes following bud break and shoot growth

1C. Assessing winter injury

Assessment

For each cultivar in a suspect block, it is necessary to take sample canes to determine percentage of primary bud survival. Making decisions for crop levels and overall vine health is best estimated from primary buds and the most efficient use of time for *V. vinifera* cultivars. This is best achieved by evaluating bud survival prior to pruning.

Selection

The canes selected for bud evaluation are those that would normally be left for tying in the spring. On most vines there are multiple canes that could be selected and the removal of a single cane is not harmful. Selection of 10 to 12 of these canes (no more than 1 cane per vine) is taken for the cultivar for assessment. Where there are obvious topographic differences or vine size differences additional samples can be taken to better represent the area.

For evaluation of the dormant sample, a cane closest to the head or center of the vine should be taken. There is no benefit from sampling lateral shoots. The selected canes are trimmed to 12 to 15 buds (up from the base). The buds closest to the base of the cane are generally the hardiest so evaluation of the first 10 buds is important

Handling

If the freeze was recent, there is a need to ensure that the buds have thawed since exposure to the cold temperatures. Samples should be routinely collected over the dormant period and held for 24 to 48 hours at room temperature before evaluating. This allows for oxidative actions to take place and the damaged bud growing points to turn brown.

Examination

For proper evaluation, the cuts must be made at the proper depth to establish whether the growing point (meristem) of the primary bud is intact or injured. Frequently for people new to completing bud examinations, the cuts are made too shallow, too deep or with a coarse tool/knife (like pruner blades) that fail to clearly allow one to assess if the bud is alive or dead. The following figures illustrate correct and incorrect cuts for bud survival evaluation

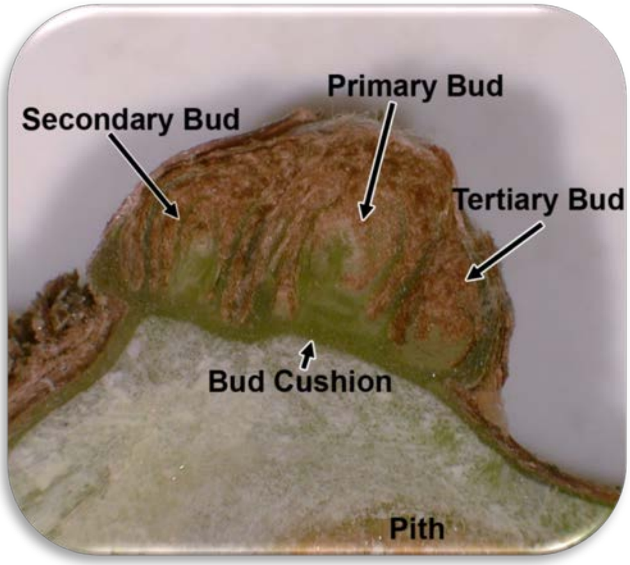

Figure 1.13a - Longitudinal section of a grapevine (cv. Merlot) bud.

Figure 1.13b & c – Too shallow of a cut to accurately assess bud damage. The tip of the primary bud may be visible however not enough to confirm if any damage has occurred.

Figure 1.13d – Too deep of a cut. Bud cushion is exposed that will appear green even if buds are damaged.

Figure 1.13e & f – Proper cut to assess primary bud. The tip of the secondary bud may be visible.

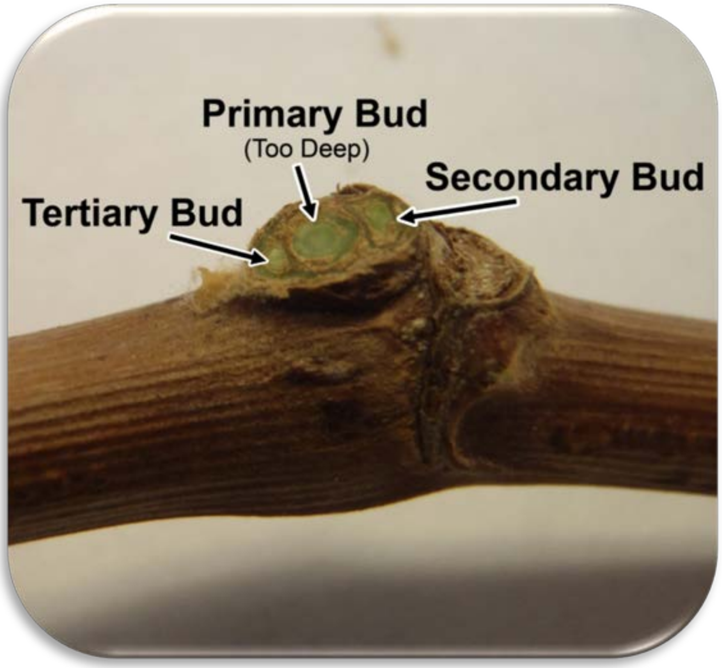

Figure 1.13g – Proper cut to assess secondary and tertiary buds but too deep for primary bud.

Recording the information

Records should be kept for each cane and collectively for each cultivar sample. Some people choose to record live/dead buds based on cane position (remember the first bud from the base is number 1 and it progresses in number up the shoot so that bud numbers 10 to 15 are near the tip of your sample cane!)

The sample should be representative of the entire cultivar in the block or just a small location within the block. To protect against sampling error, follow-up sampling 7 to 10 days apart after a single freeze injury episode is required. If additional cold temperatures are experienced where injury may have occurred, additional sampling is done 24 to 48 hours after the cold event; the samples are warmed to allow oxidation of tissue to occur and then evaluated as above.

Date				Cultivar				Block			
	Bud Position (Base 1 to 10)										
Cane	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
C1											
C2											
C3											
C4											
C5											
C6											
C7											
C8											
C9											
C10											
									Total		

Figure 1.14. Example of a recording form to document bud damage within a vineyard block

2. COLD HARDINESS IN GRAPEVINES

Grapevine bud cold hardiness is a dynamic process and changes throughout the dormant period as shown in Figure 2.1. Beginning in late August as the vine prepares itself for dormancy, the tissues begin to acclimate. This is a gradual process and, in *V. vinifera,* acclimation is in response to shorter day length and cooler temperatures. It is complex in nature and involves many factors and mechanisms. As temperatures drop to sub-freezing temperatures, the vine becomes more cold tolerant and achieves maximum cold hardiness just prior to the coldest periods experienced mid-winter, and is maintained until external temperatures begin to climb at the end of winter. Once temperatures begin to increase in the second half of winter, the vine has already completed all of its requirements to break dormancy and will begin to deacclimate. The effects are basically the reciprocal of those associated with acclimation, as it is the transition from a cold hardy to cold tender state as the vine prepares to resume growth. As shown in the Figure 2.1, this process is more rapid than the acclimation process.

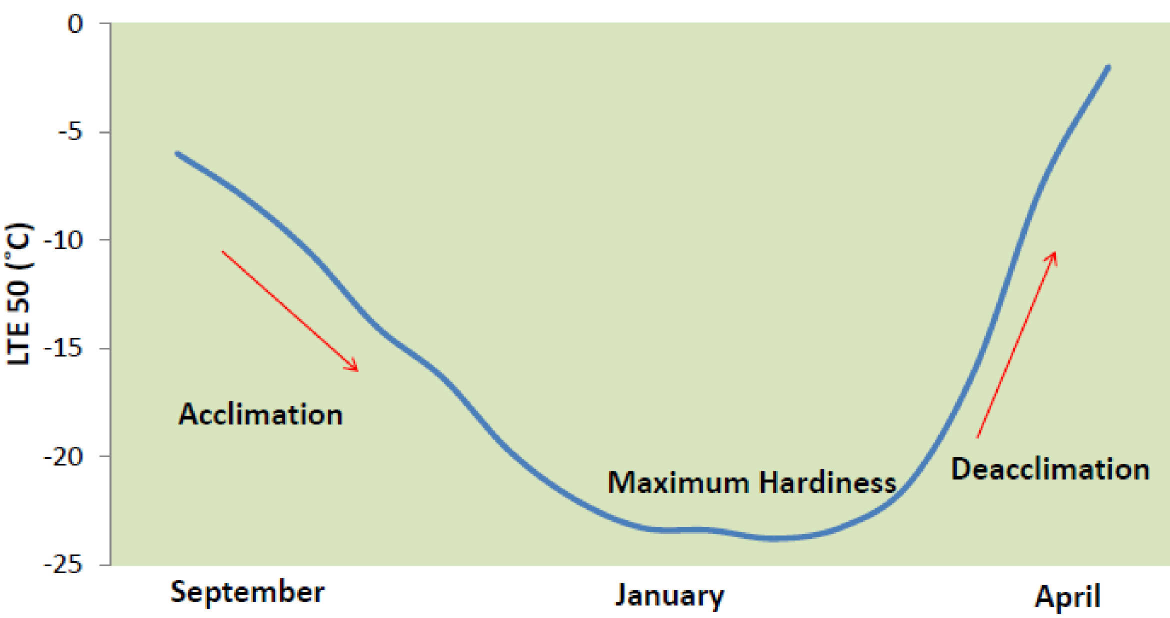

Figure 2.1. Profile of bud cold hardiness during the dormant season (CCOVI VineAlert Website)

Susceptibility to cold injury

Grapevine tissues vary in their tolerance to freezing temperatures. Woody tissues of the trunk, cane and cordon generally have higher tolerance than dormant buds or roots (Howell, 2000). Wample et al. (2000) found that phloem was most susceptible to cold injury followed by older xylem, younger xylem and vascular cambium. In terms of dormant buds, primary buds are the most susceptible to cold damage followed by the secondary buds and tertiary buds.

Cold hardiness is **not static** but varies throughout the dormant period and is determined through the grapevine's genetic potential and environmental conditions. Therefore, grapevine species and cultivars vary in terms of their cold hardiness. There are three main stages of cold tolerance: acclimation, maximum hardiness, and deacclimation.

2A. Acclimation

Cold acclimation is the ability of the plant to increase freezing tolerance. During most of the growing season grapevines are only able to withstand temperatures above freezing and any green tissue is highly susceptible to freeze injury. However, later in the growing season grapevines like other perennial woody plants begin to prepare for dormancy and cold acclimate.

This begins while there are leaves on the vine long before the first signs of frost. One of the first visual signs of acclimation is shoot maturation and the formation of periderm or browning of shoots. This is commonly known as 'hardening off'. This process occurs from base to tip of the shoot so tissue at the lower portion of the shoot is acclimating faster than those on the apical end. The shortening of day lengths and a decrease in photoperiod trigger this process, which is a key environmental cue.

Dormancy can be reached with shorter photoperiods however in order to reach full cold tolerance the vines must also be subjected to colder temperatures. Once winter hardy, the vine and its buds are not only resistant to low temperature stresses, but also those associated with dehydration as well. Vines undergo a process of self-imposed dehydration where total water content within the plant decreases significantly. This is an important physiological change since this leads to an increase in hardiness. Other changes within the plant include increases and decreases in various hormones, and accumulation of various cryoprotectants such as sugars, lipids, and proteins.

During cold acclimation, growth inhibiting hormones, such as abscisic acid, are accumulating and slowly overtaking growth promoting hormones, such as gibberellic acid, auxins, and cytokinins. This promotes cessation of growth, periderm formation, leaf abscission, and the movement of important storage compounds out of the leaves and into more permanent organs of the plant (Keller 2010, Zhang et al. 2011). Abscisic acid in particular is of significant importance due to its role in dormancy induction, water relations and increased carbohydrate accumulation (Gusta et al. 2005).

Carbohydrates, in the form of starch and various sugars also accumulate in cells. Starches are converted to sugars. Therefore, as sugar concentrations increase in plants, starch concentrations decrease. The concentration of sugars increases greatly and the presence of key carbohydrates such as sucrose, raffinose, and stachyose are associated with increased cold tolerance (Hamman et al. 1996). As with sugars, fatty acids (and fatty acid proteins) increase in concentration in cold hardy plants during the winter months and help to stabilize and protect cell membranes.

Cryoprotectants, such as the sugars and lipids previously described, protect plant cells by two major mechanisms: they either help cells tolerate extracellular ice or they allow the cells to supercool (Jones et al. 2000). To tolerate extracellular ice build-up in vine tissues, cryoprotective compounds prevent water loss within the cells. They do this by increasing solute concentrations within the cell cytoplasm that lowers the osmotic potential of the cells, therefore preventing water from exiting them.

Supercooling, on the other hand, inhibits the formation of ice by removing ice forming nucleation sites and prevents water molecules from binding together (Burke et al. 1976, Keller 2010, Wolfe and Bryant 1999). This is a key phenomenon that grapevine buds use to prevent freezing. Buds also create an impermeable organic barrier (vascular plugs) between them and the ice-filled cane that is very effective at preventing ice crystals or nucleation molecules from entering the bud site (Fennell 2004, Jones et al. 2000, Keller 2010).

2B. Deacclimation

The reverse of the acclimation process is called ***deacclimation.*** This process occurs as the vines prepare to leave cold winter temperatures and begin to resume active growth as daylight periods lengthen and temperatures rise in the spring. The dormancy we observe from mid-January onward is environmentally controlled – it is the below freezing temperatures that keep the plant from growing. During deacclimation, progressively warmer temperatures enable the vine to begin to have water redistribute back to proximity of the bud cells.

The sap flow observed in spring is the change in water concentration outside of the vine in the root zone relative to that inside the vine. Water moves from high concentration (in the soil around the roots) to low concentration (inside the vine) to re-establish a water balance.

As vines deacclimate, some of the changes inside the cells that allowed them to survive very cold temperatures are reversed. The vascular plugs are digested by enzymes, allowing water to move into proximity of the buds. Hormone levels that kept the cells dormant decline and some of the cryoprotectants that helped dehydrate the cells are metabolized. This allows the cells to rehydrate and freeze at higher temperatures Water starts to move into the roots and trunk as storage starches are metabolized into sugars in the xylem.

Of concern to many growers is the movement of water into the vine as sap flow begins and the potential for freezing injury (freezing of water inside the vine and cell injury). As water content in the vine increases and cells rehydrate, the temperature at which freezing can occur increases as cryoprotectants are lost and cell functions resume. This loss of hardiness is much faster than the rate in which hardiness developed in the fall and is extremely rapid as we approach bud break.

In Ontario, and other regions, the deacclimation period can be when vines are at the highest risk. This is due to the frequency of cold events that follow warmer periods experienced during the winter months. One of the most significant examples of this phenomenon was the winter of 2011/12 where vines (and other perennial fruit crops) lost significant cold tolerance during an exceptionally warm March. With a “cold event” of minus 6°C at the end of March and the loss of cold hardiness, this event resulted in significant losses due to freeze injury in tender fruit.

Therefore, what are some considerations growers should have during deacclimation?

1. Growers should be aware that those vines that enter dormancy earliest are likely to lose hardiness in the spring at a faster rate than those that matured later last fall. The old saying - early to bed early to rise – is pretty much true for grapes. Baco noir is picked first each fall and breaks bud first in the spring. Cabernet Sauvignon is one of the last to mature and be harvested and last to start growth in the spring.

2. Vines are reasonably hardy until sap flow begins in the spring and then hardiness levels can be lost at a rate of up to 4 degrees C or more in a week. Be aware that phloem and xylem tissue in trunks and canes are less hardy by a few degrees or more than buds, especially as sap flow resumes.

3. With no snow cover and low soil moisture at the surface, the ground is absorbing more sunlight and will warm the root zone earlier leading to earlier vine growth. Do NOT work the ground early as this will warm the soil faster and push the vines into growing even earlier!

4. If you are using wind machines, you should constantly adjust your start-up temperature as we have longer days and warmer daytime temperatures. Be aware of the www.ccovi.ca/vine-alert web page that has the latest information on bud hardiness. If you are concerned about trunk injury, you may wish to set your start up temperatures a few degrees warmer than those identified as causing bud injury

5. Vines that are pruned earliest will lose dormancy sooner (bud break will occur earlier) than those pruned late in winter.

6. Always monitor the weather forecasts and be prepared. For up-to-date hardiness levels of vines check the CCOVI VineAlert pages at www.ccovi.ca/vine-alert and PDF summaries are also available at KCMS Applied Research web pages at www.kcms.ca/research.

7. From our research in Ontario and data published in extension articles in other regions (Courtesy of Dr. Tony Wolf, Virginia Tech Univ.) the following are used as critical temperature guidelines near the end of dormancy and beginning of growth:

Growth stage	**Critical temperatures**	**Suggested Temperatures for start-up of wind machines***
Dormant bud (just prior to bud swell)	Minus 4 °C or 25 °F	Minus 1 to Minus 2 °C
Dormant swollen bud	Minus 3 °C or 27 °F	Minus 1 to 0 °C
Bud Burst	Minus 2.2 °C or 27/28 °F	0 C to Plus 1 °C
One leaf unfolded	Minus 1.5 °C or 28/29 °F	Plus 1 C to Plus 2 °C
Two or more leaves unfolded	Minus 1 to 0 °C or 30 to 32 °F	Plus 1 C to Plus 2 °C

For optimal use of wind machines, it is suggested that the start-up temperatures be set at 2 to 3 degrees warmer than the critical temperatures listed so that they can be active as the ground temperature declines and provide protection before we reach critical temperatures.

2C. Assessing Cold Hardiness

What is bud hardiness?

The ability of grape buds to resist injury from winter temperatures from dormancy (leaf fall) through to bud break in the next spring varies during the winter period. Bud hardiness testing uses bud samples in programmable freezers to measure and establish temperatures at which damage (bud death) would occur on a particular sampling date. These values are posted as the LTE values for injury. The method used is based on Washington State's published method (Mills et al 2006).

What is LTE?

LTE in technical terms is the Low Temperature Exotherm as measured by freezer testing. In grower terms, it is used to estimate the temperature at which damage is likely to occur. For posted data, the LTE 10 is the temperature at which 10% of the buds are likely to die (or 90% survival). The LTE 50 temperature is for 50% bud death and the LTE 90 is 90% bud death.

How can I use this?

Bud hardiness changes over the winter. Buds reach their hardiest levels in mid-winter (late December to early February) with a gradual loss of hardiness from there on to bud break. Knowing the current hardiness of buds (values in mid-January are very different from mid-February or mid-March) prior to a predicted cold event can help growers determine how best to use of protection practices such as wind machines.

Remember, the posted values are for vines tested in different areas. Hardiness values will vary depending on cultivar, cropping history, location, vine health (free from injury by pests and diseases) so they are merely a guide to assist in decision making. Site specific testing will always provide the best results and information.

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3. WEATHER CONDITIONS

Weather conditions during the prior growing season and during the dormant period can have an impact on vine health and hardiness to survive cold winter temperatures. Weather episodes are categorized as severe during the dormant period if temperatures go below the maximum hardiness levels of the buds.

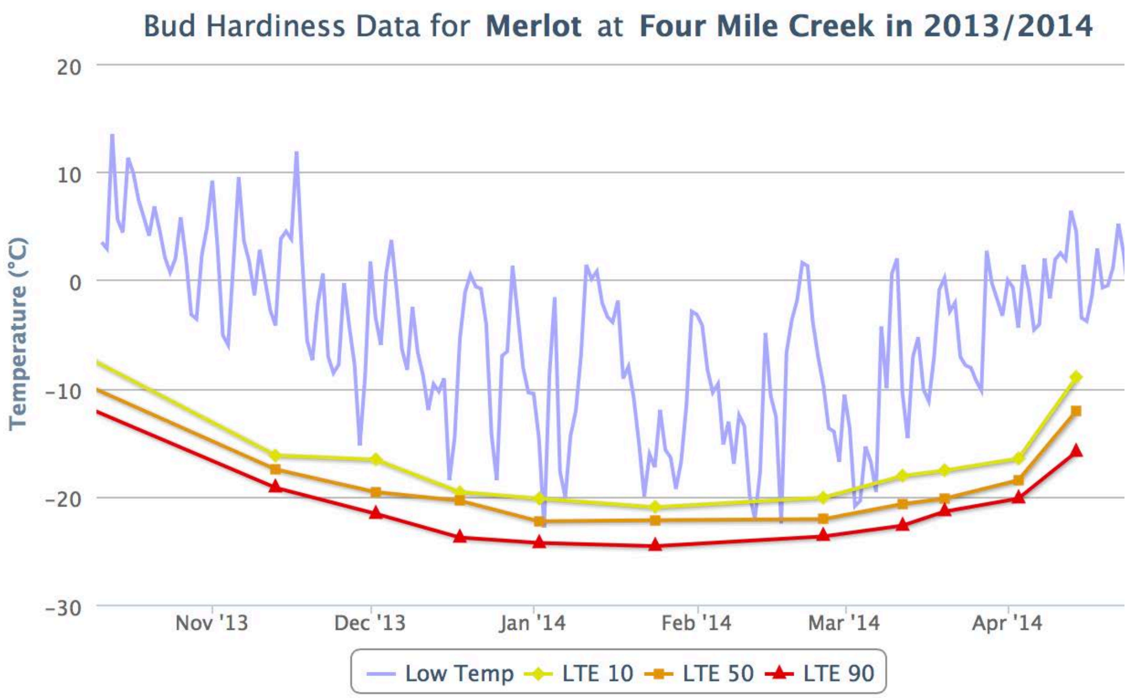


Figure 3.1. Minimum observed temperatures compared with measured hardiness of cv. Merlot winter of 2013/14

3A. Dormant Period Weather Influences

As observed in Figure 3.1 above, there were a number of severe cold temperature episodes where minimum temperatures were colder than the measured hardiness of Merlot buds. Over the course of the winter of 2013/14, there were 9 separate temperature events during which bud damage to Merlot was likely to occur.

The above figure also shows how erratic winter minimum temperatures can be with extreme fluctuations. It is important to note that bud hardiness levels can be affected by temperatures preceding severe weather episodes. Looking at minimum temperatures from 1 January 2014 to 1 February 2014, the mid-month period of January was warmer than at the end of the month and bud hardiness temperatures were slightly higher at the end of January than at the beginning of January. Next looking at February, as temperatures got colder to mid-month, the hardiness of the buds improved such that on the first severe episode in February, buds were right at the point of possibly sustaining injury. However by the end of February, a trend of warming minimum temperatures was followed by a severe episode and buds were not as hardy as earlier in the month and damage occurred during a severe temperature drop in early March.

These trends have been observed in other years. Rising temperatures or warm spells in the dormant period result in vines losing hardiness and severe temperature drops cause injury. However the same severe temperatures, if preceded by multiple days of progressively colder temperatures, results in vine hardiness being improved and buds are more acclimated to withstand cold temperatures and less likely to sustain injury.

In the figure below (Figure 3.2), cold hardiness of Cabernet franc vines is displayed for 5 distinct dormant seasons. Note the differences in cold hardiness during acclimation, mid-winter and during the spring deacclimation periods. In Ontario, deacclimation rates differ dramatically depending on temperature influences. For example, in early 2012 vines did not achieve as high of cold tolerance as some previous years and vines then lost cold tolerance at very rapid rates compared to previous cooler dormant seasons. Differences of over 10°C of hardiness occurred on the same calendar date in some instances.

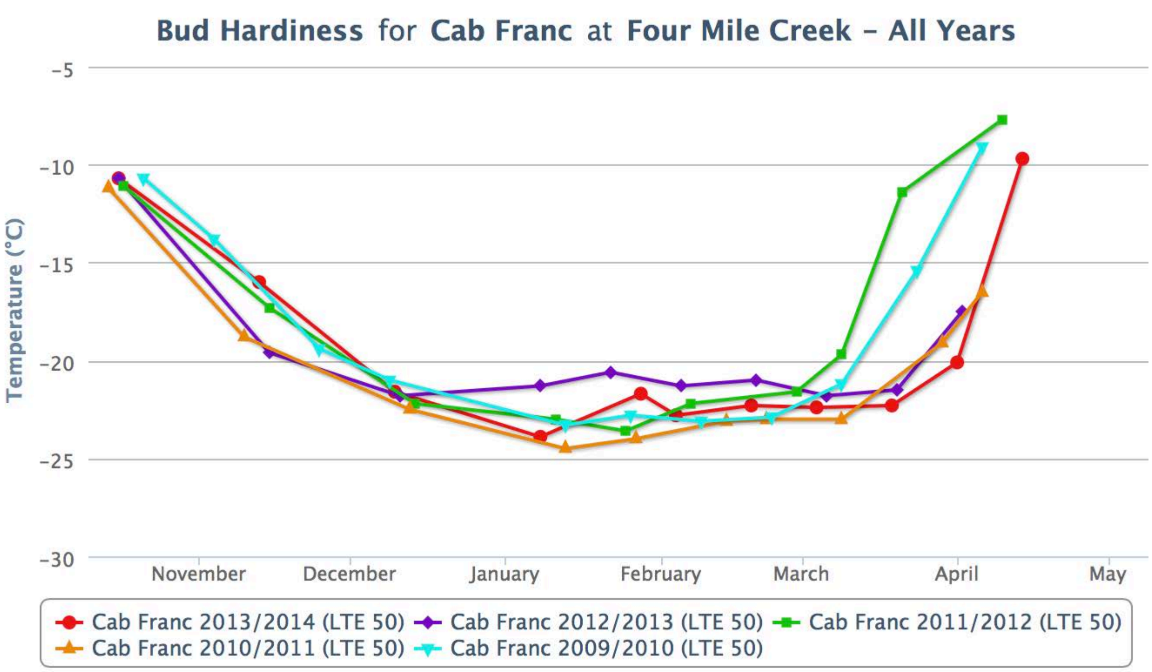


Figure 3.2. Differences in cold hardiness dynamics in Cabernet franc grapevines due to dormant season influences. 2009-2014.

3B. Impact of repeated low temperature episodes

Freeze injury can be a result of a singular event that results in significant damage or through a serious of repeated episodes. A drastic temperature drop especially during periods of acclimation or deacclimation can result in significant injury. The same can occur when temperatures drop near or below critical lethal temperatures for a significant period of time. In 2013/14, there were some episodes during dormancy where these scenarios occurred. In Prince Edward County, temperatures dropped below -30°C resulting in 100% bud kill in unprotected *V. vinifera* and damage also occurred in hybrid cultivars during the maximum hardiness period. Lake Erie North Shore experienced temperatures below -20°C for multiple days during the 'Polar Vortex'. Temperatures dropped below -25°C on some nights and sustained temperatures below -20°C lasted for over 18 hours. This resulted in significant injury (>90%) to a large percentage of *V. vinifera* due to absolute minimum temperatures reached as well as sustained temperatures at or below predicted critical lethal temperatures. Preliminary research from CCOVI indicates that if there are prolonged periods of cold temperatures near predicted LTE values that damage can be greater than if the temperature reached LTE for a short period of time.

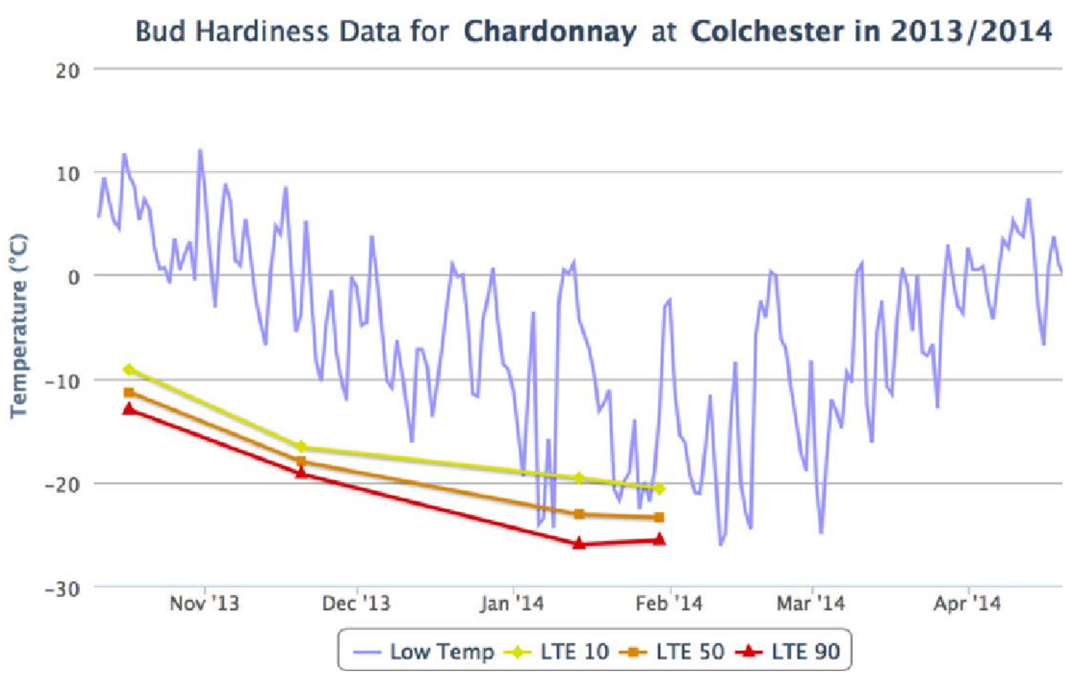


Figure 3.3. Example of a significant period of extended cold below critical lethal temperatures for Chardonnay grapevines. Following these temperatures experienced in January, there was over 90% bud damage in many cases so hardiness values could not continue to be monitored.

In addition to singular extreme cold weather events injury can occur from a series of less severe cold events. In 2013/14 the Niagara Peninsula did not generally have extremely low temperatures but had a number of repeated episodes where LTE values were reached. An example of cumulative bud damage is shown in Figure 3.4 below. No single event resulted in catastrophic bud loss but over the course of the winter, repeated injury occurred resulting in significant bud loss in some situations.

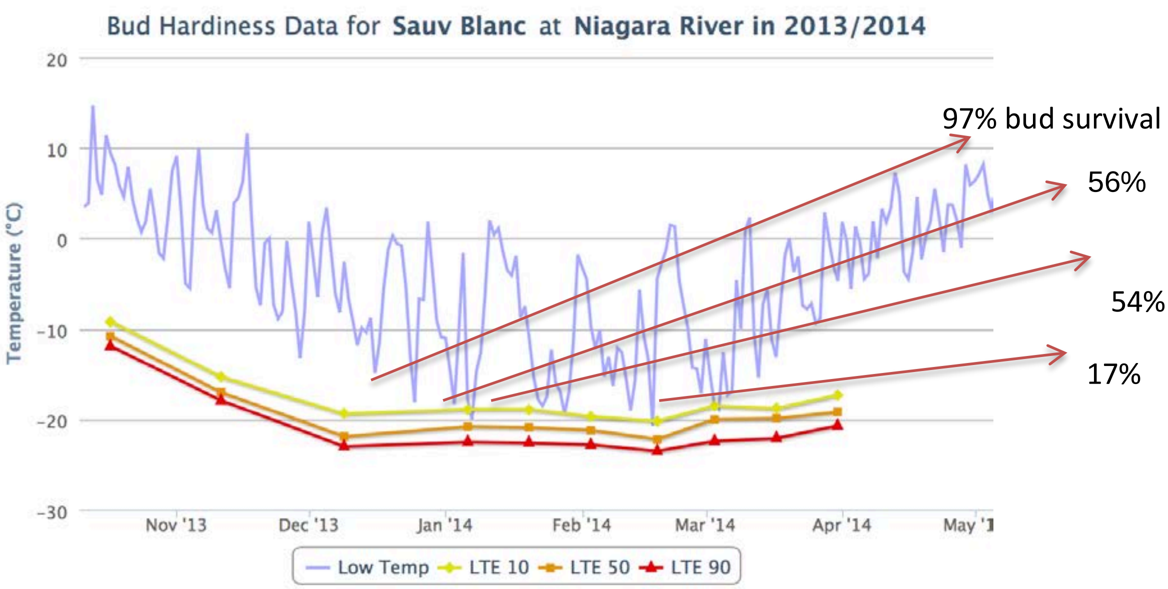


Figure 3.4. Example of cumulative freeze injury to Sauvignon Blanc primary buds, Niagara River sub-appellation, NOTL. 2013-14**.**

4. FACTORS INFLUENCING COLD HARDINESS

4A. Cultivar Attributes

Cold hardiness is a complex trait that is limited through a plant's genetic potential and its environment. Just as cultivars have unique attributes such as flavours, aromas, and harvest dates, they also possess specific traits for winter hardiness. Some cultivars are capable of withstanding lower winter temperatures compared with other cultivars grown at the same site. Figure 4.1 displays cold hardiness of different cultivars sampled within Ontario under similar site conditions. *V. vinifera* cultivars are more susceptible to cold injury and there is also much variability between *V. vinifera* cultivars. For example, varieties such as Riesling and Chardonnay are much more cold tolerant than others such as Merlot, Syrah and Semillon. Hybrid varieties are generally more cold tolerant than *V. vinifera*, however there is also variability among these cultivars as well. Vidal blanc is more cold sensitive than most of the University of Minnesota hybrids such as Marquette that can withstand -30 °C.

Figure 4.1. General maximum cold tolerance of selected cultivars grown in Ontario through differential thermal analysis. Bud cold hardiness ratings from January 22- February 14, 2013. (Willwerth, unpublished)

Cultivar	LTE10	LTE50	LTE90
V. vinifera			
Riesling	-23.1	-24.4	-26.0
Chardonnay	-21.4	-23.9	-25.3
Pinot noir	-21.4	-22.9	-24.1
Sauvignon blanc	-20.7	-22.0	-23.7
Semillon	-18.1	-21.4	-24.3
Cab Sauvignon	-21.6	-23.9	-24.9
Merlot	-17.4	-20.1	-22.4
Cabernet franc	-21.3	-22.9	-24.3
Malbec	-20.3	-21.7	-23.1
Petit verdot	-22.4	-23.9	-25.6
Syrah	-19.1	-21.0	-23.3
Gewurztraminer	-19.8	-22.6	-25.0
Tannat	-20.8	-22.5	-23.9
Tempranillo	-18.9	-21.9	-23.8
Viognier	-21.2	-23.8	-25.6
Sangiovese	-20.6	-21.9	-23.0
Auxerrois	-21.9	-24.3	-25.8
Hybrid varieties			
Vidal	-26.5	-27.7	-28.7
Gr7	-25.2	-26.5	-27.7
Frontenac	-30.7	-31.6	-32.5
Sabrevois	-27.8	-29.6	-30.8
Marquette	-28.9	-30.3	-32.5

Seasonal differences do impact a cultivar's cold tolerance so maximum hardiness levels can vary from season to season. Figure 4.2 shows data collected over a 5-year period illustrating maximum hardiness levels achieved each year. Of particular interest is regardless of growing season, the maximum hardiness level achieved for a specific cultivar is often within 1 degree Celsius. However, due to vine genetic characteristics some cultivars are hardier than others regardless of the year (for example, Riesling is on average 2 degrees Celsius hardier than Merlot or Syrah). Figure 4.2 shows how cold hardiness acclimation, maximum hardiness and deacclimation for one specific cultivar such as Cabernet franc can vary greatly from season to season. This demonstrates that the environmental interaction with cultivar is very significant and must be taken into consideration. Sites that promote poor acclimation or rapid deacclimation may compromise cold tolerance and this may differ from variety to variety. For example, varieties such as Chardonnay and Baco noir deacclimate and break bud sooner than a cultivar such as Cabernet Sauvignon. Therefore, south-facing slopes would cause faster rates of deacclimation and should be limited for these varieties in Ontario.

Maximum Hardiness Values (LTE 50 °C)

CULTIVAR	2009/10	2010/11	2011/12	2012/13	2013/14
Syrah	-22.6	-23.0	-22.9	-22.0	-22.7
Merlot	-22.7	-23.4	-22.5	-21.9	-22.8
Sauvignon Blanc	-21.9	-23.4	-23.1	-22.4	-22.5
Cabernet Sauvignon	-23.0	-23.4	-23.0	-22.6	-22.9
Cabernet Franc	-24.2	-25.1	-24.1	-23.0	-24.9
Chardonnay	-24.5	-25.3	-25.1	-24.3	-24.8
Pinot Noir	-24.7	-25.7	-24.5	-23.8	-25.0
Riesling	-24.8	-24.8	-25.6	-24.6	-25.5

Figure 4.2 Maximum hardiness values achieved for core *V. vinifera* cultivars in Ontario. 2009-2014

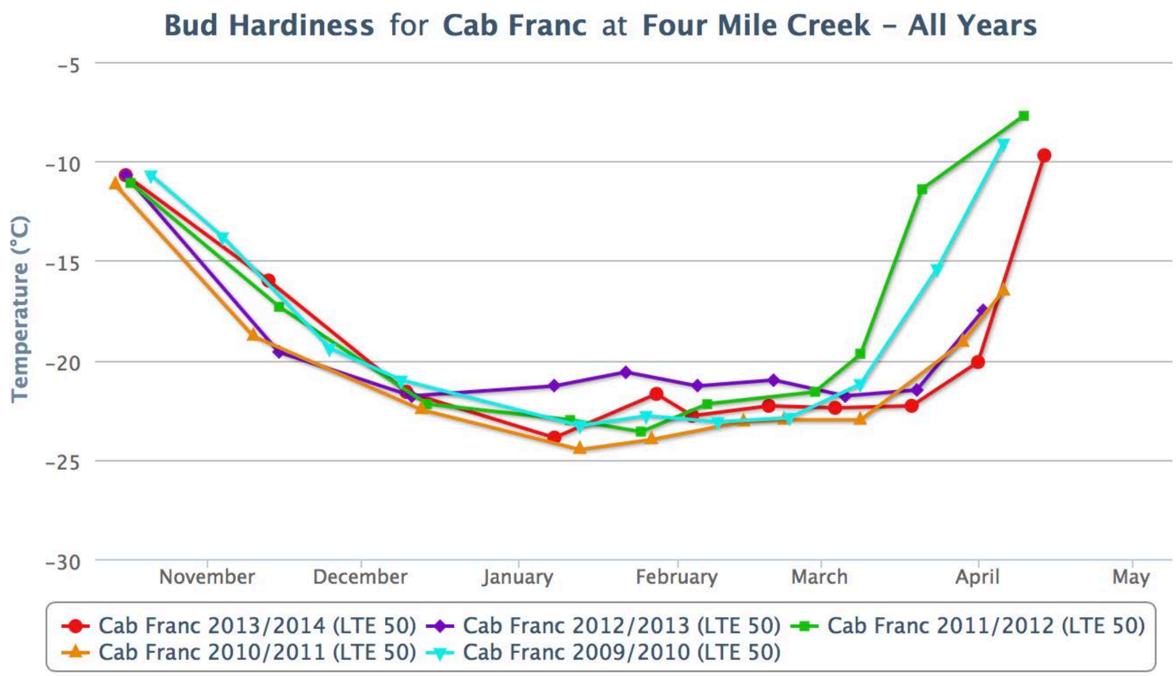


Figure 4.3. Seasonal differences of cold hardiness dynamics in Cabernet franc, Four Mile Creek sub-appellation, NOTL. 2009-2014. (CCOVI VineAlert website)

Clones

Slight variations within cultivars due to clonal mutation can impact cultivar traits such as cluster morphology, vine growth and cold tolerance. Preliminary research here in the region indicates that different clones can be more cold tolerant. Figure 4.4 shows differing cold acclimation rates for two different clones of Syrah. Furthermore, following the cold winter of 2013/14, some blocks of sensitive varieties appear to have survived the winter better and it could be clone related. Proper clone selection for Ontario's climate conditions may help mitigate some of the effects of winter injury for a particular variety. However, the impact of clonal variation on cold hardiness needs much further research.

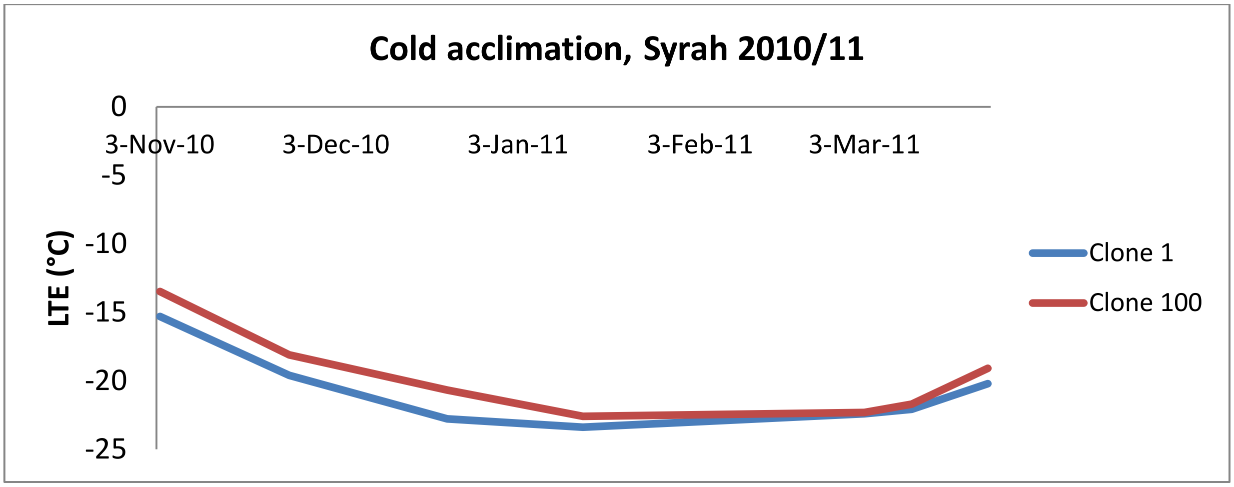


Figure 4.4. Cold hardiness dynamics for different clones of Syrah, St. David's Bench, NOTL, 2010-11. (Willwerth, unpublished)

4B. Growing Season Weather Influence

The conditions during the preceding growing season can have impact on vine hardiness and susceptibility to injury from severe weather episodes.

YEAR	Bud Break to Prebloom	Bloom to Fruit set	Fruit Set to Veraison	Veraison to harvest
2009	Wet Cool Slow	Wet Average Temps	Wet to Very Wet Cool	Dry Sept Average Oct Cold October
2010	Dry, average Warm to bloom	Very wet Average Temps	Moderate rain Warm	Average Sept and Oct Average temp
2011	Very wet Cold start	Dry Average Temps	Very dry (40 days) Very Hot July	Wet Sept and Oct Average Temps
2012	Very Early Start Hot, Dry May	Slightly Dry Hot June	Dry July and Wet Aug Average Temps	Very Wet Sept and Oct Average Temps
2013	Average Rainfall Average Temps	Very Wet Average Temps	Wet Average Temps	Average Sept and Wet Oct Warm Oct

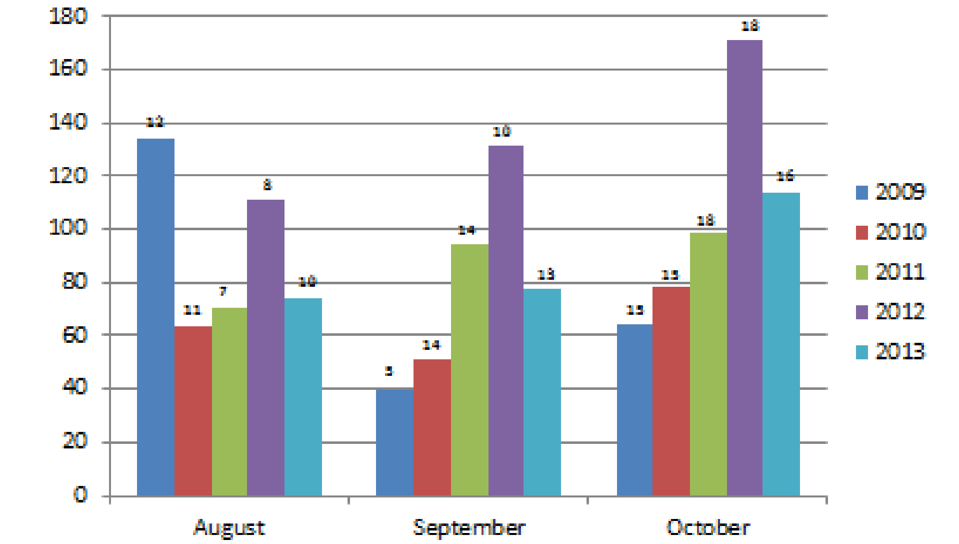
Figure 4.5. Generalized description of weather for vine development periods 2009-2013.

Figures 4.5 and 4.6 show the type of variability that can occur in Ontario over multiple years. The period from veraison to harvest is very important as this heavily influences the rate of vine acclimation and the water status of the vine and its buds, vascular system and trunk. If the season is delayed due to later bud break and weather conditions during the growing season, as was the case in 2009, 2011 and 2013, we can expect a later maturation period where heat units and weather conditions may not be as favourable. These factors can delay acclimation, whereas in 2010 and 2012, vines were 'hardening off' earlier during the fruit maturation period and acclimation rates were greater than the cooler and wetter seasons.

YEAR	BUD BREAK	BLOOM	VERAISON	HARVEST (Chard.)	GDD base 10°C Apr 1 – Oct 31	PPT mm Apr 1 – Oct 31
2009	May 15	June 27	August 27	October 19	1266	585
2010	May 6	June 14	August 15	October 1	1662	526
2011	May 17	June 24	August 22	October 12	1589	629
2012	May 2	June 12	August 9	September 28	1677	625
2013	May 10	June 17	August 18	October 11	1527	703

Figure 4.6. Key Dates of Developmental Stages for cv. Chardonnay (Queenston location) for 2009-2013.

The above figure (Fig. 4.6) shows the variability in vine growth response to weather conditions during the period 2009-2013. It is important to note that harvest dates during that period varied by up to 21 days. Variability in our seasons can impact cold acclimation considerably and therefore estimating cold tolerance of grapevine tissue by calendar date is impossible. From Figure 4.3, it can be seen that on a similar calendar day of different vintages, cold hardiness can differ upwards of 5 °C depending on growing season conditions and inherent crop size on that given year.



	2009	2010	2011	2012	2013
Veraison	August 27	August 15	August 22	August 9	August 18
Harvest	October 19	October 1	October 12	September 26	October 11

Figure 4.7. Precipitation events from veraison to harvest at Queenston, ON. 2009-13.

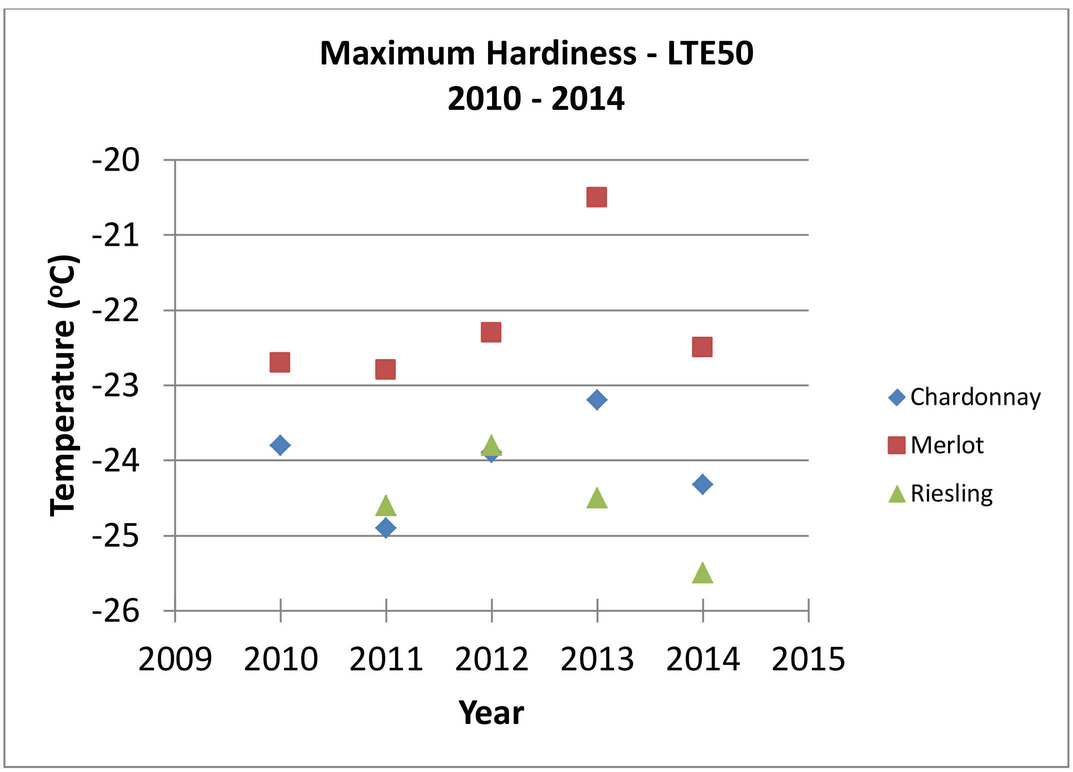


Figure 4.8. Maximum hardiness levels of Chardonnay, Merlot and Riesling located at Queenston ON 2009-2013.

Figure 4.8 show that cultivars achieve slightly different maximum hardiness levels each year. The data also shows that Riesling is generally hardier than Chardonnay and that Merlot is more susceptible to winter injury as it does not get as hardy as the other cultivars.

In looking at Figures 4.7and 4.8, late season precipitation, which results in saturated soils and delayed crop maturity, appears to have an impact on maximum vine bud hardiness. The very wet fall of 2012 had definite impact on hardiness of the cultivar Merlot where maximum hardiness only reached -20.5°C compared with -22.5°C or better in all other seasons. However Chardonnay was less affected after 2012 and this is likely explained as the crop had been harvested before the rains of October took place. Total growing degree days (Figure 4.6) did not seem to have as much impact as precipitation with respect to vine and maximum bud hardiness but did impact crop maturity.

4C. Crop level and timing of harvest

Cropping levels are extremely important to maintain vine health as it can impact wood maturation (Edson et al., 1995) and cold hardiness (Howell et al., 1978). New wine styles are emerging in the Ontario wine industry that are unique compared to still wine production. Viticulture practices that are ideal for high quality still table wine may not be optimal for premium sparkling wine, *appassimento*-style wine, or Icewine production. To create these premium wine styles, various crop levels and/or harvest dates are required to ensure product typicity that may differ from that required in still wine production. The impact of timing of harvest on *V. vinifera* cold hardiness has not been widely addressed under climatic conditions found in Ontario or in combination with varying crop levels.

Grapevines have varying levels of crop depending on variety, location, training system and end use of the grapes. Ontario is no exception and in some vineyard blocks, crop levels can be considerably higher than other blocks when used for Icewine production or target (plateau) priced for lower tier wines. Higher crop levels have been associated with lower cold tolerance in previous literature for some hybrid varieties. Furthermore, some Vidal Icewine blocks have had a tendency to show reduced bud survival following some years of Icewine production especially where they have been machine harvested or the block has been used in consecutive years for Icewine production.

Research studies were carried out using 6 different *V. vinifera* cultivars from 2011-2013 growing seasons to assess impact of crop yields on bud hardiness and survival. The varieties included Riesling, Chardonnay, Sauvignon blanc, Pinot noir, Merlot and Cabernet franc. Replicated factorial experiments of two cropping levels x multiple harvest dates were imposed on three white (Chardonnay, Sauvignon blanc, Riesling) cultivars and three red (Pinot noir, Cabernet franc, Merlot) cultivars over a 3-year period. **Crop level treatments** consisted of two cluster-thinning levels of **1 cluster/shoot (half crop)** and **2 clusters/shoot (full crop)**. The number of clusters retained per vine represented approximately 2.5 tonnes/acre and 5 tonnes/acre for half and full crop treatments, respectfully. Two different harvests occurred for each crop level treatment: one at normal commercial maturity and another after an additional hang time of 3 weeks.

In general, Chardonnay, Pinot noir and Merlot had reduced maximum hardiness due to cropping level and/or timing of harvest. Heavier crop levels and later harvests reduced maximum hardiness especially in cooler, wetter and delayed seasons. For Cabernet franc, Sauvignon blanc and Riesling, crop level and/or harvest date did not generally impact the vine's ability to reach maximum hardiness levels.

However, from these studies, cultivars acclimated at slower rates with higher crop level and later harvest date putting these vines at higher risk if a cold event were to occur early in the vine acclimation period. The combination of heavier crop levels and harvesting later in the fall resulted in slower vine acclimation. Growing season conditions and timing of maturity also played an important role in terms of vine cold hardiness. High yielding vintages with cooler and wetter conditions than average such as 2011 were found to have reduced cold tolerance, with delayed acclimation and reduced maximum hardiness (see Figure 4.9). However in warmer and 'earlier' seasons such 2012, higher crop levels and later harvests did not impact cold hardiness as the vines matured very early in 2012. Therefore there is some truth to notion of 'good fruit maturity equals good vine maturity". If grapevines are struggling to mature the crop it is very likely that cold hardiness will also be reduced and should be taken into consideration when going into the winter months. This is even more critical for some varieties such as Sauvignon blanc, which is notorious for not hardening off well and having late season growth. As shown in Figure 4.9, Sauvignon blanc with larger crops and harvested later acclimated at slower rates and did not reach maximum hardiness until a later stage of dormancy.

Over-cropping can reduce maximum hardiness but in poor growing seasons even a balanced vine may have slightly reduced hardiness as shown in previous sections (see figure 4.9 and 4.10). Pinot noir is known to be very sensitive to crop levels and quality and this true in terms of cold hardiness as well (see Figure 4.10). Pinot noir vines with more clusters/shoot had reduced cold tolerance regardless of harvest date. For other varieties larger crop levels generally reduced cold hardiness throughout all of dormancy in some years. Riesling was more of an exception and did not respond strongly to crop levels but later harvests reduced cold hardiness (see Figure 4.11). Later harvests delayed acclimation and maximum hardiness and promoted earlier deacclimation. Therefore, Riesling vines used for Icewine production may be slightly compromised in some years.

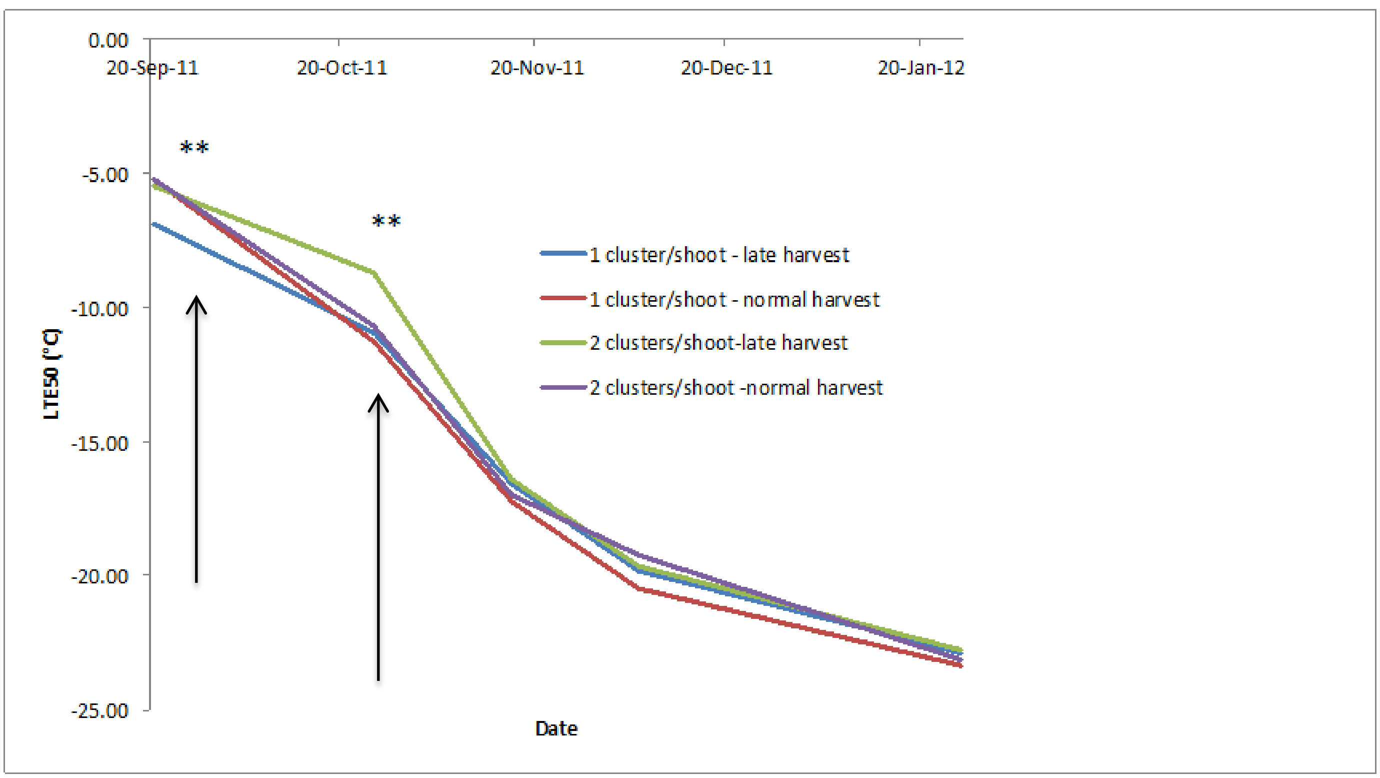


Figure 4.9. Impacts of crop level and timing of harvest on cold acclimation in Sauvignon blanc. NOTL, 2011-12. Black arrows represent the 2 different harvest dates. *** Indicate significance @ p<0.01*. (Willwerth, unpublished).

In the spring of 2014, vines with larger crops in the 2013 growing season, and not balanced in terms of crop level to vegetative growth, generally had more damage compared to those that were balanced at the same location. Through optimizing crop levels with vegetative growth and extending hang time, greater fruit quality can be achieved; however later harvests may delay cold acclimation for some cultivars. This is significant for tender varieties such as Sauvignon blanc and Merlot where reaching maximum hardiness is critical.

In general, achieving vine balance and good maturity will lead to optimized hardiness. A small to average crop will not necessarily guarantee better cold hardiness but over cropped vines that restrict vegetative growth and delay vine maturity, such as those in Figure 4.12 show a reduction in rate of acclimation and possibly maximum hardiness for most of Ontario's core *vinifera* varieties. If fruit maturity is delayed due to high cropping level or prolonged growing season it can be expected that cold tolerance will also be delayed or reduced under Ontario's climatic conditions.

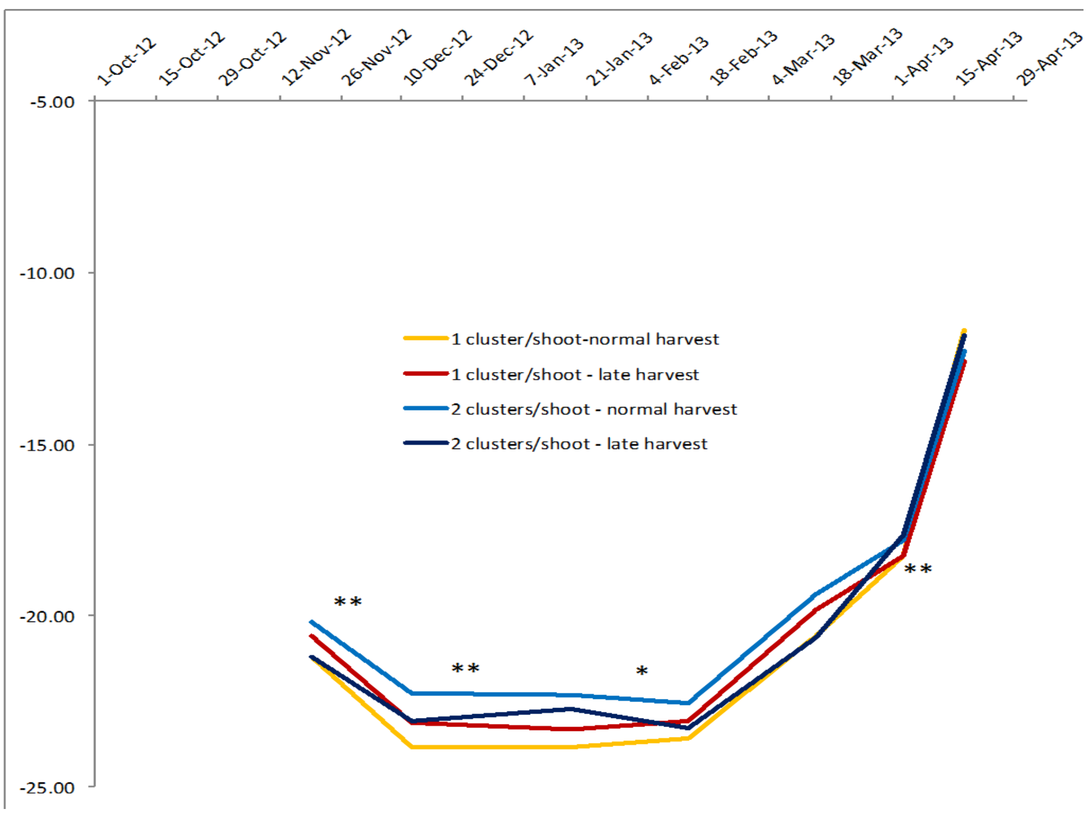


Figure 4.10. Impact of crop level and timing of harvest on cold hardiness dynamics of Pinot noir 2012/13. Vineland, ON. **, ** Indicate significance @ p<0.05, p<0.01, respectively*. (Willwerth, unpublished)

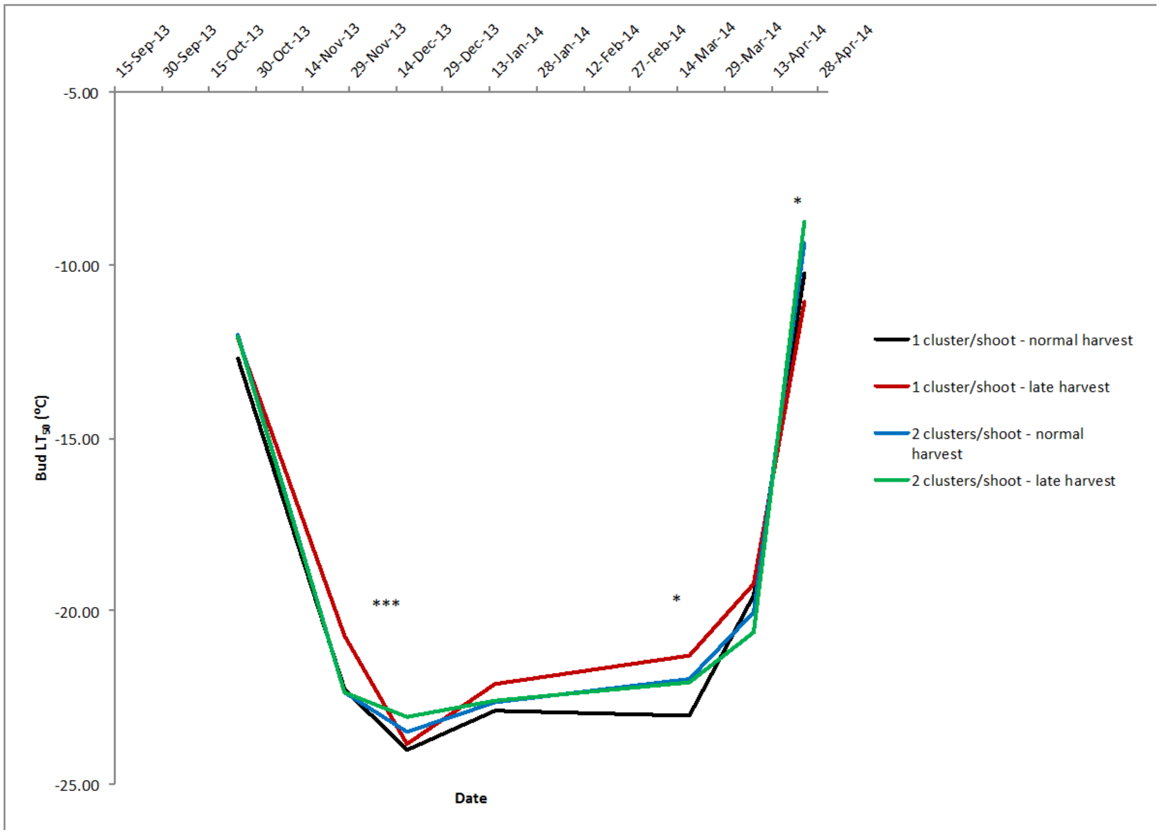


Figure 4.11. Impact of crop level and timing of harvest on cold hardiness dynamics of Riesling (2013/14). Vineland ON. **, *** Indicate significance @ $p<0.05$, $p<0.001$, respectively.* (Willwerth, unpublished)

Figure 4.12. Over-cropped vine showing severely stunted shoot growth

4D. Vine Health

Healthier vines are more likely to withstand lower temperatures and subsequent winter damage than unhealthy vines. Carbohydrate levels are higher in healthy plants allowing for higher solute concentrations inside the plant cell, which will prevent ice crystal formation. Addition of fertilizers late in the season results in prolonged growth into the fall. This late growth prevents woody tissue formation and decreases vine winter hardiness (Stafne, 2007). Optimizing vine health is critical to achieving maximum winter hardiness and if damage occurs, gives the vine the best chance of recovery.

Other factors that can compromise vine health include late season disease infections (for example powdery mildew and downy mildew) that reduce vine photosynthetic activity and carbohydrate storage. Viral infections from diseases such as Leaf Roll Associated Virus or Red Blotch Virus that restrict vine growth and maturity late in the season can potentially impair vine acclimation and maximum hardiness and may leave those vines susceptible to damage at higher temperatures than healthy vines. Based on some preliminary work, Red Blotch virus does seem to reduce bud hardiness slightly (Willwerth, unpublished), however vines that are still productive do not appear to have reduced winter survival rates.

Vines with significant loss in growth and productivity due to virus, nutrition deficiencies, water stress or other disease are likely to have reduced cold tolerance and are more likely to experience higher levels of damage or vine loss following cold winters. Heavy insect pest activity during the season for leaf injury pests like leafhoppers, Japanese beetles, phylloxera, or mites can reduce overall vine health that can lead to reduced hardiness. Good season long pest control is critical for to allow the vines to reach their potential maximum hardiness.

4E. Soil and Drainage

Proper site management is important to enable vines to properly mature a crop and properly acclimate for maximum winter hardiness. Proper site management practices that provide balanced root development for storage of carbohydrates for over wintering include the installation and maintenance of tile drainage. Lack of proper drainage can lead to water logged soils, poor root growth and delayed crop maturity that will reduce vine winter hardiness (see Figure 4.13). Biannual alternate row subsoiling to break up hardpans and to prevent soil compaction has proven to be extremely helpful in allowing vines to acclimate quickly and efficiently. Tiled soils contribute by enabling good soil microbial activity, porosity and allow for superior root development that allows for more uniform vine development and growth (Ker 2007).

Figure 4.13. Vines with 'wet feet' in poorly drained vineyard. Note poor periderm formation on canes

<u>4F. Soil and Water Status</u>

In the Niagara Peninsula, studies were performed in respect to winter hardiness in Riesling and Cabernet franc grapevines and their relationship to moisture within the soil and the vine's response. Within vineyard sites, the amount of water in the soils varies throughout the growing season and from year to year. However, the same spatial pattern is often observed with some regions having lower amounts of moisture than others. This is largely due to soil drainage and soil type (i.e. areas of heavy clay vs. sand). This can lead to vines performing similarly in one area of a vineyard compared to another section. In other words, a vine that exhibits water stress during one dry growing season is more likely to experience that same stress during other growing seasons. This consistency pertains not only to soil moisture and vine water status but also to the winter hardiness of a vine (Jasinski, 2013).

Figure 4.14, depicts spatial maps showing variation of vine water status (water stress) and bud hardiness for Cabernet franc within a vineyard block. These maps show that bud hardiness can vary within a given vineyard block, upwards to a few degrees Celsius for a given variety. Vine water status also varies within a site due to factors such as soil type and depth, drainage, vine rooting depth and due to irrigation. In Figure 4.14, regions of mild water stress (leaf ψ between -10 to 12 bars) generally had better bud hardiness than those regions with higher water stress (leaf ψ -12 to 14 bars).

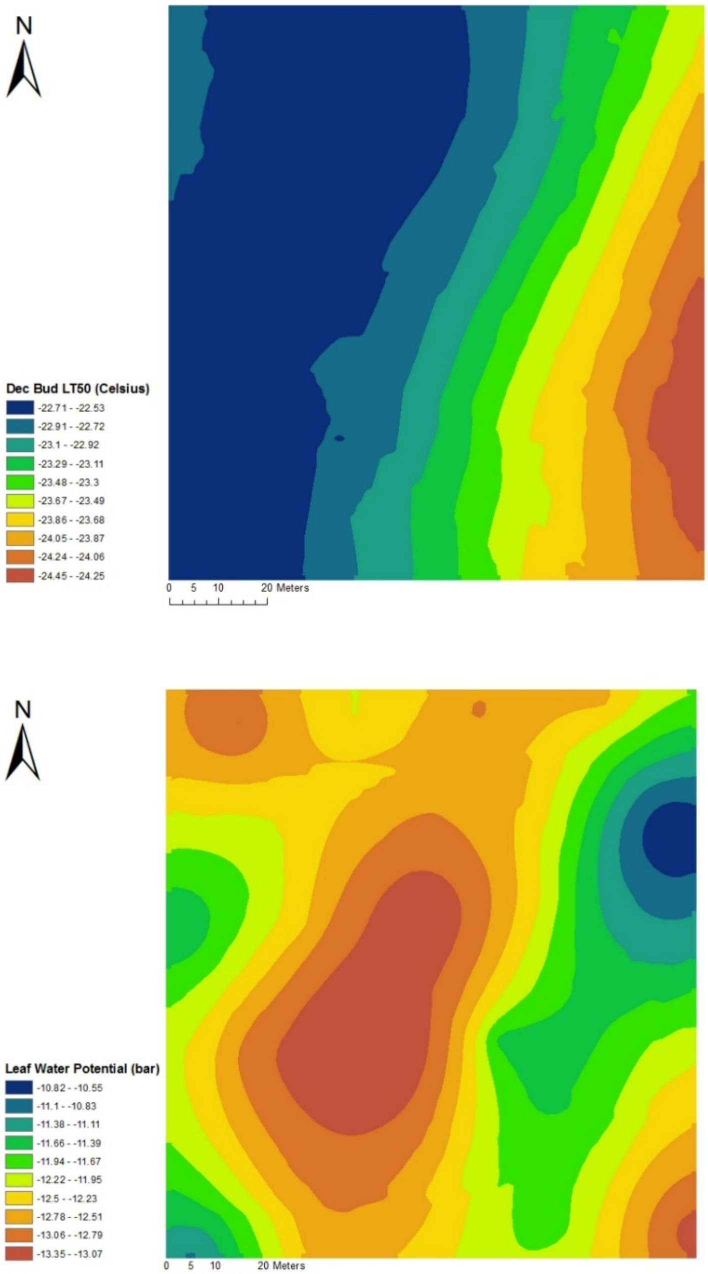


Figure 4.14. Spatial distribution of bud hardiness (upper) and leaf water potential (lower) in a Cabernet franc vineyard. Lincoln Lakeshore, 2010. Blue regions represent areas of high water status; and lower bud hardiness; orange/red regions represent low water status and greater bud hardiness.

Results show that for Cabernet franc for the 2010 and 2011 growing seasons, balanced vines (proper balance of vegetative growth and crop load) located in areas with relatively higher soil moisture were more likely to develop greater winter hardiness (Jasinski, 2013). In areas with higher moisture, vines should not be under-cropped as they may produce over-vigorous shoots and will take longer to acclimate. Different varieties require different practices – Cabernet franc vines which experience mild water stress and that are balanced are more winter hardy, especially for vines located in areas prone to frequent low temperature episodes during the winter months (Jasinski, 2013). As with Cabernet franc, Riesling should be cropped in order to balance the vine, being heavier cropped where vines are more vigorous (such as in sandier soils near Lake Ontario). However, over cropping vines can result in reduced winter hardiness as has been shown with other research such as the Crop level x harvest date studies discussed earlier. In excessively vigorous AND heavy crop situations, Riesling may not fully acclimate until later during dormancy. This delayed acclimation can result in vines being damaged if a cold event occurs early to mid-December (Jasinski, 2013).

To generalize for common grape varieties in Niagara, well-balanced vines supplied with adequate water are hardier than vines that have been under- or over-cropped. The characteristics of each vineyard will dictate how a vine must be balanced. Therefore, some vineyards or areas of a vineyard may be more susceptible to winter injury due to too much or too little water. Soil, irrigation strategies as well as crop levels influence this. These interactions should be addressed in order to reduce winter injury. For example, vines that have excess vigour and have high water status can support a larger crop and not be compromised in terms of winter hardiness. However smaller vines that are demonstrating moderate to high water stress (dry growing conditions or low water status) may not be able to support a large crop and winter hardiness may be compromised in these situations. In areas of the vineyard where vines have shown winter injury (i.e. low spots) particular attention should be paid to their vigour, crop level and water stress.

4G. Canopy Management and Training System

Proper canopy management can increase vine cold tolerance. Downward trained shoots of *Vitis vinifera* can decrease bud cold hardiness (Vanden Heuvel et al. 2004) and therefore Scott Henry trained vines can be more susceptible early in the dormant period (see Figure 5.1). Increased light exposure of shoots results in increased vine hardiness (Howell and Shaulis 1980; Wolpert and Howell 1985). Divided canopy training systems, controlling vine size, pruning levels, shoot positioning, and shoot thinning all can increase winter hardiness due to improved light conditions in the canopy (Howell and Shaulis 1980; Wolpert and Howell 1985). Large diameter canes are less winter hardy. Therefore, diverting or reducing vigour through management practices or using a divided canopy system may improve sunlight exposure of shoots and increase hardiness. Overly vigorous or shaded canopies will often grow late into the fall and shoots/buds will not harden off well nor be fruitful. Therefore, there is no substitute for good, sound canopy management and maximizing light exposure within the canopy.

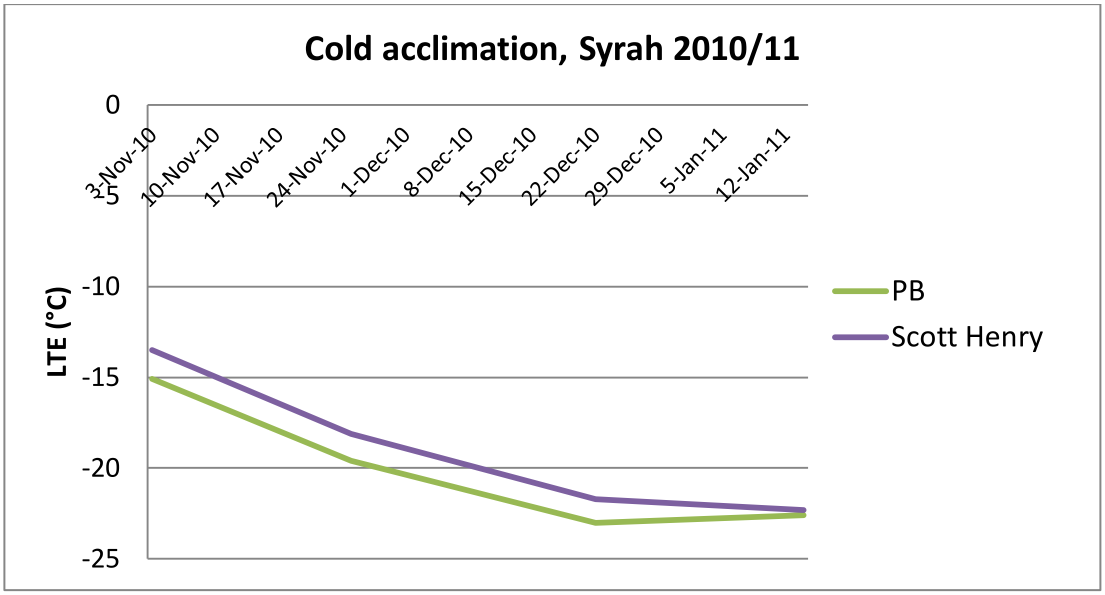


Figure. 4.15 Cold acclimation in Syrah under two training systems, Pendelbogen (PB) and Scott Henry. NOTL, 2010/11/ (Willwerth, unpublished)

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5. CULTURAL PRACTICES AND PROTECTION

5A. Management of grapevines to reduce freeze injury

Site selection

The site topography and location can affect the likelihood of experiencing winter injury. Site selection is important for vineyards, since it not only influences the potential of winter damage but other factors that are important for vine health such as soil texture, water holding capacity, fertility, drainage, proximity to wooded areas, availability of irrigation water, possible sources of disease pressure, slope and sun exposure. A moderate slope with slightly higher elevation will allow for cold air to flow downwards and away from the vineyard. Cold air is denser than warm air and will flow downward much like water does towards a drain. Vineyards with good slope and natural air drainage are found in areas such the bench areas of Beamsville, St. David's and Short Hills appellations.

Vines growing in lower parts of the vineyard or in depressions are more likely to be injured, as cold temperatures are more severe in these areas relative to the rest of the vineyard. Vineyards that have very little natural slope are also at risk as cold air can become almost static with very little natural flow. Some vineyards in Four Mile Creek and back from Lake Ontario in Lincoln are relatively flat and often use supplemental protection with wind machines. These sites often have very cold temperatures relative to higher elevation or sloping vineyards on very still nights during the winter. Impediments such as buildings, trees, forested areas, or other nearby elevated obstructions (elevated roadways, train tracks, etc.) must be noted and protective practices employed.

Proximity to large bodies of water that remain unfrozen can protect vineyards during cold events as the water can modify the ambient air temperature enough to keep it from reaching damaging level in the vineyard. An example of this is the region along the shore of Lake Ontario (which rarely freezes over) and along the Niagara River. However, it is important to recognize that if ice floes develop along shore or out into a large water body, the temperature modification effect of open water decreases as the floes reach further into the lake and leave shoreline vineyards experiencing temperatures as cold as further inland. This freezing of the large body of water means the loss of additional natural protection.

Temperature monitoring

Monitoring temperatures in the vineyard is very important. Each site has specific characteristics – topography, soils, cultivars, cropping history and many others that influence vine hardiness. The local or vineyard mesoclimate can vary within the vineyard from east to west and north to south depending on the size, natural slope and aspect. For this reason, multiple stations have been located throughout the grape growing regions of Ontario and have demonstrated that on a single night the lowest cold temperatures can differ by up to 5 °C or more. This variability in cold temperatures means that some vineyards may be subject to lethal temperatures for buds and vines while others less than 1 or 2 kilometers away may be warm enough to miss being injured at the same time. Being able to know the temperature at your particular site or vineyard area is very important as it can mean the difference in bud survival or death and can also be helpful in determining the need to use wind machines or not to prevent injury.

Use the best local weather information available to assess your site temperatures either with personal onsite temperature monitoring equipment or from regional information from nearby vineyards. To monitor for cold temperature, sensors should be located in the lowest and coldest parts of your vineyards just below fruiting wire height or lower so that activation for wind machines can be done well before the temperatures reach damaging levels. Many growers use automated sensors on the wind machines that will initiate start up at 2 °C higher than estimated temperatures that would cause injury. This early start up is to enable the machine to be operative and begin functioning as designed before the coldest temperatures occur. For additional information on Wind Machine use refer to the publication *Reducing Cold Injury to Grapes Through the use of Wind Machines 2009 – Final Report: CanAdvance Project # ADV-161* (http://www.kcms.ca/pdfs/Final_Wind_Machine_Report_2010.pdf)

5B. Management of grapevines to reduce effects of winter injury

Knowing that winter injury has occurred and where in the vineyard is just half of the process of dealing with winter injury. The second involves what mitigation strategies to use depending on severity of injury and whether the vines can be easily renewed or require re-trunking or removal and starting a new block.

There are general guidelines for how a vineyard will perform after being subjected to winter injury. Vine survival and long term health is first priority in trying to have a vineyard return to full productivity as soon as possible.

Assessing injury levels is very important, as this will be used as a guide for pruning, re-trunking or replanting. If you have not taken advantage of hilling nor have single trunks that are old and have not produced suckers for a few years, the chance of recovery is very poor to slim. Experiences after the freeze events in 2003, 2005 and again in 2014 demonstrated that many trunks were " blind" and did not push sucker growth from the scion wood to recover and instead pushed rootstock suckers or were just plain dead! Blocks with vines that had multiple trunks of different ages and hilled HAD MUCH HIGHER survival rates and successful renewal than those vineyards with a single trunk. The use of double or multiple trunks for cold tender vines should be standard, especially in higher risk locations or those not capable of using wind machines or other practices.

Additionally, vines in the 3 years and under category (no crop) and older, well-balanced vines had better survival rates than those in the 4 to 7 year category producing their full heavy crops. Unbalanced vines with excess or too little crop (with excessive shading and wood growth – large canes) had more injury than properly balanced vines.

Another observation was the increased presence and development of crown gall with winter injury. This was observed not just in the season following injury but also for multiple years afterwards. The presence of crown gall in a vine is not enough to cause galls; rather it is the infection of outer cambium cells (conductive tissue just beneath the outer bark layer of the trunk) that become infected as they attempt to heal wounds caused by freeze injury. These cells are altered such that they continue to form callus tissue that continues to enlarge and eventually block the conductive tissues and cause a physiological girdling of the vine. When this occurs, the entire vine parts above the galling area die.

Bud Mortality and Suggested Pruning Modifications	
Primary Bud Mortality (%)	Pruning Adjustments
0-15 %	None – prune as normal for balanced crop
16 to 30%	Increase buds retained by 50% Bring up renewal suckers to establish future trunks
31 to 50%	Leave double the number of buds If pruning, hedge only leaving long spurs Bring up multiple renewal suckers to establish future trunks
>60%	Don't prune Bring up multiple suckers if scion pushes any from above graft union

Pruning Strategies

The goal of pruning a vine after winter injury episodes is to get the vine back to full health, fruitful productivity and in balance. Some vines may die immediately or trunks may collapse over a period of 2 to 4 years after damage.

Removal of the parts known to be damaged or suspected as being injured should be part of the pruning process. However, do not remove old trunks if they are supporting canes to provide a better balance of bud numbers during a recovery period. There is no need to prune out a crown gall infected trunk immediately if it is supporting some buds during renewal/retraining. Once new trunks are established this crown gall infected trunk should be cut out and removed from the vineyard.

With severe winter episodes in 2003, 2005 and now 2013/14 it is apparent that we need to protect vintages and reduce risks at all times. The first recommendation is using multiple trunks and regular trunk renewal. The use of double or multiple trunks should be a STANDARD practice to provide extra protection against winter injury. This will allow for the vine to be capable of being renewed on a regular basis.

Bringing up several suckers will allow for better balance of shoot growth to establish new trunks and to support the existing large root systems and to minimize the growth of bull wood renewals. Any non-needed suckers can be removed the following year.

A **balanced vine** will have strong, but not overly vigorous cane growth (roughly pencil size in diameter) that developed all retained buds the previous season. If some canes are **weak or spindly**, this may correspond to having too many retained buds or **excessive crop levels**. This should be a guide to reduce the number of buds per vine for the next season. If some canes have a **large diameter** (thumb size diameter or greater) this is an indicator of excessively vigorous growth with likely

too small of a crop level perhaps because too few buds were retained the previous year. Other signs of excessive vigour in the previous season are dense thick canopies requiring multiple hedging and leaf removal in season, uneven fruit maturity and quality and high percentages of non-fruitful shoots (often due to excessive shading the previous growing season.

Determining Vine Balance

Assessing whether a vine is in balance or not can be undertaken in season or at pruning time. The pruning time decisions can be easily and quickly done by weighing the prunings. The following is a general table showing whether or not a vine is producing too little or too much crop and targets for balance.

For measuring pruning weights, do one vine at a time and then repeat the process on a few "average vines" in the block.

This must be done before any trimming or pre-pruning.

The pruning's you collect are only the growth of the previous season (all shoot growth – primaries and laterals from previous growing season present at time of dormant pruning). Do not include trunk or permanent cordon wood removed due to injury.

Record the pruning weight for each vine. By doing this for multiple vines you will quickly develop an eye for estimating the weight of pruning's on a given vine and can adjust the bud numbers accordingly.

Formulae were developed for ***labrusca* and *hybrid*** grapes based on vigour and size. Some may have heard of a "30 plus 10" or "20 plus 10" formula. For a large vigorous vine this meant:

• Pruning Formula: 30 + 10 meant Leave 30 nodes ("count buds") for first pound of canes removed plus an additional 10 for each additional pound. This resulted in Pruning wt = 1 lb – leave 30 nodes, Pruning wt = 2 lb – leave 40 nodes, Pruning wt = 2.5 lb – leave 45 nodes, Pruning wt = 3 lb – leave 50 nodes, etc.

For ***vinifera*** grapes, the general formula was "20 plus 20" as rarely did we have individual vinifera vines producing 2 pounds or more of canes in a single season.

However, over time these formulae proved less reliable and growers looked for other mechanisms. Information developed and used by many researchers has looked at the pruning weights and number of buds per meter of row as one component of measuring vine balance.

General guidelines have been developed, modified and adapted by others depending upon local conditions, site potential and cultivar. These were noted to ensure good, even spacing of nodes along the fruiting wire to get good shoot positions, adequate fruit exposure and optimum (not maximum but optimum) shoot and leaf development over the season and to provide for good fruitfulness in following years. In general, for *vinifera* vines, 12 to 15 buds per meter of row length have proven to be reasonably reliable for annual production.

The goal of achieving a balance between crop level and canopy/shoot growth is often a challenge. Despite the significant impact of pruning on crop levels, it is not enough by itself to achieve the desired vine balance. For instance, Pinot noir, Riesling, Cabernet Sauvignon, Merlot, etc., grown in Ontario generally requires additional crop thinning during the season to ensure complete ripening of the fruit AND proper vine maturity going into winter to achieve optimum winter hardiness. As mentioned previously, CCOVI studies indicate that crop levels can impact cold hardiness dynamics and that heavier crops can lead to slower vine acclimation and mid-winter hardiness. The impacts of crop levels on cold hardiness can also be cultivar AND vintage specific.

Balanced vines produce the best fruit each year and continue to do so for many years. To hedge our bets, we must practice “spare parts” viticulture as we may not know when we are faced with adverse winter temperatures but we can be sure they will happen!

Figure 5.1. Use of ‘spare parts’ viticulture. A vine with multiple trunks of different ages.

There is no single training system or bud number or crop level that fits all sites and environments just as no one suit fits all people that work in a single company. Keep this in mind that not all blocks and cultivars are the same even at one location. Modification to get high quality fruit and keep the vines productive and economical each and every year should be the target!

5C. OVERVIEW OF PROTECTION METHODS

Use of Wind machines

Wind machines help modify the temperatures at ground level in a vineyard by pulling warm air down from high above ground. They are used when there are strong temperature inversions (where temperatures at 15 m above ground are much warmer than those at ground level) as they mix the warm upper air with cold ground air resulting in an increase of air temperatures around grapevines. Most wind machines are stationary/fixed-in-place, engine-driven fans (powered by propane, diesel and natural gas). However there are some newer machines entering the market place that are smaller, powered by tractors and somewhat movable.

Wind machines work with fan blades angled downward from vertical. During cold episodes with a temperature inversion, these machines pull warm air from at least 15 m above the field and mix the cold air near the vines with warm air from the inversion raising the ambient ground temperature surrounding the vines. While the blades spin, the head of the fan rotates around the tower's vertical axis. Air circulates north, east, south, west then back where it started 4.5-6.5 minutes earlier, depending on machine type. The area protected covers 3-5 ha (7.4-12.4 ac) depending on topography, field layout, strength of temperature inversion, time of year and drift due to slight winds. If the machine completes this circuit too slowly, cold air can resettle or drift in from cooler areas upstream or upwind of the machine, resulting in crop injury. Synchronizing a group of wind machines to direct air all in the same direction, all at the same time might improve effectiveness, but is not currently done for logistical reasons. Wind machines need to warm up 5-15 minutes before running full speed, and the same time to cool down (Fraser et al. 2010). For a complete description of wind machine use and function please see (http://www.kcms.ca/pdfs/Final_Wind_Machine_Report_2010.pdf).

We now recommend coordinating wind machine use with the VineAlert Bud Cold Hardiness and Alerting system described in section 5.D below as the risk management system of choice for avoiding winter damage to grapevines. VineAlert provides the measurement of bud cold hardiness for grapevine varieties throughout the dormant season and alerts grape growers when vines are at risk of damage from a cold weather event (https://www.brocku.ca/webfm_send/30701). The VineAlert system is used in conjunction with wind machines to initiate protective strategies that warm up the air around vines when vines are at risk of damage to mitigate the impact of a cold weather event. The system is explained in section 5.D and the economic impact of the system used in conjunction with wind machines is summarized in the Economic Impact Study in the appendix.

Protection of vines by burying with soil or use of geotextiles

In some areas cold sensitive *V. vinifera* grapes are grown where they cannot survive winter temperatures without some form of protectionIn regions such as Prince Edward County, grapevines are commonly buried with soil for protection. Geotextiles are materials used for winter protection of crops, mainly in the nursery industry but are also used in some vineyards in Quebec where winter temperatures can be severe (see Figure 5.2). There has been greater interest in these materials for vineyard use in Ontario and some growers are currently experimenting with them.

Growers are concerned that through the process of burying/unburying (see Figure 5.3) that vines can be physically damaged leading to crown gall infection and detrimental to soils through aggressive cultivation and hilling. Furthermore, bud loss can occur due to physical damage as well as rot, particularly in wet spring and falls. Finally, timing of application and removal of protective materials and weather conditions are critical for good protection and prevention of premature bud break which can result in bud mortality due to freeze injury from spring frost. Therefore, the use of geotextiles may be a way to eliminate these concerns while helping to increase and sustain production yields.

An experiment was undertaken to test different types of geotextile materials and their impact on cold hardiness, bud survival and crop potential. To date, the use of these materials have been shown to be a very effective way of protecting buds from freeze injury, leading to better vine health and significantly better production in terms of yields. Data from the 2013 growing season show that geotextiles can double yield/vine (i.e. 2.1 kg vs. 0.9 kg/vine for Chardonnay) compared to traditional methods of using soils (http://brocku.ca/webfm_send/25980).

Figure 5.2. Experimental vineyard using geotextile materials for winter cold protection in Prince Edward County. Wellington, ON.

Figure 5.3. Dehilling of buried vines in the spring

Geotextile materials and vine burial impacts grapevine microclimates over the dormant season. These winter protection methods can improve temperatures (daily average, minimum and maximum) and therefore can be effective at mitigating cold mid-winter temperatures (as shown in Table 5.1). Temperatures under soil are generally the most consistent throughout the winter months and have the warmest temperatures during cold periods. Vines under soil also experienced the lowest absolute maximum temperature compared to higher temperatures using geotextile materials where some ‘greenhouse effects’ can occur. Temperatures under polyester felt material were more sporadic than other methods such as and were not as consistent throughout the dormant period where high and low temperature peaks were common, particularly during warm spells. Snow cover is very important for improving temperature mitigation regardless of protection method. It improves effectiveness and consistency of both geotextiles and soil, especially in situations where soils have been washed away from vines.

Table 5.1. Vine microclimate temperatures during the dormant season using different grapevine protection methods within Prince Edward County. Wellington, ON. (2012-13).

November (last 2 weeks of the month)				
	Ambient	Polyester felt	Polyester felt with black LDPE	Under Soil
Monthly mean temperature (°C)	1.0	1.1	1.2	1.8
Absolute Maximum temperature (°C)	12.1	16.5	13.8	9.6
Absolute Minimum temperature (°C)	-8.7	-7.3	-5.9	-2.9
December				
	Ambient	Polyester felt	Polyester felt with black LDPE	Under Soil
Monthly mean temperature (°C)	-0.3	-1.6	0.5	1.2
Absolute Maximum temperature (°C)	15.3	9.3	14.7	10.5
Absolute Minimum temperature (°C)	-11.3	-6.6	-6.9	-3.1
January				
	Ambient	Polyester felt	Polyester felt with black LDPE	Under Soil
Monthly mean temperature (°C)	-3.4	-2.9	-2.8	-1.5
Absolute Maximum temperature (°C)	13.4	17.4	16.4	8.7
Absolute Minimum temperature (°C)	-23.4	-19.1	-19.4	-10.3
February				
	Ambient	Polyester felt	Polyester felt with black LDPE	Under Soil
Monthly mean temperature (°C)	-6.5	-3.7	-3.2	-1.5
Absolute Maximum temperature (°C)	5.5	6.8	6.0	-0.1
Absolute Minimum temperature (°C)	-25.4	-17.6	-13.9	-6.5
March				
	Ambient	Polyester felt	Polyester felt with black LDPE	Under Soil
Monthly mean temperature (°C)	-0.3	0.7	-2.78	0.9
Absolute Maximum temperature (°C)	11.7	17.9	16.37	11.9
Absolute Minimum temperature (°C)	-11.8	-9.5	-8.9	-3.5
April				
	Ambient	Polyester felt	Polyester felt with black LDPE	Under Soil
Monthly mean temperature (°C)	4.5	5.5	5.2	6.2
Absolute Maximum temperature (°C)	19.1	22.0	22.5	16.3
Absolute Minimum temperature (°C)	-10.1	-7.3	-7.1	-0.1

Vine burial/geotextile strategies impact grapevine cold hardiness during all stages of dormancy.
Geotextile materials were found to have some minor impacts on grapevine cold hardiness with some reductions in hardiness levels (particularly LTE10 values) during acclimation and deacclimation (see Figure 5.4) In terms of geotextile materials, grapevine cold hardiness values were found to be more consistent under the PF-LDPE material with less fluctuation in hardiness compared to the other treatments. Deacclimation rates were lower using this material and buds had equivalent cold hardiness values compared to buried Chardonnay and Pinot noir vines. Polyester felt materials were more variable and had significant reductions in cold hardiness during acclimation and deacclimation. These responses are likely due to higher vine microclimate temperatures during these periods.

Removal of protection methods from grapevines in a timely manner is important to reduce later winter/spring freeze injury. Polyester geotextile materials can reduce hardiness when left on the vines during the deacclimation period. The same issue can occur with buried vines as well, however vines are less likely to experience large temperature increases under the soil compared to those under geotextiles. Uncovering vines with geotextiles is more flexible than soils and so vines can be partially uncovered to reduce loss of cold tolerance during March and April but can still provide some frost protection. One of the biggest concerns with unearthing vines is that once the process begins it is not feasible to rebury again in a timely or effective manner. This was an issue in 2012 where deacclimation and bud break occurred early and there was spring frost damage in some regions where vines are buried.

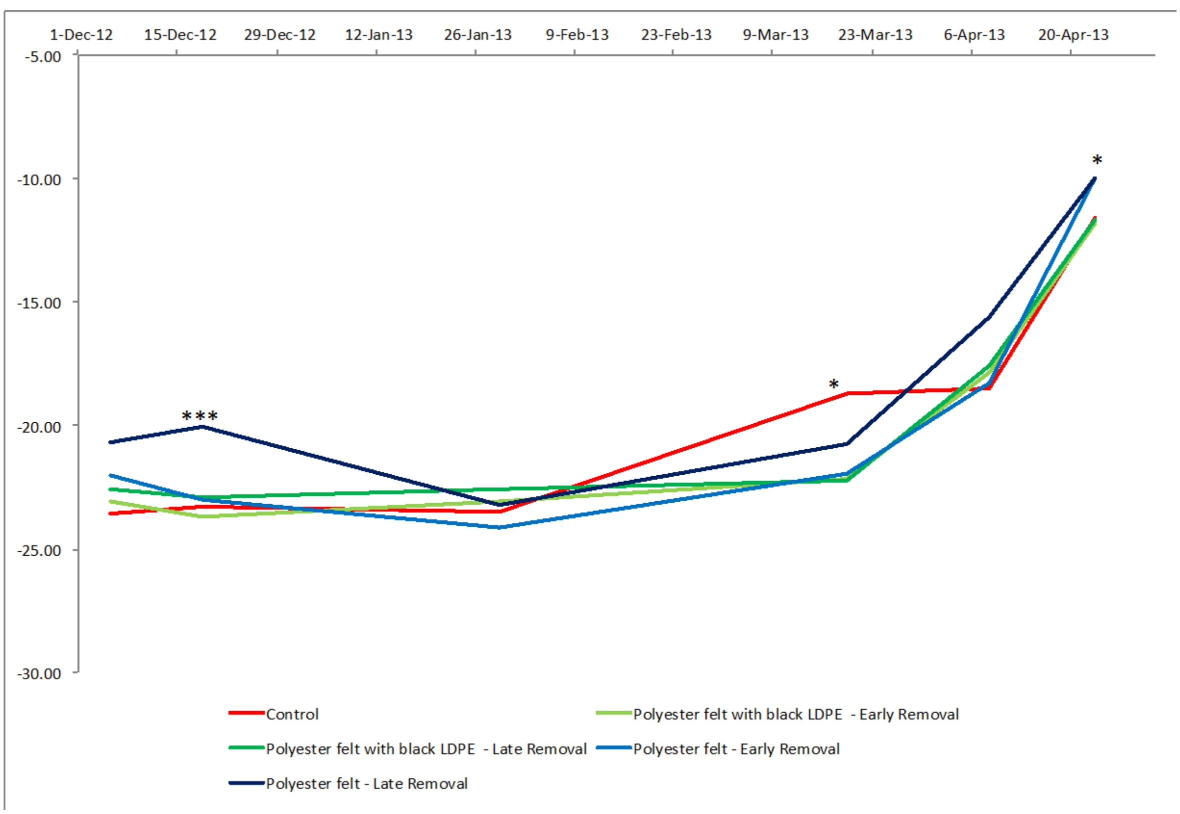


Figure 5.4. Cold hardiness dynamics (LTE50) of Chardonnay using different protection methods within Prince Edward County. Wellington, ON. (2012-13). **, **, *** Indicate significance at p<0.05, p<0.01, p<0.001, respectively.*

Research studies indicate that vines protected using geotextiles had more consistent and even bud break compared to vines that had been buried. Primary bud survival was also lower likely due to rot and physical injury. Bud health was much better when geotextile materials were used and this is evident in the shoot growth and yield component data found in Table 5.3.

Vine burial/geotextile strategies had a tremendous impact on yield potential compared to buried vines. As shown in Table 5.3, cluster numbers per vine were more than double for vines covered with geotextile compared to those that were buried. For example, in Chardonnay, vines averaged 12-14 clusters/vine when geotextiles where used compared to only 6 clusters/vine for buried vines. Similar trends where found with Pinot noir. The type of material used did not have a great impact on yields but there were some reductions in yield when these materials were removed later during acclimation. This may have been due to reductions in hardiness and greater susceptibility to cold injury during spring frosts that occurred in spring 2013. The effectiveness of these materials on bud/cane health and improving yields is very evident compared to buried vines. This must be taken into consideration when examining the capital costs of these materials and labour of installing and removing them.

Table 5.2. Influence of protective strategy on bud break on May 7, 2013. Vineland, ON.

Chardonnay					
	Polyester felt - Early Removal	Polyester felt - Late Removal	Polyester felt with black LDPE - Early Removal	Polyester felt with black LDPE - Late Removal	Control
% Bud break	51.1a	32.4b	45.1ab	32.1b	46.9a
Pinot noir					
	Polyester felt - Early Removal	Polyester felt - Late Removal	Polyester felt with black LDPE - Early Removal	Polyester felt with black LDPE - Late Removal	Control
% Bud break	27.2a	35.7a	32.8a	45.8a	34.2a

Table 5.3. Influence of protective strategy on yield components. Wellington, ON.

Chardonnay					
	Polyester felt - Early Removal	Polyester felt - Late Removal	Polyester felt with black LDPE - Early Removal	Polyester felt with black LDPE - Late Removal	Buried under soil
No. of shoots/vine	12	12	11	11	10
No. of clusters/ vine	13a	12a	14a	12a	6b
Pinot noir					
	Polyester felt - Early Removal	Polyester felt - Late Removal	Polyester felt with black LDPE - Early Removal	Polyester felt with black LDPE - Late Removal	Buried under soil
No. of shoots/vine	13a	11ab	9b	13a	9b
No. of clusters/ vine	15a	11a	4b*	10a	3b

* Material was removed from vines prematurely due to high winds

Factors to consider when using geotextiles

The use of geotextiles generally requires some pre-pruning in order to place the material over the vines. One advantage is that it may be possible to pre-prune or spur prune vines, which would reduce cane selection and tying of canes prior to burying. The materials can be placed on the vines independent of soil conditions so even if the ground is frozen they can be used. Burying of vines with soil is very dependent on the condition of the soil (i.e., not too wet) to ensure proper burying and soil can also be washed away during rainy periods or winter thaws which exposes vines to potentially damaging temperatures. Mechanization and logistics of applying and removing geotextiles needs to be studied further. There is a greater capital cost with geotextiles so durability and reuse is also a concern.

The effectiveness of these materials on bud/cane health and improving yields compared must be taken into consideration when examining the capital costs of these materials and labour of installing and removing them. Crop value, vineyard and operation size will all impact if these materials are economical for vineyard use.

One consequence that was observed using geotextile materials for protection was that rodent damage (voles, mice, rabbits) was observed in some locations (See Figure 5.5). These included damage to the trunk, buds and/or canes of 1 or more vines within these panels. Years of high snow cover also resulted in more rodent damage.

Figure 5.5. Rodent damage to grapevine.

5D. VineAlert and potential economic impact

VineAlert is a risk management system to reduce cold injury in grapevines in Ontario. The website and associated database of cold hardiness related information was launched in the fall of 2010. The information contained on the VineAlert Website (http://www.ccovi.ca/vine-alert/) is to provide grape growers with comparative levels of bud hardiness for multiple cultivars at different locations throughout the dormant period. The system alerts grape growers when vines are at risk of damage from a forecasted cold weather event to assist growers with mitigating the impact of that cold event through the use of wind machines.

Monitoring bud cold hardiness throughout the dormant period is an invaluable tool to assist grape growers in managing winter injury. The data provided from this database allows growers and researchers to see how cold-hardy grapevines are within a specific area. Cold hardiness is a **not static** but varies throughout the dormant period and is determined through the grapevine's genetic potential and environmental conditions. Therefore, grapevine species and cultivars vary in terms of their cold hardiness. Bud sampling and testing has been done throughout the entire dormant season to monitor cold hardiness through the acclimation, maximum hardiness, and deacclimation periods. This ever-changing bud hardiness data has proven to be helpful in determining when wind machine use or other freeze avoidance methods are warranted to protect the vines from winter injury.

Description of the Project 2009-2014

Regional sampling was undertaken in replicated commercial vineyards within each of the 10 designated sub-appellations of the Niagara Peninsula and the Designated Viticultural Areas of Lake Erie North Shore and Prince Edward County. The cultivars selected for the 2010/11 dormant season included Chardonnay and Cabernet Franc (the two most widely planted white and red *V. vinifera*, respectively) in all regions as well as Riesling, Pinot noir, Sauvignon blanc, Merlot and Syrah in selected regions. Temperature data was linked to each site to ensure accurate site-specific climate data that corresponded with cold hardiness data. Critical lethal temperatures for grapevine tissues were determined using differential thermal analysis (DTA) through the use of programmable freezers. Data specific to each location was updated on a rotational basis from late October until mid-April depending on the growing season. Growers and researchers were able to access data based on their geographic location, time, and cultivar in order to make knowledge-based, time sensitive decisions to mitigate the risks of cold injury. Growers are able to sign up through the VineAlert website to receive custom notifications for the location of their vineyard(s) and the cultivars that they grow. VineAlert notifies growers when updates to the latest cold hardiness and survival information is posted to the website. This ensures that users have the latest information in order to make proper decisions for protecting their vineyards from freeze injury and mitigating any effects of possible freeze damage. Prior to potentially damaging cold events, alerts are sent out to all users to notify them of the forecast and provide advice on mitigating the effects of the event. Throughout dormancy, alerts are also sent through the website informing the growers on the status of grapevine cold hardiness, acclimation, deacclimation, bud injury and bud break throughout Ontario's grape growing regions as well advice on mitigation practices and managing winter injury.

Economic Impact of VineAlert

In 2014, CCOVI contracted the MBA consultants from Brock's Goodman School of Business to complete an economic impact study on the value of VineAlert to Ontario Grape Growers. The full report is appended to this best practices manual.

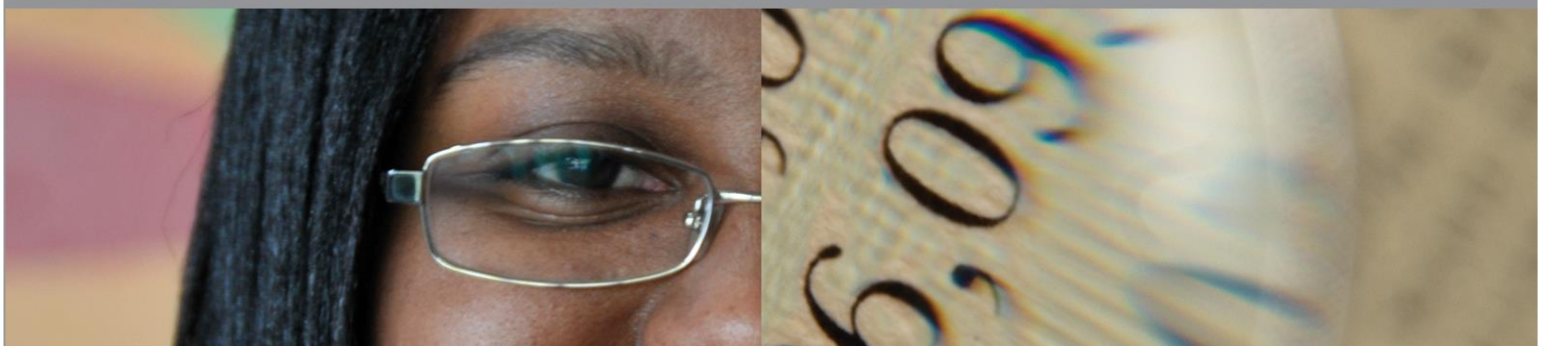
The cost analysis shows that use of the VineAlert system in combination with wind machines can potentially help Ontario Grape Growers avoid $13.8 mil in lost sales in the year of a cold weather event, $11.7 mil in lost sales for subsequent years, and $29.1 mil in vine renewal and replacement resulting from damaged or dead vines from a single event that caused 5% vine death and 20% vine damage resulting in crop loss. An additional savings of $1.0 mil per year to Ontario grape growers can be realized using the VineAlert system to reduce wind machine run time.

The combination of avoiding lost sales and renewal/replanting costs plus the additional savings of reduced operating costs for wind machines allows Ontario Grape Growers on average a potential total savings of $55.7 mil if they use the VineAlert system in combination with wind machines.

There are approximately 640 wind machines in Ontario vineyards. Therefore, VineAlert in combination with wind machines allows a grape grower on average a total savings of $87,088 per machine.

Appendix: Economic Impact Analysis of VineAlert for managing cold weather events

Goodman
School of Business
Brock University
Consulting Group



VineAlert – An Economic Impact Analysis

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Executive Summary

This report shows the economic impact of the VineAlert system in combination with wind machines and its potential benefits to Ontario grape growers through reducing the negative impacts of freeze injury.

Weather conditions during dormant periods, production volumes, and sales levels from 2000 to 2009 are presented to demonstrate the economic impact of wind machine introduction.

Cost savings from wind machine fuel, vine renewal and replacement costs, and sales losses were calculated. A cost analysis shows that use of the VineAlert system in combination with wind machines can potentially help Ontario Grape Growers avoid $13.8 mil in lost sales in the year of a cold weather event, $11.7 mil in lost sales for subsequent years, and $29.1 mil in vine renewal and replacement resulting from damaged or dead vines. An additional savings of $1.0 mil per year can be realized using the VineAlert system to reduce wind machine run time.

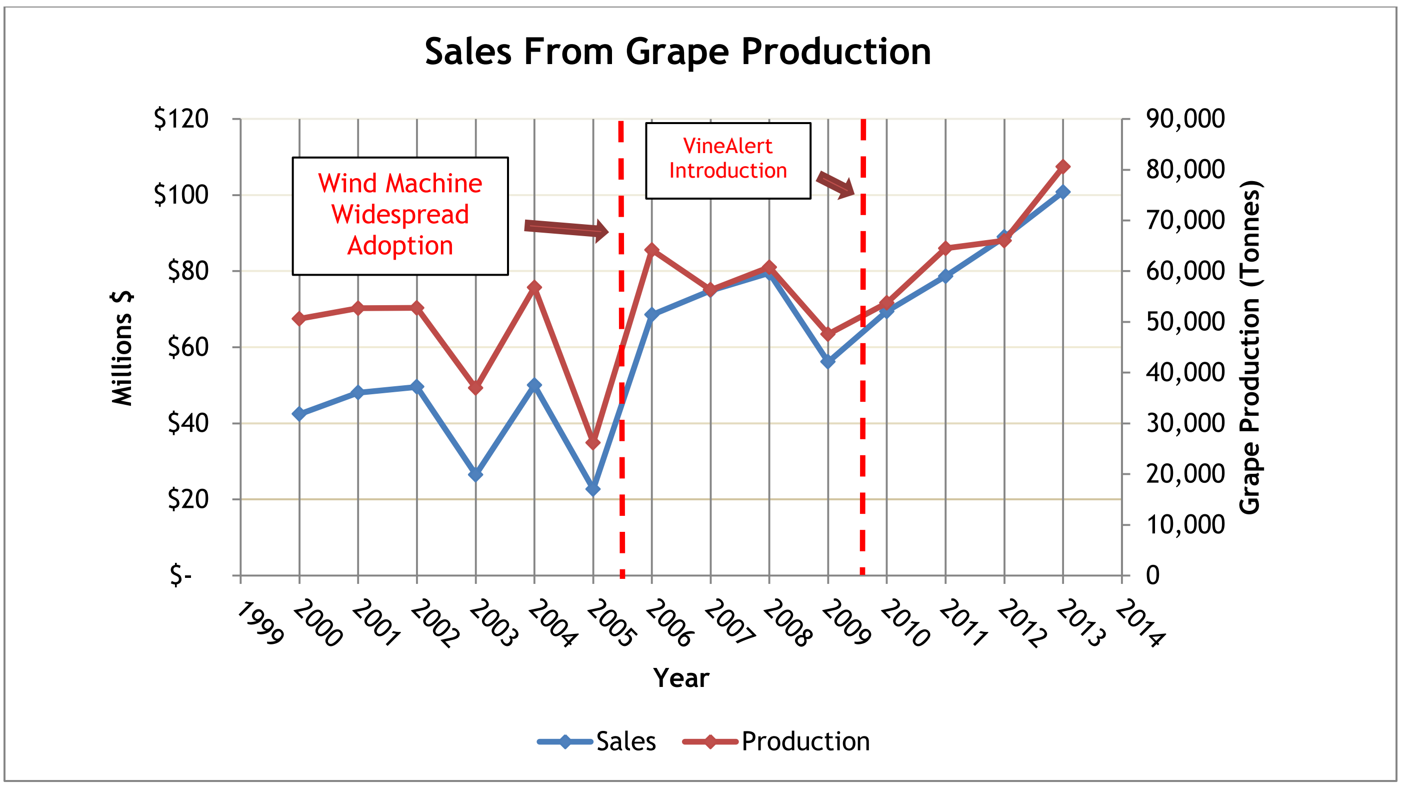
The combination of avoiding lost sales and renewal/replanting costs plus the additional savings of reduced operating costs for wind machines allows Ontario Grape Growers on average a potential total savings of $55.7 mil if they use the VineAlert system in combination with wind machines.

There are approximately 640 wind machines in Ontario vineyards. Therefore, VineAlert in combination with wind machines allows a grape grower on average a total savings of $87,088 per machine.

Southern Ontario's climate and cold event mitigation

Southern Ontario experienced considerable fluctuations in ambient air temperature during the dormant periods of 2003, 2005, 2009, and 2013. Vines are susceptible to cold temperature injury when the temperature goes below the minimum cold hardiness temperature. Factors that contribute to the bud hardiness are cultivar type, regional climate, and response to ambient temperature. The severe winters of 2003 and 2005 resulted in a 47% and 57% reduction in sales respectively (Annual Reports, n.d.). This is an example of weather conditions that damaged nearly 90 % of vineyards in Ontario (VanSickle, n.d.). 2009 was another cold winter that resulted in a 29% loss in grape sales (Grape Growers of Ontario, Annual Report, 2013).

In the hope to mitigate some of the losses caused due to temperature fluctuations and extremes, a limited number of grape growers started using wind machines in 2002. After the cold winter events of 2003 and 2005, the technology became more widely adopted by the grape growing community. This was a contributing factor in boosting the average grape sales for 2006 – 2009, an increase to $69.8 million from $39.9 million for 2000-2005 (Annual Reports, n.d.).



Wind machines, however, have not been able to entirely stabilize annual production levels. The 2009 winter caused another 29% loss in grape sales to the growers.

Table 1

	2005	**2006**	**2007**	**2008**	**2009**
Grapes sales (in $K)	22,700	68,533	74,936	79,520	56,150
%change	-55%	202%	9%	6%	-29%

In addition, running a wind machine involves substantial operating costs. According to the February 2008 report of Ontario's Ministry of Agriculture, Food and Rural Affairs (OMAFRA), the following are guidelines for the temperature levels at which a grape grower turns on a wind machine (Fraser, Slingerland, Ker, Brewster, & Fisher, 2008).

Table 2: Potential air temperatures at vine level when one could expect a wind machine to operate in Ontario

Month (s)	**Air Temperature (winds<6 km/h)**	
Winter (December)	-10C to -12C	(14F to 10.4F)
Winter (dormant season) January and February	-17C to - 20C	(1.7F to -4.0F)
Winter (March)	-10C to -12C	(14F to 10.4F)
Spring (April and May)	0C to 1C	(32F to 33.8F)

Before the introduction of VineAlert in 2010, grape growers estimated actual cold hardiness temperature of their vines. They used a combination of historical bud hardiness values, the OMAFRA's recommendations, and their own judgment. Cold hardiness temperature varies across different periods and vine cultivars such as Chardonnay, Merlot, Syrah, etc. The VineAlert system provides Ontario grape growers with up-to-date cold hardiness temperatures by variety and by location. This alerts grape growers to turn on their wind machine when ground temperature is close to a vines' cold hardiness temperature. By knowing the actual cold hardiness temperature, grape growers can drastically reduce the run time for wind machines resulting in a significant cost savings.

VineAlert Cold Hardiness: Economic Impact Analysis

The VineAlert system uses a database that contains current and historical information on cold hardiness temperatures for cultivars at different locations throughout the Niagara Peninsula, Lake Erie North Shore, and Prince Edward County. The system provides grape growers with up-to-date information on the bud Hardiness Level.

The following analysis assesses the economic impact of wind machines in combination with VineAlert during a season with a cold weather event.

Although it is not feasible to obtain data for the exact number of vines that died or were damaged during a cold weather event for any given year, the following assumptions were made in preparing this analysis:

A cold weather event results in (on average):

- 5% Vine death requiring replanting
- 20% Vine damage with no crop in the year of damage requiring vine retraining and renewal
- 75% vine damage, where through pruning mitigation, vines remain at 100% production levels. Pruning mitigation leaves more buds to make up for the lower bud survival numbers.

Vine death (requiring replanting) and vine injury (requiring retraining) estimates are conservative and consider all *V. vinifera* grapes produced in Ontario. Some Cultivars may sustain higher injury levels or incur higher recovery costs.

When determining the recovery cost from Vine death, the following assumptions were used:
For vines that died and required replanting, the crop production and additional costs for the year in which the cold event occurred (Year 0) and the years following (Years 1-5) the cold weather event were:

Year	Crop Production	Additional costs
0	0% - vine death	Removal costs
1	0% - replant year	Replant, retraining costs
2	0%	Retraining costs
3	25%	Retraining costs
4	50%	Normal costs
5	100%	Normal costs

When determining the recovery cost from Vine damage, the following assumptions were used:
For vines that were damaged and required retraining, the crop production and additional costs for the year in which the cold event occurred (Year 0) and the years following (Years 1-2) the cold weather event were:

Year	Crop Production	Additional costs
0	0% -renewal/retraining	renewal costs
1	75%	additional pruning, renewal costs
2	100%	normal

The following general assumptions were used when determining the acreage, total number of vines, yield, and sales of *V. vinifera* grapes:

Total number of vineyard acreage in Ontario	16,000
Total number of acres covered by Wind Machines	8,000
Total number of wind machines in Ontario	640
4.5 tonne/acre yield revenue*	$6,912
# of vines/acre (9 x 4 spacing)	1,210
Sales per *V. vinifera* vine*	$5.71

*based on 4.5 tonne/acre, average revenue for white and red *V. vinifera* is $6,912/acre. (*Establishment and Production Costs for Grapes in Ontario. 2009 Economic Report*. Ontario Ministry of Agriculture, Food, and Rural Affairs) with 1210 vines/acre, the sales per *V. vinifera* vine equals $5.71.

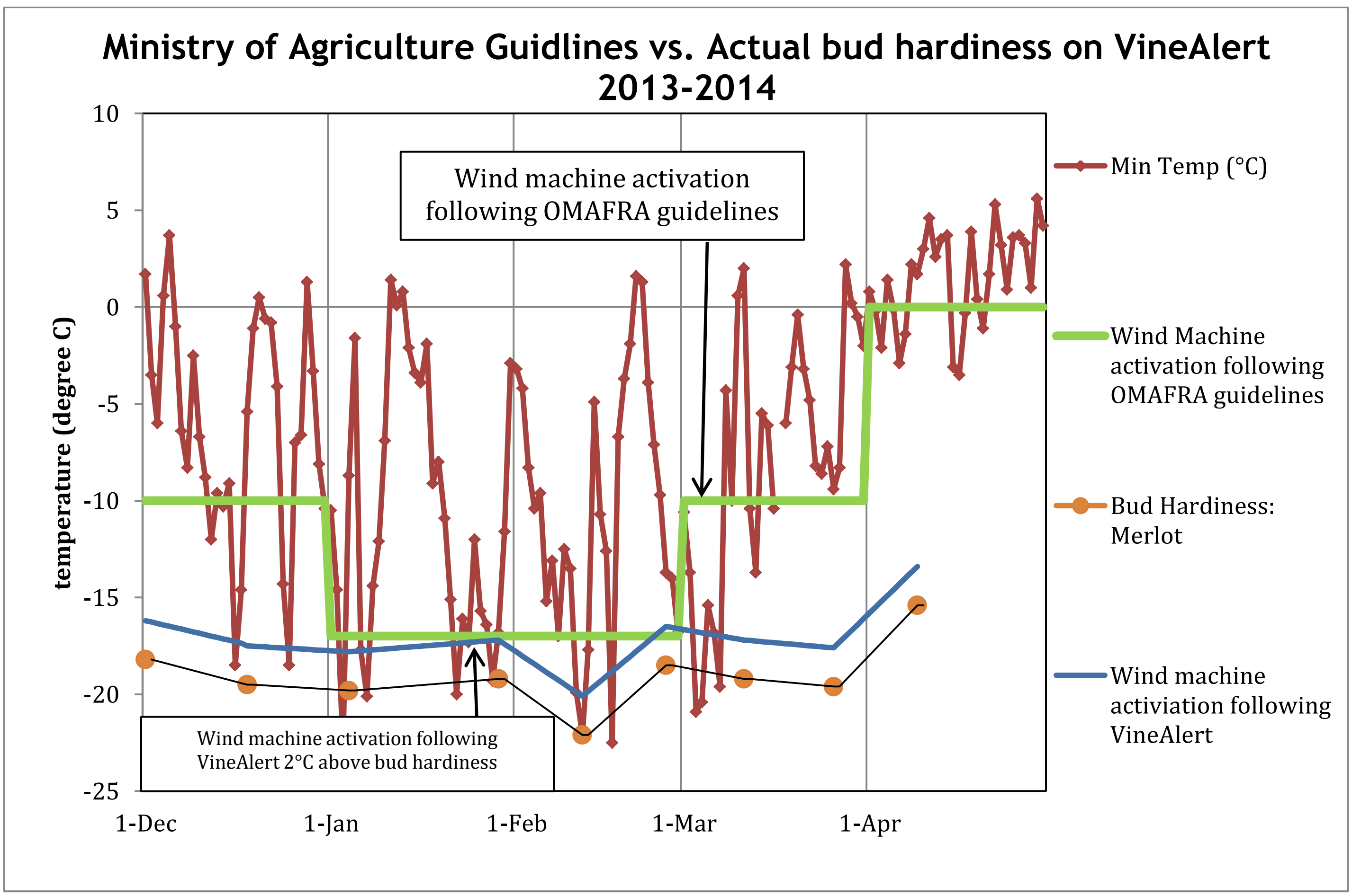
The following assumptions were used in determining the savings related to wind machines in combination with VineAlert:

Total number of acres covered by Wind Machines	8,000
Total number of wind machines in Ontario	640
Wind machine minimum operating time	3-4 Hours
Wind machine operating cost	$40-$60 / hr

Cost savings in running wind machines using VineAlert:

A wind machine, once turned on, operates for 3-4 four hours minimum (Appendix A). Based on the actual temperature levels in the Four Mile Creek sub-appellation of the Niagara Peninsula for the past 4 years (Weather Innovations, 2014) and the temperature levels at which a grape grower turns on a wind machine recommended by the OMAFRA guidelines (Fraser, Slingerland, Ker, Brewster, & Fisher, 2008), a grower turned on one wind machine an average 18 times /year or 55-73 hours /year over the last four years. Each machine costs $40 - $60 per hour to run resulting in $1,620 -$4,380 in fuel costs per machine per year (Appendix A). If these costs are multiplied by 640 wind machines currently installed in vineyards in Ontario, this tells us that grape growers spent between $1.4 -$2.8 mil to operate wind machines (Appendix B) following OMAFRA guidelines. However, following VineAlert guidelines, grape growers spent $364,800 – $729,000 to operate wind machines (Appendix C). Therefore, growers saved $1 mil – 2.3 mil when using VineAlert to determine when to turn wind machines on (Appendix D).

Based on the actual temperature levels in the Four Mile Creek sub-appellation of the Niagara Peninsula and the temperature levels at which a grape grower activates their wind machine, for 2013-2014, a grower should have turned their wind machines on only 12 days whereas following the OMAFRA guidelines, the wind machines would have been turned on 36 days. The activation point for wind machines using the VineAlert system is 2 °C above the bud hardiness temperature (see figure below).



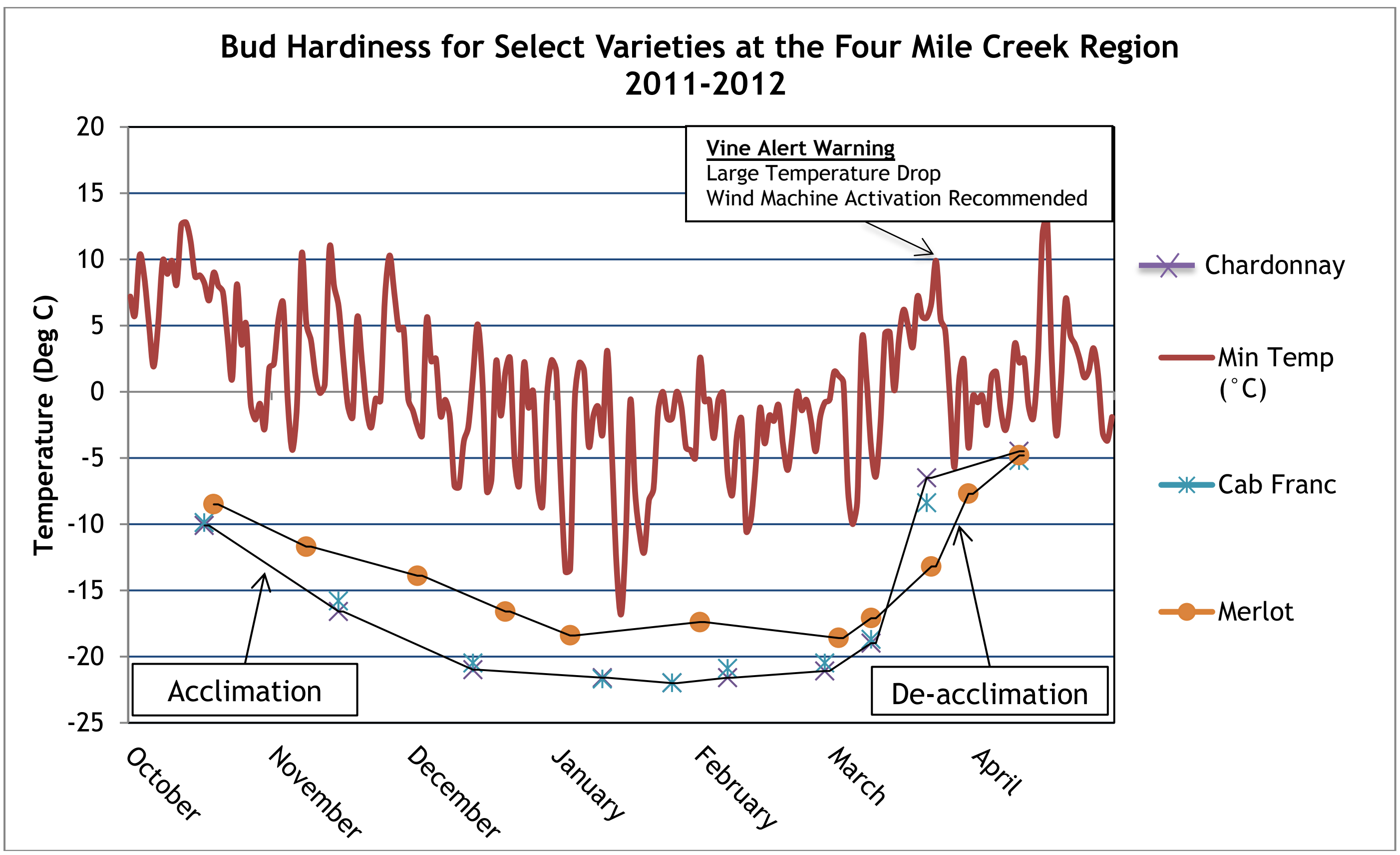
The distance between the green line and the blue line is the difference between the OMAFRA Guidelines for turning on wind machines and VineAlert's recommendation for turning on wind machines. This reduced wind machine run time saves growers $1 mil –$2.3 mil per year. Merlot is used for this comparison as it is the least cold tolerant among cultivars and therefore will give a conservative estimate of the savings in running wind machines using VineAlert versus OMAFRA guidelines.

The above graph does not show the October to November acclimation period because there were no ministry guidelines for this period. However, the acclimation and de-acclimation periods are critical because temperature fluctuations during these periods can drop below the bud hardiness temperature which is descending or ascending. The graph below shows the acclimation and de-acclimation data for Four Mile Creek for 2011-2012.

Crop loss from Vine Death and Vine Damage in the year of the cold weather event and during subsequent years during Vine re-establishment

In addition to savings on wind machines, growers can potentially avoid crop loss from vine death or vine damage using VineAlert coupled with wind machines. If during the dormant period for any given year grape vines experience temperature fluctuations where the minimum temperature drops below their current bud hardiness level, (See Figure below), they will suffer damage. Vines that are exposed to temperatures below their current hardiness temperature can die or be severely damaged causing crop loss.

For example, a cold event that results in approximately 16% crop loss due to freeze injury can translate into $13.8 million in lost sales in the year of damage and $11.7 million in lost sales for subsequent years as the vines come back into full production (Appendix E). The total $25.5 million sales loss can potentially be turned into savings for the growers with wind machines if they have access to updated bud hardiness information. This savings is based on the same cold event that results in crop loss due to 5% vine death and 20% vine damage (Appendix A).



Additional Saving from avoiding Vine Death and Vine Retraining

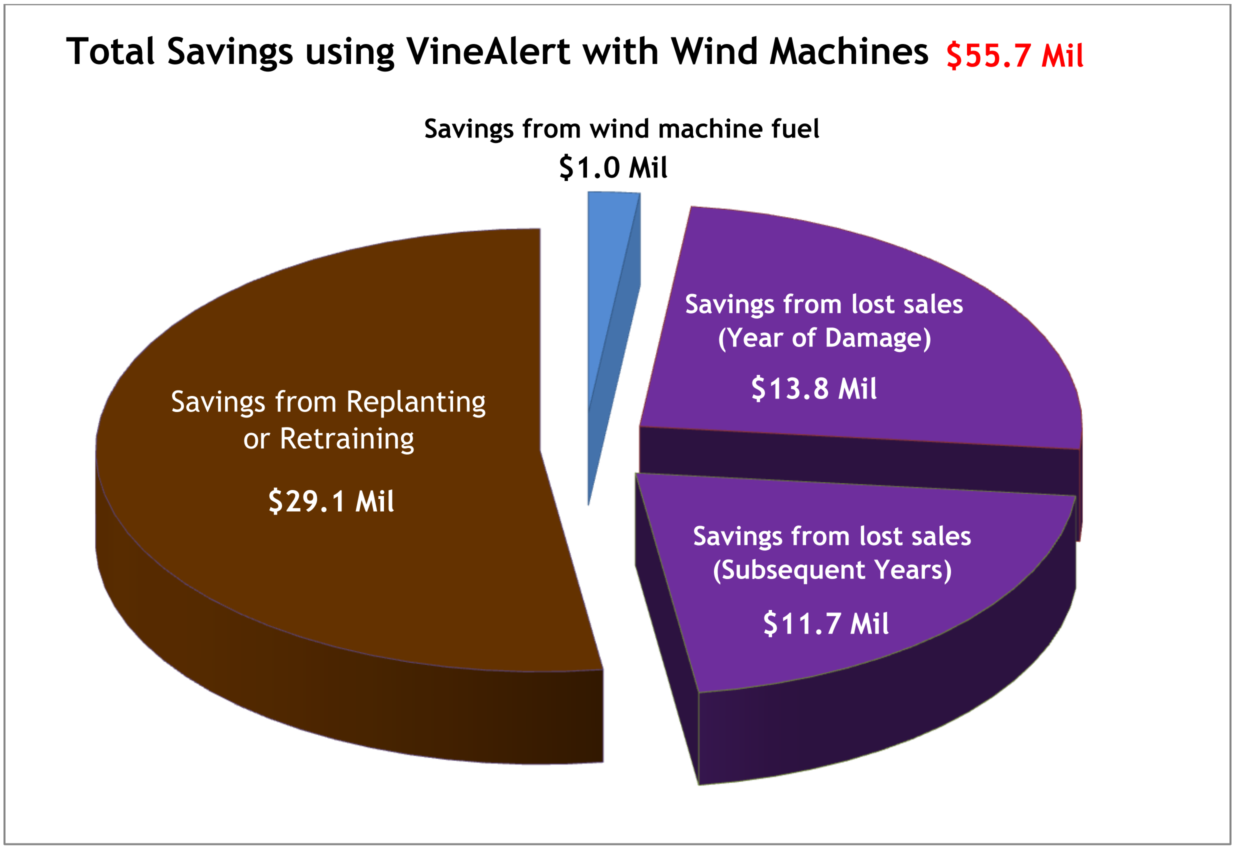
Dead vines must be replaced with new ones. It takes five years before new vines come into full production. Growers lose sales, in the year of exposure where the vine died and during the 4 subsequent years after the vine is replanted, until the vines come into full production. The annual costs over the subsequent 5 years when vines die and are replaced with new ones are outlined in Appendix F and total $20 mil.

Vines that are moderately damaged can be retrained without replacement. These vines take three years from the time of the cold event to return to normal balance and production level. Meanwhile, growers will lose revenue during that period. Growers are subject to the costs outlined in Appendix G when vines are damaged and trunks have to be retrained for plant renewal, which costs $9.1 mil over the subsequent 2 years.

By using the VineAlert system in combination with wind machines, Ontario grape growers can avoid a total cost of $ 29.1 mil in vine replacement and retraining costs over the subsequent 4 years after the cold weather event based on this example.

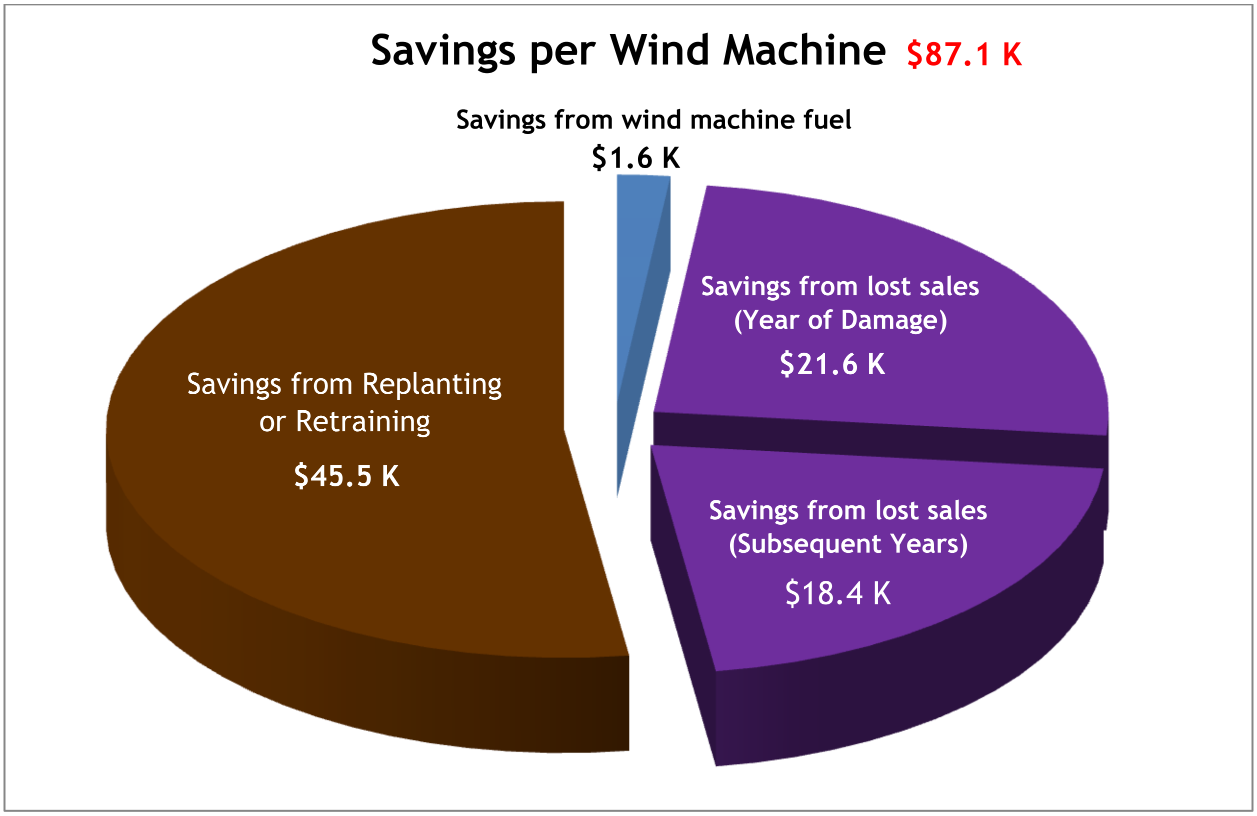
Total Economic Impact from a Cold Weather Event

A combination of avoiding lost sales and retraining/replanting costs plus the additional savings of reduced operating costs for wind machines would have allowed Ontario Grape Growers on average a potential total savings of $55.7 million if they used the VineAlert system in combination with wind machines.



Savings per Wind Machine

There are approximately 640 wind machines in Ontario vineyards. Therefore, VineAlert in combination with wind machines would have saved a total of $87,088 per machine.



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Appendix A: Assumptions

A cold weather event results in (on average):

- 5% Vine death requiring replanting
- 20% Vine damage with no crop in the year of damage requiring vine retraining and renewal
- 75% vine damage, where through pruning mitigation, the vines remain at 100% production level

Vine death (requiring replanting) and vine injury (requiring retraining) estimates are conservative and consider all V. *vinifera* grapes produced in Ontario. Some Cultivars may sustain higher injury levels or incur higher recovery costs.

Crop loss in *V. vinifera* due to winter injury	
# of vines/acre (9 x 4 spacing)	1,210
# of dead vines/acre (5%)	60.5
# of vines requiring retraining (20%)	242
Total Ontario vineyard acreage with wind machines	8,000
Total # vines requiring replanting	484,000
Total # vines requiring retraining and renewal	1,936,000
Total number of vines requiring replanting or retraining/renewal	**2,420,000**

When determining the recovery cost from Vine death the following assumptions were used:

The crop production and additional costs for the year in which the cold event occurred (Year 0) and the years following (Years 1-5) the cold weather event were:

Year	Crop Production	Additional costs
0	0% - vine death	removal
1	0% - replant year	replant costs
2	0% -	year 2 costs
3	25%	year 3 costs
4	50%	year 4 costs
5	100%	normal costs

When determining the recovery cost from the Vine damage the following assumptions were used:

The crop production and additional costs for the year in which the cold event occurred (Year 0) and the years following (Years 1-2) the cold weather event were:

Year	Crop Production	Additional costs
0	0% -renewal/retraining	renewal costs
1	75%	additional pruning costs
2	100%	normal

The following assumptions were used in determining the savings related to wind machines in combination with VineAlert:

Total number of acres covered by Wind Machines	8,000
Total number of wind machines in Ontario	640
Wind machine minimum operating time	3-4 Hours
Wind machine operating cost	$40-$60 / hr

Appendix B: Wind Machine usage costs following OMAFRA Guidelines VineAlert

	3 hrs/run	4 hrs/run
2010-2011 wind machine hours	51	68
2011-2012 wind machine hours	39	52
2012-2013 wind machine hours	21	28
2013-2014 wind machine hours	108	144
Average hours per machine per year	**54.75**	**73**
Cost per hour	$ 40	$60
Cost per machine per year	**$ 1,620**	**$4,380**
# of wind machines in Ontario	640	640
Total average cost per year	**$1,401,600**	**$2,803,200**

Appendix C: Wind Machine usage costs following VineAlert

	3 hrs/run	4 hrs/run
2010-2011	9	12
2011-2012	0	0
2012-2013	12	16
2013-2014	36	48
Average hours per machine per year	**14.25**	19
Cost per hour	$ 40	$ 60
Cost per machine per year	**$ 570**	**$ 1,140**
# of wind machines in Ontario	640	640
Total average cost per year	**$364,800**	**$729,600**

Appendix D: Fuel Cost savings when running wind machines with VineAlert

	3 hrs/run	4 hrs/run
Wind machine usage cost per year without VineAlert	$ 1,401,600	$ 2,803,200
Wind machine usage cost per year with VineAlert	$ 364,800	$729,600
Cost Savings per year	**$ 1,036,800**	**$ 2,265,600**

Appendix E: Sales loss

Crop loss in *V. vinifera* due to winter injury	
# of vines/acre (9 x 4 spacing)	1,210
# of dead vines/acre (5%)	60.5
# of vines requiring renewal (20%)	242
Total Ontario vineyard acreage with wind machines	8,000
Total # vines requiring replacement	484,000
Total # vines requiring renewal	1,936,000
Total number of vines requiring replanting or retraining	**2,420,000**

Year 0 crop loss from dead and damaged *V. vinifera* vines where neither will yield a crop	
4.5 tonne/acre yield revenue*	$6,912
Sales per vinifera vine*	$5.71
Total number of vines damaged	2,420,000
Total sales loss in the year of damage	**$13,818,200.00**

* based on 4.5 tonne/acre revenues for white and red *vinifera* with plantings of 1210 v/acre (OMAFRA, 2009
Establishment and Production Costs for Grapes in Ontario. 2009 Economic Report. Ontario Ministry of Agriculture, Food and Rural Affairs.

Year	5% Vine Death		20% Vines Damaged		Total
	Crop Production Loss	Sales losses	Crop Production Loss	Sales losses	
Year 0: The year of the cold event	0%	**$2,763,640**	0%	**$11,054,560**	**$13,818,200**
Year 1: The year of replanting (vine death) or renewal/retraining	0%	$2,763,640	75%	$2,763,640	$5,527,280
Year 2	0%	$2,763,640	100%	$0	$2,763,640
Year 3	25%	$2,072,730	100%	$0	$2,072,730
Year 4	50%	$1,381,820	100%	$0	$1,381,820
Year 5	100%	$0	100%	$0	$0
Total sales losses for the subsequent years		**$8,981,830**		**$2,763,640**	**$11,745,470**
Total sales losses for the year of the cold event		$2,763,640		$11,054,560	$13,818,200
Total sales losses for the subsequent years		$8,981,830		$2,763,640	$11,745,470
Total Sales losses		**$11,745,470**		**$13,818,200**	**$25,563,670**

Appendix F: Cost of dead vines

Additional production costs for replanting including vine replanting costs, increased hand labour costs for vine removal, new vine establishment, and weed management over the first 4 years following winter injury

Year 0				
Operation costs: Hand	Labour hrs	Labour costs	Machine costs	Total Costs
Removing vines	20	248	144	392
Total Hand Labour	20	248	144	392
			Total	**392**
Year 1				
Variable costs				Total/acre
Replacement vines				250
Operation costs: Hand	Labour hrs	Labour costs	Machine costs	Total Costs
Replacing vines (5%)	13.2	228	144	372
Weed Control: Hand Hoeing	8	$99		$99
Summer training, tying, trunk est	20	248		248
Total Hand Labour	41.2	575	144	719
			Total	**1131**
Year 2				
Variable costs				Total/acre
Replacement vines (2%)				100
Operation costs: Hand	Labour hrs	Labour costs	Machine costs	Total Costs
Replacing vines (2%)	4.4	76	48	128
Weed Control: Hand Hoeing	8	$99		$99
Summer training, tying, trunk est	20	248		248
Total Hand Labour	32.4	423	48	475
			Total	**575**
Year 3				
Variable costs				Total/acre
Replacement vines (2%)				100
Additional costs				
Operation costs: Hand	Labour hrs	Labour costs	Machine costs	Total Costs
Replacing vines (2%)	4.4	76	48	128
Weed Control: Hand Hoeing	4	$50		$50
Summer training, tying, trunk est	10	124		124
Total Hand Labour	18.4	250	48	302
			Total	**402**

Year 4 and 5 use normal production costs for mature vineyard.

Estimated total additional costs/acre for replanting vines in mature vineyard

Year	**Additional cost/acre**
Year 0: Removal	392
Year 1: Replant	1131
Year 2	575
Year 3	402
Year 4	0
Year 5	0
Total cost per acre over 5 years	**2500**
Total number of dead vines/acre	**60.5**
Cost per vine	**41.32**
Total number of dead vines	484,000
Total replanting/retraining costs	**19,998,880**

Appendix G: Cost of Damaged Vines

Assumptions: Additional production costs for retraining/renewal include increased hand labour costs for pruning, retraining, tying, and trunk establishment within the first 2 years following winter injury

Additional production costs for retraining/renewal

Year 0				
Additional costs				
Operation costs: Hand	Labour hrs	Labour costs	Machine costs	Total Costs
Weed Control: Hand Hoeing	8	$99	$0	$99
Summer training, tying, trunk est.	20	248	$0	248
Total Hand Labour	28	347	$0	347
			Total	**347**
Year 1				
Custom Pruning - $.46/vine (based on Martinson & White, 2005)				448
Operation costs: Hand	Labour hrs	Labour costs	Machine costs	Total Costs
Weed Control: Hand Hoeing	8	$99	$0	$99
Summer training, tying, trunk est.	20	248	$0	248
Total Hand Labour	28	347	$0	347
			Total	**795**
Years 2-5 Normal costs for mature vineyard				

Estimated total additional costs/acre for renewing/retraining 20% vines in mature vineyard

Year	**Additional cost**
Year 0: Renewal/retraining	$347
Year 1: additional pruning	$795
Year 2	0
Year 3	0
Year 4	0
Year 5	0
Total cost per acre over 5 year period	$1,142.00
Total number of damaged vines/acre	242
Cost per vine	$4.72
Total number of damaged vines	1,936,000
Total renewing/retraining costs	**$9,136,000**

LINKS

CCOVI VineAlert Website

http://www.ccovi.ca/vine-alert

CCOVI/KCMS factsheets

Grapevine Critical temperature and Growth Stages
http://www.brocku.ca/webfm_send/21240

Cold Injury Strategies

http://brocku.ca/ccovi/research/research-updates/cold-injury-strategies

January 6, 2014 - Dealing with cold injury

January 6, 2014 - Strategies to recover from winter damage

January 6, 2014 - Making decisions after winter damage

March 8, 2011 - What does deacclimation mean to me?

How has the warm weather impacted the vines?

http://www.brocku.ca/webfm_send/21015

Historical Bud Injury Data

http://brocku.ca/ccovi/research/research-updates/winter-injury

Wind Machine and Cold Injury Information
OMAFRA Wind machine Factsheet:
http://www.omafra.gov.on.ca/english/engineer/facts/10-045.pdf

http://www.brocku.ca/ccovi/files/research_updates/Infosheet_Wind_Machine...

OMAFRA Freeze Protection Strategies for Crops:
http://www.omafra.gov.on.ca/english/crops/facts/85-116.htm

KCMS - Reducing Cold Injury to Grapes Through the use of Wind Machines:
http://www.kcms.ca/pdfs/Final_Wind_Machine_Report_2010.pdf

Weather Information
http://www.vineandtreefruitinnovations.com/
http://www.theweathernetwork.com/index.php?product=weather&pagecontent=cancitieson_en
http://www.weatheroffice.gc.ca/forecast/canada/index_e.html

Grapevine cold hardiness research in other regions

Cornell University

http://www.cals.cornell.edu/cals/grapesandwine/outreach/viticulture/weat...

Washington State University

http://wine.wsu.edu/research-extension/weather/cold-hardiness/

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